TAPE RECORDERS

HOW THEY WORK

by CHARLES G. WESTCOTT

A Howard W. Sams PHOTOFACT PUBLICATION · TRW-1

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To Dr. W. W. Wetzel

whose pioneering efforts and practical

applications have made the American magnetic

recording industry a reality.

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PREFACE

The miracle of magnetic recording is suddenly upon us. Everywhere one sees tape recorders in action: In the home, in schools, offices, recording studios, Hollywood sound stages. Magazines everywhere refer to magnetic tape recording as the "new medium". And yet the art is very old, even though it has come into use largely within the last decade. Much has been published about tape recording, from microphone placement to long compilation of recorder uses for the whole family. Paradoxically, however, little has appeared about how the tape recorder operates.

The purpose of this book is a modest one. We do not propose to suggest new uses for your recorder, nor is this book devoted to lengthy considerations on recording techniques. In this book we have endeavored throughout to tell you "what's under the cover". Service technicians will see diagrams and schematics typical of most present-day recorders. Hi-Fi enthusiasts will find, for the first time, information on what makes good frequency response and low noise, what to look for in the way of magnetic heads and motorboards. Recordists will see what is necessary in order not to "overload" the tape and how to obtain the best bias setting.

This book is based on the principal that in order to make best use of one's recorder, it is first necessary to understand thoroughly how it operates. A thorough understanding of its electronic and mechanical operation is important. While it is possible to make recordings on home-type machines that are superior to many so-called professional recordings, knowledge enables one to predict in advance what the results will be from his recording. This book will, then, serve as a guide towards selecting equipment necessary for specialized recording problems.

The prospective buyer of a tape recorder will be acquainted with the features that make a truely fine recording mechanism. Terminology such as "flutter and wow", "signal-to-noise ratio", and "frequency response" are explained and the components necessary to yield the best in performance are described in detail.

The past several years have seen a tremendous increase in the number of tape recorders selling between $100 and $250 (which often rival the professional recorders of a few years ago). But as is so often true "one generally gets what he pays for". This book will simillify the complex task of selecting one's first recorder by showing important differences between recorders in both the low-and high-priced brackets.

If you buy, sell, service, or operate magnetic tape recorders we hope that this book will prove an invaluable store of information on "Tape Recorders — How They Work".

Charles G. Westcott

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CHAPTER 1

A Bird's Eye Perspective of the Magnetic Recording Industry

The history of magnetic recording covers a period spanning more than half a century. Yet magnetic recording remained practically undeveloped until shortly before the beginning of World War II. From its inception in 1898 until its real commercial application in Germany, starting in 1935, magnetic recording remained little more than a scientific curiosity. Historians of invention during that era regarded it as scarcely worth mentioning.

Fig. 1-1. Valdemar Poulson of Copenhagen, Denmark, Built the First Magnetic Recorder in 1893. Called the Danish Edison, He is the Father of Important Inventions in the Field of Magnetic Recording.

Valdemar Poulsen of Copenhagen, Denmark, pictured in Fig. 1-1, built the first magnetic recorder in 1893. His "Telegraphone" magnetically recorded crosswise on a steel piano wire, but the wire would twist which threw the crosswise recording out of alignment, thus ruining its quality. To overcome this difficulty, Poulsen replaced the wire with a more bulky and combersome steel tape which could not twist. Shown in Fig. 1-2 is the Telegraphone manufactured in the United States by the American Telegraphone Company around 1920. The spools of wire are mounted horizontally and turned by a 100-volt motor. No provision for automatic rewind was made. Spools of wire were interchanged for rewind and playback.

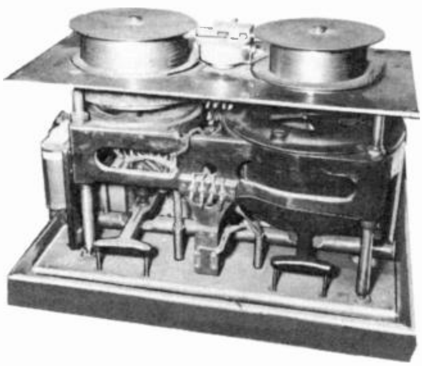


Fig. 1-2. The "Telegraphone" Designed by Valdemar Poulsen and Manufactured in the United States by the American Telegraphone Company Around the Year 1920. (Courtesy of Popular Electronics.)

In his United States patent granted on the "Telegraphone," illustrated in Fig. 1-3, Poulsen called it an "aparatus for electromagnetically receiving, recording, reproducing, and distributing articulate speech."

Poulsen's invention was completely unique and original, not the outgrowth of further refinement of a fundamental discovery made earlier. Recorded scientific history does not disclose or even give a possible clue as to where Poulsen got his idea. Although historians of invention passed Poulsen's invention by with scarcely a nodding mention, the "Telegraphone" was nevertheless a sensation in its day. In 1900 at the Paris Exposition the "Telegraphone" won the Grand Prix. Technical journals and newspapers were filled with references about the recorder.

The "Telegraphone" particularly captured the imagination of investors in the United States. Poulsen was able to raise without great effort the then princely sum of $5,000,000 in capital stock at a par value of $10 a share for the manufacture of the "Telegraphone." Its backers visualized its chief use as an office dictating device. The machine was capable of recording for 30 minutes with its wire traveling at an amazing velocity of 7 feet per second. The machine required earphones, operating without an electronic amplifier which was not destined to be discovered until twenty-five years later.

A series of financial misfortune beset Poulsen's United States firm, the American Telegraphone Company. Lacking present day persuasive promotion and selling techniques coupled with inherent defects in the recorder itself, the firm soon collapsed and the stock became valueless. A Danish firm was also organized in 1909 to manufacture the "Telegraphone." It closed its doors in 1916 without having commercially marketed a single recorder.

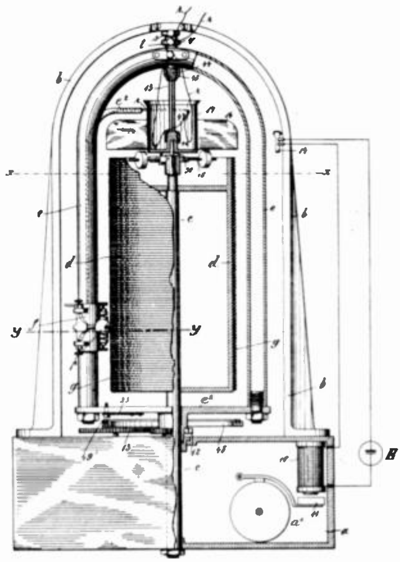


Fig. 1-3. A Drawing of Valdemar Poulsen's "Telegraphone" Taken from the American Patent.

Electronic engineers who examine Poulsen's patent today are amazed at how closely his machine, crude as it was, resembles the modern magnetic recorder. His recorder worked, and Poulsen proceeded to commercially market the "Telegraphone." Oscar Dupue, in an account of his experiences with Burton Holmes, then the world's leading travelogue exponent, recalled having used the "Telegraphone":*

"I have mentioned previously the second trip to Norway in 1907 to make another film of the fjord trips. It was on this trip that I purchased a Poulsen wire recorder in Copenhagen . . . I was able to operate it in my steamer cabin while en route home. I had a lot of fun talking into it and playing back, and soon I had a procession of passengers eager to record and hear their own voices. Several theatrical notables were present, including the famous Jimmie Powers . . . . he was full of hit songs and stories, so we recorded a few. When he finished, I spoke into the recorder saying that Powers' record was made on the twenty-eighth day of August, 1907, in

*Oscar Dupue, "My First Fifty Years in Motion Pictures." Journal of the society of Motion Picture Engineers, December, 1947.

mid-ocean aboard the S. S. Augusta Victoria. Thirty years later, I re-recorded Powers' voice on film. The wire had retained the record as clearly as when it was first made."

Since Poulsen had a working magnetic recorder fifty years ago, why did magnetic recording have to wait until World War II to be fully developed? One obvious answer to this question lies in Poulsen's recorder. Since the recorder originally employed wire and later a steel tape, it was undoubtedly very awkward and difficult to operate.

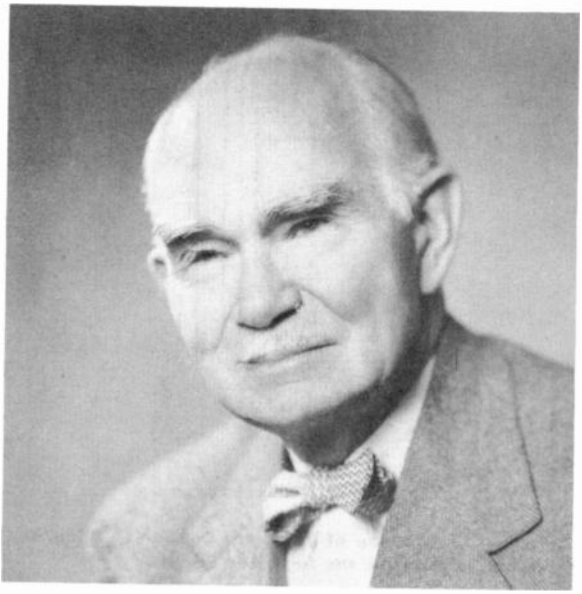


Fig. 1-4. Dr. Lee de Forest, Pictured Here, Invented the Vacuum Tube Which Made It Possible for the First Time to Satisfactorily Reproduce the Weak Signals Recorded on Magnetic Tape.

Because the speed at which the tape traveled in recording was as fast as was practical for the mechanism to handle, it was impossible to speed up the rewind time. Also, since it recorded crosswise, or in a perpendicular direction, the quality could not have been too good, although undoubtedly it represented an achievement when contrasted to the sound standard prevailing at the time. Frequency response was limited. The dynamic recording range did not exceed approximately 20 decibels. The noise level was excessively high. However, the main reason for the lack of development can be attributed to the low acoustical output of magnetic recording in comparison with the then competitive mechanical systems such as disc recordings.

Not until Dr. Lee de Forest, pictured in Fig. 1-4, invented the vacuum tube grid was it possible to obtain sufficient amplification to satisfactorily reproduce the weak signal on magnetic tape. In fact, the relative positions of the now fast rising magnetic recording medium and phonograph industry might today have been reversed through a little-known experiment conducted in 1912. But as is so frequent in the history of invention, the full significance of the experiment was not realized at the time.

Dr. Lee de Forest himself writes:

"Speaking of the necessity for the three-electrode tube amplifier in connection with magnetic tape recording and reproducing, you may be interested to know that in the spring of 1912 I used the tube as an amplifier in connection with the old steel wire Poulsen Telegraphone. I am sure this is the first combination of those two great inventions. No one could foresee at that early date the immense development and priceless applications of the magnetic tape Telegraphone. In fact, one of the very first applications of the three-electrode tube as an amplifier was in connection with the Telegraphone."

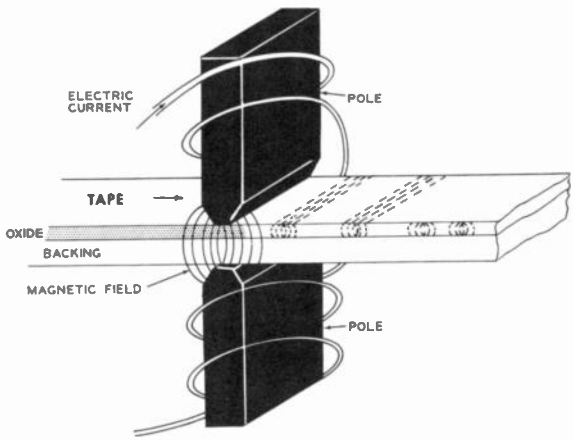


Fig. 1-5. In Perpendicular Magnetic Recording, High Frequencies are Possible Only at High Tape Speeds Since the Magnetic Field From the Head Is Not Concentrated. The Magnetization is Perpendicular to the Tape.

Other roadblocks besides amplification to be removed were the abandonment of perpendicular magnetization in favor of longitudinal magnetization and the discovery of AC or high frequency bias technique.

Originally the magnetic field was recorded perpendicular to the recording medium (wire, steel band, or tape). (See Fig. 1-5.) While this system worked, it required very high tape speeds since the magnetic field in the region of the tape could not be concentrated but covered a rather wide area.

However, with the invention of the ring type head the magnetic field could be confined as far as the tape is concerned to the area between the pole pieces or to the magnetic gap. This permitted recording wavelengths as short as .00025 inches (for video recording, wavelengths are now being recorded to even a fraction of this amount).

Thus, with the ring type head and longitudinal recording (recording in the direction of tape travel rather than perpendicular to it as illustrated in Fig. 1-6), engineers were able to make practical low tape speeds and the storing of a large amount of information on a small reel.

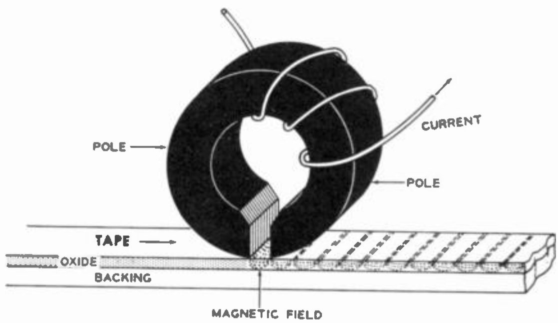


Fig. 1-6. In Longitudinal Magnetic Recording, High Frequencies at Far Slower Speeds Are Possible Since the Magnetization Is in the Direction of Tape Travel.

The AC or high frequency bias technique was discovered by W. L. Carlson and G. W. Carpenter of the U. S. Navy. The AC bias technique eliminated the high background noise generally associated with recordings made using the older DC bias method. However, even with the removal of these obstacles, the progress of magnetic recording was slowed for many years through lack of imagination and any serious desire to perfect existing techniques.

The present high state of development is due in large measure to the work of such leaders in the field as AEG in Germany, manufacturers of the Magnetophone; the Bell Telephone Laboratories; Lynn Holmes of the Stromberg-Carlson Company; S. J. Begun of the Brush Development Company; Marvin Camras of the Armour Research Foundation; and, Minnesota Mining and Manufacturing Company's Dr. W. W. Wetzel. (See Fig. 1-7.)

When magnetic recording bobbed up from obscurity during the middle twenties, the Naval Research Laboratory saw in Poulsen's invention a promising method for transmitting telegraph signals at an exceptionally high speed. It was hoped that, at normal speed, messages could be recorded on wire, then transmitted at high speed to cut down sending time. The project was subsequently abandoned because of the difficulty in handling wire at high speeds. However, the discovery of the AC biasing theory resulted as a by-product from the Navy's early developmental work.

Also during the twenties in Germany, a promoter gifted with imagination and vision, impressed with the future of magnetic recording, formed a company, the Telegraphic-Patent-Syndikat. This

Lynn Holmes, Stromberg-Carlson

S. J. Begun, Brush Development Co.

Dr. W. W. Wetzel, Minnesota Mining and Manufacturing Co.

Marvin Camras, Armour Research Co.

Fig. 1-7. Pioneers in the Development of Magnetic Recording in the United States.

firm, founded by Kurt Stille, was organized to sell manufacturing licenses to produce a magnetic recorder-reproducer. Using high impact sales methods uncommon in Europe, Stille sold his license to produce a modified and improved "Telegraphone" to a variety of European concerns. One recorder, produced under Stille's licensing agreement, used steel tape. Known as the "Blattnerphone", this recorder was seriously considered for early talking motion pictures. In England several movies were completed, actually using a sound track recorded on synchronized steel tape.

In Germany, particularly, a variety of magnetic recorders were marketed during the early thirties, all operating with either wire or steel bands. One of the more prominent German concerns was the Echophone Company to whom Kurt Stille sold a license agreement. It was the first recorder to use a magazine load device rather than reels, considerably simplifying loading and threading the recorder. The Echophone Company subsequently sold out to the International Telephone and Telegraph Company which then resold its patents to the C. Lorenz Company, another German firm, who completely re-designed the machine. The new recorder was marketed under the trade name "Textophone."

The "Textophone," among other magnetic recorders, were on the German domestic market in 1933 when the Nazi Party swept into power. The Nazi Party and the Gestapo were large consumers of magnetic recording equipment of all types.

Working independently, another German, an inventor named Pfleumer, was busily engaged conducting experiments with various types of recording mediums including paper and plastic tapes coated with iron oxide particles. Sensing a large and growing market, the Allgemeine Electrizitats Gesellschaft (AEG), the German equivalent to General Electric Company, joined hands with the I. G. Farben Company, and took over Pfleumer's early pioneering work in coating paper and plastic materials. The grain size of the magnetic materials was relatively large. The early paper tape, coated with the powdery magnetic substance, closely resembled sandpaper. When the tape was run through recorders, a spray of powder clouded the air.

The first Magnetophone, produced by AEG, was exhibited in 1935 at the German Annual Radio Exposition in Berlin. Although the Magnetophone was inferior to many earlier German magnetic recorders, it was an instantaneous success, the hit of the exhibition. Employing coated paper tape as opposed to wire or steel bands, the magnetic recording tape cost only fifteen cents per minute of recording time; the price of steel bands was a dollar or more per minute. Naturally, paper tape was less wieldy, threaded easily, and was infinitely more convenient to store.

Meanwhile, in the United States, Bell Telephone Laboratories was the only large corporate name in the electronics field to be associated with magnetic recording. Bell Telephone Laboratories designed a steel tape recorder, the Mirrophone, that was put to work announcing the weather and time signals on the telephone. At the New York World's Fair, the Mirrophone amazed thousands of visitors who recorded their voice into the machine and gasped in surprise to hear a chance remark of a moment instantly played back with full fidelity. The Mirrophone was also a featured electronic performer in the Bell Telephone exhibits which toured the schools of the nation as part of a continuing public-relations program.

Fig. 1-8. An Early Brush Development Company Soundmirror with Cover Removed.

Magnetic recording equipment had not been manufactured commercially in the United States until 1937 when the Soundmirror, a steel tape recorder, was placed on the market. Brush Development Company purchased rights to the Soundmirror which was originally built by Acoustic Consultants. Fig. 1-8 shows one of the early Brush Soundmirror recorders. The cover is removed so that the mechanical layout may be seen. Although the machine could record only one minute on a steel tape, countless applications were immediately found for it. Brush inaugurated an intensive research program which made many fundamental contributions to the body of knowledge comprising magnetic recording techniques. During World War II, Brush built large quantities of magnetic recording equipment for the Armed Services. In cooperation with the Office of Scientific Research and Development, Brush helped develop coated paper-tape and plated-wire recording mediums.

Armour Research Foundation was also prominent in the early development of magnetic recording. The chief contribution of the Armour Research Foundation lies in its intensive campaign launched to acquaint the public with the full potentialities of magnetic recording. It also supplied magnetic recording equipment to the Armed Services during World War II. However, because of limited shop facilities, General Electric and several other companies took over production of the Armour Research Foundation's recorder.

Immediately following the end of World War II, Webster-Chicago and Sears, Roebuck and Company began large-scale wire recorder production. War workers with pockets still filled with money provided a wide market base of home consumers, topped off with specialized office dictation uses and other applications. Encouragingly large quantities of wire recorders were sold during the first few months of large-scale production. However, commercial television began to show promise of sweeping the country and with automatic home appliances, automobiles, and other types of consumer products increasingly available, sales of wire recorders began to slow. The anticipated wire-recording boom failed to materialize.

During World War II all avenues of exchanging technical information between Germany and the outside world were closed. But work on the magnetic recording process progressed, despite shortages and hardships imposed by the war. Substantial improvements were being made on the AEG Magnetophone.

Near the close of World War II, a corps of Allied scientists and technicians was sent to Germany to investigate reports of a highly developed magnetic tape and tape recorder system for general recording purposes.

American technicians were amazed to find that the Magnetophone, employing AC bias and using a coated paper tape, was able to record a full 10,000 cycles with a low signal-to-noise ratio and negligible wow and flutter. Although experimental American wire recorders under carefully controlled conditions could now attain 10,000 cycles, wire had many defects when compared to tape. Quick to see the advantages of the tape system over other recording methods, the investigators returned prototypes of the recorder and samples of the tape to the United States. Immediately an intensive developmental program was begun, aimed at opening up the field of magnetic recording.

The United States Alien Property Custodian held all patents on the Magnetophone and would license any American firm to produce the equipment on application. Although any company that wished to duplicate the Magnetophone could do so, large corporations still showed little interest. For the first few years following the war, practically all manufacture of professional recorders was done by three small and then little-known organizations: Magnecord, Inc., Rangertone, Inc., and Ampex Electric Company. Samples of early units manufactured by these companies are shown in Fig. 1-9A, B, and C.

While the early American recorders were directly copied from the German AEG Magnetophone, the German magnetic tape was found to be far from satisfactory.

The early German tapes used a type of oxide known as "raven red," a term borrowed from the barn paint of the same name. Literally a high grade of barn paint, the oxide was painted on a paper backing. The major deficiencies of the German tape were three in number.

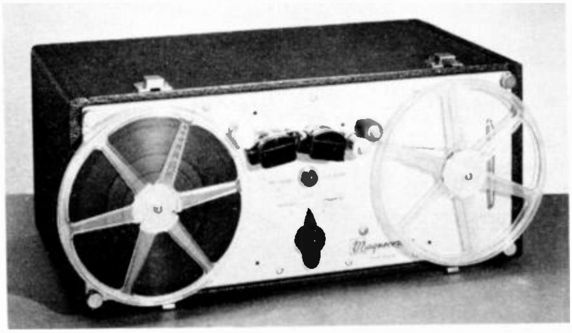


Fig. 1-9A. The Magnecord PT6-A, An Early Professional-Type Tape Recorder.

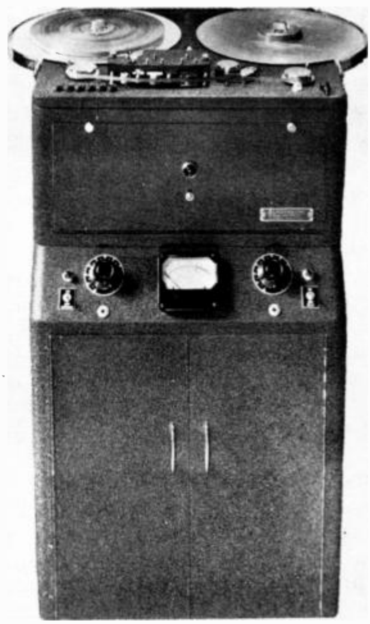


Fig. 1-9B. An Early Rangertone Magnetic Recorder.

First, the output available from German tape was very low and required large amplifiers in the recorders for satisfactory performance. Second, the tape had poor response at short wave lengths, and this necessitated driving the tape at a high velocity to maintain adequate frequency response. Finally, the uniformity of the German tape lot to lot and even within a single reel varied widely and made standardization of equipment and recording procedure difficult.

Fig. 1-9C. An Early Ampex Magnetic Recorder.

Because of the limitations imposed by the German tape, in building the Magnetophone, the Germans arbitrarily selected a high velocity speed that would give good frequency response within practical limits. The first American machines were built with a tape speed as close as possible in round English numbers to the German speed, 76 centemeters per second. The first American recorder speed turned out to be 30 inches per second, the approximate English numerical equivalent, enabling the playback of recorded German tape.

Early attempts at manufacturing magnetic tape were made by the Brush Development Company and Indiana Steel who used a unique magnetic iron material with high coercive force but which was difficult to record and erase. Minnesota Mining and Manufacturing Company in mastering the production of high-quality magnetic tape, made substantial improvements over the earlier German attempts. The task was not an easy one. The technical specifications for the production of quality magnetic tape were substantially more exacting than any other type of tape coating process previously known.

The problem of high tape speed was solved by the introduction of a new type of magnetic oxide. The new oxide gave the American tape about 12 db more output than was available with the German tape. The higher coercitivity of the oxide gave the tape excellent high frequency response characteristics, making possible the adoption of slower tape speeds.

TABLE I.

Uninterrupted Recording Time for Various Magnetic Tape Speeds and Tape Lengths.

Reel Size	Tape Length	TAPE SPEED (inches second)					
		15/16 I.P.S.	1 7/8 I.P.S.	3 3/4 I.P.S.	7 1/2 I.P.S.	15 I.P.S.	30 I.P.S.
3"	150'	30 min.	15 min.	7 1/2 min.	3 3/4 min.	1 7/8 min.	15/16 min.
4"	300'	1 hour	30 min.	15 min.	7 1/2 min.	3 3/4 min.	1 7/8 min.
5"	600'	2 hours	1 hour	30 min.	15 min.	7 1/2 min.	3 3/4 min.
5"	* 900'	3 hours	90 min.	45 min.	22 1/2 min.	11 1/4 min.	5 5/8 min.
7"	1200'	4 hours	2 hours	1 hour	30 min.	15 min.	7 1/2 min.
7"	*1800'	6 hours	3 hours	90 min.	45 min.	22 1/2 min.	11 1/4 min.
10 1/2"	2400'	8 hours	4 hours	2 hours	1 hour	30 min.	15 min.
10 1/2"	*3600'	12 hours	6 hours	3 hours	90 min.	45 min.	22 1/2 min.
14"	4800'	16 hours	8 hours	4 hours	2 hours	1 hour	30 min.
14"	*7200'	24 hours	12 hours	6 hours	3 hours	90 min.	45 min.

*"Extra Play" magnetic tape.

(All recording times are computed on basis of single track only. For dual track recording, time is doubled.)

With the improvements made in magnetic tape, recorder speeds were progressively halved, first from 30 to 15 inches per second, then from 15 to 7 1/2, 3 3/4, and 1 7/8. Table I gives the recording time obtainable at each speed for various size reels. Since in copying or duplicating tapes, it is easier to build machines that work in multiple speeds of each other, each progressive speed change was obtained by dividing by two.

At the present time there are more than forty brands of magnetic tape on the American market alone, the great majority being private labels. Some of these brands are shown in Fig. 1-10. The major manufacturers of magnetic tape in the United States are Minnesota Mining and Manufacturing Company, Audio Devices, Reeves Soundcraft, Orradio Industries, Technical Tape Corporation, and Ferro Print Company. Fig. 1-11 shows a sampling of magnetic tapes available throughout the world. The magnetic tape field is a very competitive one, accounting for rapid technological advances and improvements.

Tape speed is one important factor in determining the upper frequency limit of a recorder. Until recently it was possible to obtain, using an arbitrary rule of thumb measurement, one thousand cycles of response for every inch of tape speed. For example, if a recorder operated at a tape speed of 15 ips (inches per second), it was possible

Fig. 1-10. Samples of Magnetic Tape Brands.

Fig. 1-11. Samples of Brands of Magnetic Tape Available Throughout the World.

to get 15,000 cycles response. However, recent improvements in magnetic heads, recorder design, and still further advances in magnetic tape construction permit the doubling of frequency response. Tape response at 7 1/2 ips now goes out to 15,000 cycles and beyond.

The Revere Camera Company helped expand the growing home market for recorders by pioneering the 3 3/4 ips speed, made possible by subsequent developments in the manufacture of magnetic tape.

Fig. 1-12. A Typical Professional Recording Studio Installation of the NBC Radio Network, New York City.

Professional tape speeds have narrowed down to 15 inches per second for high quality audio work, while 7 1/2 ips is quite popular in the radio broadcasting field. In the recording industry 15 ips is the most popular speed for its convenience in editing. The home tape recorder speeds are now generally standardized at 3 3/4 and 7 1/2 ips. Voice and ordinary music recordings taped from the radio use 3 3/4 inches per second, while 7 1/2 ips is preferred for serious high fidelity home recording. At both extremes are the 30 ips speed, which still finds some advocates in the recording industry, and the 1 7/8 ips used for long time, voice-quality recordings, primarily in dictation applications.

Fortunately, however, the length of playing time need not be sacrificed for faster tape speeds since the recent introduction of a much thinner magnetic tape. With a reduction in the coating thickness of 50% and backing thickness of 30%, 1800 feet of magnetic tape can now be wound on a single 7-inch plastic reel which formerly held only 1200 feet. This, in effect, represents a 50% increase in playing time.

The tape recorder has now become the fundamental recording tool for all professional applications. A typical professional installation is shown in Fig. 1-12. Even though discs are marketed in large numbers, they are but copies from master magnetic tapes. Voices from theatre screens were originally recorded, re-recorded and edited on magnetic film. Packaged regional and network radio shows, as well as much local programming, are broadcast from magnetic tape. In all professional recording applications tape has virtually replaced every other recording medium as the prime source of high quality sound.

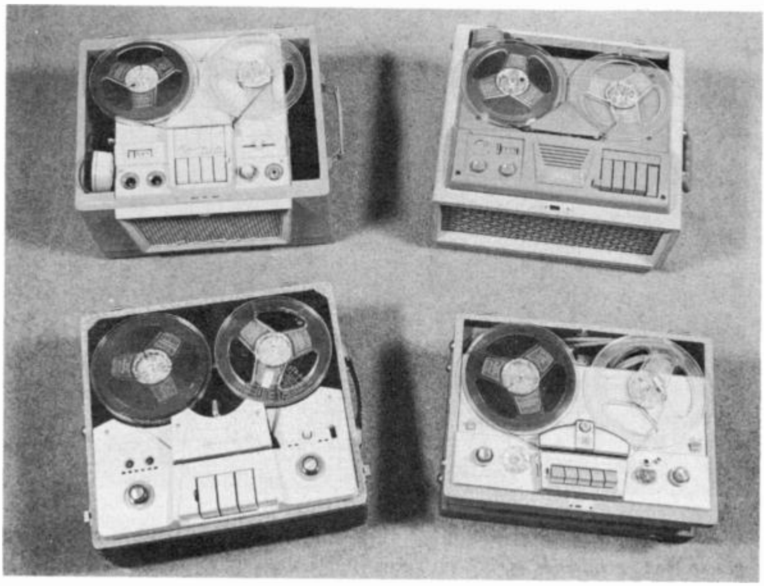


Fig. 1-13. A Number of Home-Type Recorders Featuring Push-Button Operation.

The more recent tape recorders have been ingeniously designed to make recording as simple as possible. A number of machines are pushbutton operated (see Fig. 1-13), still others have greatly simplified control mechanisms. Well on its way toward becoming America's new pastime hobby, home tape recording is as simple as clicking a camera shutter for ever increasing thousands of American sound enthusiasts. No matter how inexperienced or inept the tape recorder owner may be, the chances are overwhelming that he will come up with acceptable sound on his tapes.

CHAPTER 2

Theory of Magnetic Recording

When Dad first brings home a tape recorder to record the children's voices or practice his speech for the Company's forthcoming Founder's Day banquet, the entire family gathers around. Following the first flush of excitement and after everyone has recorded his voice, Dad is asked the inevitable question, "How does it work?"

Typically, Dad might reply, "Why, with push buttons, of course."

Yet an increasing number of tape recorder owners have not been content to be mere "button pushers," and as a result have started the still-growing cult of amateur sound hunters and golden ear addicts that have turned high fidelity into a challenging but highly rewarding hobby.

As the tape recorder owner's enthusiasm increases, his ear slowly changes from the tin to golden variety. He will drive miles to compare his tapes with those of fellow amateurs or with the results of local professionals. And, as a result, he will invariably seek to improve his technique.

And just as the camera fan soon realizes that he can improve his pictures by learning what happens when he clicks the shutter, the tape enthusiast learns how to get the most out of his recorder when he understands how it works.

There has been an abundance of papers presented before technical society synopsiums on the theory and principles of magnetic recording. The technical journals repeatedly carry highly detailed scientific material and some books have already been written on the subject of magnetic recording. Nevertheless, physicists and engineers are still not in complete agreement on some of the finer points. Synopsiums have broken up in disagreement. Controversy is still prevalent among magnetic-recording theoreticians, a healthy sign of industry growth and progress.

To thoroughly understand the technical phase of magnetic recording requires a considerable amount of prior knowledge and experience in electricity and magnetism. However, the basic principles are not too difficult to understand. To thoroughly grasp the fundamentals of magnetic recording is basic to getting the most in performance out of any tape recorder, from the simplest home machine to the finest studio recorder.

Sound Waves — Electrical Waves

Sound, by its very nature, is an auditory sensation experienced through the ear. Sound is caused by an alteration in pressure, particle displacement or particle velocity produced when the air is set into

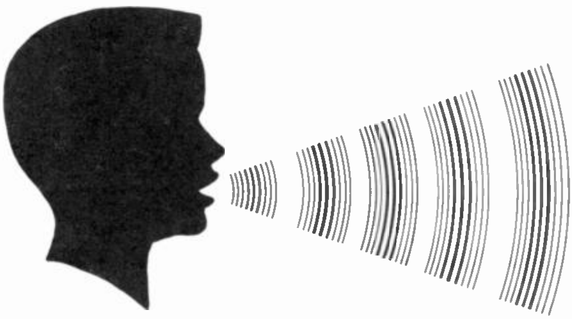


Fig. 2-1. Sound Is Caused By Alteration in Pressure, Particle Displacement, or Particle Velocity Produced When the Air is Set in Motion.

Fig. 2-2. The Action of Sound Waves Radiating From a Single Source Can Be Compared to Dropping a Stone Into a Still Pond.

motion. (See Fig. 2-1.) The action of sound waves radiating from a single source can be compared to dropping a stone into a still pond. The waves of water move outward in all directions, continuously expanding as shown in Fig. 2-2.

Sound may be produced by a vibrating body such as the diaphragm of a loudspeaker or a violin string or, for example, an intermittent air stream such as a human voice or lip-reed instruments. Sound travels through the air in surges of energy, consisting of a condensation or a high-pressure pulse of air followed by a rarefaction or a low-pressure pulse. Anyone who has stood at the seashore, fascinated with the ocean waves crashing against the beach, will note another similarity to sound waves. The ocean wave surges forward, draws back, and its crest plunges forward once again.

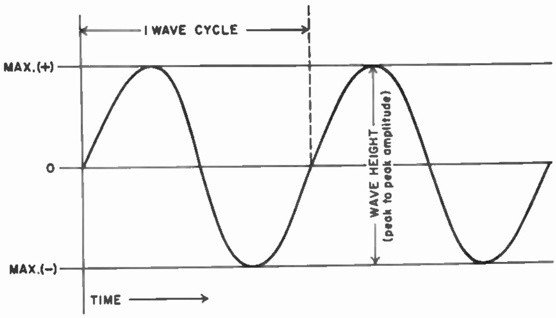


Fig. 2-3. A Sinusoidal Wave.

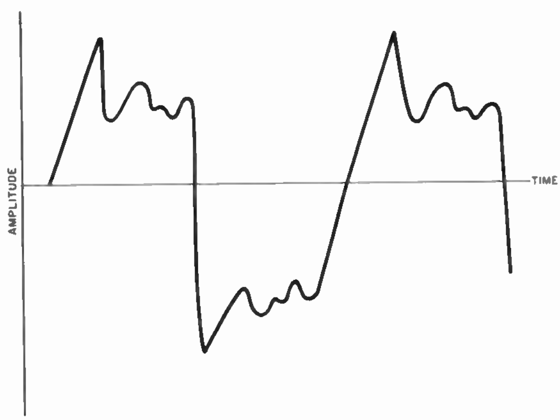


Fig. 2-4. A Complex Waveform.

The human ear receives the sound waves and converts them into electrical impulses which are "translated" by the nervous system of our body.

Sound waves, like electrical waves or impulses, can be graphed. Variations of pressure — concentration and rarefication of the air particles — when plotted, form a wave. If the sound consists of only one frequency and is of constant strength, the wave will be sinusoidal in shape. Sound waves of a human voice or a musical instrument are composed of many frequencies, each with its own particular strength, all existing at one time.

Fig. 2-3 shows the amplitude of a sinusoidal wave and the number of time it repeats itself in a second. The height of the diagramed sound wave indicates the intensity or loudness of a sound, while the number of complete wave cycles per second gives the pitch of sound. The more wave cycles per second, the higher the pitch. Fig. 2-4 shows a complex wave form indicating a number of frequencies of different amplitudes existing at one time.

Again, this phenomena can be compared to dropping a stone into still water. The smaller the stone, the weaker and smaller the ripples. When a large stone is dropped into the water, the waves will be large, strong in force, and will radiate further.

The Decibel — Db.

Resembling a variable amplifier, the human ear is ingeniously designed. It is sensitive to the weak sound of a scampering mouse while limiting the valcanic roar of a jet engine to a tolerable limit. Nature enables us to hear sound intensity logarithmically for our survival and protection. The louder the sound, the less sensitive our ear is to it. The variation in sound intensity between the dropping of a pin and the explosion of a bomb is many millions of times. If we were to suddenly hear linearly, or in exact proportion to the intensity of sound, it is doubtful if we could survive hearing the blast. Fig. 2-5, shows the difference between a linear and logarithmic function.

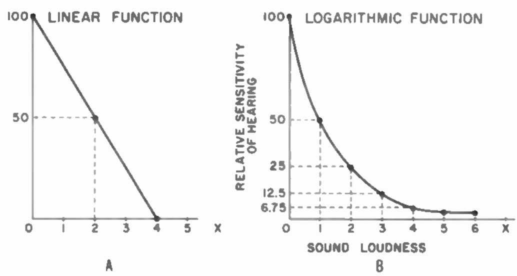


Fig. 2-5. Graphs Showing the Difference Between a Linear Function (A) and a Logarithmic Function (B).

Electrical energy can be expressed and measured in several ways, such as in volts or watts. The volt is a unit of electrical potential and the watt is a measure of power. However, since in recording, sound is received by a microphone and converted into an electrical wave, the intensity of this wave is expressed in decibels. This is proportionate to the log of a voltage or power ratio, representing the acoustic properties of our hearing.

The bel is named after Alexander Graham Bell, pictured in Fig. 2-6, who discovered that humans hear sound intensity logarithmically. The audible range of sound is so large it is more convenient to use a smaller measure scale, decibels. The decibel is one-tenth of a bel and is an expression of the ratio of one power to another power.

If we double the electric power in a system, we increase the sound level 3 db, or a perceptible amount. A really trained ear can hear a 1 db difference in level while most people can just distinguish a 2 db change in the sound level of voices or music. Therefore, when we double the loudness of a sound, it is in effect only 3 db higher. When a sound is four times as loud, it is 6 db higher. If a sound were eight times louder, the difference would be 9 db.

Fig. 2-6. The Bel is Named After Alexander Graham Bell Who is Pictured Here.

If an electric circuit such as an amplifier is terminated in a reasonably constant load such as a loudspeaker, decibels can also be expressed in terms of voltage. The relationship becomes such that if one doubles the voltage, there is an increase of 6 db.

Frequency

The number of waves per second — the frequency of the wave — is measured in terms of cycles per second (cps) in the case of both sound and electricity. A low-pitched tone causes the air to vibrate slowly, perhaps only 30 times a second, the lowest frequency audible. The highest frequency is generally between 14,000 and 18,000 cps for young and middle-aged people. Older people often cannot hear above 5 or 6,000 cps.

When the vibrating air waves reach the sensitive diaphragm in a microphone, they cause it to generate an alternating electrical current of the same frequency. As the diaphram moves in, it creates a positive current, and as it moves out, it creates a negative current or vice versa.

Intensity

The intensity of the vibrations of the sound wave are also faithfully reproduced in terms of voltage, generally expressed in db.

The microphone translates a loud sound into a large voltage, while a softer sound results in a weaker signal.

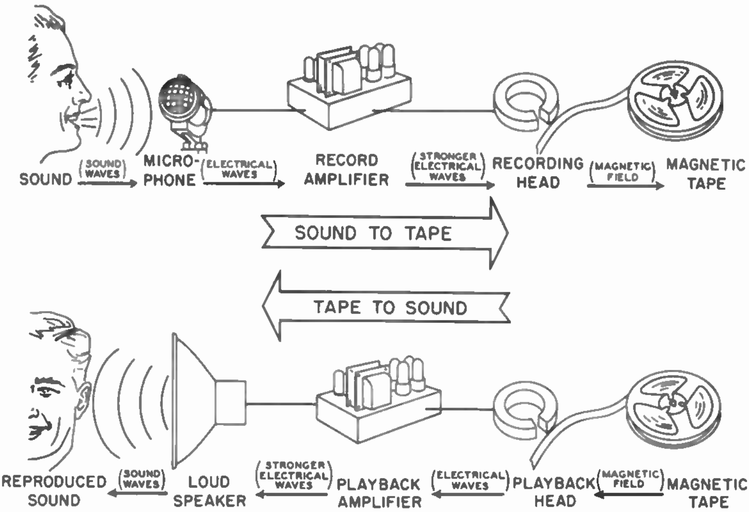


Fig. 2-7. From Sand Waves to Tape and From Tape to Sound Waves.

The electrical waves of alternating voltage go from the microphone through several stages of voltage amplification, through a low power stage; and then transformed into current, they enter the recording head which is actually an electromagnet. This process is clearly shown in Fig. 2-7.

Electromagnets

Magnetic recording is an extremely complex process, involving a study of advanced physics. The labyrinthics of magnetic theory are deep and dark, and even experienced academicians sometimes lose their way. The following explanation is intended to give a general idea of the magnetic recording process rather than a specific, highly technical explanation of how it works. No mention is made of either a direct current or an alternating-current bias, since the theories involved are lengthy and require considerable use of higher mathematics and special treatment of the characteristics of magnetic materials.

An electromagnet is made by wrapping an iron core with wire to form a coil. When current flows through the wire, the core becomes a magnet. One end, or pole, of the iron core is a north pole. The other end is a south pole. If the direction of the current flow changes, the polarity of the electromagnet is reversed.

A strong current produces a strong magnetic field, while a weaker current results in a correspondingly weaker field. Similarily, an alternating-current cycle causes each pole of the electromagnet to change through one complete cycle in polarity from north to south and back to north.

Around any magnet is an area of magnetic attraction commonly known as a "field," which is illustrated in Fig. 2-8 in terms of lines of magnetic force. The more closely spaced are the lines, the stronger the magnetic attraction.

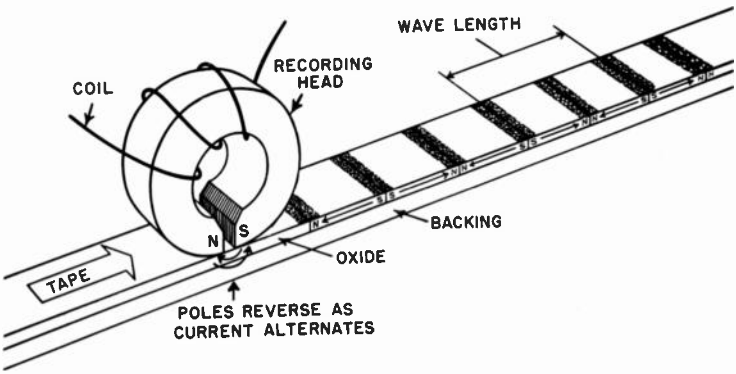


Fig. 2-8. Around Any Magnet is a "Field". A Strong Current Produces a Strong Field and a Weaker Current Produces a Correspondingly Weaker Field.

These lines of magnetic force also have direction. Physicists have arbitrarily defined force lines as going from north to south outside the magnet, then completing their circuit by going from south to north inside the magnet.

The Magnetic Recording Head

In the case of the recording head as shown in Fig. 2-9, the core is cut in a retilinear shape with the poles almost touching, as little as .00025", or 1/4-mil apart. This distance is referred to as the "gap" of the head.

The cores of the recording head are magnetically "soft." That is, the head becomes magnetized easily and instantly when current flows into the coil, but loses its magnetism just as rapidly when the current stops. The recording head is unlike a permanent magnet, or even the oxide on the tape itself, which is made from a magnetically "hard" material. The iron oxide coating on the tape, being magnetically "hard," will hold its magnetism for an indefinite period of time.

Whenever a surge of positive current from the microphone goes through the coil, it magnetizes the recording head in one direction.

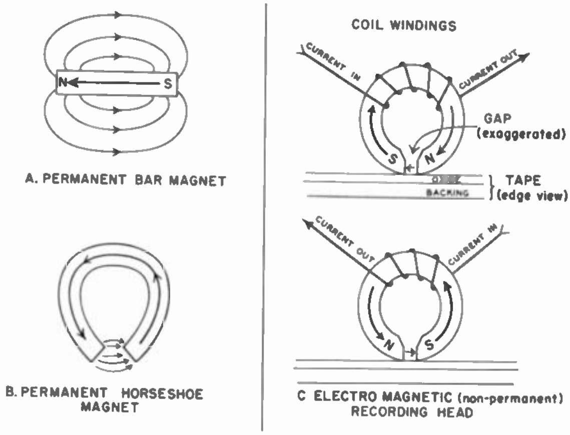


Fig. 2-9. Similarity Between a Permanent Magnet Structure and a Magnetic Recording Head.

When the current alternates and sends a surge of negative current into the coil, the head is magnetized in the opposite direction, or the poles alternate between north and south.

Tape Magnetization

When the iron-oxide coated tape is in contact with the recording head, it offers an easier path for the magnetic lines of force to follow than does the air gap. Therefore, following the course of least resistance, most of the magnetism gets across the gap by flowing through the iron-oxide coated tape.

While the magnetically "soft" iron ring of the electromagnet loses its magnetism when the current stops, the magnetically "hard" coating on the tape retains its magnetism and the magnetized area becomes a small bar magnet itself. Because the lines of force left inside the tape point in one direction, that direction must necessarily be north. The other end, therefore, becomes south. This is shown at A, in Fig. 2-10.

At B, the current entering the coil is zero at its point of alternation and, consequently, does not create a magnetic field at that time. As a result, the tape moves a fraction of an inch without being magnetized any further.

However at C, when a surge of negative current comes into the coil, a magnetic field in the opposite direction is set up, causing the polarity of the electromagnet to reverse itself.

Again, the lines of magnetic force at the poles find it easier to flow through the iron-oxide coated tape than across the air gap. Thus the tape is permanently magnetized, but this time, in the opposite direction.

At D, the tape has again moved, but since the current is not flowing, no new lines of force are set up at that point.

As a result, the surges of alternating current leave the tape permanently magnetized by setting up a series of lines of force of opposite polarity, creating a series of bar magnets on the tape.

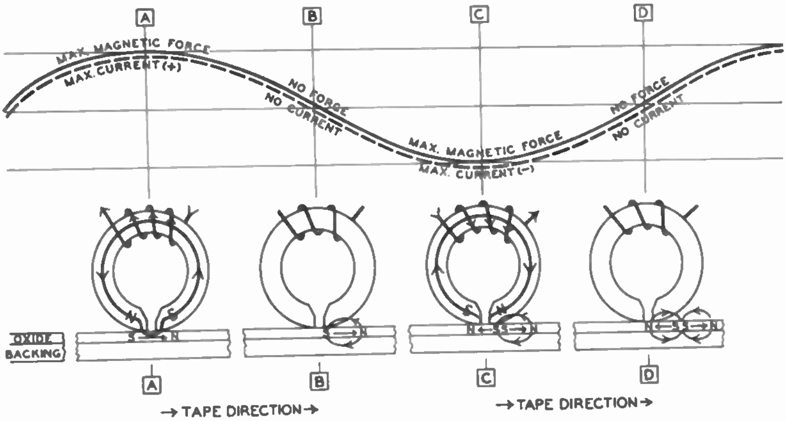


Fig. 2-10. Shown Here is the Magnetization or Recording Process. Effects of Bias and Hysteresis are Not Shown to Simplify the Drawing.

Because the tape is moving, these poles occur at recurring intervals along the tape, in a definite pattern. The frequency of the signal and the speed at which the tape moves, determines the distance between poles, while the strength of the current, or voltage, determines the magnetic strength of each pole.

As shown in Fig. 2-10, the magnetic pattern on the tape, for a 30 cps tone, consists of 30 magnetic fields pointing toward south, alternating with 30 magnetic fields pointing toward north.

In effect, the oxide coating of the tape is broken up into 60 individual bar magnets, laid end to end, every second the tape moves across the gap. On a tape recorder operating at 7 1/2 ips, the 60 bar-magnet patterns would cover a space of 7 1/2 inches on the tape. A 10,000 cps note would be represented on the tape as 20,000 such magnetic patterns in the same space of 7 1/2 inches.

Some of the actual magnetic patterns on tape can be made visible by a simple process. A short piece of recorded tape is dipped into a solution of lighter fluid and carbonyl iron, then is allowed to dry. As the lighter fluid evaporates, the very fine particles of carbonyl iron will remain magnetically attracted to the tape in definite patterns visible to the naked eye. (See Fig. 2-11.) A much more definite pattern can be observed through a microscope as shown in Fig. 2-12.

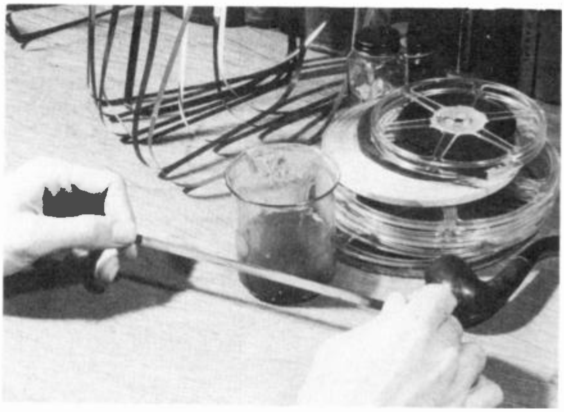


Fig. 2-11. After the Solution of Lighter Fluid and Carbonyl Iron Has Dried, Very Fine Particles of Carbonyl Iron, Visible to the Naked Eye, Will Remain Attached to the Tape.

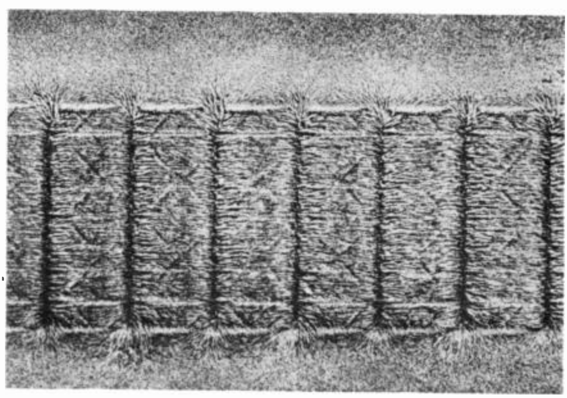


Fig. 2-12. Microscopic Enlargement of Visible Magnetic Tracks.

The heavily magnetized intervals on the tape — the poles — attract the most carbonyl iron particles, appearing as narrow lines across the tape. The stronger the pole, the heavier the line. The lower the frequency of the current, the greater distance between lines. The actual wave length of the original tone is equal to twice the distance between lines.

WRH

The Recording Process

In summary, then, sound waves pulsate through the air, and cause the diaphragm in the microphone to vibrate accordingly. This produces corresponding electrical pulsations in the microphone which are boosted in strength by an amplifier. The amplified pulsations are then fed into the recording head where corresponding magnetic fields are created, which, in turn, leave their magnetic patterns on the tape.

The Playback Process

In playing back a recorded tape, the recording process is more or less repeated, only in reverse. During the recording process, an electric current in a coil was used to create a magnetic field. In playback, a magnetic field moved through a coil is used to create an electric voltage.

A basic principle of electricity is that a surge of electrical voltage can be generated by moving a bar magnet (or its surrounding magnetic field) through a coil. By moving a series of magnets of opposite polarity (or their fields) through a coil, an alternating electrical voltage will be produced. In the recording process, the tape was figuratively broken up into just such a series of short, permanent-bar magnets.

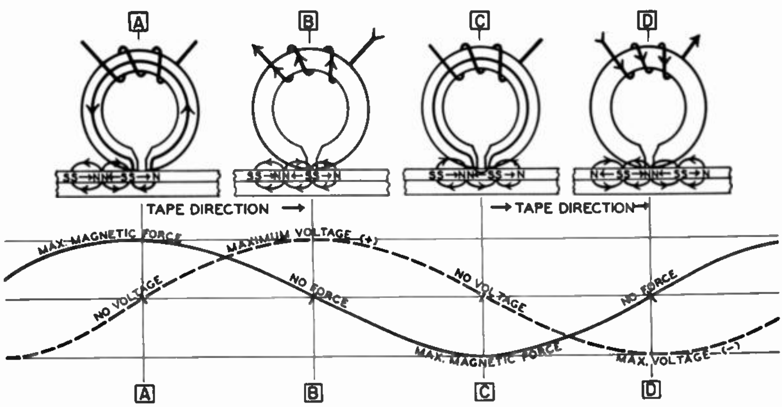


Fig. 2-13. The Playback Process.

What actually produces the voltage is the change in the magnetic field from positive to negative. The peak surge of current comes at the moment the polarity of the field is changing most rapidly. Therefore, when the magnetic force in the head is maximum, no voltage is produced. See point A in Fig. 2-13. At the point where the polarity of the head is reversing, the maximum voltage is produced as shown at B in Fig. 2-13.

In the playback process, the bar magnets on the tape are not actually moved through the coil of the electromagnet. Part of the magnetic field of each bar magnet, however, is. What happens is that the iron ring of the electromagnet playback head temporarily routes the bar magnet's field through the coil.

In Fig. 2-13 at A, it can be seen that a north pole and a south pole are on either side of the gap. Normally, the lines of magnetic force stay close to the tape, but because it is easier for the magnetic field to follow the iron ring (a much better conductor) than jump the air spaces at the gap, it does just exactly that.

At A, therefore, the magnetic force in the head is maximum but the voltage is zero.

When the tape has moved a fraction of an inch farther, as at B, a strongly magnetized line, a south pole, this time is at the gap. The iron ring of the electromagnet serves no useful purpose to the field, so it is ignored, and magnetic strength in the head is reduced to zero However, since this is the point where polarity of the head changes most rapidly, maximum voltage is produced.

But at C, the situation again occurs where one pole is on one side of the gap, and an opposite pole on the other. As in A, the magnetic field again takes the easiest route and flows through the soft iron ring. Maximum magnetic strength is produced in the head, but no voltage, since this is the point of alternation in the voltage wave from positive to negative.

At D, polarity of the head is again at the point of reversal, and consequently this sudden change in magnetic force results in the maximum surge of voltage. Since the surges of voltage alternate between positive and negative with the same frequency as that which was recorded on the tape, they can be amplified and fed into a loudspeaker to once again produce the original sounds.

CHAPTER 3

The Motorboard—Tape Transport Mechanism

The tape recorder is not only an electronic instrument but is also mechanical in its operation. A television set, by way of comparison, consists of a series of electronic components and has, in theory, an eternal life. Tubes will wear out and require replacement. Occasionally a capacitor may break down. But there is no friction to limit its life. A tape recorder; however, is exposed to mechanical wear through its moving parts.

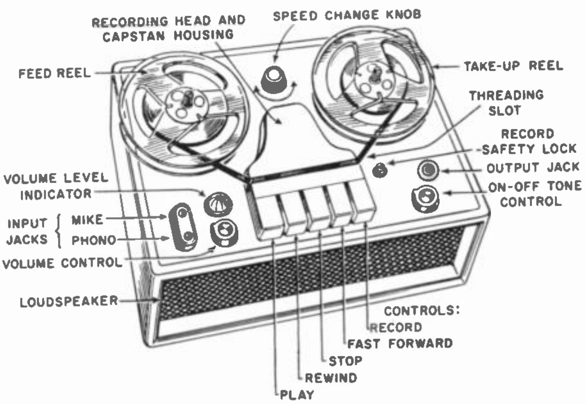


Fig. 3-1. A Typical Two-Speed Recorder with Principal Features Indicated.

The tape recorder operates on basically simple mechanical concepts. Most people with mechanical ability can study the mechanism and determine how it works and what each part is supposed to do. In many cases tape recorders are less complicated than record changers since there are no critical trip or cycling adjustments. However, many more stringent requirements are made on the tape mechanism.

The job of a record player is to rotate a disc, while the job of a tape recorder is to pull a tape, although both are designed to operate at a constant speed, the problem of pulling a tape past a magnetic head at a constant speed is considerably more complex than rotating a turntable. The disc player turntable serves as a flywheel, providing excellent instantaneous speed characteristics. A tape has very little inertia and its stabilization must come from an external flywheel.

A disc player turns only a single shaft at one, or at the most, three or four speeds. In contrast, the tape recorder capstan must often be able to operate at one of two different speeds. Its take-up reel operates at an infinite number of speeds within a given range. Its supply reel spindle must both rotate freely during certain operations and supply back tension during others, while having the ability to operate at high speed during rewind. All the shafts must be controlled by a system of clutches and brakes to facilitate rapid changes in tape direction and speed, still providing sufficient tension to avoid tape slack. The drawing in Fig. 3-1 illustrates a typical two-speed tape recorder with its principal features pointed out.

Primary Function of the Motorboard

The motorboard is the actual mechanism of the tape recorder. The motorboard moves the tape past the magnetic head at a uniform rate of speed, winds it on a take-up reel, rewinds it, and has the ability to go fast forward. The fast forward and rewind functions enable the rapid location of any desired portion of the recording within the reel. A typical motorboard — top and bottom view — is shown in Fig. 3-2A and B.

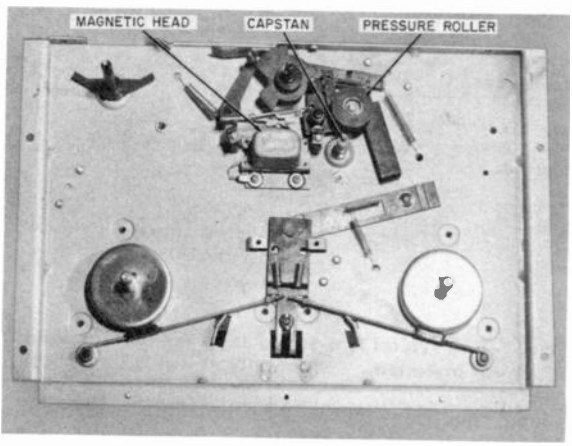


Fig. 3-2A. Top View of the Ekotape Motorboard with Top Plate Removed.

Secondary Functions of the Motorboard

A definite evolution in simplicity of recorder operation and design can be traced from the early professional tape recorders to the machines of present construction. The complexity of early home-type tape recorders frightened most housewives intent on recording Junior's early prattlings. School teachers were equally alarmed but later proved to be one of the biggest single consumers of tape recorders during the early years of the magnetic recording industry's growth.

The threading of early tape recorders was a major undertaking, similar to threading up a motion picture projector. The magnetic

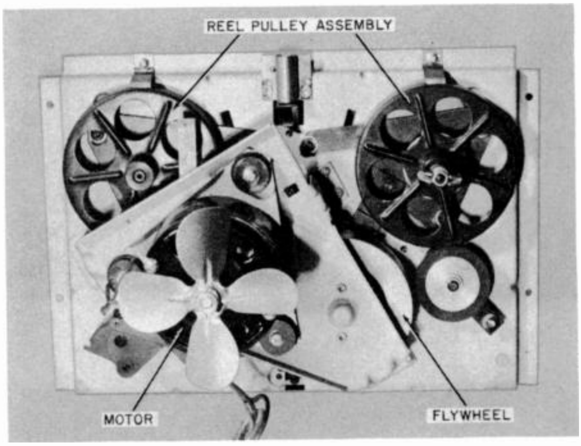


Fig. 3-2B. Bottom View of Ekotape Motorboard.

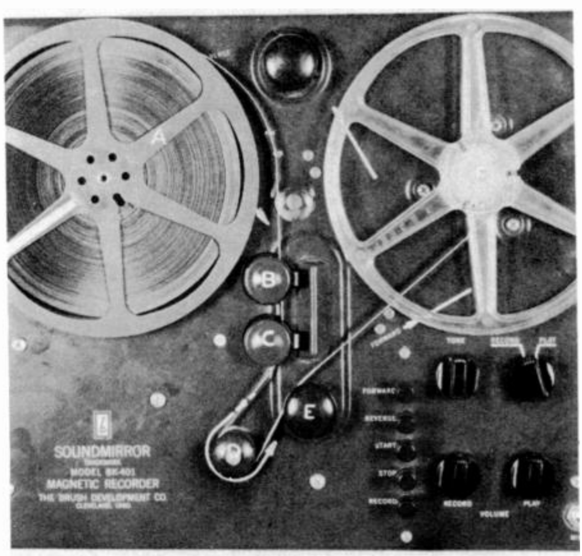


Fig. 3-3. The Threading Process of the Early Brush Recorder Model BK-401.

tape was first wound about a series of guides, past the head, to the capstan, and then onto the take-up reel. (See Fig. 3-3.) Present day machines are threaded up by simply dropping the tape into a slot and winding it about the take-up reel as shown in Fig. 3-4.

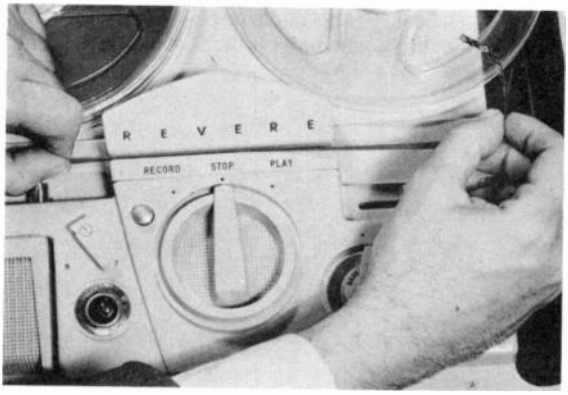


Fig. 3-4. Threading of a Present-Day Recorder.

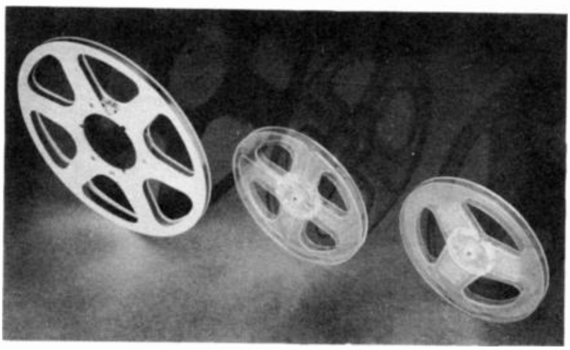


Fig. 3-5. Three Types of Reels Now in Use.

There has also been a steady improvement in plastic reel design to make threading as simple as possible. The "Scotch" brand 7-inch plastic reel facilitates threading, for example, through its slot thread-up device. It is merely necessary to place the tape in a slot and rotate the reel a turn to anchor the tape. Ampex introduced to the 10 1/2-inch NARTB reel, the simplified loop, and post threading device. The RCA 7-inch reel follows the pattern used in many European Countries, with a slot running the entire length of the reel, as shown in Fig. 3-5.

There is also a well-developed trend away from knob type controls toward push-button or piano keyboard operation, again simplifying operation.

It was relatively easy for the novice to damage the earlier recorders through improper use. Today's recorder is ingeniously designed to make it as fool-proof as possible. If the wrong button should be depressed, it is not possible to damage the recorder or break the tape.

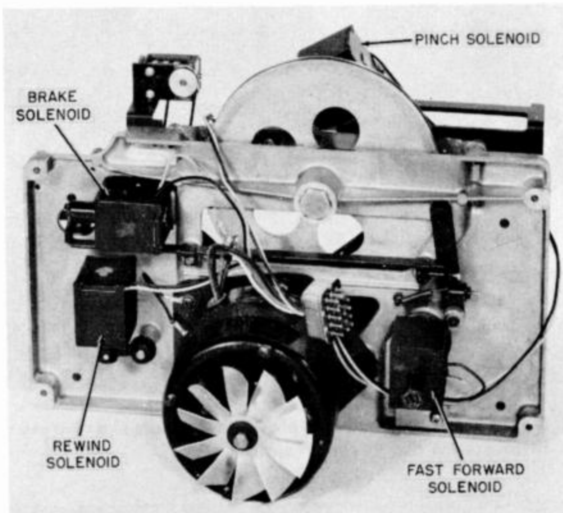


Fig. 3-6. The Ampro Recorder Uses Solenoid Controls for All Mechanical Functions.

Solenoid controls are now incorporated on practically all of the professional recorders and some home-type recorders. As an example, the Ampro recorder, shown in Fig. 3-6, uses solenoid controls for all mechanical functions. There are four solenoids in all used, and perform the following functions: (1) engages the rubber pressure roller against the capstan; (2) operates reel spindle brakes; (3) engages rewind drive; (4) engages fast forward drive. They also serve to disengage the rubber rollers when the machine is not in operation. This eliminates the possibility of accidentally leaving the capstan and rubber pressure roller engaged, producing flat spots on the rubber roller.

Earlier machines were also damaged by twisting control knobs too hard which bent lever linkages. It was also easy to spill tape from a reel, wrapping it around the capstan and pressure roller.

During rewind several recorders prevent excessive head wear by disengaging the magnetic head from the tape during fast forward or rewind. Magnetic tape construction has also been improved, eliminating the possibility of gumming up the record head with oxide accumulations which flaked off the tape. In addition, lubricants have been added to magnetic tape to minimize head wear and eliminate squealing and high-frequency flutter.

Most recorders incorporate a safety interlock on the record control so that the record button cannot be accidentally depressed, erasing the desired recording. Only when the safety interlock is disengaged, as shown in Fig. 3-7, is it possible to depress the record key.

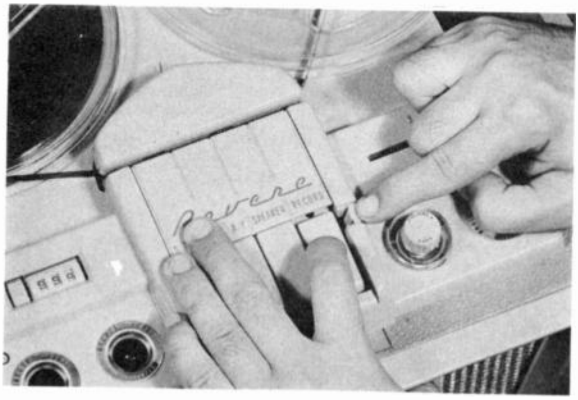


Fig. 3-7. A Recorder Which Incorporates a Safety Interlock on the Record Position.

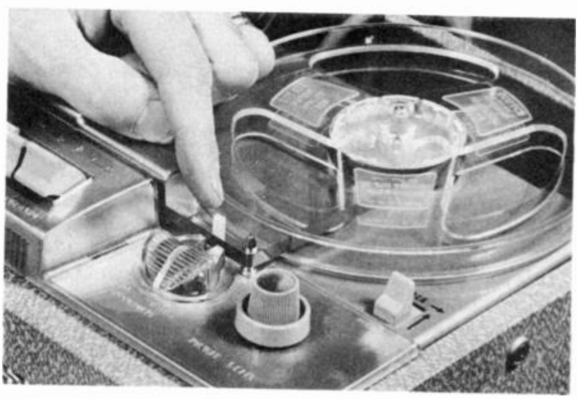


Fig. 3-8. This V-M Tape Recorder Employs an Automatic Shut-Off Switch.

The V-M model 700 tape recorder, shown in Fig. 3-8, incorporates an automatic shut-off switch. When the tape is threaded through the guides the shut-off switch is engaged. The recorder is then shut off automatically if the tape should break or the end of the reel is reached.

The ability to rewind the tape, operate the recorder at a fast forward speed, simple threading, and fool-proof controls are all secondary functions of the motorboard. The primary function of the motorboard is to provide a drive mechanism to move the tape past the magnetic head at as uniform a rate of speed as possible.

Speed Variations

The necessity of maintaining a constant speed is critical in all tape recorders and has required a major amount of engineering time to satisfactorily solve the problem. Simplified controls have added immeasurably to the tape recorder's popularity and have helped mushroom the magnetic recording industry's sales growth since 1947. But the problem of simplifying the operation of the tape recorder is easy contrasted to devising a positive method of obtaining constant tape speed.

Long-Time Speed Variations

There are two types of speed variations affecting the performance of a tape recorder. They are: (1) long-time speed variations, and (2) instantaneous speed variations.

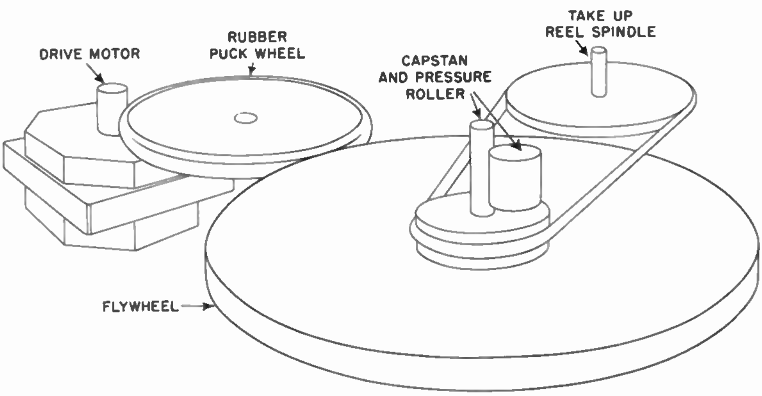


Fig. 3-9. A Typical Friction-Drive System.

Long-time speed variation is especially important in radio broadcast work. If a radio station makes a 29-minute recording, it is imperative that it last precisely 29 minutes, not running thirty minutes or only twenty-eight.

Among the reasons why tape does not run at a constant long-time speed are these: (1) Tape is pulled by a capstan and pressure roller which permits a certain amount of slippage to take place. (2) Tape itself expands and contracts with changes in temperature and humidity, causing the playing time to vary. (3) Tape recording mechanisms often use non-synchronous or induction-type motors in which speed is affected by variations in load and line voltage. Even on machines using synchronous motors, the capstan flywheel assembly is generally driven by a rubber puck drive or belts which are not positive in their drive. (See Fig. 3-9.)

In tape recorders the tape is pulled by a capstan, a shaft around which the tape is wrapped. Therefore, the tape is not positively driven. In a positive drive system, teeth in one gear engage teeth in another, or teeth on a sprocket engage perforations in a film, providing a drive in which slippage is impossible. In a friction drive, one roller turns another roller, both rollers having a smooth surface. Traction is obtained by friction and is not positive. In any type of friction drive system, a certain amount of slippage is always present. Gear drives introduce flutter which require an elaborate filtering mechanism to remove.

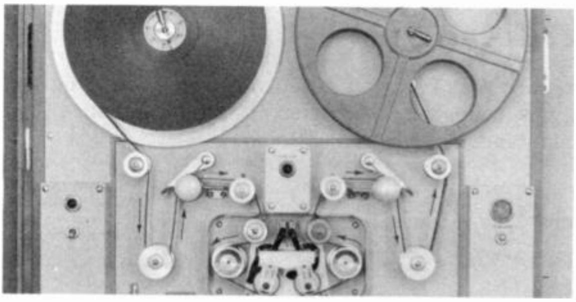


Fig. 3-10. This Westrex Magnetic Film Recorder Uses a Positive-Drive System.

Excessive cost of positive drive systems and perforated film for these machines is the prime reason for using friction drive and tape for most recording applications. An Ampex 300, costing approximately $1,700, will give comparable recording quality to the Westrex magnetic film recorder, for motion picture use shown in Fig. 3-10, which incorporates a positive drive system, and leases for $8,500 for 12 years. For 33 minutes of recording, 35 mm magnetic film for the Westrex costs about $125 while the quarter-inch tape for the Ampex Costs $3.30. Both will do approximately the same recording job. However, positive drive is necessary in motion picture recording to have sound synchronized exactly with the lips of the actors.

Expensive tape recorders designed for critical broadcast work generally have speed variations of only a few seconds in a 30-minute recording. In the less expensive home machines the speed variation in extreme cases might run as much as several minutes in a 30-minute recording.

Apart from the necessity of maintaining exact speed in professional broadcasting and recording work, long-time speed variations also affect true pitch. Although no wow or flutter is present, if a recorder is running slow the pitch will be low. If music is played at other than true pitch, the effect is disconcerting. Even though the variation is slight, musicians and music lovers with a trained ear are able to detect the pitch change.

Instantaneous Speed Variations

Another critical feature of a tape drive mechanism is the importance of instantaneous speed stability. Instantaneous speed variations are of an exceedingly short duration, generally less than a very short fraction of a second or, at the most, a half a second. Speed variations of a short duration cause wow and flutter, twin menances to good recording results. The wow meter, shown in Fig. 3-11, will measure these variations in speed which are then expressed in percentages.

Fig. 3-11. A Wow-Meter Which Measures Minute Variations in Tape Speed and Expresses Them in Percentages, Manufactured by Furst Electronics.

Among the factors causing instantaneous speed variations are these: (1) Flat spots which develop on the rubber rollers. (2) Slipping of the drive rollers and tape on the capstan. (3) Sticking of the tape to the heads or guides. (4) Bent or eccentric shafts. (5) Motor "hunting" or "clogging." (6) Irregular feed or take-up reel operation.

Wow and flutter are particularly noticeable even to untrained ears and have a very disturbing quality. It is without question the most objectionable feature of low-priced tape recorders. It is interesting to note that the ear can detect instantaneous speed variations of as little as one-tenth of one per cent. Many of the home type tape recorders have instantaneous speed variations above one-half of one per cent.

Wow is a relatively low frequency speed variation, noticed especially on sustained notes such as in piano or organ music and chimes. When wow is present, a musical note that is held will sound unsteady. Its pitch will waver, producing a very irritating effect.

WRH

A still shorter speed variation will result in flutter. Flutter causes the sound to be of a garbled nature, again showing up in piano music especially. Often when a recording does not sound clean the cause will be flutter, even though it may not be diagnosed as such. High-frequency flutter is often mistaken for other types of distortion.

Capstan Drive

The very heart of a tape recorder is the capstan drive. The tape is pulled by a roller pressing the tape against a rotating shaft. The rotating shaft is known as the capstan. In many older machines rubber or composition covered shafts were employed to pull the tape. The rubber capstan was attached to a common shaft with a flywheel and was motor driven. The early Brush, Eicor, and International Electronic Company tape recorders, for example, used a rubber roller to pull the tape. The early Eicor tape recorder is shown in Fig. 3-12.

Fig. 3-12. An Early Eicor Tape Recorder.

However, the introduction of lubricated magnetic tape in 1949 necessitated a more positive drive and required the use of a pressure roller against a steel capstan. This is shown in the photo of the Magnecord model PT6-A (Fig. 3-13).

Importance of a Large Capstan Diameter

Because of necessary physical stability, a fairly large diameter capstan is required. If the capstan is at all eccentric it will pull the tape faster at one point in its revolution than at another, introducing serious wow and flutter. A small capstan will also have a tendency to whip. To obtain the required rigidity, it is generally necessary to use large diameter capstans.

Another reason for a large diameter capstan is to minimize speed variations caused by differences in the caliper of magnetic tape.

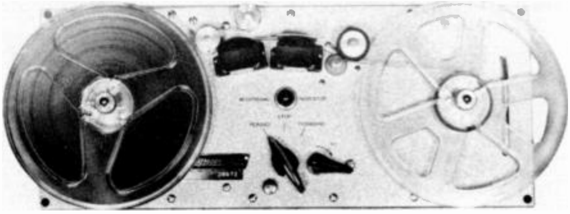


Fig. 3-13. The Magnecord Model PT6-A Tape Recorder.

Since magnetic tape is wrapped around the capstan, the portion of tape next to the capstan will be compressed and the portion of tape away from the capstan will be elongated. The velocity of the tape will be at some point midway between its two surfaces. Therefore, if the tape thickness should vary, its velocity will also vary. But if the capstan is large in comparison to the tape thickness, variations in tape thickness will be, for all practical purposes, negligible.

However, large capstans have one main disadvantage. If the capstan size is increased, the flywheel size must also be large, since more inertia is needed to stabilize a large, slow speed capstan than one that is small but high speed. The capstan size of most recorders varies from slightly under an eighth of an inch to approximately five-eighths of an inch.

Methods of Motor Drive

In order to stabilize the capstan's rotation and provide the most uniform tape speed possible, a flywheel is attached to the capstan shaft. The motor then drives the flywheel by one of the following methods: (1) Puck drive. (2) Belt drive. (3) Direct drive.

Puck Drive

The high speed of the motor shaft requires that some method of speed reduction be incorporated into the drive system. The puck drive is a method of driving the rim of the flywheel by a friction process. In some mechanisms such as the Ampex 300, the flywheel is equipped with a rubber tire and is driven directly by the motor shaft as in Fig. 3-14A. Another type of puck drive, shown in Fig. 3-14B, which is used by nearly all home-type recorders, employs an intermediate puck roller which in turn drives the flywheel.

The rim-drive method, although lacking some of the possibilities of the other drive methods, results in very satisfactory performance, even when produced to meet competitive prices.

For rim-drive applications, the motor shaft is usually equipped with a metal pulley of small diameter. This pulley is a bushing positioned onto the shaft by means of a set screw.

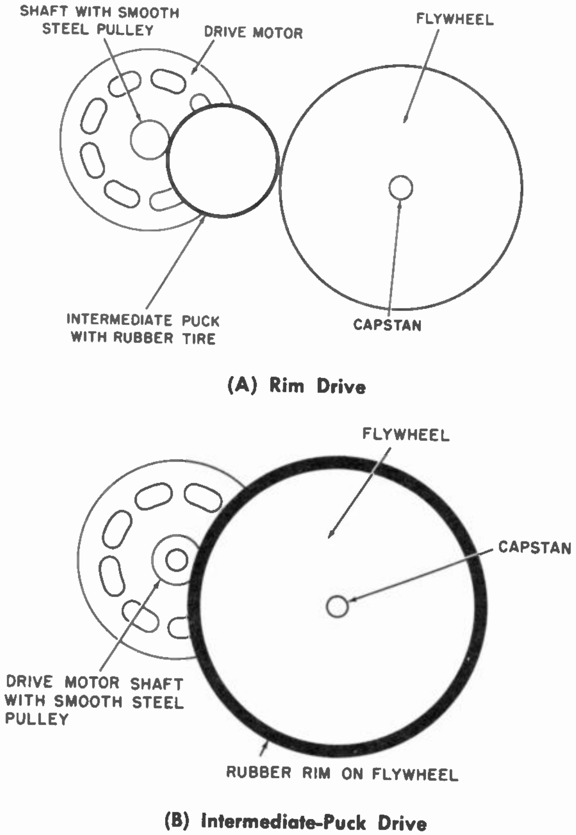


Fig. 3-14. Two Methods of Puck Drive.

For the intermediate puck drive system a rubber tired wheel, called the idler wheel (see Fig. 3-15), is mounted so that the motor pulley will drive it. The idler wheel, in turn, will drive the capstan flywheel rim. The center bearing of the idler wheel is mounted on a plate. Although there are design variations in the mounting of this bearing, the purpose of each is threefold: (1) Insure a correct wedge angle of the idler wheel between the flywheel rim and the motor pulley, exerting enough traction to transmit the torque and yet not stall. (2) Keep the idler wheel movable horizontally so that spring tension may be applied to the bearing mounting in the direction of the wedge angle, providing constant pressure of the idler wheel against both the flywheel rim and the drive pulley, and (3) Maintain alignment of the idler wheel in a vertical plane, with the motor pulley and the flywheel rim. An exploded view of a typical bearing mounting system is shown in Fig. 3-16.

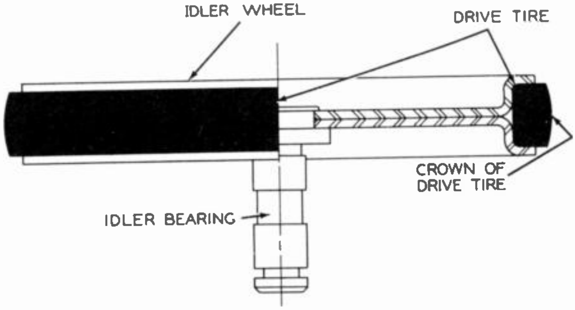


Fig. 3-15. Construction Detail of an Intermediate Rubber-Puck Wheel.

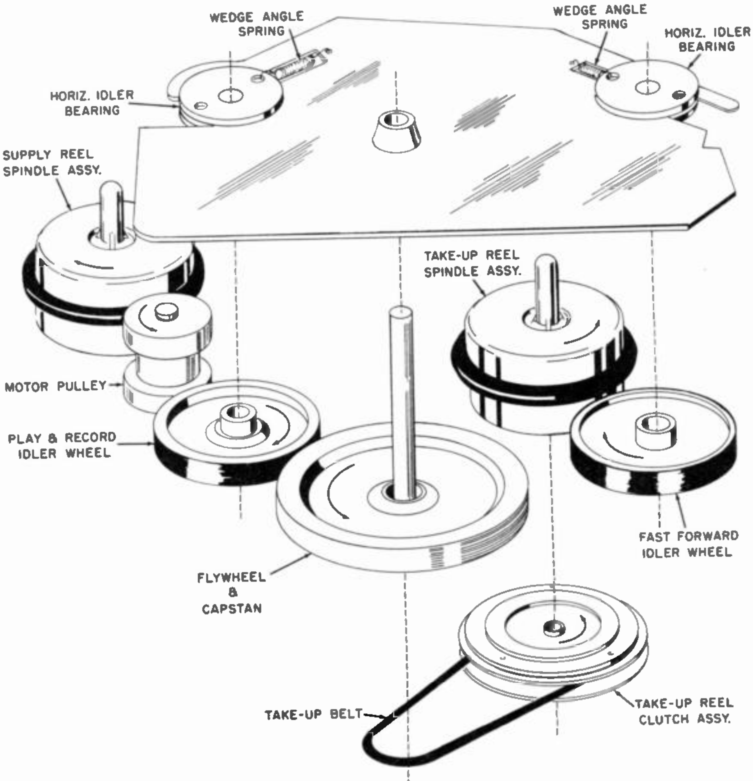


Fig. 3-16. Exploded View of a Typical Bearing Mounting.

The diameter of the motor pulley is determined by the diameter of the flywheel, the speed of the motor shaft, the capstan diameter, and the loss in working the rubber of the drive tire. The diameter of the idler wheel does not affect the speed ratio but is selected and designed according to the curvature which will best deliver the torque required.

Due to the sturdiness of the motor itself, the greatest source of trouble in rim drive motors is associated with the idler drive wheel. All parts of the idler wheel mounting should be inspected for extraneous material or gumming. The parts should be thoroughly cleaned and re-lubricated, if needed, in order to prevent speed reduction. The sleeve bearings of the idler wheel are usually lubricated through a felt washer.

This bearing is in most cases lubricated for the life of the motor, but if it is felt necessary to add lubrication, it should be done with extreme care to avoid over-lubrication.

The tire of the idler wheel is of natural or synthetic rubber and, after being cemented to the idler wheel, it is ground with a crown to be absolutely concentric with the axis of the idler stud. The radius of the crown and the hardness of the rubber are design factors dependent upon the torque required. For this reason, it is advisable, if a damaged tire is encountered, to replace the entire idler wheel with an exact duplicate.

Puck drive systems give very good instantaneous speed regulation, tending to reduce wow and flutter. However, the condition of the surface of the rubber rollers is of utmost importance. Indiscriminate lubrication or an "oil bath" treatment is a very hazardous practice. Oil has a tendency to creep or run over surfaces, spraying the rotating puck with a minute amount of oil. This results in slippage and deterioration of the rubber parts. One of the commonest troubles encountered is slippage due to a film of oil on the idler tire.

If slippage results from excessive oil, it is best to replace the idler wheel and pucks after first cleaning all nearby surfaces. These include the flywheel rim, motor pulley, and idler plate. Use a cloth moistened with carbon tetrachloride. If the idler wheel is not replaced, wash the entire wheel in carbon tetrachloride, making sure to remove any oil in the crevices between the rubber tire and the metal of the wheel.

Since in a puck drive one of the rollers must be rubber in order to get friction, there is danger that flat spots may develop from leaving the roller engaged with one of the shafts, thereby indenting the rubber. When a rubber roller develops flat spots, it makes a disagreeable thumping noise and introduces wow each time the flat spot rotates. This dent can sometimes be removed or minimized by running the recorder for half an hour before using.

Time and wear will develop a glaze on the surface of the rubber, resulting in slippage. The glaze may be removed by carefully holding a piece of fine sandpaper against the tire while the idler wheel is being driven by the motor. However, this practice is usually not worthwhile since, by the time a glaze develops, the material has probably deteriorated to a point where wheel replacement is advisable.

Flutter, a tremulous quality of reproduced sound, often results from modulation by motor noise. This is caused by: (1) Insufficient mechanical isolation between the motor and the remainder of the drive system. (2) Excessive vibration of the motor due to unbalance of its rotating parts.

Belt-Drive Systems

The second major drive system is the belt drive. Two types of belts are employed: composition and rubber.

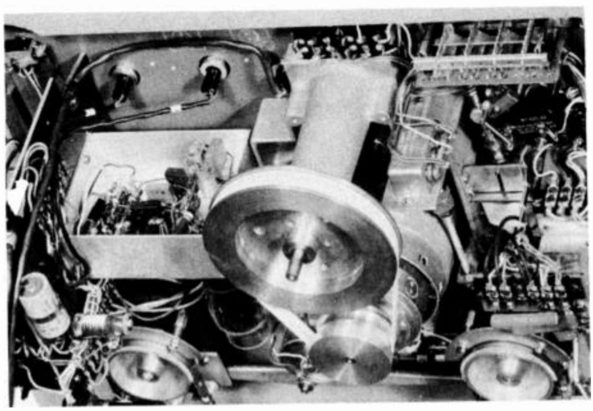


Fig. 3-17. The Presto SR11 Uses a Woven Flat-Belt Drive from Motor to Flywheel.

The composition belt is flat in construction, running between the motor and the flywheel. Generally, a tension roller arm is also employed to keep the belt taunt. This is a comparatively expensive drive because an extra idler roller is required. However, this is fundamentally a good drive system, making for excellent speed stability. The composition belt is used in the Presto professional recorder and the Ampex 600. The Presto model SR11 is shown in Fig. 3-17.

The other type of belt is a round rubber belt, also linking the motor to the flywheel. The use of a rubber belt means that an idler is not needed because the rubber has enough tauntness to remain tight. However, the rubber belt in time will become loose and cause slippage. Hard spots may develop, also introducing wow. When slippage develops, the rubber tends to wear away and fills the recorder with rubber shavings. The round rubber belt is used to drive the capstan on the Brush Soundmirror and is now also used in the new Ampro recorder and the Presto long-play recorder units. The Ampro recorder is shown in Fig. 3-18.

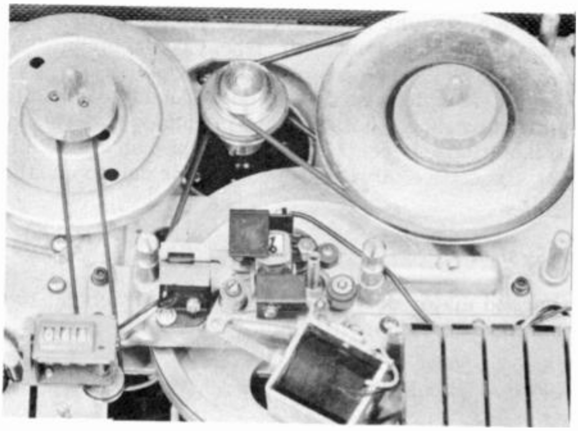


Fig. 3-18. The Ampro Model 755 Uses a Round Rubber Belt Drive.

Direct-Drive Systems

The third type of drive system, becoming increasingly popular in professional recording equipment, employs the motor shaft as the capstan shaft. If there is a flywheel in the system, the flywheel is attached directly to the motor shaft. This drive operating directly from the motor, has many advantages since there is only one rotation shaft with no transmission of power from one shaft to another. Therefore, there is no need for rubber puck rollers which may become dented and introduce wow. There are no belts to stretch and develop hard spots.

However, to rotate the capstan and have a reasonable capstan diameter, relatively slow speed motors must be used. For example, to operate at 7 1/2 ips, and have a capstan diameter of approximately .24 inches, one needs a 600-rpm motor which is expensive, large, and heavy. Professional equipment can tolerate a motor of this type. However, its cost, size, and weight preclude its use in portable home-type equipment.

Still another disadvantage of the direct drive is that motor irregularities in its core structures and variations in damping as the motor armature rotates tend to introduce a certain amount of wow and flutter in the tape. These irregularities, however, can generally be damped by careful design of the motor. By adding flywheels, excellent flutter characteristics can be obtained.

Induction Motors

Any drive system can use two types of motors: induction or synchronous. A conventional induction motor has, generally, fairly stable speed characteristics. It has good instantaneous speed regulation, including very little flutter and wow. It is inexpensive, compact, runs relatively cool and gives a lot of power for its size. Non-synchronous or induction motors, however, are subject to speed variations caused by changes in load and line voltage.

Synchronous Motors

The other type of motor, used on professional equipment only, is a synchronous motor. The synchronous motor has absolutely perfect long-time speed regulation since its speed is controlled by AC power alternations. However, it tends to introduce a certain amount of instantaneous speed variation during its rotation, resulting in some flutter. It is an expensive motor, runs quite hot, and is large for a given amount of power.

Take-Up Reel Drive

The capstan, of course, is used to pull the tape at a constant speed past the magnetic head. However, tape moving at a constant speed must then be spooled onto a take-up reel. Because the tape goes from a small diameter at the beginning of the reel to a large diameter at the end, the reel speed must change since the tape speed remains constant. The rpm of the reel changes considerably from a large to a small diameter. Therefore, all recorders employ some type of variable-speed drive.

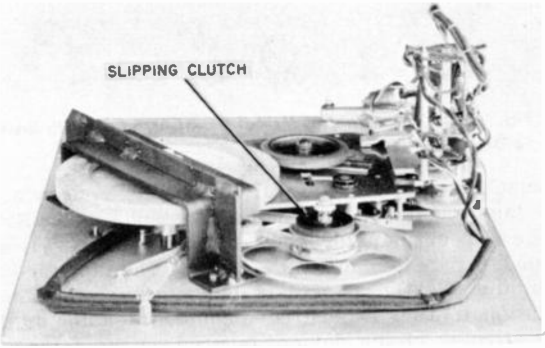


Fig. 3-19. The Ekotape Model 101 Slipping-Clutch Variable Speed Drive.

The most common variable speed drive is the slipping clutch used in the Ekotape model 101 shown in Fig. 3-19. Generally, the clutch consists of a rotating disc that is driven at a constant speed, often by the same motor that drives the capstan. Next to this disc is placed a piece of felt. The felt slips on the disc and drives another disc which, in turn, drives the reel shaft.

The slippage between the drive disc, the felt, and the reel disc applies a more or less constant torque on the take-up reel. This constant torque is something of a disadvantage, since when the reel is nearly empty, the lever arm is short and tension on the tape will be high. However, when the reel is nearly full,tension on the tape will be very low since the lever arm is long.

Fig. 3-20. The Use of Thinner Tape Permits an Increase in Hub Diameter.

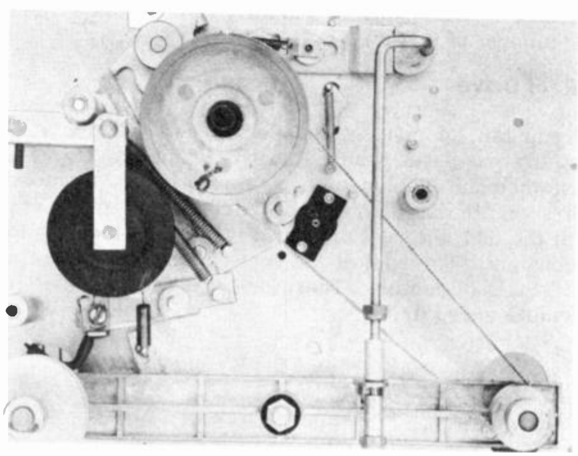


Fig. 3-21. The Pentron Model 9T-3C Uses a Cloth Belt to Drive the Take-Up Reel.

Because the tape is being pulled past the head by a capstan, in theory the tape should be moved at a constant speed. However, due to the change in reel diameter, the tape is under heavy tension at one time and under light tension at the other. The tape tends to slip by the capstan at a slightly faster rate under heavier tension. Because of this variation, it is desirable to have constant tension on the take-up reel. The slipping clutch device as used on most tape recorders does not provide, however, constant tension. To help solve this problem tape manufacturers have developed thinner tape, permitting an increase in the hub diameter of the reel, thus reducing tension difference between the inner and outer reel diameter as illustrated in Fig. 3-20.

The other method of revolving the take-up reel is by use of a stalled induction motor. This method is used by several of the professional recorders such as the Ampex. It is also used on such home recorders as the TDC model 130. In this method of variable speed drive, the reel is attached to the motor shaft or is driven by the motor shaft. The motor is, in turn stalled, not being allowed to run at its full speed. Therefore, the motor exerts a torque on the reel. By careful design of the motor, a nearly constant tension can be maintained regardless of how full the take-up reel may be. Also, the motor take-up is more dependable, since it is unaffected by changes in temperature, humidity, and lubrication as is the slipping felt-clutch device.

A third method of driving the take-up reel is by a slipping cloth belt on a polished pulley. The Pentron, Crescent and Telectrosonic use this system. The belt is driven at a high rate of speed around a very smooth pulley which, in turn, drives the take-up reel. The belt drive suffers many of the same problems as the felt clutch since the tape tension will vary from time to time depending on lubrication, temperature, and humidity conditions. The Pentron model 9T-3C is shown in Fig. 3-21.

Rewind and Fast-Forward Mechanisms

The remainder of the motorboard mechanism is designed to rewind the tape. In addition, practically all tape recorders incorporate a fast-forward speed, enabling the tape to move at a higher than operating speed, facilitating rapid location of selections within the reel of tape.

During both fast forward and rewind, very little back tension is applied to the feeding reel. This allows the tape to be moved at a high speed with a minimum of mechanical power.

In home recorders, generally a mechanical linkage shifts the reel shaft or puck shaft into position to be driven by the motor. By using a minimum amount of mechanical power with little back tension, a "soft" tape wind is achieved. It is essential that tapes be softly wound to prevent physical distortion in which one edge of the tape is stretched.

If a tape which is tightly wound is subjected to a sharp change in humidity or temperature, tremendous tape tensions will be built up on the reel. Each layer of tape contributes a progressively stronger pressure on its adjoining inner layer which will often stretch the tape beyond its yield point, thus permanently deforming its shape. In extreme cases of physical distortion, the cumulative pressure becomes so great that the plastic reel hub shatters under the tremendous tension.

It is regretable that the more expensive professional machines are the worst offenders in respect to tape distortion. These recorders, using a direct-coupled motor drive for either rewind or fast forward, invariably wind the tape "hard." The direct motor drive exerts a more or less constant tension on the tape during operation, thus building up considerable pressure with each turn of the reel.

Many tape engineers feel that the constant-torque reel drive used on most home recorders contributes to the best tape storage, since the outer turns are wound with far less tension than the inner turns. However, as pointed out earlier in this chapter under capstan drive, the professional recorder manufacturers are faced with the necessity of obtaining constant tension throughout the reel to eliminate capstan slippage. There is little doubt that the manufacturers of professional machines, faced with a choice between two evils, favored a direct coupled motor drive with little capstan slippage over a constant torque reel drive providing a soft tape wind.

Two-Speed Drive

In the professional field, two tape speeds are becoming standardized throughout the industry. The 15-ips speed is being widely used for original recording where the highest possible fidelity is desired. However, with the tremendous improvement in performance at 7 1/2 ips, this speed has been widely accepted as standard for the bulk of broadcast work. Therefore, the professional studio machine should have both speeds.

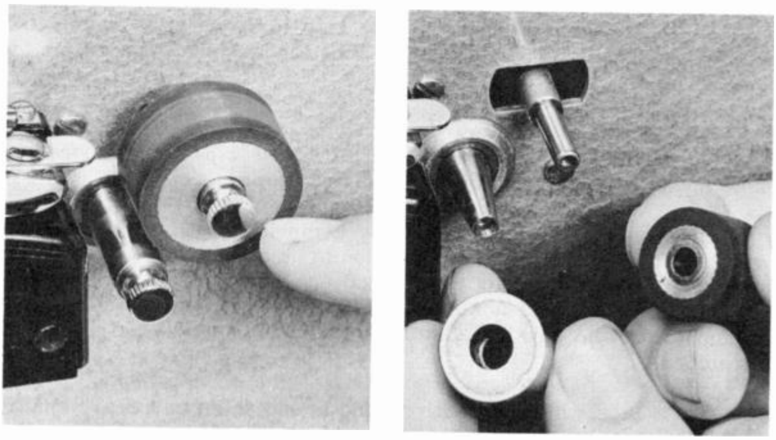


Fig. 3-22. The Speed of the Magnecord Model PT-6 is Changed by the Physical Transfer of Capstans. (A) Capstan and Pressure Roller to be Removed. (B) Replacing with Capstan and Pressure Roller of Different Size.

In most professional equipment the speed change is now accomplished by means of switching the fields in the synchronous drive motor. Since most professional machines use this type of motor, it is possible to change from a four-pole motor, running at 1800 rpm, to an eight-pole motor, running at 900 rpm. A synchronous drive motor with six poles, running at 1200 rpm, can be changed to a twelve-pole motor running at 600 rpm. The speed change is simply accomplished by flipping a switch which connects the proper number of motor fields in the circuit.

By contrast, the speed of one make of professional recorder can be changed by the physical transfer of capstans as shown in Fig. 3-22. A removable pressure roller and capstans of different diameters are used for different speeds. This method, while perhaps bothersome and time-consuming, serves the purpose. A well machined tapered shaft is used, making the removal and fitting of the capstan easy. However, the pressure of dirt on the capstan shaft will make the capstan eccentric with resulting wow and flutter.

Among the home recorders, both the 7 1/2-and 3 3/4-ips speeds are of vital importance. The 7 1/2-ips speed is generally used for higher quality musical recordings while the 3 3/4-ips speed serves primarily for voice applications. It is true that some recorders operating at 3 3/4 ips give better performance than others operating at 7 1/2 ips, but this depends upon the design and precision of the recorder itself.

It is more difficult to obtain good performance at slower tape speeds for two reasons: First, the high frequency response is limited and the output is reduced. This subject will be fully treated in the

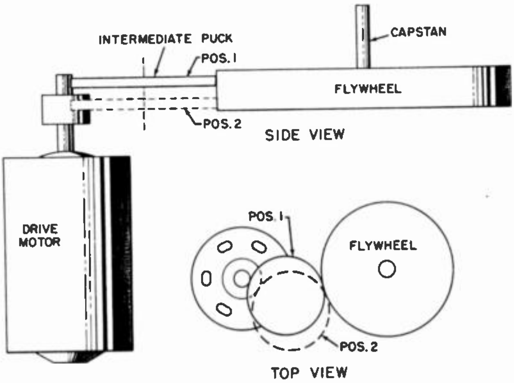


Fig. 3-23. Changing Speed by Changing the Position of the Intermediate Pucks.

chapter on magnetic heads. Second, the wow and flutter is increased since there is less inertia in tape systems operating at slower speeds. Also, any minute variation in tape speed has a tendency to adversly affect the recording when the tape is traveling at slow speeds.

In the home recorder field, the majority of recorders change speed by changing the position of the intermediate puck from one diameter on the motor shaft to another as illustrated in Fig. 3-23. Generally, the intermediate puck is moved between two steps on the motor shaft of different diameters.

While this system works very well as a speed changing device, the method of shifting the pulley is of great importance. On some recorders the pulley is actually forced over the edge of the step. If the recorder is in a neutral or off position, the speed change can be easily and safely accomplished. However, if the recorder is running, the pulley will severely nick the intermediate puck roller. The nicked edge will result in serious wow and flutter.

The more desirable method of speed change used in many of the newer home recorders is accomplished by actually removing the intermediate puck from both the motor drive shaft and the flywheel. The intermediate puck is then shifted to its new position and is re-engaged, eliminating any possibility of nicking its edge.

In most home recorders the intermediate puck roller is the heart of the drive system. The smoothness and consistency of the surface about its center axis is all important in keeping wow and flutter to a minimum. Care must be exercised in operating those machines which, in changing speeds, do not remove the intermediate puck from the shaft, motor pulley, and flywheel. It is a wise precaution to check the type of speed change used by the recorder before changing speeds.

Several home machines still change speed by varying the capstan size. However, this method is gradually being discarded. Because of cost considerations, in home machines a tapered shaft, precision-machined, can not be used. Consequently, if the capstan fits well it is difficult to remove and put on. If the capstan is easy to remove, the fit is so poor that the capstan will be eccentric and wow and flutter will develop.

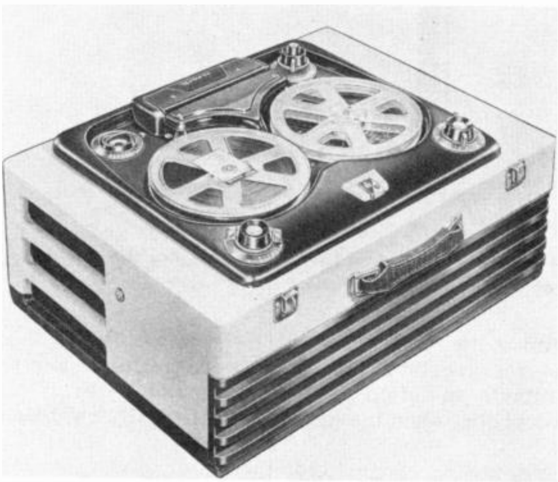


Fig. 3-24. The Webcor Model 2130 Incorporates a Dual Direction Design Which Permits Tape Operation in Either Direction.

Dual-Direction Mechanism

A number of recorders are specially designed for longer playing time, continuous operation, repetitive loops, etc. One very popular home machine, the Webcor (Fig. 3-24), incorporates a dual-direction design which permits operation in both directions.

In dual or half-track recording, as used on this machine, one track is recorded in one direction, the other track in an opposite direction. This eliminates turning over the reel when the end of the tape has been reached as is customary in other dual-track recorders that operate in only one direction.

Braking Mechanisms

When the recorder is put in the stop position the reels must break as rapidly as possible without causing damage to the tape. Generally, the breaks consist of a metal wheel which engages a rubber rim on the reel shafts. Also, a rubber or felt pad can be used which rubs on a metal disc on the reel shafts.

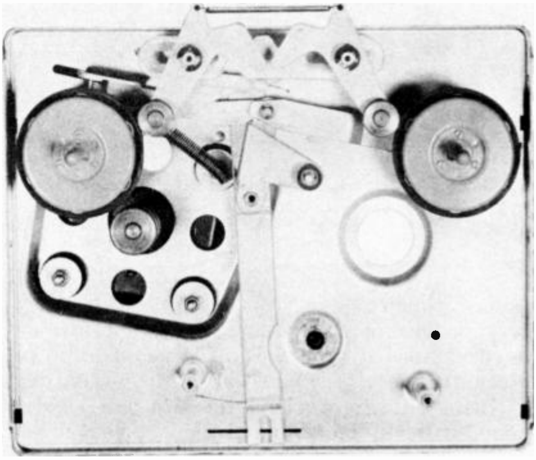


Fig. 3-25. Brake Mechanism of the Revere Model T700.

In normal operation the brakes are removed, but in the stop position they are suddenly released and applied to the revolving reel spindle shafts, causing them to abruptly halt. The brake mechanism of the Revere model T700 is shown in Fig. 3-25. It is always important that the feeding reel, the reel from which the tape is being drawn, be stopped first. Otherwise tape spillage will result.

The adjustment of the brakes is critical in many machines to prevent tape spillage and still not cause physical damage or stretching of the tape. Several machines, such as the Pentron, use no brake action whatsoever. The tape is braked only by reversing the direction of drive on the reel spindles. An interesting approach to braking is also found in the new Crescent recorder which applies braking pressure toward both reel spindles while stalling the motor, rapidly halting the tape with no danger of spilling or breaking the tape.

Position Indicators

Position indicators are becoming increasingly common. They are counters that are driven by the feed or the take-up reel and count the revolutions of the reel. This feature enables rapid location of selections within a reel of tape. Fig. 3-26 shows the position indicator on the Ampro recorder.

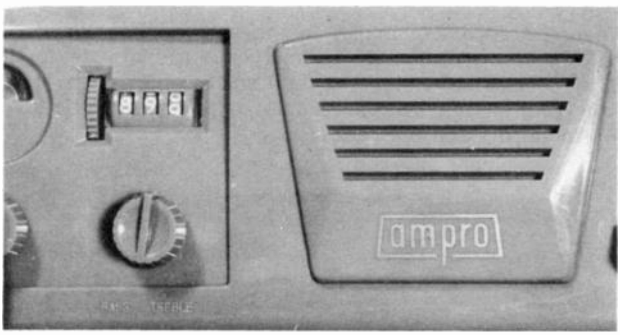


Fig. 3-26. Position Indicator Used on the Ampro Model 755.

Maintenance

Since a recorder motorboard is a mechanical device with shafts and bearings, occasionally a drop of oil is required to keep all parts exposed to friction or wear turning freely. Most recorders, however, require very little oil. Because of the slippage problem caused by oil on the rubber rollers, excessive oiling is a real threat.

Most recorder bearings are manufactured from a power bronze material, such as "oil-lite". This is a very dependable, life-long bearing in which oil is actually impregnated into the powdered bronze bearing material. Since most recorder shafts turn at slow speeds, they will last a long time.

Like any mechanism, the biggest menace to a recorder is dust, dirt, and grit particles working between the shafts and bearings, scouring them and causing wear. To keep any tape recorder at peak operating performance, the motorboard mechanism should be kept clean and free from dust and grit. When worn, an occasional shaft or bearing may require replacement.

CHAPTER 4

Drive Motors For Tape Recorders

The drive motor is one of the most critical parts of the drive mechanism since it must supply the power which drives the tape. The main requirement of any tape-recorder motor is that it hold a constant, normal running speed. The quality of the recording and subsequent playback is, of course, dependent upon the linear velocity of the tape which is, in turn, dependent on the rotational speed of the capstan.

Any deviation in the capstan rotation speed will affect tone or pitch. The audiophile with the legendary "golden ear" will easily recognize that the tape speed is not perfect, even though the variation may be exceedingly minor.

Other requirements for motors are that they resist overheating despite being small and lightweight. In addition, the suitability of the tape-recorder motor is determined by such factors as elimination of stray magnetic fields, ruggedness, dependability, silent operation, and infrequent maintenance.

Two types of motors are used in tape recorder design: the induction motor and the synchronous motor.

Home Recorder Induction Motors

The vast majority of small home recorders use as their drive motor an induction motor of the single-phase shaded-pole type. The shaded-pole induction motor provides an acceptably constant running speed for home recorders, and is quite small, compact, simple in design, and very inexpensive. With normal use the motor is very rugged and practically indestructible. A typical induction motor is shown in Fig. 4-1.

The induction motor is able to withstand relatively long periods of "stalled" operation without serious overheating. This condition may occur when some part of the drive mechanism jams and the whole system, including the motor, is blocked until it receives attention.

Motor speed, which is stepped down to capstan speed commonly by rim driving is, in the majority of recorders, slightly under 1800 rpm. Average power consumption is of the order of 60 watts.

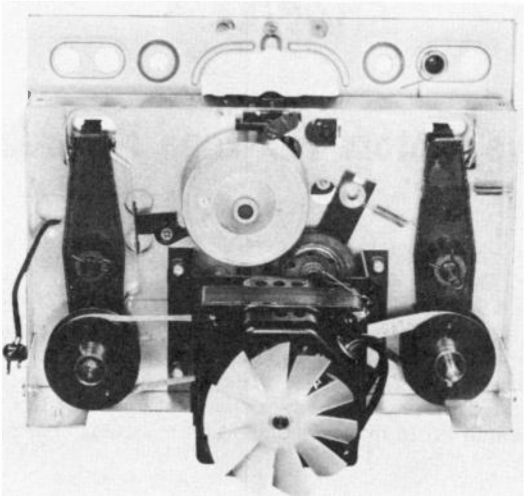


Fig. 4-1. A Typical Single-Phase, Shaded-Pole Type Drive Motor—Shown is the Crescent Model 900 Series.

Components of Induction Motors

An induction motor is composed of a stationary field structure, the stator, and a rotating element, the rotor as shown in the drawing in Fig. 4-2. The stator consists of coils which are wound on projecting iron cores or poles. The open end of each core, the pole face, extends toward the rotor. The pole faces partially encircle the rotor.

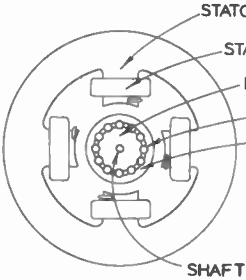


Fig. 4-2. Construction of an Induction Motor.

The rotor is mounted in the center of the fields. This rotating element is a cylindrical, laminated, iron core carrying lengthwise conductors in slots on its surface. The conductors are shorted by a ring at each end of the core.

The purpose of the stator is to provide, although remaining stationary, a revolving magnetic field around the rotor. The magnet is placed so that its pole is near the rotor conductors, and the magnet is revolved around the rotor. As the magnet revolves, its magnetic field revolves with it, causing the lines of force to cut the rotor conductors.

How the Induction Motor Works

The induction motor works with a relative slippage between the rotating magnetic field, set up in its stator or field coil, and the rotation of the armature or rotor.

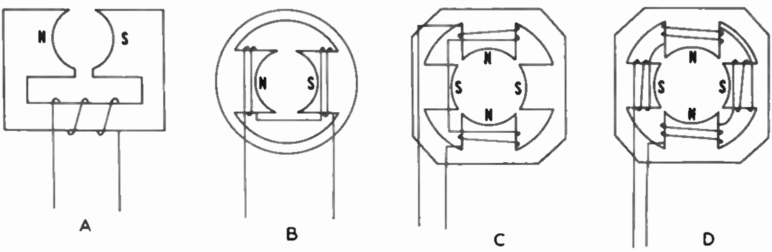


Fig. 4-3. Methods of Stator Construction. (A) Single-Coil, Two-Pole Stator. (B) Two-Coil, Two-Pole Stator. (C) Two-Coil, Four-Pole Stator. (D) Four-Coil, Four-Pole Stator. The Magnetic Polarization Shown Is That Which Would Exist Once During Each Cycle of the Applied Voltage.

As we have seen, the induction motor consists of two main parts, the stator and the rotor. The stator, the stationary part of the motor, is fastened to the frame. The rotor or armature, the rotating member of the motor, is supported by bearings on each end and supplies the power to the recorder.

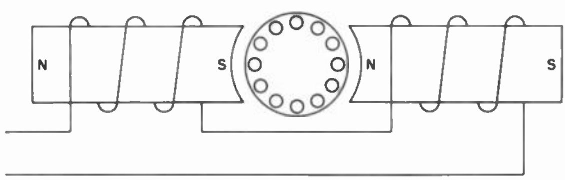


Fig. 4-4. The Number of Poles Determines the Speed of the Motor. In a Two-Pole Motor the Magnetic Field Is Reversing Between Each Pole at 3600 Times a Minute.

The stator is equipped with magnetic poles around which are wound the field coils. These poles are electromagnets and, of course, are supplied by alternating current going on and off at the rate of the line frequency or are going through a complete cycle, north and south poles, 60 times a second. (See Fig. 4-3.)

The number of poles determine the speed of the motor. It is easy to see that in a two-pole motor the magnetic field is reversing between each pole at 3600 times a minute. (The alternating current is changing polarity 60 times a second, and there are 60 seconds in a minute.) Therefore, in a two-pole motor with the magnetic polarity changing 3600 times per minute, the armature would normally try to make 3600 revolutions in a minute in an attempt to keep up with the magnetic field as illustrated in Fig. 4-4.

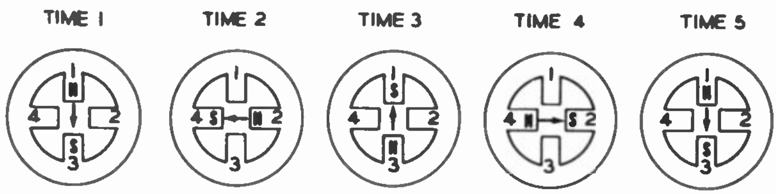


Fig. 4-5. A Four-Pole Motor, Instead of Turning a Complete Revolution, Needs to Turn Only Half a Revolution Before It Meets a Pole of Opposite Polarity.

In a four-pole motor, illustrated in Fig. 4-5 the armature, instead of turning a complete revolution, needs to turn only half of a revolution before it meets the pole of opposite polarity. Consequently, it rotates only 1800 times a minute.

A six-pole motor rotates 1200 times a minute and an eight-pole motor rotates 900 revolutions per minute.

However, as we have seen, the armature attempts to keep up with the rate of magnetic polarity change, trying to rotate at the same speed as the magnetic field. The speed of the rotating field is known as the synchronous speed. It depends upon the frequency of the applied voltage and the number of poles in the motor.

There is a constant difference between the rotation of the magnetic field and the rotation of the armature. Consequently, the rotor speed can never reach the speed of the revolving field because it is necessary that the rotor bars continue to cut the flux of the stator field. The difference between the rotor speed and the synchronous speed of the revolving magnetic field is known as the "slip" of the motor.

The slip between the synchronous speed of the magnetic field and the rotation of the armature is just enough to create a current in the armature. That is, if the armature were to run at the same rate as the rotation of the magnetic field, no current would be created. However, the greater the difference between the speed of armature rotation and the synchronous speed of the revolving magnetic field, the greater the current and the greater the torque within its operating range of speeds.

The slip may be as high as 40% of the synchronous speed, depending on the load, the friction in the drive system, and the condition of the bearings. With increase in load, the speed is slower.

Therefore, more flux lines are cut and greater torque is developed, depending upon the speed-torque characteristics of the motor.

With the input line frequency of 60 cycles, the synchronous speed of a two-pole motor is 3600 rpm and that of a four-pole motor is 1800 rpm. The slip of the average two-pole motor is greater than

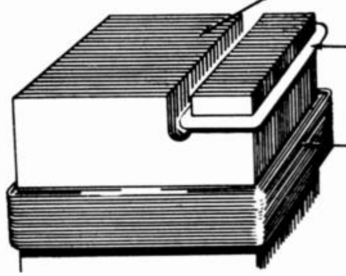


Fig. 4-6. Position of Pole-Shading Coil, or Ring, in Pole Face.

that of the four-pole type. Shaft speed of a two-pole motor will probably be within a range of 3000 to 3500 rpm and of a four-pole motor between 1400 to 1750 rpm.

This is, essentially, the operation of the induction motor. Various means have been devised to start the induction motor and get it rotating.

It can be seen that if the armature is standing still, the magnetic fields are simply reversing. Consequently, there is no incentive for the motor to turn. This necessitates placing additional poles in the motor structure which become energized at a slightly different time or out of phase with the applied voltage to the regular poles.

Single-phase induction motors are named and distinguished from one another according to the starting method or phase shifting. A phase shift in a winding can be accomplished by means of a series capacitor or by making one winding with more inductance than another winding, or finally, by means of shading a pole.

Most tape recorder motors use the shaded pole principle. Starting torque is provided by pole shading, effecting a movement of magnetic flux across the pole faces of the field structure. This is done by notching each pole face and inserting a copper ring which encircles approximately one-third of the pole face as shown in Fig. 4-6.

The copper rings oppose a change in the magnetic field. Thus, when the main pole becomes north, the secondary pole created by the slot in the coils refuses to become north. Consequently, when the main pole is being reduced from north and is moving toward south, the little slotted area becomes north, giving a rotational field which starts the motor.

The four-pole motor is more satisfactory for use in tape recorders because it gives a lower external magnetic field. Two-pole motors have a tendency to induce a hum field in the magnetic head.

Other advantages of the four-pole motor include the slower speed reduction necessary to drive the capstan. Also, quieter operation is achieved due to a lower vibration frequency, and the use of a larger rotor which can be dynamically balanced more easily, thereby further reducing motor vibration.

The four-pole, two-coil motor is seldom used in tape recorders due to its excessive external magnetic field which is almost as bad as the two-pole design. The four-pole, four-coil motor is more commonly used.

How the Synchronous Motor Works

The second type of motor used in tape recorders is the synchronous motor. In the synchronous motor the armature rotor

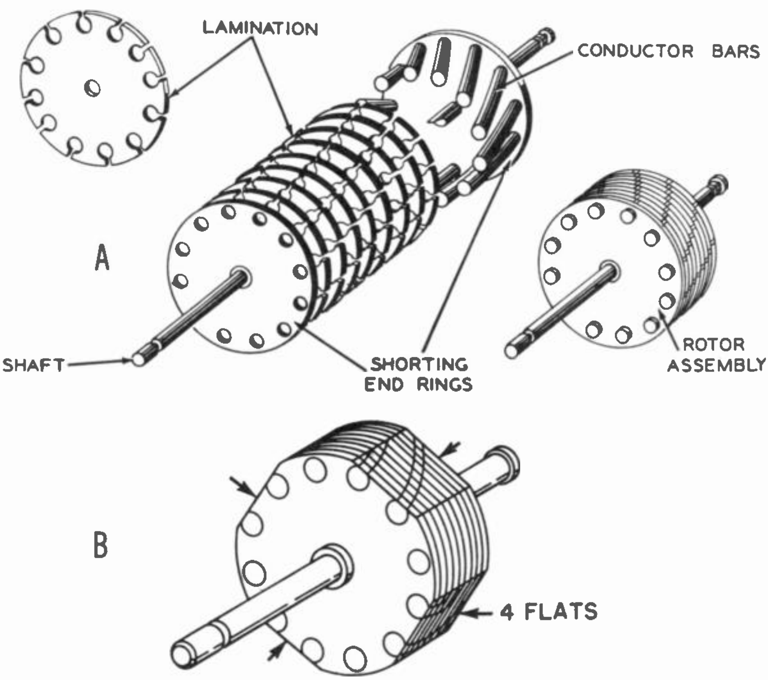


Fig. 4-7. Construction of Rotor for (A) Induction Motor and (B) Salient Pole, Synchronous Motor.

travels at exactly the same rate of speed as the magnetic field. With the exception that the shaded pole principle is not used (either the series capacitor or high inductance winding is common), the stator or pole structure is exactly the same as in an induction motor. The difference lies in the speed of the armature.

A synchronous motor, true to its name, runs at an exactly synchronous speed. If the magnetic field of the stator is rotating at 1800 rpm, the armature also will rotate at exactly 1800 rpm.

Synchronous armature speed is achieved by two methods. In the salient pole synchronous motor illustrated in Fig. 4-7, the armature is exactly the same as in an induction motor, using the same type of core structure that supplies torque. However, as shown in the comparison of the two armatures in Fig. 4-7A and B the armature is milled with flat spots on it. As the motor comes up to speed, these flat spots will lock into the rotation of the magnetic field. Thus, an easier path for the magnetic field is supplied through one side of the armature than the other. The armature will tend to follow the magnetic field exactly rather than slip behind it, thereby running at synchronous speed.

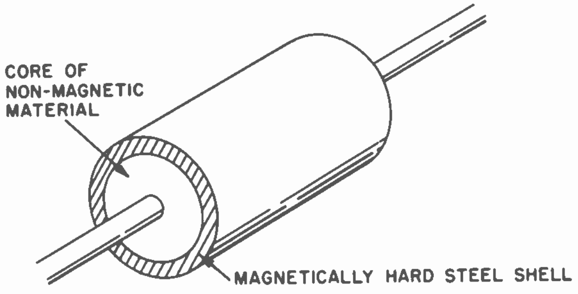


Fig. 4-8. Construction of Rotor of Hysteresis Synchronous Motor.

The other type of synchronous motor, the hysteresis synchronous motor, is commonly used in present-day professional-type recorders. In a hysteresis synchronous motor, the armature is surrounded by a thin ring of very magnetically hard material (see Fig. 4-8), which becomes highly magnetized. As the motor comes up to speed, the rotating flux of the last cycle, before locking into synchronization, will magnetize one end of the armature north and one end of the armature south. These poles will lock in with the rotating magnetic field, and the motor will run at synchronous speeds.

The synchronous motor has the advantage that its speed will never vary. The speed of the hysteresis synchronous motor will be as constant as the line voltage, and the recordings will last exactly the right length of time, providing all of the other drive system parts are functioning without slippage.

Induction Vs. Synchronous Motors

A synchronous motor tends, however, to have less desirable instantaneous speed characteristics. For example, the synchronous motor has trouble "hunting" or vibrating about a common speed which introduces some flutter and wow into the recordings. On the other hand, the induction motor is not a constant speed motor and is always slipping somewhat. The rate of slip may be different under low voltage than high voltage. The voltage applied to the induction motor changes its speed, hence introducing timing error.

However, the induction motor has very constant instantaneous speed characteristics, introducing little wow or flutter to the system.

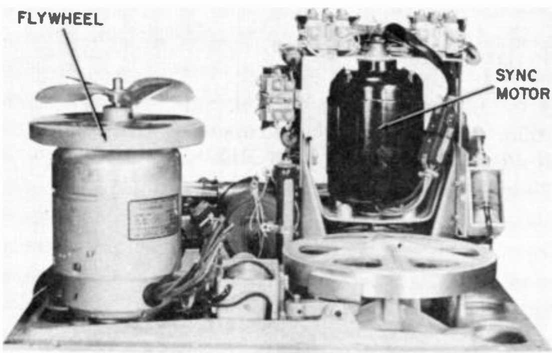


Fig. 4-9. Underside of the Ampex Model 400 Motorboard.

The synchronous motor is most widely used on professional recording equipment where elaborate methods are used to insure a constant speed, eliminating both instantaneous and long term speed variations. The underside of a typical professional recorder motorboard showing the motor and its associated components is illustrated in Fig. 4-9.

The induction motor is used on home-type tape recorders where long term speed variations are not of critical importance.

Motor Maintenance and Repair

Both the shaded-pole induction motor and the synchronous motor operate without any sliding electrical contacts. The only connection between the stator and rotor is magnetic. With normal use, the motors should be trouble-free.

Any motor repair or maintenance is generally limited to cleaning, lubricating, or readjusting of pucks, springs, bearings, or other parts of the motor-drive system. (See Fig. 4-10.) Faults found in recorders that may be traced to an improperly operating or damaged motor or drive assembly consists of a fuse blowing, overheating, mechanical noise, wow caused by speed variations, or a capstan speed that is too far above or below the standard speed for satisfactory reproduction.

Accidents or rough handling may break or short stator coils, bend the shaft, cause misalignment of parts, and break or loosen shading rings or shunts. Stator windings will become burned out or shorted by application of DC to 60 cycle motors. Over-lubrication may result in slippage of the drive system due to oil on the idler. Lack of lubrication may cause bearing wear or freezing due to overheating when dry. Dirt, dampness, lubricants that gum, and accumulations of dust are enemies of moving parts.

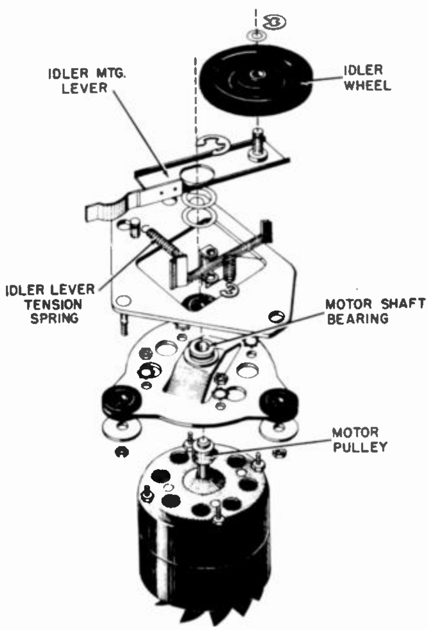


Fig. 4-10. Exploded View of Revere Model T100 Motor Drive Mechanism.

If the capstan does not operate, fuses blow, or coils are overheating, check first for mechanical overloading. With a rim-drive motor this can be done by spinning the capstan and the rotor shaft with the idler disengaged. Then test the idler for sticking. All three should turn easily and freely. If they do, the next step is to check the electrical circuit of the motor. Mechanical noise and speed troubles require a more detailed physical inspection of the entire motor and drive mechanism.

All parts, surfaces, and dimensions that can affect the speed are of a critical nature. Intermittent slippage of some part of the drive system or parts that are not absolutely concentric with their axes of rotation will cause wow.

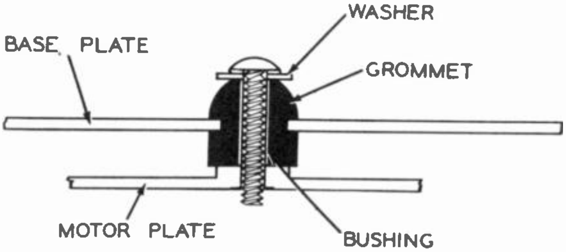


Fig. 4-11. A Vibration Mounting Between Motor Plate and Base Plate.

A motor will inherently transmit vibration to surrounding objects unless adequate provision is made to "float" it, so that it is not solidly mounted, cushioning its movement. Rubber vibration mountings or grommets, surrounding the bolts or bushings, are used to fasten the motor plate to the under side of the base plate of the motorboard as shown in Fig. 4-11. If the vibration mountings are under compression, they cannot accomplish their purpose. There should be a small gap between the rubber and the hold-down washer. With some motors a spacer is included which is placed over the bolt and inside the grommet, preventing any erroneous tightening of the bolt. It is also essential that the rubber is resilient. Grommets that have hardened, collapsed, or become oil-soaked should be replaced.

Lubrication of the self-aligning type rotor shaft bearings should seldom, if ever, be necessary. However, motor manufacturers' advice concerning this lubrication vary in details. Nevertheless, all manufacturers caution against over-lubrication and insist that any lubricant used must contain an oxidation inhibitor. It is also important that the viscosity remain nearly the same over a fairly wide temperature range. An oxidation inhibitor prevents the tendency of the oil to thicken, becoming gummy, or turning to a varnish under high temperature conditions or long exposure to air.

Do not use any light household oils to lubricate motor parts, since these may not contain an inhibitor to prevent gumming. This risk can be avoided by buying regular motor oil that is known to contain an inhibitor. SAE No. 10 motor oil of high quality generally is satisfactory.

Shaft bearings that are gummy from being lubricated with a non-inhibited oil will need to be cleaned with carbon tetrachloride before being re-lubricated. Apply only one or two drops of oil to the felt bearing washer, and after it has become saturated, wipe off thoroughly any excess oil that has reached other parts of the motor, giving special attention to the motor pulley and idler tire.

The air gap between the rotor and the stator is very narrow. To test for worn or misaligned bearings, check the shaft for play. See Fig. 4-12. If the shaft can be moved at right angles to its axis, the rotor will, when revolving, be scraping the internal circumference

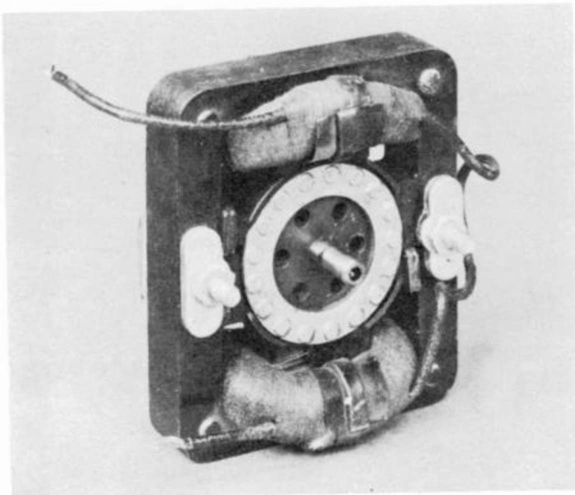


Fig. 4-12. To Test for a Misaligned Bearing, Check the Shaft for Play.

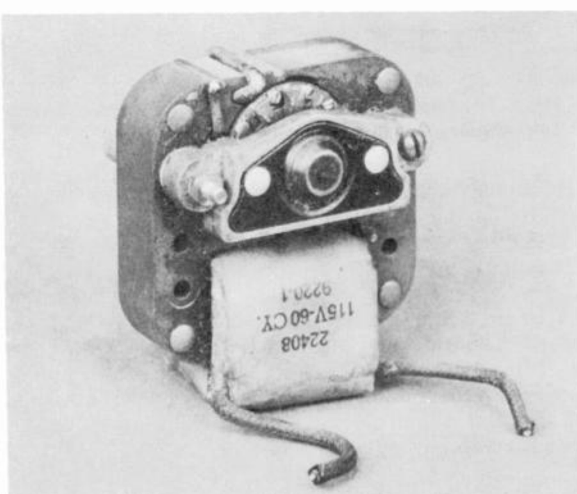


Fig. 4-13. A Typical Motor Using Sleeve-Type Bearings

of the stator laminations. Sometimes alignment of the sleeve-type bearings can be regained by tapping the bearing bracket. A typical motor using sleeve-type bearings is shown in Fig. 4-13. Tap the side

WRH

of the gap that is narrowest with a light hammer, preferably a wooden or raw-hide mallet. If the fault is due to the bearings being worn to a considerable extent, the motor or its bearings should be replaced. An exploded view of a typical end bracket and bearing assembly is given in Fig. 4-14.

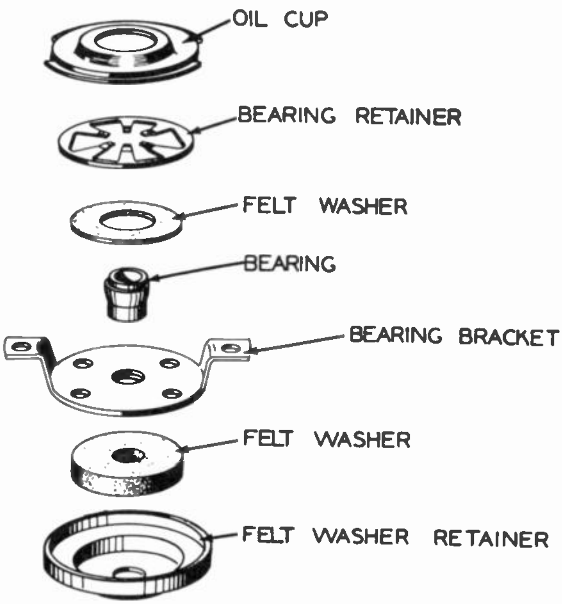


Fig. 4-14. Exploded View of a Typical End Bracket and Self-Aligning Bearing Assembly.

Ball bearing motors are designed so that the bearings have a light press fit on the motor shaft and a sliding fit in the bearing housing. Adjusting the tightness of the case screws may be necessary with a ball-bearing motor before proper freeness is attained.

Worn or misaligned bearings, or a bent rotor shaft, will cause capstan speed variations by varying the friction of the motor pulley against the idler drive wheel. When the motor is running with the idler wheel removed, the appearance of the rotor shaft, viewed from the end of the motor pulley, should be circular and not a "wobbly" or elongated pattern.

Such parts of motors as laminations, shading rings, magnetic shunts, bearing brackets, and screws which hold the motor to its mounting plate, must be tightened securely to prevent buzzing. For this reason, the laminations are usually varnish impregnated and are tightly secured by rivets while being subject to a pressure of several tons.

Rivets that are loose should be tightened or driven out and replaced with new rivets or bolts. When tightening the bearing brackets, care should be taken that the alignment of the rotor and shaft are correct. Loose or broken shading rings may be soldered or welded and clinched. Broken shading rings will also cause a lowering of the speed under load. Buzzing shunts should be pressed out, bent slightly, and replaced. Due to the vital role of these bridges in motor performance, care should be taken to replace them in the same position they originally occupied. These bridges will sometimes be found with "off-center" holes or slots that affect motor operation.

If the capstan does not rotate and the motor is not stalled, all parts rotating freely, the electrical circuit should be investigated. Continuity tests should be made from line input point through switch to motor coil. The resistance of the windings will probably be between 25 and 50 ohms. Opens external to the coil itself may be repaired. Connections between coils, on motors of more than one coil, must be kept in their original order. Incorrect connections will result in reversal of the fields which, with a two-pole, two-coil motor, would cause excessive current drain and no torque, and with a four-pole motor, would cause a great reduction of speed and torque.

Shorted turns in the coil will affect motor speed and can ordinarily be detected by the coil overheating and the unusually high current drain.

It is not advisable or economically practical to try to rewind burned-out coils or those that have shorted windings. Since most of these motors do not employ layer windings, a special type of winding machine is required. Repairs necessitated by mechanical wear and strain can often be made reliably and at less cost by replacement of the motor.

When selecting the range for an ammeter to be used in a motor circuit it should be kept in mind that the power factor of the motor is apt to be quite low. Therefore, generally, the amount of current calculated by using the voltage and wattage rating of the motor should be approximately doubled. Also, motor ratings are usually given for "running" condition; the starting power will be much higher. For the small skeleton-type motor a current range of approximately .3 to .8 amps should be expected if the motor is in good condition. It is recommended that initial measurements be made with an AC ammeter of 1 ampere full-scale. Because of the relatively low efficiency of these motors (approximately 30%) there is little difference in the power demand between the heavy-duty motors and the smaller ones.

In most units hum will result if the connection from chassis ground to a solder lug attached to the laminations by one of the mounting bolts is broken. An ohmmeter should be used to check that the winding is not grounded to the laminations. Grounded windings would, in most cases, result in fuse blowing. They also may cause hum in the output.

Not much can be done through design to improve the efficiency of either the shaded-pole induction motor or the synchronous motor. As far as operating cost is concerned, it is relatively unimportant that there is a waste of power in the motor because the total amount required is so small. It is of more importance that the inherent inefficiency results in the watt-loss being converted into heat. Design compromises necessitated by starting torque requirements, space limitations, choice of materials and manufacturing cost considerations tend to further reduce efficiency to such an extent that the operating temperature of these motors is generally almost as high as regard for safety will permit.

Underwriters' Laboratory specifications for motors in recorder applications permit a coil temperature, as measured by thermocouple, of 194° fahrenheit when the room ambient is 77° fahrenheit with the motor in normal operation in the unit, and with the maximum rated voltage and frequency applied. The temperature of the coil windings may rise to 221° fahrenheit when resulting from a heat source external to the coil. Temperatures should not exceed 347° fahrenheit under abnormal conditions such as locked rotors.

Shaded-pole motors are for alternating current use only, usually for 60-cycle frequency. Replacement motors for 50-cycle operation are available from most manufacturers. Consistent with the manufacturers' recommendation, conversion from 60 cycle to 50 cycle operation can sometimes be accomplished by changing the motor pulley to one of a larger diameter. This pulley must be supplied by the manufacturer of the recorder and the conversion is possible only if the laminations and coil have been designed for use on both frequencies.

It is possible to convert the recorder from 117-volt 60-cycle AC to 117-volt DC by the addition of a vibrator inverter. Several of these small power supplies are on the market for recorder use.

CHAPTER 5

Volume Indicators

In every recording medium, to obtain optimum recording results, the recording level or volume must be adjusted to avoid distortion.

Cause of Distortion

In magnetic recording, distortion is caused by the fact that if a given signal becomes progressively stronger and stronger, eventually the tape's magnetism will no longer increase. The tape is then said to be "overloaded." The overload point of a magnetic tape is also called saturation of the tape. One obviously wants to record considerably below tape saturation to avoid distortion. Fig. 5-1 shows the effect on a complex wave when recorded at too high a level.

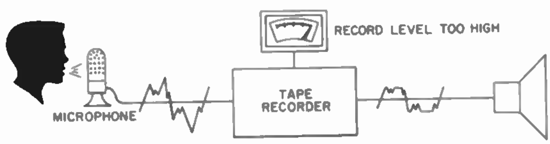


Fig. 5-1. When a Complex Wave Is Recorded at too High a Level, the Peaks Will Overload the Tape and The Wave Itself Will Be Distorted on Playback.

Tape records symmetrically. That is, when the tape leaves the erase head and before it passes across the magnetic record head, it is essentially neutral or in a demagnetized condition. As a signal is recorded on the tape, the tape is magnetized first in a north-pole direction and then in a south-pole direction. Since magnetization occurs symmetrically, there is no even order harmonic distortion from the tape. However, when too strong a signal is applied to the tape and tape saturation is encountered, the peaks of the waveform are clipped. Serious third harmonic distortion results, as shown in Fig. 5-2.

The normal method followed in adjusting the recording level of the tape is to record so that volume peaks never exceed 3% third harmonic distortion. When we speak of peaks in recording music or voice, the wave form is very irregular. At times the amplitude will

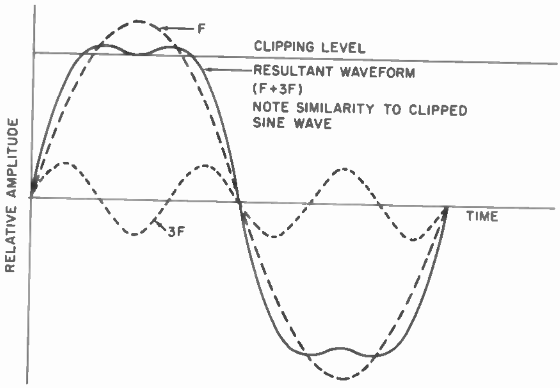


Fig. 5-2. If a Pure Tone (Sinusoidal Waveform) is Recorded at too High a Level, the Peaks Will be Flattened or "Clipped". If We Add, Point by Point, A Sine Wave of One Frequency (F) and a Sine Wave of Three Times the Frequency of the Fundamental (3F), The Resultant Waveform is Almost Identical to the Clipped Waveform Caused by Over-Recording.

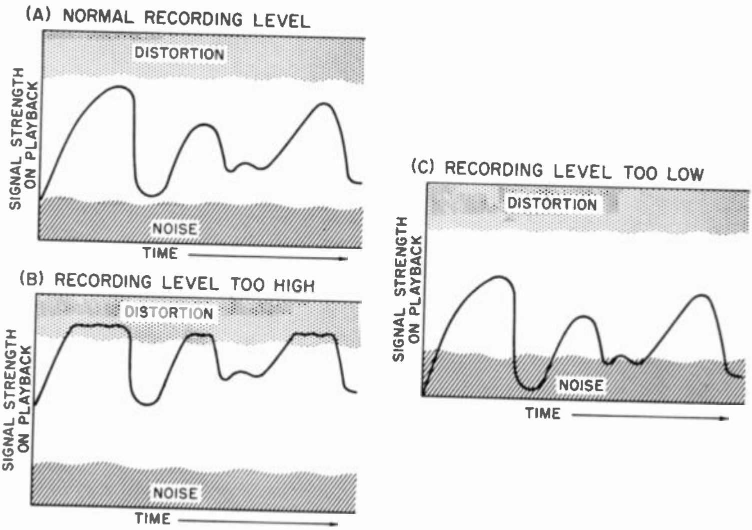


Fig. 5-3. One Should Record at as High a Level as Possible Without Entering the Distortion Region; Otherwise, with a Weak Recording the Background Noise will be Excessive.

be very weak. At other times it reaches very loud or electrically strong proportions as shown in Fig. 5-3A.

When recording very strong passages, care must be exercised to avoid overloading the tape as illustrated in Fig. 5-3B. On the other hand, it is vital not to record with too low a level so that weak passages are swallowed up in noise during playback as in Fig. 5-3C.

Therefore, it can clearly be seen that the recording level determines the signal-to-noise ratio and the distortion. The prime rule to follow is to record at as high a level as possible without entering into the tape's distortion region.

Present Day Recording Volume Indicators

To avoid the pitfall of entering a tape's distortion region, some type of volume indicator is required to permit adjustment of the recording volume or signal amplitude as it is being fed to the tape.

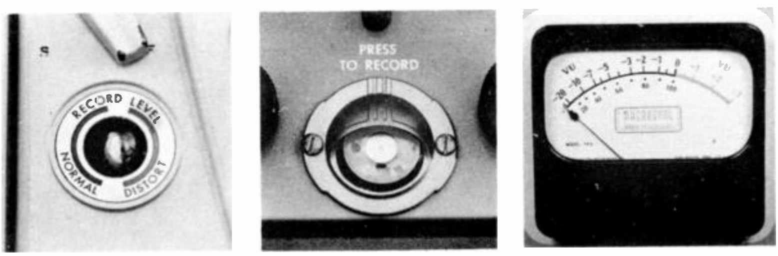


Fig. 5-4. Present Day Tape Recorders Employ Three Types of Recording Indicators: (A) Neon—A Peak Indicating Device (B) Electron Eye—Also a Peak-Indicating Device (C) V-U Meter—An Average Indicating Device.

Over the years a number of different types of recording indicators have been tried. On present-day tape recorders there are three main types: the neon, a peak indicating device; the electron eye, again a peak indicating device; and the VU meter or an average indicating device. A photo of these three types of recording indicators is given in Fig. 5-4.

The Neon Volume Indicator

The neon volume indicator is the most common type of volume indicator used in home-type recorders. A neon bulb is used which will not light until its applied voltage reaches a certain point. Then, suddenly, it will ignite and glow. Thus, it can be used as a peak or volume indicator.

A peak is reached whenever the applied voltage exceeds the ignition or firing point of the neon bulb, causing it to light. Consequently, in the less expensive recorders using one neon bulb, the volume-level indicator will be adjusted so that when the signal reaches approximately 3% distortion (or generally a little less to provide a safety margin), it will light.

When recording, it is necessary to adjust the volume so that the bulb will only occasionally light. This means that during most recording the volume is adjusted well below the distortion point, with only the peaks entering the distortion region.

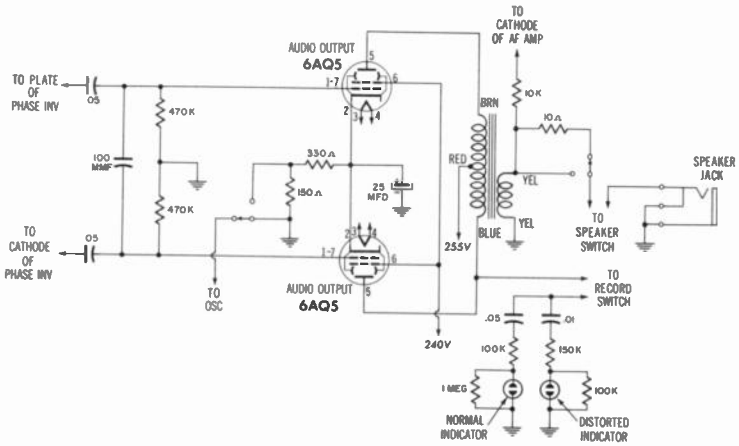


Fig. 5-5. A Typical Neon Bulb Volume-Indicating Circuit—Shown is the TDC Model 130.

A further refinement of the neon bulb indicator is accomplished by using two neon bulbs. One neon bulb is set to fire when the recording signal reaches, say, 3% harmonic distortion, whereas the other bulb is set to fire at a point somewhat under 1%. Consequently, the latter bulb serves as a lower level volume indicator and the first bulb serves as a peak volume indicator. During recording one neon bulb is lit most of the time, indicating a normal recording level. When the second neon bulb fires, the peaks are entering the distortion region. The two-bulb system is a basic improvement and is now incorporated on several of the newer home-type recorders. A partial schematic of a typical recorder using two neon bulbs is given in Fig. 5-5.

The Electron-Eye Volume Indicator

The second volume-indicating device is the electron-eye tube. This tube has an electron beam that strikes a fluorescent surface, causing an iris-shaped image to appear. In the peak or fully modulated position, the electron-eye tube is as shown in Fig. 5-6. During recording, the two halves should be vibrating so that they never overlap in the manner shown in Fig. 5-7.

The electron-eye has an advantage over the neon bulb in that a visual indication of the recording level is provided, even during weak signals. By contrast, in the one-bulb neon system, weak signals are not indicated, making it impossible to judge their amplitude.

Fig. 5-6. The Electron-Eye Tube Shown in the Peak or Fully Modulated Condition.

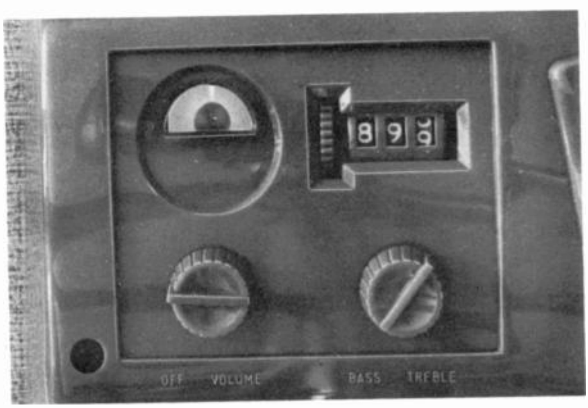


Fig. 5-7. During Recording, the Two Halves of the Electron-Eye Tube Should be Vibrating So That They Never Overlap in the Manner Shown Above.

Both the neon bulb and the electron-eye tube suffer from several disadvantages. The neon bulb will respond only to a given voltage, then will suddenly light, serving only as a peak indicating device. The electron-eye tube responds linearly to the applied voltage. That is, it does not follow our hearing characteristics which are logarithmic. In effect, this means that weak signals are completely lost or are barely indicated on the electron-eye. Relatively strong signals are required to get a volume indication.

To avoid these disadvantages, giving an exact logarithmic indication of both weak and strong signals, a third device is used on practically all professional recording systems. It is the VU meter.

The VU Meter

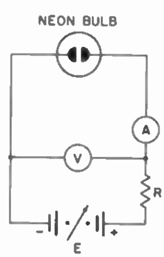
The VU meter is an electrical meter responding in a logarithmic manner to an applied voltage or current. The VU meter is also an average indicating device. A certain inertia is built into the needle so that on a varying signal input, it will respond in a damped manner which gives an average indication of the signal level.

All VU meters are carefully built to have the same damping factor. Consequently, a recordist accustomed to reading one particular VU meter may look at a VU meter on any other recorder and judge the correct reading volume.

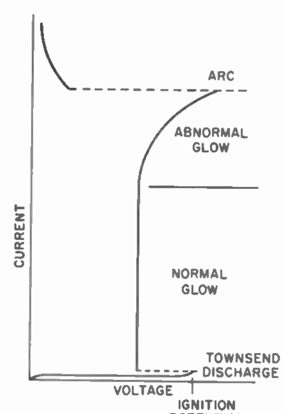
Since "0" level on a VU meter is an average and is considerably below the peak amplitude of the recording signal, it is necessary to locate the "0" level somewhat below the distorted region of the tape. Generally, "0" level on the VU meter, or 0 - VU, is 8 db below 3% harmonic distortion. This 8 db margin gives ample protection for loud passages or loud peaks that are too rapid to show on the meter.

Tests for Proper Adjustment

A series of fairly simple tests will quickly determine whether or not the volume indicating device of a recorder is properly adjusted and is correctly functioning.



METHOD OF MEASURING THE VOLT-AMPERE CHARACTERISTICS OF A NEON TUBE.



VOLT-AMPERE CHARACTERISTICS OF A TYPICAL NEON TUBE.

Fig. 5-8. Voltage Verses Current Curve For a Typical Neon Bulb.

The neon bulb indicator is generally connected across the output of the recording amplifier, just before the signal is fed into the recording head. Its reference level is established by applying a current of DC voltage to it. For example, if the bulb is intended to fire whenever the signal's amplitude goes beyond 5 volts and the ignition point or light voltage required to light the tube is 60 volts, 55 volts of direct current should be applied to the tube. Then the signal will be superimposed on the direct current so that whenever the signal amplitude reached 5 volts the tube will fire. A voltage versus current curve for a typical neon bulb is given in Fig. 5-8.

All adjustments are generally fixed on most recorders. The resistances which determine the applied DC voltage are generally fixed values so that the neon bulb will light at a predetermined signal level. However, it can be checked with a distortion-measuring device. The neon bulb should fire at somewhere between 1% and 3% third harmonic distortion.

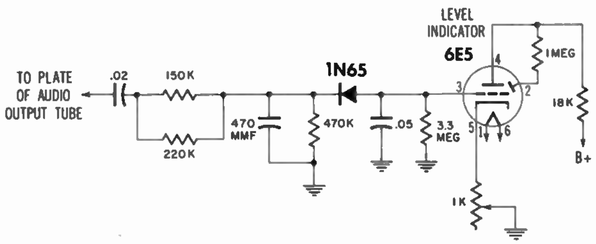


Fig. 5-9. Circuit Employing an Electron-Eye Tube as the Volume Indicator— Shown is The Webster-Chicago Model 2010.

Slightly more complicated than the neon-bulb indicator, the electron-eye tube gives the voltage instantaneously as the audio signal fluctuates. Since the audio signal fluctuates so rapidly, one would normally expect to see just a blur. However, in order to make readings possible, generally a capacitor network is used to remove rapid fluctuations and pass only gradual voltage changes, tending to give an averaged value of output somewhat similar to a VU's damping effect. A partial schematic showing a typical electron-eye circuit is given in Fig. 5-9. However, the fact still remains that the electron-eye indicator is a linear function of applied voltage, whereas in the VU meter it is a logarithmic function.

The most common cause of trouble in a VU meter is that the needle becomes bent or the movement is actually burned out or damaged. Without exception, if the VU is damaged it should be sent to the factory for repair or replacement.

WRH

CHAPTER 6

The Bias Oscillator

A jack of three trades, the bias oscillator serves the all-important function of making linear and distortion-free low-noise recordings while erasing the tape. But unlike the proverbial jack of all trades who was master at none, the bias oscillator performs all three functions admirably.

Two General Bias Methods

There are two general bias methods employed in magnetic recording. One is direct-current bias; the other is alternating-current bias.

The early wire and steel band magnetic recorders of Valdemar Poulsen used direct-current bias. One of the chief limitations of the Poulsen magnetic recorder was the use of direct-current bias, which prevented the recorders from finding wide public acceptance. Despite Poulsen's brilliant design, the use of DC bias inevitably resulted in distorted recordings with considerable hiss and noise.

However, with the introduction of alternating-current bias in the middle twenties, magnetic recordings of high quality became possible for the first time. This discovery of W. L. Carlson and G. W. Carpenter of the U. S. Naval Research Laboratory opened up an entirely new vista for magnetic recording.

The purpose of alternating bias is to produce a linear recording characteristic. This means that if the signal is doubled, one will obtain twice the output from the tape during playback. If the recording characteristics were non-linear, and the signal were doubled, one might obtain either more or less than twice the output.

In the magnetic recording process, the recording characteristics must be linear. In magnetizing any iron or steel substance, a hysteresis curve is encountered. A typical hysteresis curve is shown in Fig. 6-1.

When an increasing magnetizing force is applied to the tape, and then removed, the tape will have a certain remanent flux. In magnetic recording, the remanent flux is the actual magnetic field that creates the signal during playback. Ideally, if the tape were

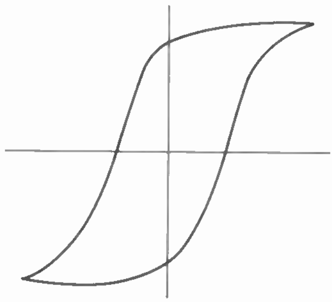


Fig. 6-1. Hysteresis Curve of Typical Magnetic Recording Material. The Horizontal Axes Indicates the Strength of the Recording Signal. The Vertical Axis Gives the Amount of Magnetic Field Left in the Tape.

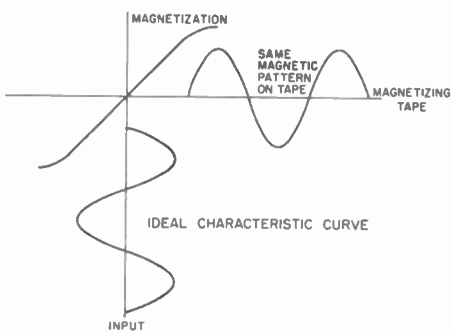


Fig. 6-2. Ideal Recording Characteristic—If We Had an Ideal Magnetic Recording Medium a Given Amount of Recording Signal Would Produce a Magnetic Field Exactly Proportional to It on the Tape.

recorded linearly for a given magnetic force recording signal, an equal remanent flux would be obtained. (See Fig. 6-2.) If we were to double the recording signal, we would, theoretically, in turn double the remanent flux. However, from the curve shown in Fig. 6-3 it can be seen that the magnetic field on the tape is no longer proportional to the recording signal.

Theory of DC Bias

The first serious bias attempt was the DC bias method discovered and incorporated by Poulsen in his Telegraphone recorder. It is interesting to note how DC bias operated. In DC bias, the tape was completely magnetized by a permanent magnet, generally serving also as the tape eraser. Thus, when the tape met the recording head, it was in a completely magnetized condition. All the magnets were

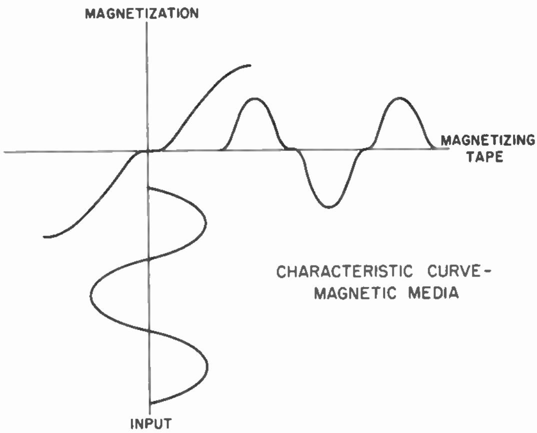


Fig. 6-3. Actual Magnetic Recording Characteristic With No Bias—Notice the Magnetic Field on the Tape is No Longer Proportional to the Recording Signal.

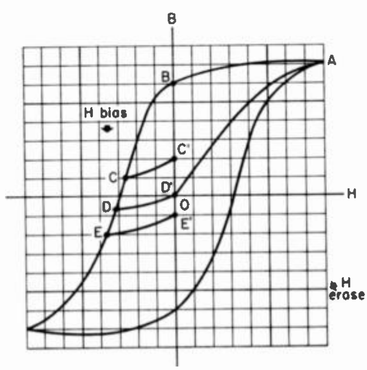


Fig. 6-4. DC Record Curve.

oriented in one direction. Then, as a recording signal was applied, the recording signal surved to demagnetize the tape. The amount of demagnetization was determined by the strength of the signal. At the same time a certain amount of direct current was applied simultaneously to the head. The direct current was used to place the operating signal within a more or less linear region of the hystersis curve.

When recording is to be accomplished by means of DC bias, the procedure involved is the following: The recording medium is, first of all, magnetically saturated in a certain direction with a DC erase head, as indicated by OAB in Fig. 6-4. Then in the record head, the function of the DC bias is to bring the medium to a point such as D. For no signal, on leaving the record head, the tape will be in the magnetized state D'. In the presence of a signal, the tape coming from the state B may reach the points DCE etc., and hence, have a recorded signal on it corresponding to C', D', E', and etc.

When employing DC bias very little of the potential magnetization of the tape was used, resulting in noisy recordings with a high hiss level. Unless elaborate precautions were taken to adjust the DC or permanent magnetic fields accurately, a large amount of distortion would also result.

The defects of the DC bias method led to the development of the alternating-current bias. AC bias is now used in all magnetic recording applications for audio work.

Frequency of the Bias Supply

It is obvious that an alternating current is needed to supply an AC bias system. The bias current is generally many times the strength of the recording current. Consequently, far more bias is needed in the record head than audio signal. The amount of bias may be as much as 10 times the strength of the audio signal although, generally, it is only several times as great.

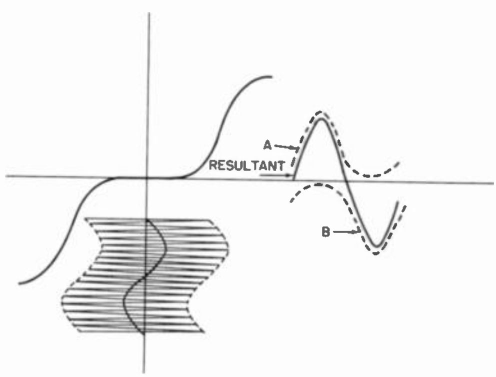


Fig. 6-5. Magnetic Characteristics With Bias. When a Bias Frequency Is Added to the Audio Signal the Resultant Magnetic Field Is Made Proportional to the Recording Signal.

Fig. 6-5 illustrates the action of AC biasing. A field which is a mixture of the AC bias and an audio signal is shown applied to the residual flux-density curve. In Fig. 6-5 the projection of the positive peaks on the residual flux curve at each instant of the audio signal produces curve A. The projection of the negative peaks forms curve B. The addition of curves A and B represents the effective flux signal that will be reproduced. Although some distortion is present in the resultant curve, it is a great improvement over reproduction without bias.

In order not to be heard, the bias must be at a higher frequency than the audio signal. The frequency of the bias, while not critical, must be well above a certain value. This point is generally five times the highest audio frequency to be reproduced. This is necessary in order to avoid beats or whistles in the audio frequencies being heard during the recording process. The harmonics of the audio signal that beat with the bias frequency cause a whistle or heterodyne.

When a whistle develops, two alternating currents of different frequencies are mixed together in a slightly non-linear recording system. For example, if an audio frequency of 10,000 cycles were recorded and a bias frequency of 35,000 cycles was used, the third harmonic of the audio frequency would be 30,000 cycles. Since the bias frequency was 35,000 cycles, a 5,000-cycle note intermittent whistle would be heard in the recording.

Generally the second and third harmonic components of an audio signal are the strongest. The fifth harmonic component is relatively weak, giving little trouble. Therefore, if the highest audio frequency to be recorded is 15,000 cycles, the bias frequency should be at least 60,000 cycles. Or, again, if the highest audio frequency to be recorded is, say, 7,500 cycles, the bias frequency should be at least 30,000 cycles. The trend of recent recorder design is toward higher and higher bias frequencies in order to avoid any chance of heterodyne.

In present-day professional recorder design, bias frequencies generally are in the region of 80 kc. Home recorders use bias frequencies in the region of 40 to 50 kc. A few home recorders still operate at bias frequencies as low as 30 kc.

Erasure

There is no limitation on how high a bias frequency can be used except for those limitations imposed by the bias and erase currents.

Since the bias supply serves as a supersonic oscillator, it forms a handy source of power for the erase head for use during erasure of the tape. The erase head requires considerable power to completely erase the tape. With the trend toward higher and higher bias frequencies, it is becoming increasingly difficult to apply sizable amounts of power to an erase head. Therefore, it is desirable from a design standpoint to use a relatively low bias frequency in order to have sufficient power to operate the erase. However, sound-wise it is best to have as high an audio frequency as practical.

Bias Strength

Another crucial aspect of bias is its strength. From the curve shown in Fig. 6-6, it can be seen that as the bias strength is increased, with more and more bias current applied to the record head, the low frequency signal output from the head will also become progressively stronger but will reach a peak, and then slowly taper off. In order to determine the proper bias strength or bias amplitude current to be fed to the recording head, it is necessary to know some of the properties of bias.

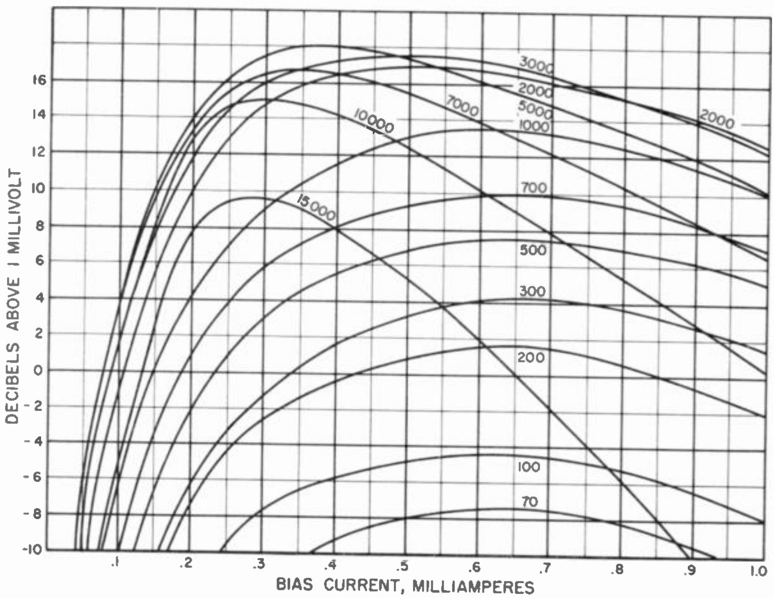


Fig. 6-6. Notice the Above Graph Shows the Self-Erasure Effect of Bias in High Frequencies, As the Bias is Increased, the High Frequency Response is Attenuated.

The point at which the bias current gives the greatest amount of output with a low frequency audio signal is known as peak bias. This term is somewhat misleading since peak bias would seem to indicate a stronger bias. However, the word peak refers only to the strength of the audio signal during playback of the tape.

Most machines operate in an over-bias condition. Over bias means that the bias is stronger than that required to obtain peak output which, in turn, reduces the output. If the bias is so strong that it will reduce the output by 2 db, the recorder is referred to as being 2 db over-biased.

If the bias is less than that required to give peak audio output, not only will the output suffer, but the signal-to-noise ratio will also be adversely affected, and severe distortion, together with poor uniformity, will set in (see Fig. 6-7). Even the nodules and imperfections on the tape surface itself will be accentuated with low bias.

However, the main disadvantage of low bias is the high distortion and low-signal output encountered.

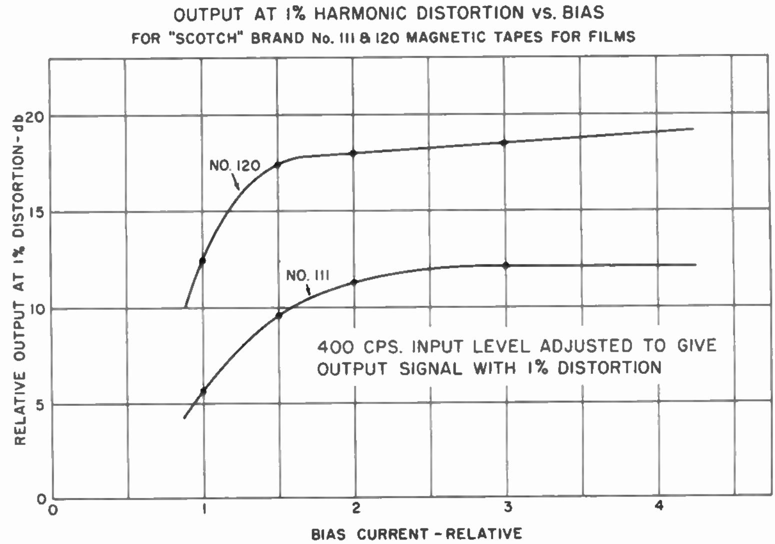
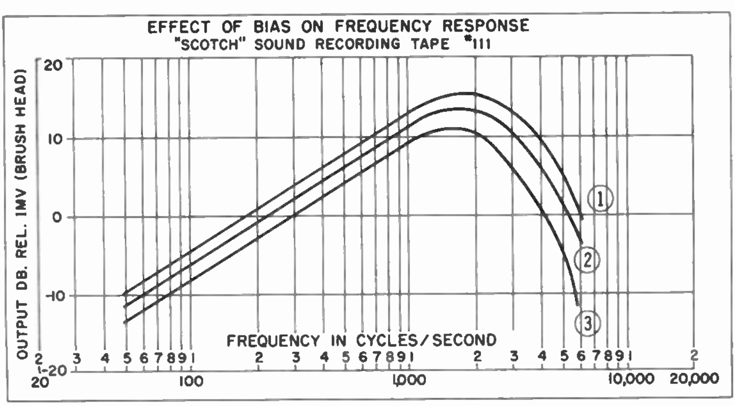


Fig. 6-7. Curve Showing Distortion in Output as a Function of Bias.



AUDIO	BIAS
db. rel. 1 ma.-	Ampere Turns
(1) 17.0	2.4
(2) 15.0	3.2
(3) 9.5	8.0

Fig. 6-8. Curve Showing the Effect of Bias on the Output for a Constant Input Signal of Low Frequency.

In the case of over-bias, the distortion is generally somewhat reduced beyond the point of peak bias. In fact, as the bias is increased the distortion becomes progressively less. However, the signal output begins to drop, though slowly, causing a reduction in the signal-to-noise ratio.

The main disadvantage of over biasing is the marked loss of high frequencies (see Fig. 6-8). As the bias strength is increased, the bias actually serves as an erasing field for the tape, erasing the weaker high-frequency signals on the tape. Since high-frequency signals are more easily erased than low frequencies, the bias is actually erasing the high-frequency audio signals on the tape. By increasing the bias by one or two db over-bias, the high frequencies will begin to be attenuated, although they are not severely affected with this amount of over-bias. On an oscilloscope the surface uniformity will look better, and the distortion characteristics are generally improved.

Therefore, in summary, if the bias is too low, distortion will result. If the bias is too high, a loss of high frequencies will occur. The decision, then, is this: Should a recorder be operated at peak bias or slightly over peak bias? Operation at peak bias generally makes possible the best high frequency response since it is in a very

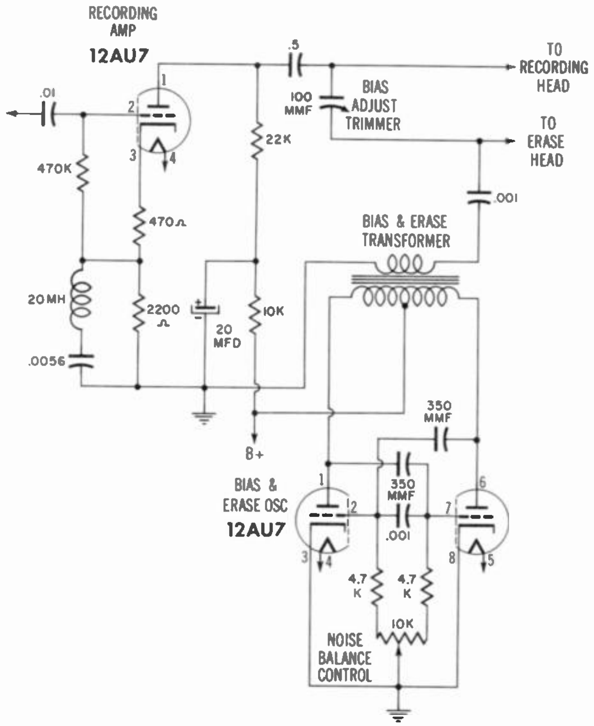


Fig. 6-9. Circuit of Ampex Model 600 Recorder Showing Variable Capacitor in Series With Head Circuit Providing a Means to Adjust Bias Current.

good region as far as distortion is concerned. If distortion is very low, peak bias generally will also give the best signal-to-noise ratio. The only disadvantage of peak bias is that the surface irregularities of magnetic tape have a tendency to be somewhat more pronounced. However, thanks to recent improvements in magnetic tape construction techniques, nodules and other surface irregularities are relatively unimportant as far as audio applications are concerned.

Adjustable and Fixed Bias

The philosophy of most machine manufacturers, if they do not incorporate an adjustable bias in their recorder, is to build machines fixed at somewhat over-bias. This technique, due to variation in production components, will allow a few machines to be biased at peak bias while a few machines will also be substantially over-biased. However, most machines will fall in a region of approximately 2 db over-bias. In general, the performance of most machines can be improved if an adjustable bias is incorporated in their design. Most professional recorders have an adjustable bias. The adjustable bias circuit used in the Ampex model 600 is shown in Fig. 6-9. Ampex requires operation at peak bias while several of the other professional manufacturers specify operation at 2 db over-bias. The trend in later years has definitely been toward the use of peak bias for all professional recording equipment.

Bias-Oscillator Design

The bias oscillator itself is generally a simple L-C circuit with either a tuned plate or a tuned-grid class-C oscillator employing a triode tube. In some of the professional recorders, dual triodes are used in push-pull, as shown in Fig. 6-10, in an effort to reduce second harmonic distortion.

A common cause of distortion arises from an improper bias waveform. In the bias signal wave, if one side of the wave has greater amplitude than the other, the tape will become magnetized and, as discussed earlier, second harmonic distortion will be introduced. Therefore, it is extremely important that the bias supply have good sinusoidal wave form. In an effort to do this, the professional manufacturer almost invariably will use push-pull oscillator tubes to eliminate any second harmonic component in the bias waveform that could possibly introduce second harmonic distortion in the tape recording itself.

While very little bias current is needed for the recording process, the bias oscillator is also called on to supply considerable current for the erase head. The current required for erasure is often as much as ten to thirty times as high as the current required for the recording process. Therefore, an oscillator must have substantial power to deliver the current for erasure. Most erase heads need almost 4 watts of power to do a complete job of erasure. This means that the oscillator must be capable of supplying up to 4

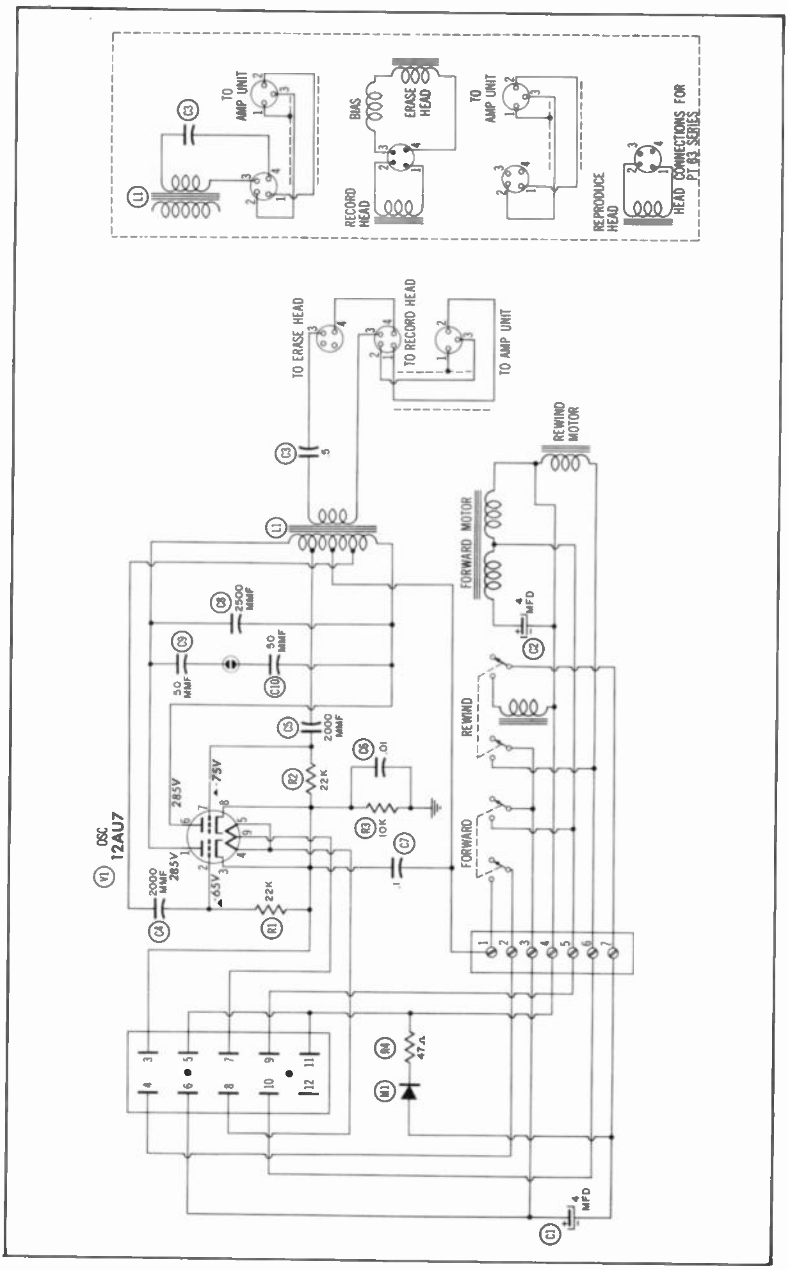


Fig. 6-10. In the Magnecord Model PT6 A Push-Pull Bias Oscillator Provides a Bias Current Free of Second Harmonic Distortion.

watts of power at a high frequency. In general, this is the frequency limitation imposed on the bias oscillator.

It is desirable, as we have seen earlier, to have the frequency as high as possible to avoid beats. However, it is difficult to design an oscillator to deliver considerable power at high frequencies without involving added expense. Therefore, the design of the bias oscillator represents a compromise between sufficient output for tape erasure and high enough frequency to avoid heterodynes in the recording signal. The lower-priced home-type recorders generally use single tube class-C oscillators which, for most purposes, serve quite well. A few recorders use a tube operating as a low-power oscillator tube and use the output stage of the amplifier to amplify both the audio signal and the bias signal. This performs quite well if the output stage of the amplifier introduces no distortion in either the audio signal or the bias waveform. Generally, it is considered better practice to feed directly into the head.

Bias Feed

There are two types of bias feed to the record and erase head. One is series feed, shown schematically in Fig. 6-11, very prevalent

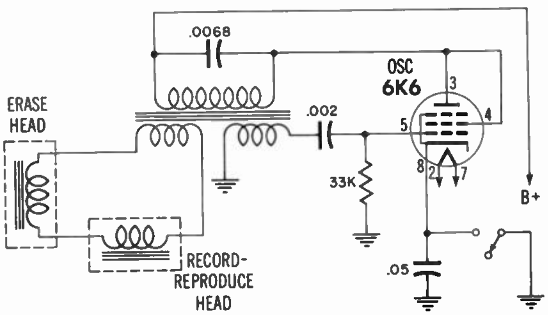


Fig. 6-11. Method of Applying Bias to Record Head by Means of a Series Circuit.

in early recorder designs. The second is shunt feed, most commonly known today. See Fig. 6-12. The bias frequency is actually added to the audio frequency. The audio frequency does not modulate the bias frequency as in the case of AM (amplitude modulated) radio waves. But rather a waveform is produced such as those shown in Fig. 6-13.

The series feed has the disadvantage that the bias is not easily controllable. If one adjusts the bias on the record head, either the erase current will be lowered or if the bias is shunted through the record head, a load will be placed on the audio signal. Therefore, the series feed method does not lend itself toward an adjustable bias control which has been the reason why this method of feed has been generally abandoned.

In shunt feed, it is possible to regulate both the erase current and the bias current. The most common type of bias feed in use today, shunt feed, requires a simpler head design and permits the use of high-impedance heads.

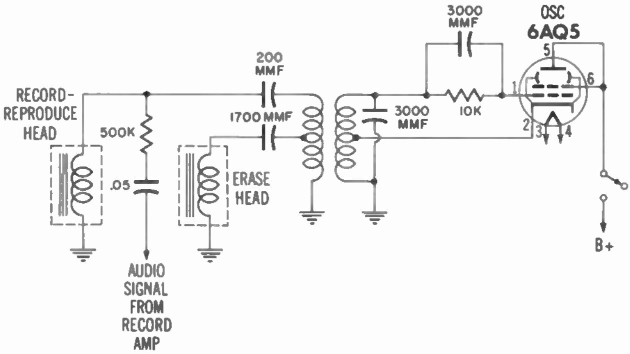


Fig. 6-12. A Parallel Bias Fed Circuit.

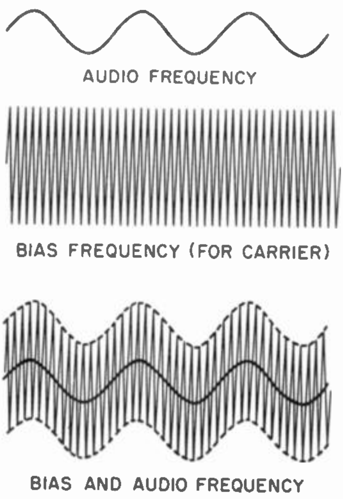


Fig. 6-13. Waveform Obtained When Audio and Bias Frequencies are Mixed (Added) Before Going to the Recording Head.

Trouble Hunting

If a recorder has severe distortion in the audio signal, one of the first places to look is in the bias oscillator. Is the bias oscillator tube functioning? Is it functioning well?

If the oscillator tube becomes at all weak, both the erase will suffer and the bias will, of course, be reduced while the signal will become distorted.

If the tube is not faulty and the signal is still found to be weak, look for faulty components. The bias waveform should be checked with an oscilloscope to obtain a rough approximation of its shape. It can be easily seen if the output is a good sinusoidal wave. If the waveform is not sinusoidal, definitely something is wrong in the oscillator and should be corrected to obtain good, low distortion recording results.

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CHAPTER 7

Equalization Circuits

If a constant amplitude signal were fed into a magnetic recording head and then played back, one would expect to obtain a flat or uniform amplitude over the frequency band. In reality, the resulting curve is far from uniform and flat.

This can be seen by examining the graph in Fig. 7-1. It will be noted that even though a constant amplitude input was fed to the tape, the output curve is insufficient in both low and high frequencies. The reason for this is that in magnetic recording the voltage induced in the playback head is proportional not only to the strength of the magnetic fields recorded on the tape but also to their rate of change or frequency.

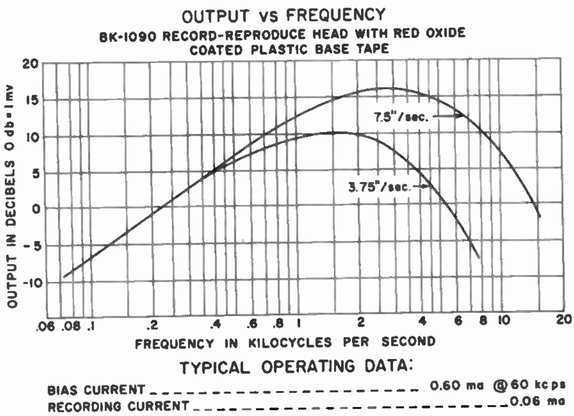

Fig. 7-1. Output From a Typical Magnetic Reproduce Head When Playing a Tape Recorded With a Constant Current for All Frequencies.

Since a high-frequency signal has many more magnets and its field is changing faster than a low-frequency signal, it will produce a greater amplitude. In practice, a 200-cycle signal will give exactly twice the output voltage of a 100-cycle signal. That is, if we double the frequency, we double the output in magnetic recording.

By a simple computation, we can see that by doubling the voltage, a 6 db increase in amplitude is obtained. Therefore, the magnetic recording characteristics rise at a rate of 6 db per octave. If the frequency is raised one octave or doubles, the output increases 6 db.

This accounts for the falling off at the low frequencies. Around 1,000 to 2,000 cycles, the output reaches a peak and then tapers off at higher frequencies. This tapering off is due to losses in the head due to gap effects and the magnetic head core structure.

Need for Equalization

Losses at both the low and high frequencies means that to obtain good frequency response on a magnetic recorder, one must equalize or compensate for these losses at both the low and high end.

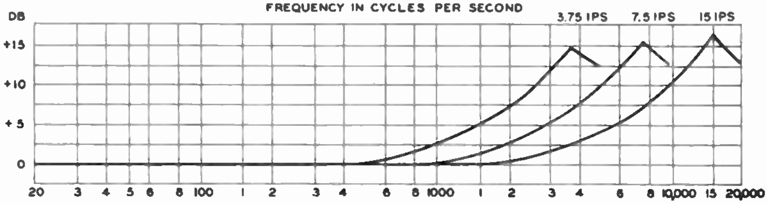

Fig. 7-2. Magnecord Record Curve With Circuit.

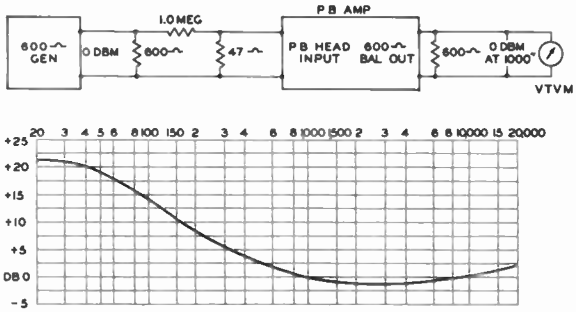

Fig. 7-3. Magnecord Playback Curve with Circuit.

The equalization may be accomplished by a variety of methods. However, in professional recording equipment, generally the tape is recorded with a boost in the high frequencies as shown in Fig. 7-2 and played back with an amplifier that boosts the low frequencies as in Fig. 7-3. Thus, the low frequency loss is corrected in playback and high frequency loss is corrected in recording.

The reason for equalizing in this manner is to obtain the best possible signal-to-noise ratio without entering the distortion range. To obtain the best signal-to-noise ratio, it is desirable to put as strong a signal as possible on the tape regardless of frequency, without overloading at any frequency. This means that if the tape has a strong signal recorded on it, only a minimum of amplification will be required during playback.

The noise level in magnetic recording is generally due to tube hiss, microphonics, and hum created in the playback amplifier and does not result from the tape itself. In theory, tape has no surface noise, but has only modulation noise.

High-Frequency Equalization

If we should record with a "flat" record amplifier (gain constant at all frequencies), the high frequencies would be very weak when reproduced from the tape due to the losses at high frequencies, and we would need excessive gain to reproduce them at their normal level. However, if we should boost the high frequencies during the recording process, it would compensate for the losses and it would still be impossible to overload the tape. This is because sound waves as generated by the human voice or musical instruments have less strength at high frequencies and the tape overloads at essentially the same amplitude regardless of frequencies. Therefore, high-frequency equalization can be accomplished during the record process without entering into the distortion range.

Low-Frequency Equalization

Low-frequency equalization is another matter. The power centered in vocal and musical sound waves is located in the low frequency range. Consequently, low-frequency equalization must be accomplished during playback to avoid overloading or distorting the tape.

However, in less expensive recorders, low-frequency equalization is often accomplished both in the record and playback process.

While this does not give theoretically the best signal-to-noise ratio, in practice this method yields the best results on lower-priced machines. The reason for this is that in small, inexpensive home-type recorders components such as the motor, power transformer, and amplifier produce quite large hum fields. Without expensive shielding, the magnetic reproduce head tends to pick up from these fields an excessive amount of hum.

If the full low-frequency equalization is accomplished in playback, the hum will be greatly amplified. However, if part of the low-frequency equalization is accomplished during the record process, less amplification will be needed at low frequencies during playback, thereby helping eliminate the hum.

Still other recorders, in an effort to simplify the record-playback switch functions, use only one equalization circuit for both record and playback. Therefore, both low frequencies and high frequencies are equalized in recording and playback.

The method of equalization used in the record process is known as pre-equalization. The equalization used in the playback process is referred to as post-equalization.

Differences in Equalization

Due to differences in equalization between recorder manufacturers, tapes recorded on one machine will not necessarily sound good on another machine. For example, consider a tape recorded on a professional recorder with no low frequency pre-equalization but using the full high frequency pre-equalization. The recording will sound unduly sharp and harsh with shrill highs and very little bass when played on a home-type recorder designed to have both low-and high-frequency equalization take place in the record and playback process.

Equalization for Dual-Speed Recorders

From the graph, Fig. 7-4, it can be seen that if the tape speed is doubled, the region of peak output is raised one octave or 6 db. When designing an equalization system for a dual-speed recorder, compensation must be made for the 6 db per octave loss at the low

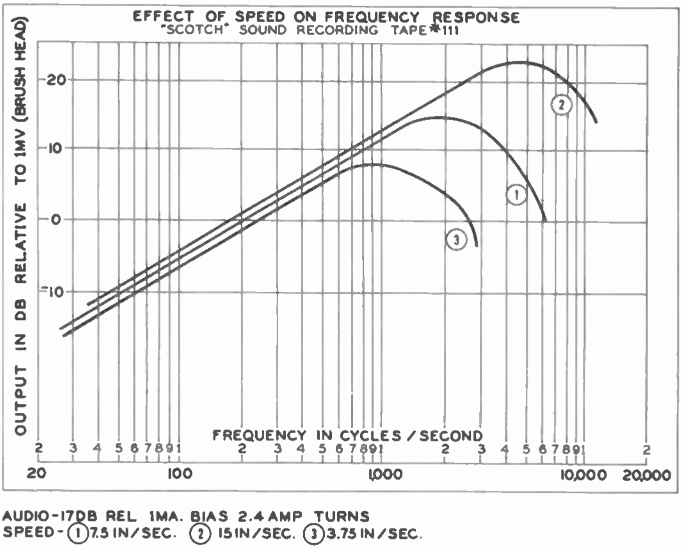

Fig. 7-4. Graph Showing the Effect of Speed on Frequency Response.

frequencies and for magnetic head gap and core losses at the high frequencies. In dual-speed recorders, to obtain maximum performance it is imperative that an equalizer be designed for each speed. See Fig. 7-5.

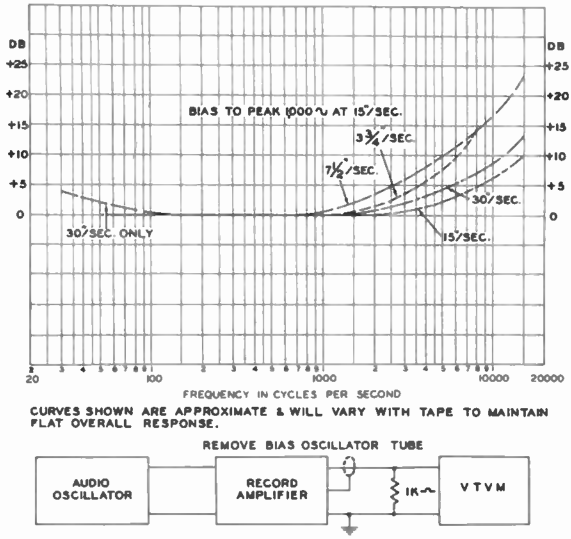

Fig. 7-5. Ampex Record-Amplifier Response.

On dual-speed professional machines, to accomplish peak performance, two separate equalizer networks are provided. Only the pre-equalization is changed in several professional recorders. The post-equalization or low-frequency equalization is the same for both 7 1/2 and 15-ips speeds. See Fig. 7-6. By changing only the high-frequency equalization, flat response is obtained at both speeds. In other dual-speed professional recorders both the high-and low-frequency equalization is changed to compensate for the change in speed.

In many home-type, dual-speed recorders, the amplifier circuits embody only one equalization circuit. This circuit may be designed in three ways:

First, the equalization circuit may provide for optimum results at one speed only. In the case of most home recorders which operate at both 3 3/4 and 7 1/2 ips, the equalization circuit is designed for the higher speed or 7 1/2 ips. This means that at 7 1/2 ips, optimum performance is obtained from the machine.

However, when the speed is switched to 3 3/4 ips, not only is response lost through the decrease in speed but far from optimum results are obtained since the equalization circuit is not designed for the 3 3/4 ips speed. Consequently, when a tape is played at 3 3/4 ips on an equalization circuit designed to compensate for losses at 7 1/2 ips, the results can not help but be disappointing.

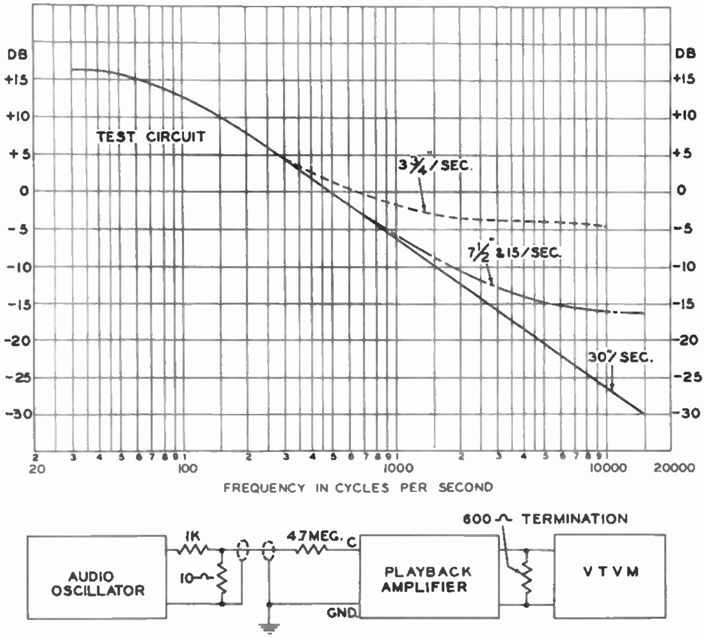

Fig. 7-6. Ampex Playback-Amplifier Response.

The second approach sometimes used in dual speed home-type recorder equalization circuits is to provide equalization for a non-existant intermediate speed. As an example, the equalization circuit may give optimum results at a speed of 5 ips. Therefore, when a machine is operating at either 3 3/4 or 7 1/2 ips, the results are naturally not as good as could be expected. True, the 7 1/2-ips speed will give better results than at 3 3/4 ips. However, neither speed will be entirely satisfactory. A frank compromise, this type of equalization circuit is designed to improve the 3 3/4-ips response while sacrificing some of the advantages obtained with a 7 1/2-ips speed response.

A third method of equalization of dual speed home-type recorders is finding increasing favor. This type of equalization recognizes the limitations in a short-cut, compromise approach and, instead, employs two different equalization circuits. See Fig. 7-7.

Those recorders that use two separate equalization circuits generally switch between the circuits with the same knob that controls the speed. For example, when switching to 7 1/2 ips, the equalization is automatically adjusted for that speed.

When purchasing a dual-speed machine, it is important to check the type of equalization circuits used and the method of switching, if any. There is little doubt that if optimum performance is expected from a recorder, the machine must change equalization for each speed.

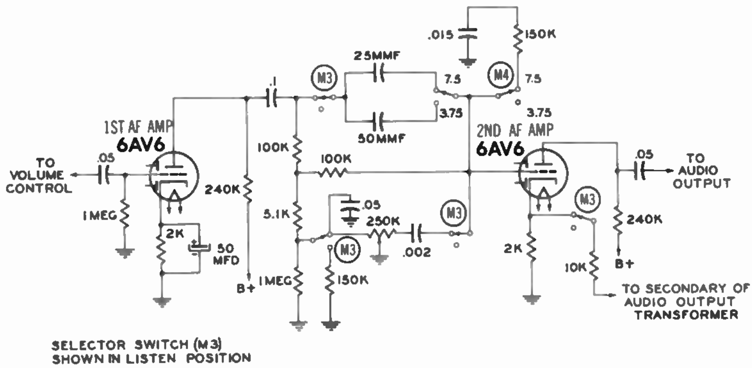

Fig. 7-7. Playback Equalization Circuit used in Ekotape Recorder.

Standardization of Playback Equalization

The National Association of Radio and Television Broadcasters has already adopted a standard professional playback equalization characteristic curve. Tapes are then to be recorded in such a manner that when played back with the standard playback characteristic, the output will be essentially flat.

However, in the home recorder field no such standardization yet exists. The lack of standardization represents a sizable roadblock in the path of the fast growing pre-recorded tape industry. In fact, even among professional recording machines, few follow the NARTB standard. However, in most professional machines the equalizations are sufficiently close that good results are obtained when tapes are recorded on one machine and played on another.

A standard is definitely needed among home recorder manufacturers. Up to the present time, each manufacturer has gone his own way in developing the equalization circuit that is best suited to his individual machine.

The Magnetic Recording Industry Association has formed an aggressive standardization committee to work out equalization circuits among all American recorder manufacturers early in the industry's growth. In addition, those foreign tape recorder manufacturers interested in importing their machines into the American market have also been invited to participate.

If tape is to compete on an even basis with present-day discs for the broad home-music market, standard playback curves must be established on home-type recorders so that pre-recorded music on tape will sound equally good on all machines. It is obviously an economic impossibility to expect dealers to stock a line of pre-recorded tapes, specially equalized for each of the major home-type recorders.

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CHAPTER 8

The Record and Playback Amplifier

The signal from the microphone is extremely weak, at the most only a few millivolts. Therefore, during recording an amplifier is needed to raise the feeble signal from the microphone to a relatively high level before feeding into the magnetic head. Adding still further complication during playback, the signal obtained from the magnetic reproduce head is also very weak, at the most approximately 8 millivolts. Again, an amplifier with very high gain is required to raise the signal strength sufficiently to drive a loudspeaker.

Because of the weak signal from both the microphone and magnetic reproduce head, it is easy to see that the record and playback amplifiers play a crucial role in the tape recording process. Both amplifiers operate from the same basic principles and have the same limitations. The only difference between the record and playback amplifier lies in the amount of gain required and the type of equalization used, a discussion of which is covered in another chapter.

Amplifier Characteristics

As the name implies, an amplifier is constructed to amplify or build a weak signal into a strong one. That is, the amplifier takes a very weak electrical signal, generally an electrical voltage, whether produced by a microphone or the signal from the magnetic reproduce head in the playback process, and raises this voltage many thousands of times. The signal is subsequently converted into current which is, in turn, used to drive a loudspeaker.

The amplifying process or the amount of amplification is technically known as the gain of the amplifier. There are two types of gain: voltage gain and power gain. Supplying voltage gain is the principal function of both the record and playback amplifiers, except for the output stage in the playback amplifier where voltage is converted to power.

To obtain gain a vacuum tube is employed. The vacuum tube, similar in function to a valve, enables a relatively weak voltage to control a large current or voltage. If the gain from one tube is insufficient, the tubes can be cascaded. In cascading, the output from the first tube is fed into a second, the output from the second is fed into a third. Then if each tube amplified, say, 10 times, two tubes would amplify 100 times, and three tubes 1,000 times.

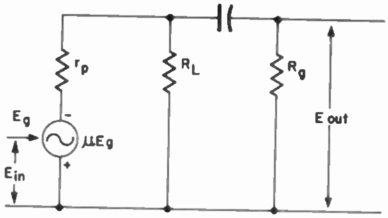
In tape recorder applications, generally the gain of the first stage, which can be either a single pentode or a dual cascade triode, may be several hundred. The following stage usually has a gain of between 10 and 60. So, therefore, in the first two stages of tubes in the cascade chain, there may be a gain of well over 2 or 3 thousand.

The gain of the amplifier is determined by three factors. First, the type of tube; second, the values of the circuit components; and third, the mode of operation of the tube.

Type of Tube Required

In the early stages of a tape recorder's record-playback amplifier, a very high amplification is necessary to raise the weak signal to a satisfactory level while introducing as small an amount of noise as possible. In order to accomplish this objective, it is desirable to amplify the weak signal as rapidly as possible and then to amplify a relatively strong signal in the subsequent stages.

The pentode-type tube has an amplification of from 100 to 300 times. In this respect it is very desirable since it has high gain. However, it suffers from being more noisy than the triode and introduces somewhat more distortion, although distortion is not a big problem in the early amplifier stages. A triode, while it has less gain, has far less noise and substantially less distortion. However, to duplicate the gain of the pentode, two triodes are necessary. The total results are often very similar, regardless whether amplification is obtained with two triodes or with one pentode. The number of circuit components is very nearly the same.



$$A = \frac{\mu R_L}{r_p + R_L}$$

A = AMPLIFICATION

Fig. 8-1. Electrical Equivalent of a Triode Amplifier Stage and the Mathematical Equivalent Showing its Amplification at Mid Frequencies.

Recent developments have led to the adoption of low noise tubes. Several excellent pentodes are now available, and the trend in recorder manufacture seems to be toward tubes like the 5879, which give a high amplification with little noise.

The amplification at mid-frequencies may be easily determined by the following formula:

$$A = gm \frac{R_1}{r_p + R_1}$$

where

gm = amplification factor of the tube
r_p = plate resistance of the tube
R_1 = the load resistance, and the grid resistance of the following stage, in parallel. That is:

$$R_1 = \frac{R_L \times R_g}{R_L + R_g}$$

The vacuum tube, whether it be pentode or triode, can be represented as a generator whose output is the grid signal or the input voltage to the grid of the tube, times the amplification factor of the tube. In series with this generator is the plate resistance inherent in the tube. See Fig. 8-1.

By knowing these values, the circuit can be designed to give the desired gain while still possessing satisfactory frequency response.

Signal-To-Noise Ratio

It is obvious that the amplifier, while providing gain, should introduce as little noise as possible. In magnetic recording this is especially crucial because the signal-to-noise ratio of a tape recorder is primarily limited by the playback amplifier.

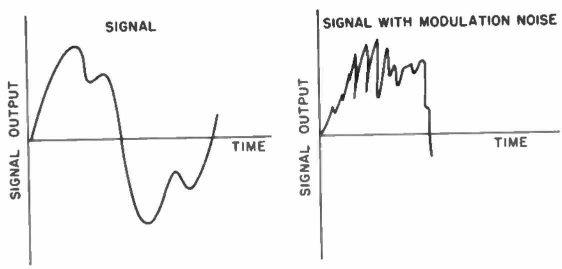


Fig. 8-2. The Effect of Modulation Noise on a Recorded Signal.

Signal-to-noise ratio, simply stated, is the maximum signal obtainable from the amplifier before distortion sets in compared to the noise inherent in the system. In tape recording, the medium of magnetic tape introduces no surface noise. That is, if there is no signal recorded on the tape and, providing the tape is completely demagnetized, the tape will be completely noise free.

True, when the tape has a signal, as shown in Fig. 8-2, the output will vary and this is called modulation noise.

However, in determining the signal-to-noise ratio of the system, the maximum signal from the playback amplifier, generally 3% distortion, is compared to the completely erased tape. Since the tape, when completely erased will give no noise, the only noise present in the system is from the playback amplifier. Therefore, the signal-to-noise ratio of tape recorders is determined by the playback amplifier.

Noise-Reduction Techniques

Great care is taken in tape recorder design to reduce the noise inherent in the input stage of the amplifier. The reason why particular care is devoted to the input stage is that when the signal has been amplified to a sufficiently high level in the first stage, noise contributed by the second and third stages of the amplifier is relatively insignificant.

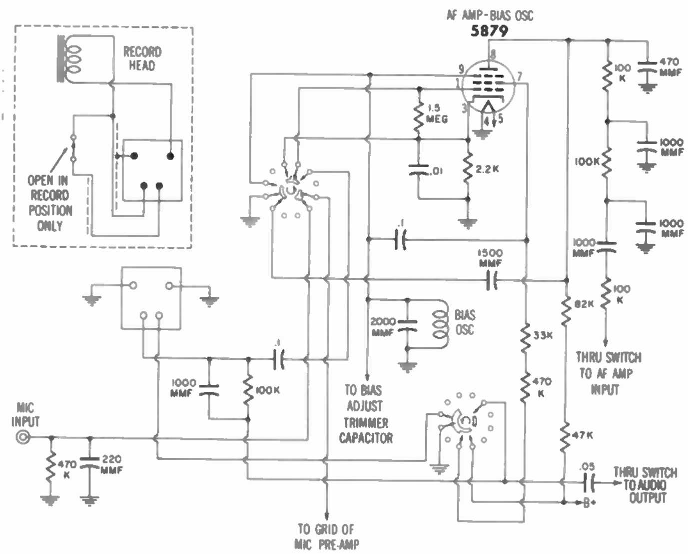


Fig. 8-3. The Input Circuit Used in the Wilcox-Gay Model 3C10 Recorder.

It is interesting to note that the more expensive the tape recorder, the more care has been given to the reduction of noise in the first stage of the playback amplifier. The technique most commonly used is to employ very low noise tubes. The 6SJ7, the 6J7, and the 1620 are all well-known, time-tested friends of the audio engineer. These tubes, all pentodes, possess high gain with low noise. More recently, the 5879, a miniature tube also possessing low noise, has been introduced on the market. This tube is finding wide acceptance in recent years in the design of home tape-recorder amplifiers. A typical circuit using a 5879 tube as a combined AF amp and bias oscillator is shown in Fig. 8-3.

In the field of triodes, the 12AY7, a very low noise tube, has been developed. Several home recorders use the 12AX7 which gives very high gain. See Fig. 8-4. It has a tendency, however, to be somewhat noisy.

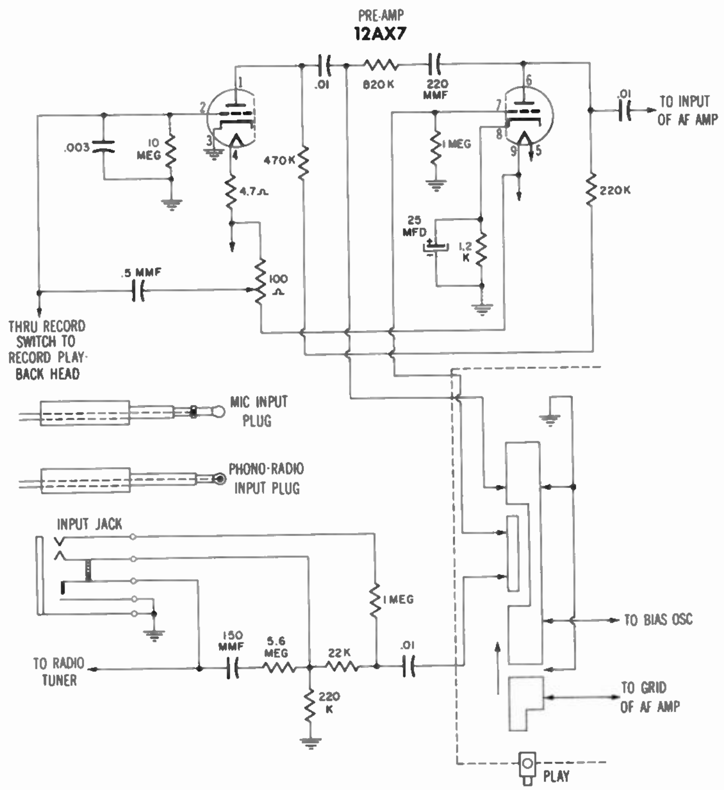


Fig. 8-4. Revere T-700 Input Circuit Using One-Half of a 12AX7 Tube.

Types of Noise

The most common type of noise in a tube is hum. Hum is most often introduced from the alternating current used to light the filament of the tubes. In more expensive recorders, as shown in Fig. 8-5, direct current is used to light the filament of the input tube. This, of course, eliminates any possibility of hum being introduced from the tube's heater. However, in less expensive recorders alternating current is used on the filament. In this case it is very important that the filament supply be ground at a neutral point. The cathode also must be adequately bypassed to eliminate hum (see Fig. 8-6). Frequently hum in the input stages is due to the cathode-bypass capacitor losing its capacitance.

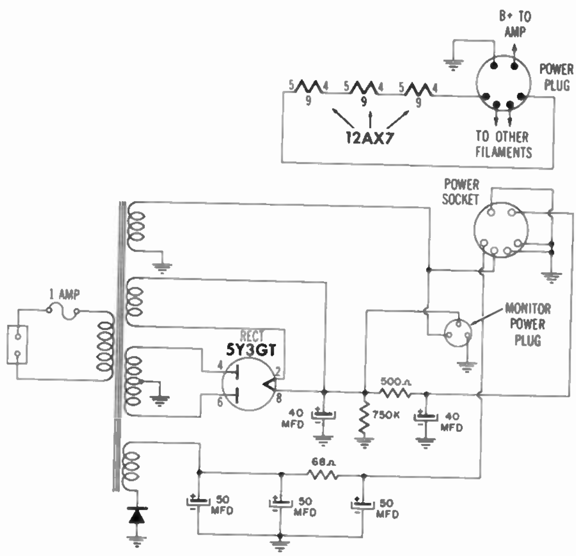


Fig. 8-5. Direct-Current Filament Supply Used in the Concertone Model 1401 Recorder.

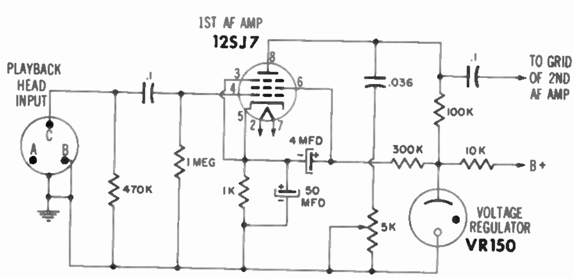


Fig. 8-6. Input Stage Showing Cathode - Bypass Capacitor and Plate Circuit of the Ampex Model 300 Recorder.

Another common type of noise in a tube is shot noise. This is caused from the electrons leaving the cathodes in groups or clusters rather than in a continuous stream. Then, when they strike the plate, the shot noise sounds similar to the rush of a waterfall. Due to the irregularity of electrons striking the plate, low-noise tubes are especially designed to reduce this effect.

Still another type of noise common in input stages is thermo noise. That is, if a current flows through a resistance a certain type of noise is generated. It is also called white noise since it covers a wide band of frequencies at almost constant amplitude.

In designing input stages, the more expensive recorders use wire wound or carbon deposited resistors rather than the less expensive cast-type resistors to eliminate noise. Often by the simple replacement of the plate resistor and cathode resistor in a home recorder with a wire wound or carbon deposited resistor, a tremendous reduction of noise can be achieved in the input stage. While these resistors do not represent much money as a replacement item for a single recorder, cost makes their use prohibitive in mass production of home-type recorders. This is one trick, easy to perform, that will generally greatly improve the performance of the average home recorder.

Another type of noise common in the input stages of amplifiers is a microphonic condition. This type of noise can be caused by either microphonic tubes or microphonic parts such as a resistor. Microphonic means that a component is sensitive to vibration and will alter its electrical characteristics when vibrated, operating in a manner somewhat similar to a microphone. The worst microphonic offenders are tubes in the input stage. These can be readily detected by tapping the tube. Generally a loud ringing sound will result.

Microphonics are especially bothersome in compact, home-type recorders where the amplifier is mounted next to the motorboard. The motor, of course, creates considerable vibration which is readily picked up by any input tube that is microphonic. Also, since the speaker is mounted in the same case as the amplifier, the vibrations from the speaker will often feed back through the input tube causing an oscillation or howl to build up when the volume control is advanced.

Fig. 8-7. Input Tube Mounted on Rubber Shock Mounts.

To eliminate this condition, low noise tubes are also designed to be non-microphonic as much as possible. However, often it is necessary to specially select tubes for low microphonics. In some cases, such as in the case of 12AX7 tubes, it is necessary to select perhaps one out of ten, or one out of 20 tubes, to get a really low microphonic tube. Practically all recorders mount the input tube on rubber mounts, as shown in Fig. 8-7, which isolate it as much as possible from any vibration. Some manufacturers even hang weights on the tube itself to give it inertia, helping damp out any transmitted vibration. All of these methods help reduce the bothersome microphonic problem.

Harmonic Distortion

While the primary job of both the record and playback amplifier is to amplify or provide gain, it must also give gain while introducing as little noise and distortion as possible.

There are, basically, three types of distortion: harmonic distortion, inter-modulation distortion, and cross-modulation distortion. Many audio engineers staunchly support the dictum that inter-modulation distortion is the only true test of an amplifier's performance. An equal number of engineers take the opposite stand, feeling that harmonic distortion is the only correct criteria of measurement. Actually, all three are mathematically related and should, under most conditions, give similar results even though the method of measurement is different. For purposes of this discussion, when we refer to distortion, we are referring to harmonic distortion.

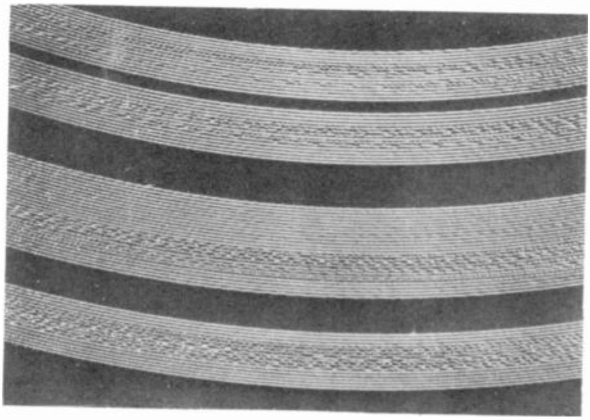


Fig. 8-8. Over-Cut Disc Grooves.

Harmonic distortion refers to the fact that when a frequency signal is recorded during playback, say a pure 400 cycle tone, not only is the 400 cycle tone received but also is reproduced an 800, a 1600, and a 3200 cycle tone, etc. These are the even order harmonics or even multiples of the fundamental frequency. Also reproduced from a 400 cycle tone will be a 1200 cycle tone, a 2000 cycle tone, a 2800 cycle tone, etc. These are the odd order harmonics or odd multiples of the fundamental frequency.

In magnetic recording it is theoretically impossible to get even or second harmonic distortion. If an even harmonic distortion condition exists its cause will originate in the amplifier or be due to magnetized tape. One of the outstanding characteristics of magnetic recording that has made it today's quality recording medium is the fact the process is inherently free of second harmonic distortion.

However, if we should put in a signal stronger than the tape can record, thereby overloading or saturating the tape, the tape reaches a point at which it can no longer be magnetized. Therefore, with additional increases in the signal strength there will be no increase in the tape output, causing an effect known as clipping. Clipping, in turn, results in third harmonic distortion.

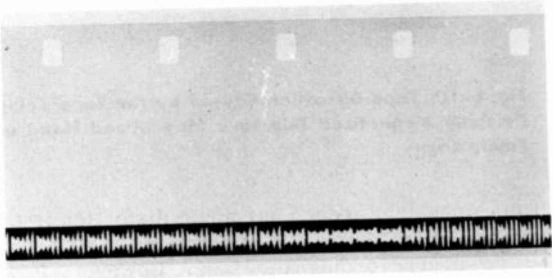


Fig. 8-9. Over-Modulated Optical Sound Track.

The clipping that results from tape overload is not as severe as in other recording methods. For example, in the disc recording process, if the disc is over-recorded, one actually cuts into the adjacent grooves of the recording, resulting in almost total ruin as shown in Fig. 8-8. In photographic recording, by over-recording, the peaks of the waves are chopped flatly off, causing a very harsh type of distortion as shown in Fig. 8-9. However, in magnetic recording, if one over-records there is a tendency to flatten the peaks of the curve in a gradual manner as shown in the graph in Fig. 8-10. This means that although third harmonic distortion is introduced, it is far more gradual compared to other mediums.

Using disc or photographic recording systems, the recording level must be carefully guarded at all times because of disastrous results if the recording were made at too high an amplitude. In contrast, using the magnetic recording medium, even if the amplitude is several times higher than the normal record level, the resulting distortion will often not be too objectionable.

Using a magnetic tape recorder, it is almost impossible for an inexperienced 12-year old child to make a totally unacceptable recording. Understanding this inherent advantage, it is not difficult to realize why magnetic recording is so popular in the home.

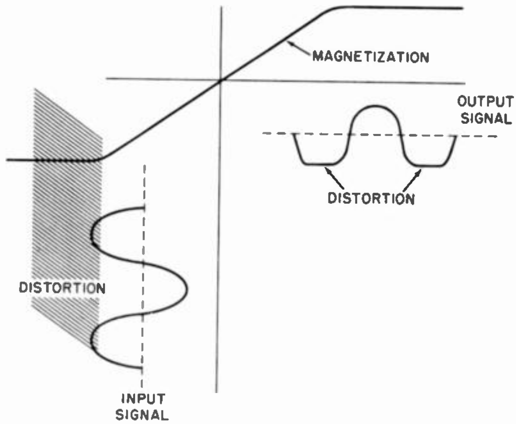


Fig. 8-10. Tape Distortion Caused by the Tape Being Partially Magnetized Due to a Magnetized Head or Faulty Erase.

We have seen that second harmonic distortion is theoretically non-existent and third harmonic distortion is introduced only by overloading or overrecording the tape. However, if we measure recorders, we will see both second and third harmonic distortion in the output amplifiers. Second harmonic distortion is mainly introduced by faulty design in the amplifier circuits. The output stage of most recorders uses a single pentode tube which often introduces 5 or more per cent of total harmonic distortion, a large amount of it being even or second harmonic distortion. The better recorders use large amounts of feedback together with push-pull output stages which tends to reduce this type of distortion, giving better performance.

Second harmonic distortion can be also introduced in the magnetic process if the tape recording condition is at all shifted from its symmetrical counterpoint. That is, if the tape is at all magnetized during the recording process, severe second harmonic distortion is possible. (See Fig. 8-11.) The magnetization of the tape can be caused by any one of the magnetic heads becoming magnetized or from the erase system.

The preferred method of checking for magnetized heads is first to demagnetize the heads with a head demagnetizer to determine if the performance has improved. If the diagnosis was correct, there will be a drastic reduction in noise followed by a reduction in distortion.

Still another method is to move, during the recording process, a permanent magnet around the recorder to determine if the amount of noise or distortion is reduced. This will occur if a head is magnetized. The field of the permanent magnet will cancel the residual magnetic field of the head.

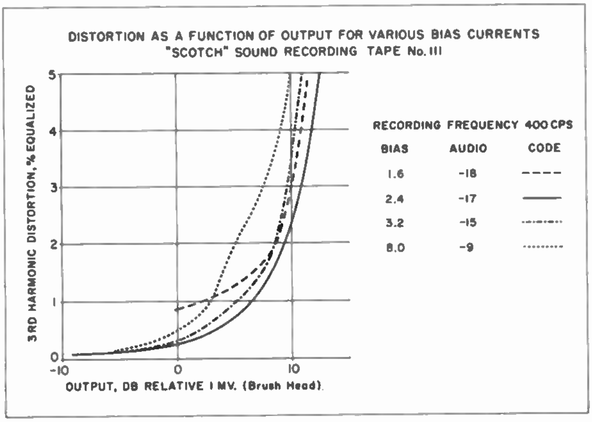


Fig. 8-11. Distortion as a Function of the Signal Level for a Typical Magnetic Tape.

If the permanent magnet is found to result in lower noise or distortion, the source of magnetization such as a magnetized head should then be chased down and corrected.

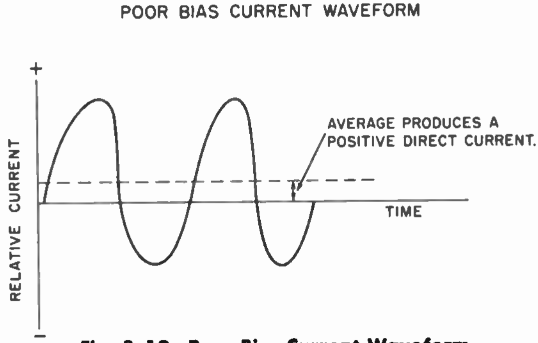


Fig. 8-12. Poor Bias-Current Waveform.

Another cause of second harmonic distortion results from poor bias waveform as shown in Fig. 8-12. The amplitude of the waves in one direction are stronger than in another direction in the output of the bias oscillator. The bias waveform can often be checked on an oscilloscope to determine if the waveform is symmetrical about its center axis.

The distortion introduced in the amplifier itself is sometimes caused by faulty original design such as a pentode output stage with insufficient feedback. Other possibilities are improper bias on the tubes, caused by a resistor changing value in the cathode circuit of a tube or leaky coupling capacitors resulting in a positive voltage on the grid of the tube, thus changing the bias.

Frequency Response

In addition to amplification gain, low noise, and distortion, an amplifier must also have good frequency response. In the chapter devoted to equalization, it was explained that the type of equalization chosen primarily determines the over-all frequency response of the recorder. However, the amplifier circuits themselves must be designed to adequately pass the frequencies within the desired range. The equalizer circuits, while still a part of the amplifier, are treated separately to facilitate better understanding of their operation.

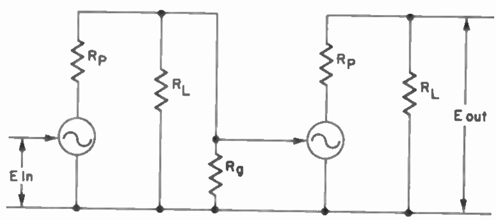


Fig. 8-13. Equivalent Circuit of a Two-Stage Triode Amplifier for Mid-Frequencies.

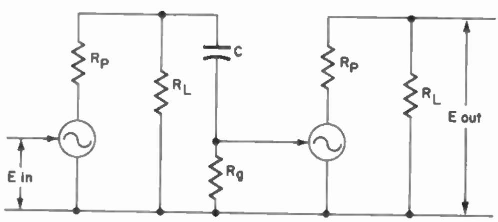


Fig. 8-14. Equivalent Circuit of a Two-Stage Triode Amplifier for Low Frequencies.

In an equivalent circuit of an amplifier stage followed by another amplifier stage, Fig. 8-13 shows middle frequencies configuration. At low frequencies, the amplifier circuit appears as shown in Fig. 8-14. Note the series capacitor with the grid resistance of the following tube. This capacitor at low frequencies has a high resistance and serves to pass high frequencies and reject low frequencies.

To improve the low frequency response of an amplifier, the size of the coupling capacitors, therefore, should be increased. The larger the capacitor, however, the higher its cost. Because of cost considerations, most manufacturers generally use as small a capacitor as possible, settling for the minimum acceptable low-frequency response. Nevertheless, it should be remembered that there are other factors besides inefficient capacitors that limit the low-frequency response. These factors are covered in detail in the chapters devoted to equalization and magnetic heads.

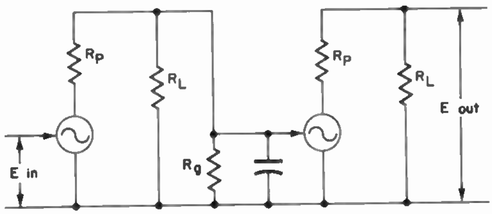


Fig. 8-15. Equivalent Circuit of a Two Stage Triode Amplifier for High Frequencies.

The high frequency equivalent circuit appears in Fig. 8-15. Note that the equivalent input capacitance of the following stage then serves to limit the high frequencies. In other words, at low frequencies the capacitance is small compared to the grid resistance. This equivalent capacitance has no effect on the circuit. However, at higher frequencies this capacitance tends to short out the incoming signal and limit the high-frequency response. The equivalent capacitance of the following tube cannot be changed except by changing tube and circuit design, which generally does not substantially improve the situation. Therefore, it is necessary to lower the load resistance of the preceding tube. This, in effect, makes the reactance of the shunt equivalent capacitance small in respect to the load resistance of the preceding tubes. While this design will pass higher frequencies, the gain will be adversely affected.

Therefore, the value of load resistance in the tube circuit is a compromise between gain or amplification and high-frequency response. The lower the resistor, the less gain and the better the high-frequency response. Conversely, the higher the resistance, the more the amplification is boosted although the high-frequency response becomes more limited.

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CHAPTER 9

Magnetic Recording Heads

The magnetic recording head is the most critical and precision device in the entire recording mechanism. Built to a tolerance as close as a ten-thousandth of an inch, the magnetic head requires an exceptionally high degree of precision in its construction.

Good fidelity in recorder operation, at the present-day speed of 3 3/4 ips, has been achieved. This, in large measure, has been made possible through basic improvements in magnetic heads. Magnetic heads not only determine the low- and high-frequency response of a recorder but also help establish the signal-to-noise ratio.

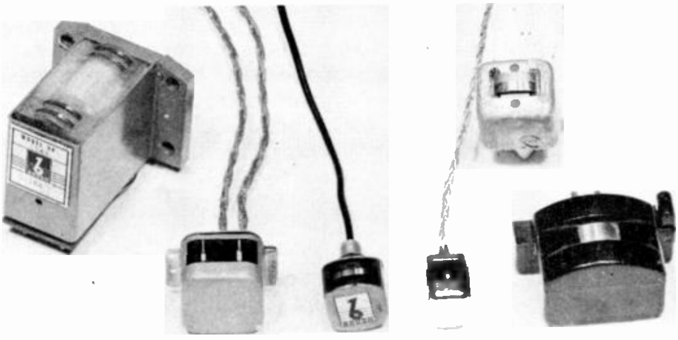


Fig. 9-1. Various Typical Magnetic Heads.

It is imperative to get the strongest signal possible out of the magnetic head since a strong signal means that less amplification is required to reproduce sound at an audible level. As we have seen, noise in magnetic recording mainly originates in the playback amplifier. Consequently, a head that gives a strong signal means that less amplification is needed and less noise will be introduced. The magnetic head is, therefore, the very heart of the magnetic recording process. Fig. 9-1 shows a sampling of some of the magnetic heads in use.

In most discussions it is common to speak of three magnetic heads. First, the erase head, which has the function of obliterating or "wiping" off any signal on the tape, leaving the tape in a completely demagnetized condition. Second, the record head which serves to place a signal in the form of magnetic impulses on the tape. And third, the reproduce or playback head which has the function of converting the stored magnetic impulses on the tape into electrical energy to be amplified for reproduction.

In respect to design, the record and reproduce heads are practically identical. In the majority of machines, especially home-type tape recorders, the same head is used for both record and playback functions. This is accomplished by merely switching the head from the output of the amplifier during the recording process to the input of the amplifier during the playback process. Therefore, we will discuss only the erase head and the record-reproduce head.

The Erase Head

As previously mentioned, the first function of the erase head is to completely obliterate any signal on the tape from the prior recording. The second function is to leave the tape in a completely neutral or demagnetized condition. To completely wipe off any previous signal from the tape is, of course, important since an echo or background of the previous recording would disturb the new recording. The tape must also be left in a completely neutral or demagnetized state in order to eliminate all distortion and noise.

To accomplish both objectives in tape erasure, a magnetic field is needed which is considerably stronger than the strongest signal on the tape. This field must be designed in such a manner that it will highly magnetize the tape in one direction obliterating the previous signal, and then demagnetize the tape, leaving it in a completely neutral state.

Permanent-Magnet Erase

Many early recorders and several present-day machines use what is known as permanent-magnet erase. This is a permanent magnet generally made out of "Alnico" material that is so constructed that one pole completely magnetizes the tape, saturating it to a state far more magnetized than the strongest previous signal. Thus, the permanent-magnet erase serves to obliterate any signal on the tape. Then, either a second magnet, a series of magnets or, still, a diagonal magnetic gap is used to demagnetize the tape and leave it in a neutral state. A typical permanent-magnet erase head is shown in Fig. 9-2.

The chief disadvantage of the permanent-magnet erase is that it must be mechanically operated. This is accomplished during playback by moving the erase head away from the tape by a mechanical linkage so as not to erase the tape. However, the head must be engaged during the recording process. This is somewhat more complicated than the electromagnetic erase head in which only an electrical circuit is opened and closed.

Another disadvantage of the permanent-magnet erase is that it is difficult to obtain a demagnetized tape that is in a completely neutral state. Extreme care must be taken in adjusting the magnets so as to remove the saturated field. The Wilcox-Gay uses an ingenious system that involves a diagonal magnetic gap which does a very effective job of neutralizing the magnetic field of the tape.

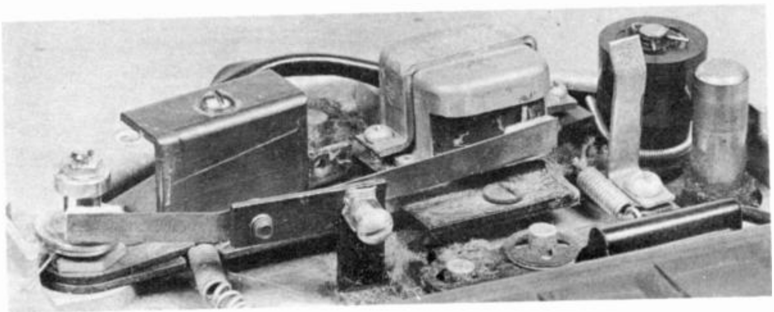


Fig. 9-2. A Typical Permanent-Magnet Erase Head.

The permanent magnetic erase head, however, has several positive advantages. No strong high-frequency signal source is required, thus eliminating the major demand on the bias supply. (See the chapter on the bias oscillator.) This greatly simplifies the design of the bias oscillator, meaning that an amplifier can be built with a smaller power transformer. Since there is a smaller tube in the bias oscillator, many economies result in the amplifier design.

High-Frequency Erase

The high-frequency erase head is a head with a rather wide gap that uses a very high frequency, generally the bias frequency, to erase the tape. The source for the current in this case is described in the chapter devoted to the bias oscillator. In the high-frequency erase process, as the tape passes over a wide gap (see Fig. 9-3), a series of reversals take place in the magnetic field on the tape. When the tape leaves the gap, it is in an essentially neutral or demagnetized condition.

The high-frequency erase head makes an ideal method of tape erasure. If the signal is strong enough and if the head is correctly designed, the high-frequency erase method will completely obliterate any previous signal, leaving the tape in a completely neutral condition.

It should be pointed out that if this head should become magnetized, which will result from suddenly turning the bias oscillator off, the tape will be left in a magnetized condition, introducing distortion and noise. Therefore, the erase head should be occasionally checked to be sure that it is demagnetized. A head demagnetizer is a useful tool for all magnetic recorders. The demagnetizer should be run slowly across the gap and gradually removed with the current still on as shown in Fig. 9-4. This effectively removes any residual magnetism in the magnetic head.

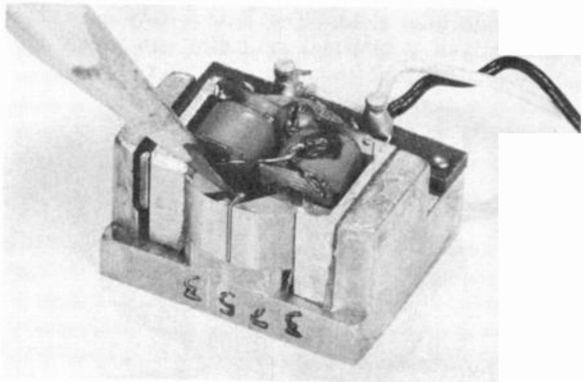


Fig. 9-3. A Typical Erase Head—Note the Long Gap Length Which Allows a Number of Magnetic Alternations to Take Place on a Given Tape Area During Erasure.

Fig. 9-4. Using a Head Demagnetizer (Degausser) to Remove Residual Magnetism From a Recorder Head.

Low-Frequency Erase

Still another method of erasing the tape is with a low frequency alternating current source such as that used in the Ampro recorder shown in Fig. 9-5. A 60-cycle field is applied perpendicular to the tape, using a gap that gradually decreases the magnetic field as the tape passes across the erase head. While in theory this method should perform satisfactorily, there is a tendency to leave a low-frequency 60-cycle note recorded on the tape. However, this note is not bothersome since few speakers provided with tape recorders are capable of reproducing this low a frequency. Nevertheless, the signal still remains on the tape, a potential source of trouble if ever a high quality external speaker system is used.

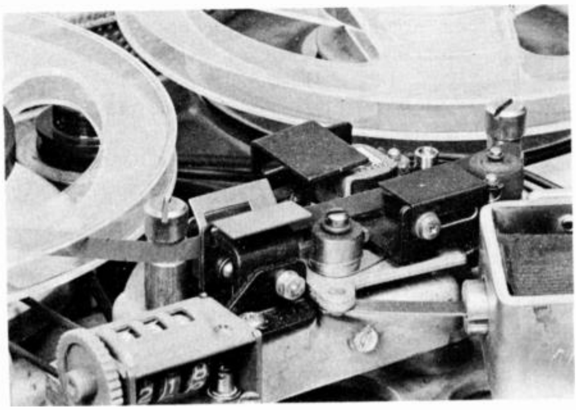


Fig. 9-5. Low Frequency AC Erase Head Used in Ampro Recorder.

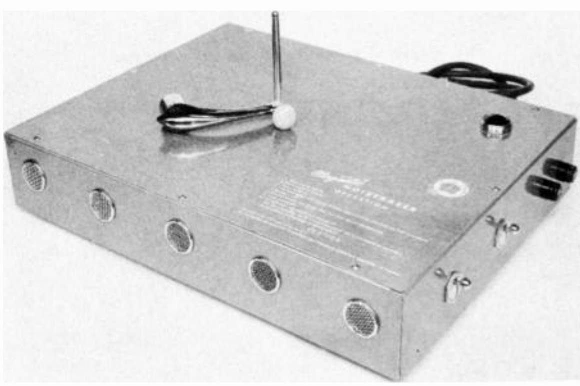


Fig. 9-6. A Typical Bulk Eraser.

Bulk Erasure

The final method of tape erasure is accomplished with a bulk tape eraser such as shown in Fig. 9-6.

If a recorder's erase system is working right, it will completely erase any normal signal on present red oxide or dark green high output oxide tapes. However, if a tape is severely overrecorded, or if an old black oxide tape happens to be used, signals can be completely removed by use of a bulk eraser. Certain recorders have no erase system and thus require an external erasure of the tapes. It is for these reasons and the ease that an entire reel of tape may be completely and cleanly erased that a bulk eraser is used.

The tape is placed on a bulk eraser from which a large alternating current field, generally 60 cycles, radiates. The tape is slowly rotated in this field and then is gradually and uniformily withdrawn from the field. It is this gradual withdrawal which makes for a perfect bulk erasing job. It is obvious that if the bulk eraser were turned off while the tape was in its vicinity, there would be a good chance of leaving the tape highly magnetized which is undesirable. Therefore, the tape should be placed on the bulk eraser, the bulk eraser turned on, and the reel very slowly rotated to completely cycle all sections of the

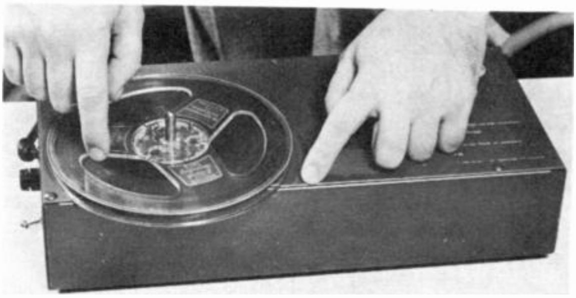


Fig. 9-7A. Tape Placed on Bulk Eraser.

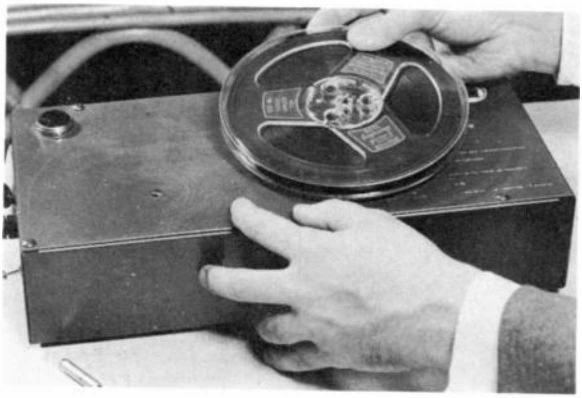


Fig. 9-7B. Tape Being Removed From Bulk Eraser.

tape as shown in Fig. 9-7A. Then, as the tape is gradually withdrawn (see Fig. 9-7B), the tape will be first strongly magnetized in one direction and then in the other direction less strongly, then in the original direction still less strongly, eventually wiping off all magnetization.

The two chief errors in bulk tape erasure is that either the tape is rotated and withdrawn from the bulk eraser too quickly, or the bulk eraser is turned off with the tape in its proximity. The tape should be withdrawn at least two feet before turning off the bulk eraser to assure complete erasure of the tape. Since there is no need to erase virgin magnetic tape supplied from the manufacturer, the tape may be directly recorded.

The Record-Reproduce Head

Since the record-reproduce head is generally the same head in most machines, serving a dual function, this discussion will cover the general design of only one head.

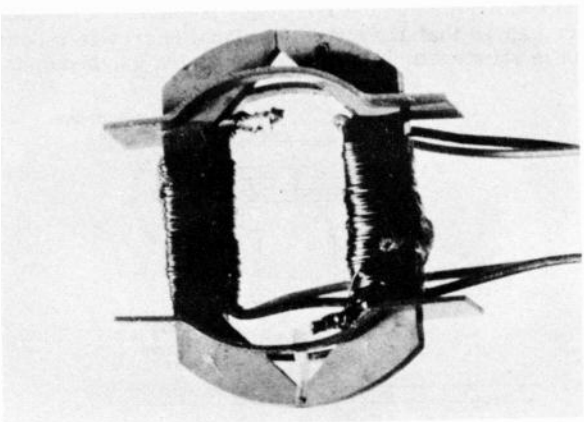


Fig. 9-8. The Ring Head is a Closed Magnetic Circuit With a Gap at One Point. Shown in the Construction of the Brush BK-1090 Head.

In general, the magnetic record-reproduce head is a closed magnetic circuit with a gap at one point. The physical configuration is the reason why it is sometimes called a ring head. (See Fig. 9-8.) On the ring is wound a coil to which the electrical signal is applied during record and during playback the signal is drawn from the same coil.

Frequency Response

During the playback operation, the high frequencies on the tape are generally limited in reproduction by the length of the gap. That is, as the recorded wave lengths on the tape approach the physical size of the head gap, the signal becomes greatly attenuated. In simpler terms, a 7,500 cycle signal wave recorded at 7 1/2 ips will occupy a space of a thousandth of an inch on the magnetic tape. However, from the discussion of the theory of magnetic recording, we saw that for one wave length there are two bar magnets laid on the tape facing each other. Thus, each magnet will be only 5 ten-thousandths of an inch long. Therefore, to properly reproduce a signal of the frequency of 7,500 cycles at 7 1/2 ips, the recording gap must not be any larger than 5 ten-thousandths of an inch or the signal will be greatly reduced.

Because of the present trend toward extending frequency response at lower speeds, it is not uncommon for several home-type recorders, as well as professional machines, to go up to 15,000 cycles at 7 1/2 ips. This means that the gap length must not be longer than 2.5 ten-thousandths of an inch long. It is obvious that extreme precision is required to make a gap of this narrow width.

One might logically reason: Why not make the gap as short as possible to record the highest frequency possible? The disadvantage of a short gap is that the available signal energy is reduced as the gap length is shortened. In other words, as the gap becomes smaller

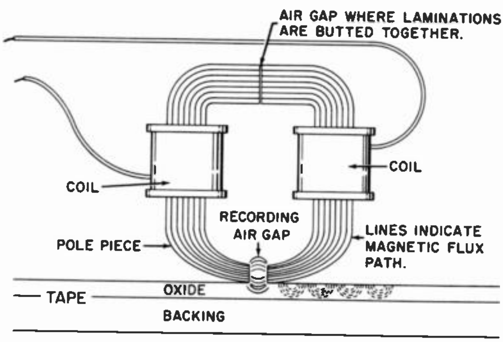


Fig. 9-9. Diagram Showing Flux Through the Ring.

and smaller, more and more of the magnetic flux lines flow across the gap instead of around the entire core length which encircles the coil. Of course, the only signal produced is that generated by the flux that passes through the coil. See Fig. 9-9.

Therefore, it is desirable to have a wide gap for maximum signal. However, it is desirable to have a narrow gap for maximum high-frequency response. Generally, the gap length is made as narrow as possible to a point where the desired signal output is still obtained. Present gap lengths generally range between 2.5 to 5 ten-thousandths of an inch long.

The shape of the head at the gap is an important consideration. From the standpoint of wear, the gap should be as deep as possible. Thus, when the tape passes over the head, wearing it down as any sliding friction inevitably will, there should be a good depth of metal before the gap length becomes longer, ruining the high-frequency response. The effects of poor head contact are shown graphically in Fig. 9-10.

It is obvious that when the head has been worn down as shown in Fig. 9-11, the high frequency response will be greatly impaired. Therefore, it is desirable to have a deep gap to prolong head life. A deep gap, however, is undesirable from the standpoint of output. A deep gap has the same effect as a narrow gap in that it prevents all the flux from going through the coil, but rather shorts out the flux through the air gap. Again, a compromise is reached in head design between long wear and high output.

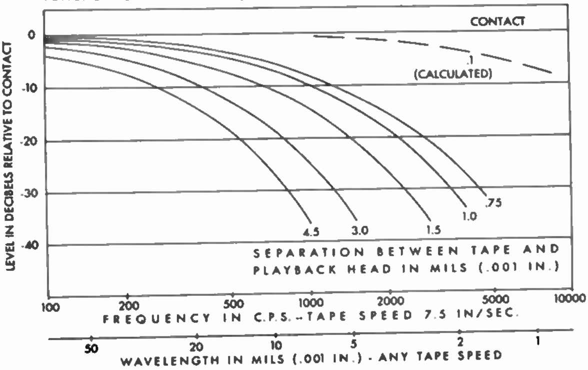


Fig. 9-10. Signal Attenuation Caused By Poor Contact in Playback as a Function of Frequency for Various Separations Between Tape and Head.

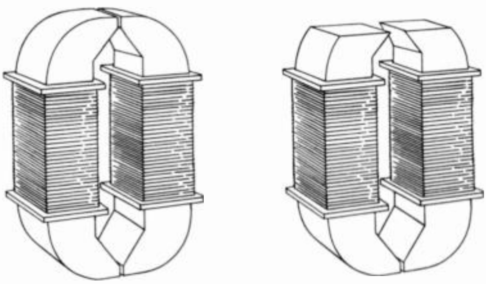


Fig. 9-11. A Badly Worn Head Compared to a New Head. Note Severe Lengthening of the Gap When the Head Wears Beyond the Parallel-Gap Phase.

Magnetic Head Construction

There are generally three methods of magnetic head construction. One is the lamination method (see Fig. 9-12) such as used in the Brush Redhead, the Ampex Therca, and Presto heads, as well as most other professional recorder heads. In the lamination method, thin laminations are stamped to give the desired gap profile and core structure. The laminations are then stacked together to thus form a magnetic head.

If two windings are used on the head, and if the head is made small with symmetrical core structure, the hum field can be nearly balanced out. This is especially important in home-type recorders because close proximity of motors and power transformers produce strong magnetic fields which are picked up by the reproduce head. Thus, if a reproduce head can be correctly designed and adequately shielded so that it will pick up a minimum of hum, a far better signal-to-noise ratio can be obtained in the recording process.

The laminated head design is an excellent construction. Since the laminations are stamped out, any desired gap depth can be made. Thus, a head of very long life can be made by using the lamination method.

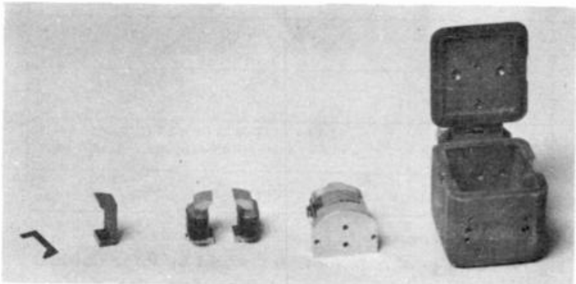


Fig. 9-12. The Lamination Stack Type Head. Shown is the Head Used in the RCA RT11B Magnetic Tape Recorder.

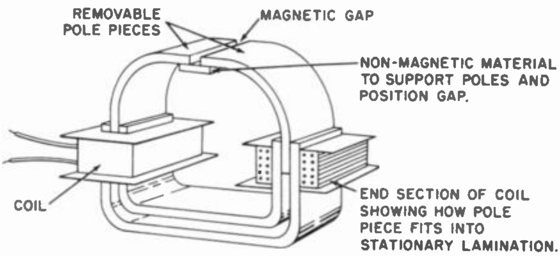


Fig. 9-13. Construction of a Head Using a Butted Single Lamination Gap.

The second common type of head construction is found in the Magnecord, the Webcor, the Pentron, and the DuKane recorders. In this type head construction, a single lamination is butted against the end of another lamination to form a gap. (See Fig. 9-13.) The laminations are ground down on the inner surface to provide the necessary gap profile. Then the laminations are in turn inserted between two U-shaped laminations, thus completing the pole structure. This type of construction provides a satisfactory head design.

It suffers, however, from two disadvantages. The magnetic flux path is rather narrow, thus restricting an easy travel through the core structure, resulting in generally lower output. Also, the point at which the gap occurs is rather thin, giving the head a relatively short life. However, one big advantage is that the pole pieces are removable and a new gap can be inserted as shown in Fig. 9-14 without necessitating the purchase of an entire new head and coil assembly. Thus, when the gap is worn and the high-frequency response is impaired, a new but relatively inexpensive pole piece can be inserted. This is generally a factory operation.

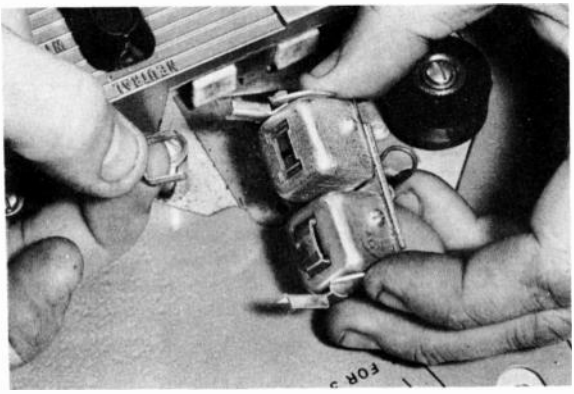


Fig. 9-14. In a Butted Lamination Head the Pole Pieces are Easily Removed as Shown Here.

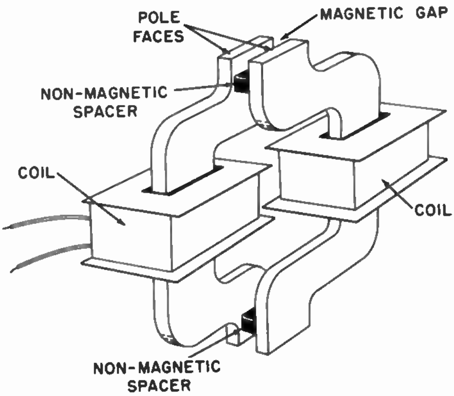
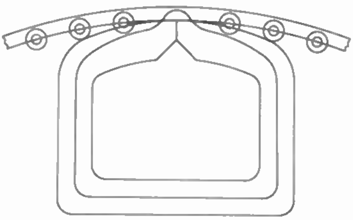


Fig. 9-15. Construction of a Head Using Two Laminations and a Spacer to Form the Gap.

Still a third type of head construction is used by Shure Brothers and the Maico Company in their magnatronics head. This type of construction uses a spacer between laminations to form the gap providing a long gap to assure an extended life and a very short gap for good high-frequency response. (See Fig. 9-15.) However, the main disadvantage of this head is the limited amount of tape contact with the head for satisfactory low-frequency response. In order to properly reproduce low frequencies the head surface should be sufficiently long and in close proximity to the tape. The long wave lengths such as those recorded below a hundred cycles at normal recording speeds must be allowed to encircle the gap through the magnetic ring of the head. See Fig. 9-16.



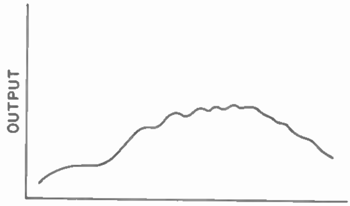


Fig. 9-16. As Long as the Recorded Fields are No Longer Than the Total Length of the Pole Face on the Reproduce Head, They Will Satisfactorily Intercept the Gap and Will Encircle the Flux Path. However, If the Recorded Fields are Longer than the Pole Faces These Low Frequencies Will Be Attenuated as Shown.

If, as in the case of the Shure Brothers head, the gap is relatively short, it would, under ordinary circumstances, be difficult for the long wave lengths to encircle it, resulting generally in rather poor low-frequency response. However, the Shure Brothers head (see

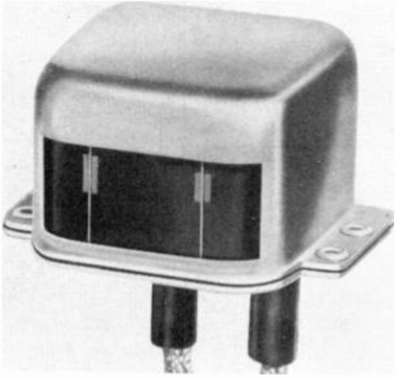


Fig. 9-17. The Shure Brothers TR-5 Erase-Record Head. Note the Two Lamination Ends and Spacer Which Form the Magnetic Poles and Gap. The Erase Poles are the Wider Poles on the Left and the Record-Play Poles are on the Right.

Fig. 9-17) employs an ingenious method of using a wider lamination on one side than on the other, providing for some increase in low-frequency response. While this increase still does not adequately provide for good low-frequency response, the head possesses excellent wear characteristics and good high-frequency response.

Frequency Response and Output

As we have already seen, in magnetic head construction the pole pieces should be long enough to reproduce low frequencies and the gap should be sufficiently short to reproduce high frequencies. In brief, this is the main criteria for frequency response in the magnetic head.

As mentioned earlier, to obtain a satisfactory output from the tape, the magnetic flux path should be large through the coil area and should be very small at the gap area. Thus, it is desirable that the flux travel through the coil very easily, yet jump over the gap with difficulty. Consequently, the major portion of the flux will pass through the coil rather than the gap. This provides for high output.

One might logically ask: Why cannot a great many turns be wound on a magnetic head to provide high output? Of course, the more turns that are wound on a magnetic head, the greater will be the output voltage. However, when one winds on more than a certain number of turns, the capacity in the winding will become so great as to restrict the high-frequency response.

In many head designs, the resonant point is at the top end of the audio frequency, now occurring near 15,000 cycles. Thus, if any more turns were added to the head, it would be impossible to reproduce the high frequencies since the resonant point would be lowered. Therefore, to obtain good high-frequency response, no more than a certain number of turns can be put on the head. To obtain good output, as many turns as possible are required.

Some heads serve as a low impedance device. Using a head with relatively few turns, the signal can be fed to a transformer which steps it up to a high impedance output. Fig. 9-18 shows a circuit using this method. However, the combined capacitance of the transformer and in the head yields nearly identical results to using a high impedance head. The high-frequency response, then, also limits the output of the head.

Several methods have been proposed to overcome this deficiency. One of the most novel methods still in the development stage is to design a head that feeds a transformer with two different turns ratios. That is, a head would feed a filter network which would separate the low and high frequencies. The low frequencies would be fed to the transformer, having a great turns ratio, providing high output at low frequencies. The high frequencies, however, would be fed to a lower turns ratio which would not suffer from capacitance. From the chapter on equalization, it can be seen that this technique gives the desired effect since the low frequencies are reproduced at far less amplitude than high frequencies. By properly designing this network, it would be possible to obtain all the equalization in the input stage and obtain high signal level. However, in most recorders, the conventional head feeds a very high gain amplifier with as low a noise as possible after which the equalization is applied.

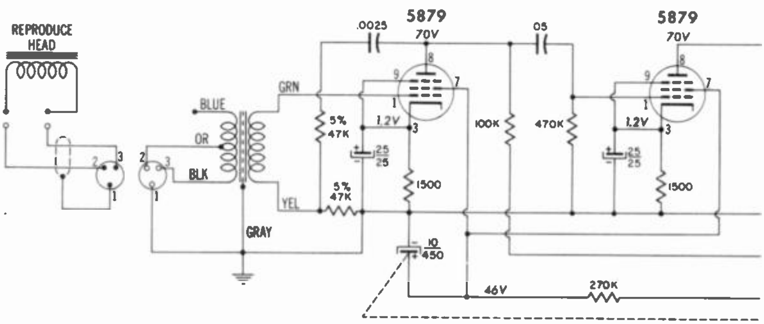


Fig. 9-18. The Magnecord Low-Impedance Input Circuit.

Magnetic Head Wear

Magnetic head wear has long been considered a great problem by many people. It is true that in early recorder designs, head wear was a major problem. However, with the introduction of lubricated magnetic tape in 1949, the problem of head wear has been greatly reduced. Modern magnetic tape construction incorporates a lubricant which will generally last the life of the tape.

Many misconceptions surround the problem of head wear. Most people feel that head wear is due solely to the fact that the iron-oxide tape coating is extremely hard while mu-metal is soft. It is true the iron-oxide coating of magnetic tape is almost twice as hard as the mu-metal used in the recording head. The slipping friction of the coated iron oxide particles against the soft mu-metal head may seem at first glance to be abrasive. However, the contact of the hard tape against the soft head is analogous to the action of a bearing.

In bearing construction, the shaft is generally hard and the bearing material itself is soft. This means that the shaft rotating within the bearing runs smooth and free. The lubricating film between the shaft and the bearing provides good protection, assuring an almost indefinite life as long as the lubrication is there. However, it is the dirt that works into the bearing that causes wear, necessitating replacement. The same is true for magnetic tape. It is the dirt that collects on the tape which tends to scour and abrade the head far more than the iron-oxide coating.

The magnetic head, being considerable softer than iron oxide, serves the same function as the soft bearing. The hard iron-oxide tape coating can be compared to a steel shaft turning on the bearing.

Thus, it can be seen that a mu-metal head sliding against magnetic tape provides a reasonably good combination for long head life.

Many materials harder than soft mu-metal have been explored as a possible head replacement. Ferrite core heads have often been

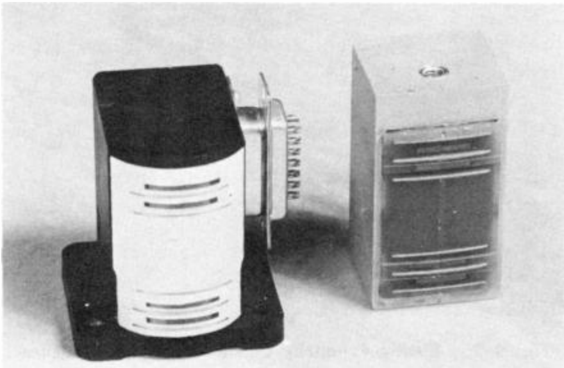


Fig. 9-19. An Experimental Ferrite Core Multi-Track Head.

suggested since ferrite is a very hard material, more than twice as hard as mu-metal (see Fig. 9-19). However, in practice, this means that ferrite has almost the same hardness as the iron-oxide coating of the tape. Just as in the case of a steel bearing turning in a steel shaft, the two will scour and abrade. Much the same action occurs the between oxide coating of magnetic tape and the ferrite head. At the present time, the mu-metal head would seem to possess the best all-around wear characteristics. Although ferrite does possess advantages at high frequencies, its wearing properties have so far prevented its widespread use. It is more than likely that in the near future a head material will be developed that is far harder than the iron-oxide coating on tape, solving the head wear problem.

In general practice, however, the average head will wear a thousand hours or more. If the head is of laminated construction, many thousands of additional hours can be expected. The laminated gap construction also provides many thousands of hours of trouble-free performance, wearing as well as the laminated construction. However, if the head is of the single lamination construction, generally 500 hours is a reasonably good life expectancy.

Pressure Pads

Intimate head contact is essential in attaining high-frequency response. The professional recorders use a high tape back tension that figuratively stretches the tape across the head, holding it in contact by tension.

However, in home machines, where very little if any back tension is applied, pressure pads are used to hold the tape against the head. The pressure pad is generally a good device to assure intimate tape contact with the head. However, the pressure pad tends to wear the

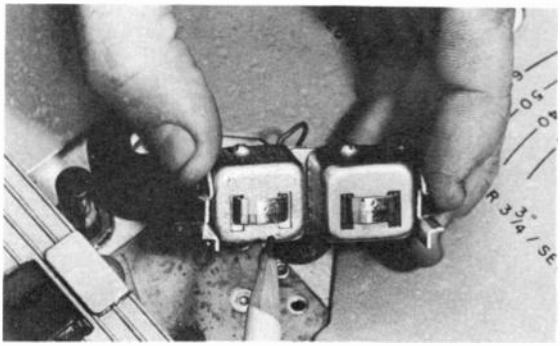


Fig. 9-20. Pitting Primarily Caused by Worn Pressure Pads.

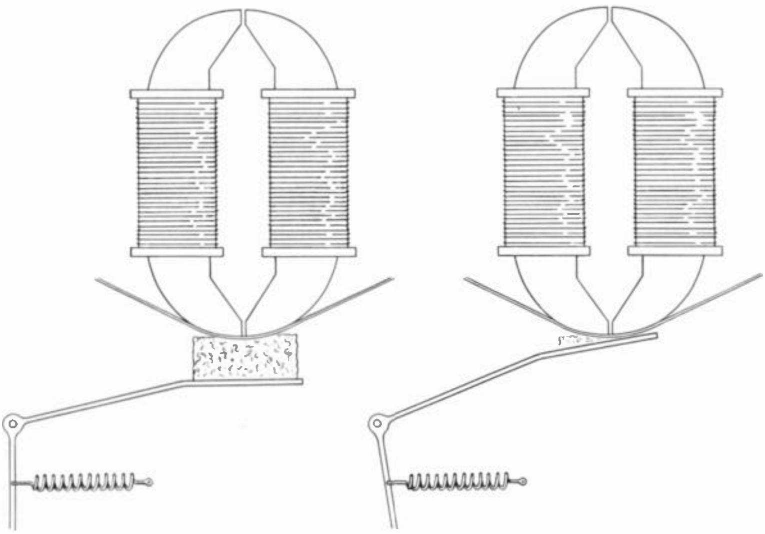


Fig. 9-21. A New Pressure Pad Compared with a Worn One.

head somewhat unevenly, developing pits and craters in the head as shown in Fig. 9-20. This will eventually lead to poor tape conformity to the head and loss of high frequencies. Of course, pressure pads themselves are subject to wear and require occasional replacement as shown in Fig. 9-21.

Tape Guides

When tape passes across the head, it is essential that it is accurately guided, enabling it to pass over the head in a straight

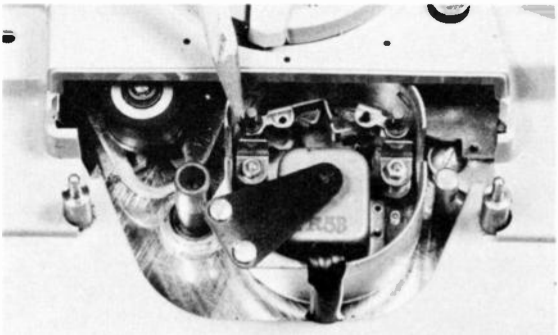


Fig. 9-22. The Tape Guides Employed in Revere Recorder.

rather than a zigzag manner. The tape must be guided to close tolerances so it will attain the same path on each playback. For example, if the tape is poorly guided, it tends to weave back across the head. The head is then thrown out of alignment with respect to the tape, reducing the high frequencies or causing severe amplitude variations.

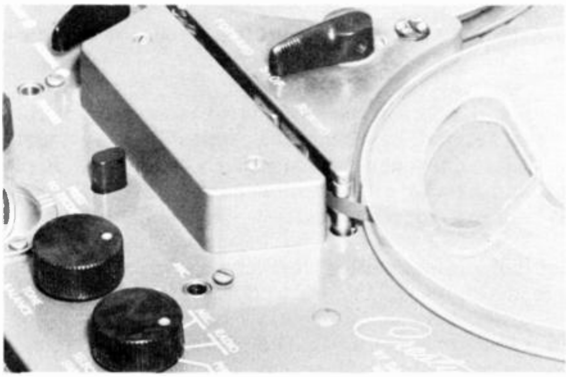


Fig. 9-23. The Pre-Positioning Tape Guides Used in the Crestwood Recorder. Notice the Tape Fits Into an Accurately Machined Recess in the Guide Post.

A number of guiding systems are employed. Most of them have restricted guides on each edge of the tape placed before the record and reproduce head to guide the tape in a straight path as shown in Figs. 9-22 and 9-23. Several professional recorders employ glass tape guides.

Head Alignment

As we have seen, when the tape is poorly guided it is thrown out of correct azimuth alignment. In correct azimuth alignment, the gap in the head should be exactly perpendicular to the tape, assuring that tapes recorded on one machine will reproduce properly when played on another.

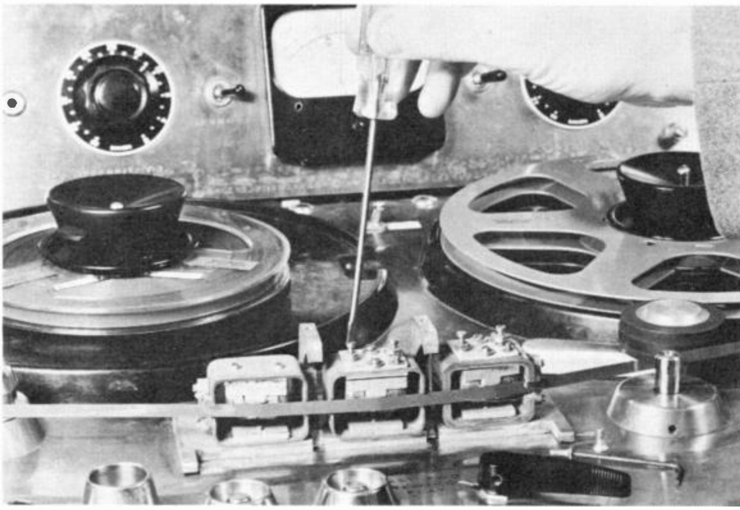


Fig. 9-24. Adjustment of The Ampex 300 Recorder Using a Standard Alignment Tape.

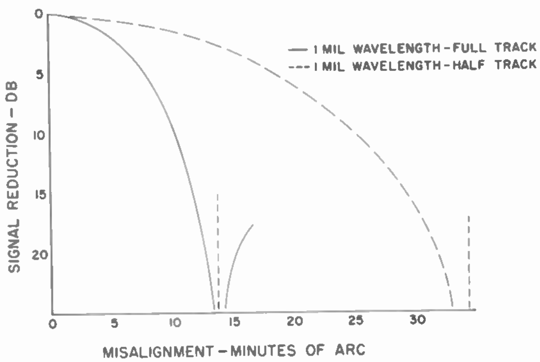
It is true that when the same head is used for both record and playback, the azimuth can be out of perpendicular alignment and the tape can still be reproduced satisfactorily since both heads will have the same angle. However, for interchangeability of tapes, it is vital that the azimuth be correctly set.

Excellent azimuth alignment tapes can be obtained from the L. S. Toogood Company, the Dubbings Company, and others. These tapes have a high-frequency signal at short wave length recorded on the tape at a very precise 90-degree angle from the edge. The alignment tapes are accurate within several minutes of arc. When adjusting an alignment on a machine, the normal procedure is to play the tape, then adjust the reproduce head for maximum output as shown in Fig. 9-24. Care should be taken to reach the point of maximum output since a lesser peak in output will occur on each side of the maximum output position. The illustration in Fig. 9-25 shows the affect of head misalignment on the output.

When maximum output is obtained, the record head, if a separate record head is used, can be adjusted as shown in Fig. 9-26 by recording a high frequency tone on the tape of approximately one mil wave length where:

$$\text{Wave length} = \frac{\text{Tape Speed}}{\text{Frequency}} .$$

Then the azimuth of the record head can be adjusted until the maximum output from the reproduce head is obtained. Since the reproduce head has been previously set to an accurate azimuth, the record head will also be set accurately.



HIGH FREQUENCY SIGNAL REDUCTION DUE TO MISALIGNMENT

Fig. 9-25. This Illustration Graphically Shows the Importance of Head Alignment.

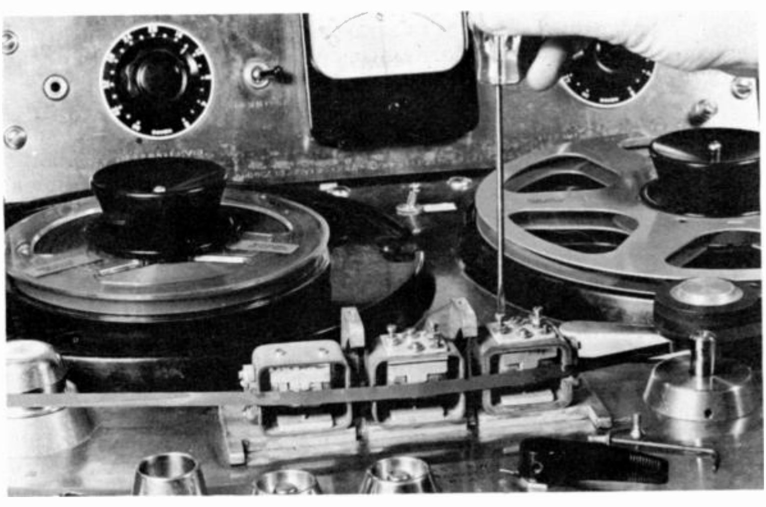


Fig. 9-26. Adjustment of The Record Head of the Ampex Model 300 Recorder.

Full Vs. Half-Track Recording

The terms "full" and "half-track" recording are sometimes referred to as single and dual tracks. Dual track means, of course, that two tracks are not recorded but, rather, half of the tape width is used to record a single track instead of the full width of tape. A comparison of the heads used for full and half track recording is given in Fig. 9-27A and B.

(A)

(B)

Fig. 9-27. The Presto Full Track Head (A) Compared with the Half Track Head (B).

Much discussion has been devoted to the merits of full versus half-track recording. Considering the attention and controversy which has surrounded this subject, it is strange that misunderstandings still remain. A persistent folklore abounds which is unsubstantiated by facts.

In theory, a full-track recording should give twice the output voltage of a half-track recording. Or, it should give a 6 db better signal-to-noise ratio, assuming the noise occurs in the amplifier as it generally does.

However, when making a narrower width gap head required for half track, generally a better and more efficient head is obtained. Therefore, in practice, the difference in output between a half and full-track recording is usually only about 3 db. Consequently, one may expect approximately a 3 db better signal-to-noise ratio using a full-track recording rather than a half track.

The saving in tape economy is, of course, obvious with a half-track recording, obtaining twice the recording time on a single reel of tape. Also the half-track head, since its gap width is shorter, is not quite as critical in respect to azimuth adjustment as is the full-track head which is still another feature in its favor.

The chief disadvantage of the half-track head recording system lies in the problem of physical tape distortion. If the tape has a long edge or has a wavy surface, use of the half-track head will affect performance more adversely than a full-track head. When the tape is physically distorted, the long edge of the tape will tend to lift away from the head. In recorders using a full-track head, this is often not likely to be serious. In the case of half-track recording, if the tape should lift up on one edge, and if this is the edge upon which the half-track recording is being made, severe amplitude fluctuations will result.

Contrary to popular belief, the frequency response is no way affected by the track width. Only the output or signal-to-noise ratio is affected. As was previously explained, in theory a 6 db better output is obtained by using a full-track head as opposed to a half-track head. However, due to the more efficient construction made possible with half-track heads, a full-track head can generally reproduce only 3 db more signal than a half-track head. The frequency response in either case should be identical, assuming identical gap lengths and construction of the heads.

Head Replacement

Each recorder head requires a different amount of bias for maximum performance. Generally, at the time of manufacture of the recorder, the bias is either adjusted or permanently set to fall within a region of proper operation when used with a given head. In professional recorders with adjustable bias, when replacing a head on a machine, the bias should be always readjusted to give optimum performance.

As was noted in the chapter on bias oscillators, the bias must be adjusted properly for if it is too low, serious distortion will result. If it is too high, the high frequencies will be lost. Therefore, one generally should not put in a head of another manufacturer in a machine designed for a specific type of head since the bias requirements are likely to be different unless, of course, care is taken to properly adjust the bias for the new head.

Heads also vary as to the amount of equalization necessary, especially at high frequencies. Therefore, if changing heads to that of another manufacturer, not only the bias, but also the equalization often will need readjustment. However, on most home-type machines, the head can be replaced with the head of the same manufacturer without difficulty. The only precaution that must be observed is to be sure that the head is properly aligned in respect to azimuth.

Cleaning Heads

It is important to keep magnetic heads free from any deposits of dirt, oxide, or adhesive which may have oozed from poor splices. Generally, a soft cloth or pipe cleaner lightly moistened with carbon tetrachloride as shown in Fig. 9-28 is satisfactory. However, too

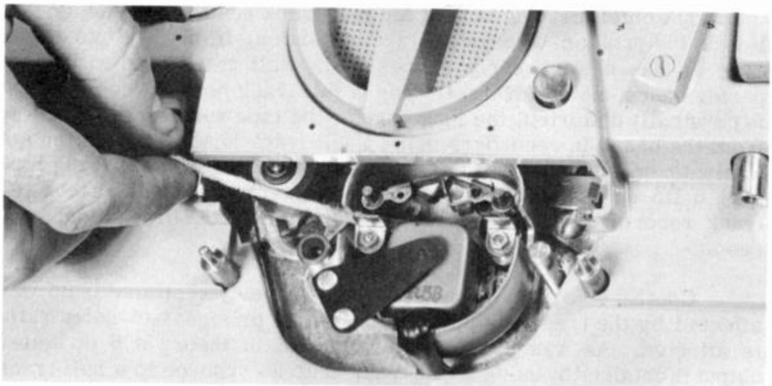


Fig. 9-28. Cleaning a Magnetic Head Using a Pipe Cleaner and Carbon Tetrachloride.

much carbon tetrachloride should be avoided since it tends to corrode the mu-metal head surface and in some cases even dissolves the lamination spacers. Often it is possible to remove any foreign material simply by wiping the head surface with a soft cloth.

CHAPTER 10

Magnetic Recording Tape

Present-day magnetic recording tape is vastly different from the early pre-war German magnetic tapes. As we have seen in an earlier chapter a more potent oxide, a form of gamma Fe_2O_3, has been developed. The new oxide displayed a 14 db superiority in output and vastly improved frequency response over German tapes. Known as "red oxide," the new type of magnetic oxide is now accepted as the international standard for magnetic tapes and films. This oxide is now used on all tapes manufactured in this country and is gradually being adopted abroad.

Thanks to the superior magnetic properties of red oxide, coupled with basic improvements in head design, recording speeds have been reduced from the initial 30 ips to 7 1/2 and 3 3/4 ips with excellent results.

Tape Manufacture

Magnetic tape itself is actually composed of many substances, each making an important contribution toward improved physical and magnetic performance. In tape construction, the basic recording material is a magnetic oxide. There are several forms of magnetic oxide which will be discussed.

Magnetic tape is generally made by coating the oxide dispersion, combined with a binder material, on a wide web of plastic backing. Again, there are a wide variety of backing materials in use at the present time, several of which will be examined later in this chapter.

The oxide is made to adhere to the base material by means of an adhesive or binder incorporated in the tape construction. The binder serves two purposes. One, it holds the iron-oxide particles tightly together in as dense a mass as possible. Two, it holds the oxide firmly to the base material.

The binder also carries a plasticizer, used to keep the tape soft and supple, and a lubricant to help the tape pass the guides and magnetic head with a minimum of friction and wear.

The wide web of coated magnetic oxide is then slit into a variety of widths and lengths. The most common size for home and professional recording studio application is the quarter-inch width. However, telemetering, video tape recording, and other special applications require tapes that are slit to a variety of widths up to a foot or more wide. In addition, magnetic film is available in the standard motion-picture sizes which are 35, 17.5, and 16 mm. The base is identical to motion-picture film. However, instead of being coated with a photographic emulsion, a magnetic iron oxide dispersion is used.

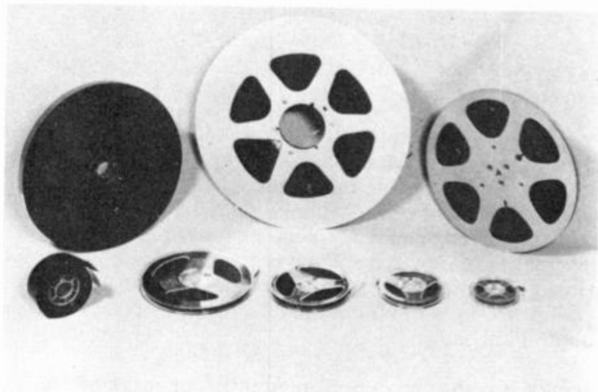


Fig. 10-1. Various Sizes of Magnetic Tape Available.

The quarter-inch tape is available in these standard lengths: 150, 300, 600, 1200, 2400, and 4800 feet. The reel sizes are, respectively, 3, 4, 5, 7, 10 1/2, and 14 inches in diameter. The new "extra play" magnetic tape, offering 50% additional recording time, is currently available in 900, 1800, and 3600-foot lengths. Some of the various sizes of magnetic tape available are illustrated in Fig. 10-1. Table I in Chapter 1 illustrated the playing time for various lengths of reels at the different speeds. The manufacturers generally supply more than the labeled footage to allow for threading and to serve as a "cushion" on the reel hub. Thus, a 1200-foot reel generally has about 1240 feet.

Backing Materials

The early German tapes used paper as a base material. Paper has several desirable characteristics in that it is quite stable in respect to temperature and humidity changes. However, a big physical limitation to paper-base magnetic tape is that it is fragile and not too pliable or flexible. It will wear easily. Paper tape has also a rough and non-uniform surface. In magnetic-tape coating, the uniformity of coating is extremely important to obtain a consistent output from the tape. If a magnetic oxide dispersion is coated on a rough surface, it naturally will adhere to the counter of the peaks and valleys of the backing surface.

To obtain a more uniform coating surface with greater potential frequency response, a plastic-base tape was introduced. The base used was cellulose.

Cellulose acetate is, to this day, the most common form of backing for magnetic tapes. It possesses several excellent characteristics, having the smoothest surface of any plastic tape yet developed. Consequently, it gives the smoothest magnetic coating which, in turn, yields a more uniform output.

Cellulose acetate is, also, surprisingly strong. The standard quarter-inch tape has a tensile strength of 5.5 pounds. The new extra-play magnetic tape, using a 30% thinner acetate backing, has a tensile strength of 3.4 pounds. Considering that the maximum tension exerted by tape recorders with proper use does not exceed a few ounces (including the sudden stress on the tape when braking and reversing), cellulose acetate is relatively rugged and holds up well.

The main disadvantage of cellulose acetate is that it is not stable with temperature and humidity. Thus, when the humidity goes up, the tape tends to expand. When the humidity falls, the tape has a tendency to shrink. Expansion and contraction physically distorts the tape.

The ideal backing would have a high strength without stretch, a very low coefficient of humidity expansion, be stable over a wide temperature range, have a perfectly smooth surface, and cost very little.

Unfortunately, however, all these ideal qualities are not combined in one tape backing as can be seen in Table II. A newer base material, showing great potentialities, has been recently introduced. Known as polyester film, its common trade name is "Mylar", a registered trade mark of the E. I. du Pont de Nemours and Co.

The polyester backing has some very interesting properties, making it especially suited for tape recording. It is very stable with respect to temperature and humidity. That is, the temperature and humidity can vary widely and it will retain its original shape and size. It has greater strength than acetate, with little yield stretch. And it still has a relatively smooth surface.

The outstanding property of acetate, accounting for its wide use today, is its excellent surface and thickness uniformity. Polyester suffers in surface uniformity when compared to acetate. However, recent production advances indicate that the surface smoothness of polyester may soon equal that of cellulose acetate.

Magnetic tape backing exhibits both a yield point and a break point. Like bending a green twig, the yield point is the point at which the tape, upon being stretched, will not return to its original length but remains partially elongated and misshapen. When a tape is stretched beyond its yield point, the recording on it will be distorted and the tape will be damaged. The graph in Fig. 10-2 illustrates the yield point of various backing materials. When tension reaches the break point, the tape will, of course, snap in two.

TABLE II.

A Comparison of the Types of Backing Used for Magnetic Tapes.

	MAGNETIC	PHYSICAL	COST
PAPER	POOR	GOOD	LOW
PLASTICS	GOOD	FAIR-GOOD	MEDIUM
METAL	GOOD	EXCELLENT	HIGH
LAMINATES	FAIR	GOOD	HIGH

Therefore, it is far better to have the magnetic tape snap rather than approach its yield point without breaking, thus distorting the recording.

Polyester at 150 gauge exhibits a very excellent stretch recovery, showing no dead stretch up to five pounds tension per 1/4 inch. By

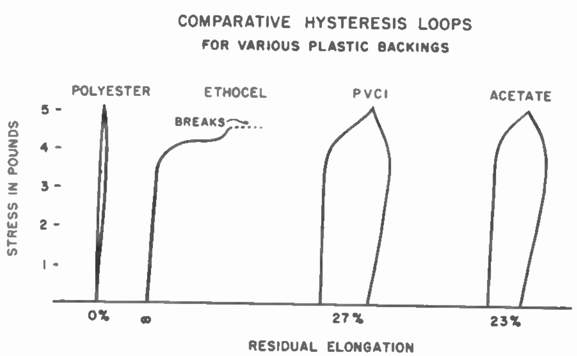


Fig. 10-2. Yield Point in Tensile Strength of Various Plastic Tape Backings.

contrast, 140 gauge acetate shows a 23 per cent residual elongation at five pounds stress. However, as we have already seen, any consideration of backing strength is largely academic because tensile strength is more than adequate for the tape handling mechanisms that exist today. The additional strength of polyester, while giving an extra margin of safety, is seldom required.

Polyester backing is still substantially more expensive than cellulose acetate, consequently its prime use lies, at the moment, in applications where dimensional stability is of prime importance. For home use it is doubtful that, considering cost, there is a prime advantage of polyester over cellulose acetate backing. A comparison of the physical properties of various backings is given in Table III.

TABLE III.

Physical Properties of Plastic Backings Used in the Manufacture of Magnetic Tape.

	ACETATE	POLYESTER	ETHOCEL	VINYLS
Tensile (Lbs.)	5.5	9	6	8.5
Relative Humidity expansion coef.	6.0	5	11	7
Maximum Operating Temperature	200°F(+)	200°F(+)	200°F(+)	150°F *
Thickness Uniformity	±.00003	±.0001	±.00005	±.00012
Surface Uniformity	EXCELLENT	POOR	VERY GOOD	POOR

*DETERIORATES

Cellulose acetate backed tape has a superior signal output uniformity to that of other commonly used backings. This is shown graphically in the pen motor charts for cellulose acetate, polyester, and paper given in Fig. 10-3.

OUTPUT UNIFORMITY OF VARIOUS BACKINGS....

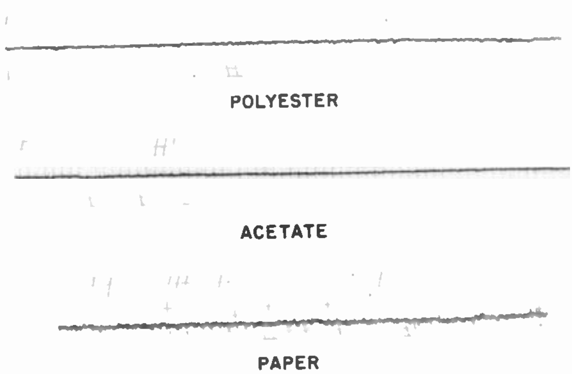


Fig. 10-3. Pen-Motor Charts Which Plot the Signal Output Uniformity of Polyester, Acetate, and Paper Backing.

New Tape Construction Trends

An interesting trend in tape construction is toward the use of thinner and thinner backing material to obtain greater recording time. Reducing the thickness of the backing material, coupled with a reduction in the thickness of the oxide coating, does not, surprisingly enough, greatly affect its strength. For example, reducing the backing thickness of cellulose acetate from 140 to 100 gauge, or by 30%, reduces its strength by only 15%. Consequently, tapes of thinner backing material can readily work on all recorders with no particular problem.

The thinner backing possesses several advantages in that it conforms more readily to the head, resulting in greater frequency response. Any magnetic tape backing should be limp and flexible, enabling the tape to conform perfectly to the magnetic head contour. A thick backing material tends to contact the head improperly, causing amplitude variations. Therefore, a thinner backing material gives better high frequency response with more uniform output.

In addition to cellulose acetate and polyester, there are several other plastic films in use today. They are ethyl cellulose and tensilized polyvinyl chloride, more commonly known as Luvitherm. Luvitherm is now being used extensively in the German magnetic recording industry. Like polyester, the outstanding characteristic of Luvitherm is its low coefficient of humidity expansion. Luvitherm, however, is limited by upper operating temperature, undergoing deterioration at just above 150 degrees Fahrenheit.

Magnetic Oxides

The early German tapes used a type of oxide known as raven red. This term was conveniently borrowed from the barn paint of the same name. Literally a high grade of barn paint which was painted on a paper backing, the raven red oxide had lower output, especially

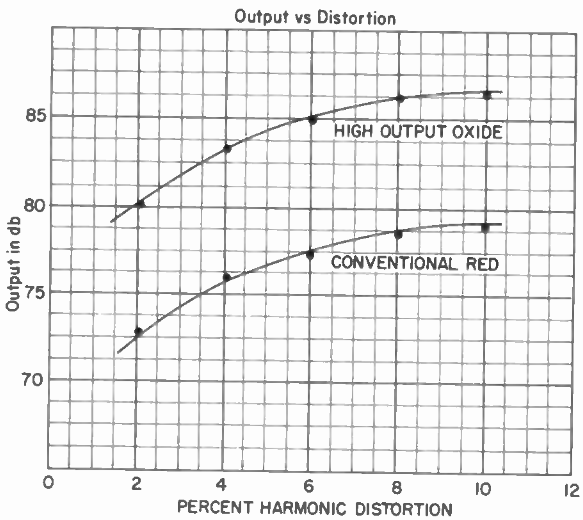


Fig. 10-4. Performance Curve of High-Output Magnetic Tape Compared with Conventional Red-Oxide Tape.

at high frequencies. A substantially higher tape speed was required to attain a satisfactory signal-to-noise ratio and frequency response.

However, with the introduction of black-oxide tape in America, a tremendous increase in output was attained with greatly improved frequency response. The black oxide proved to be an excellent recording medium. However, it possessed the undesirable property of being extremely difficult to erase because of its memory effect. That is, once the tape was erased during subsequent recordings,the supposedly erased recording would tend to reappear in the background.

In order to develop a tape that would avoid this difficulty, and yet maintain good high-frequency response and high output, the present "red oxide" was developed. It has now become a standard in the recording industry.

A still more recent development has been the introduction of high-output oxide. This oxide possesses even greater output (8 db) than the conventional red oxide, for a given distortion as shown in the graph in Fig. 10-4. It is especially useful where noise is a problem in the reproduce process. For example, in home recording equipment where the close proximity of the power transformer and drive motor to the reproduce head induces serious hum, the use of high-output tape with 8 db more output will require 8 db less amplifier gain, reducing noise by that amount.

Also, in self-powered portable recorder applications, the extra sensitivity of the high-output oxide (4 db) means that the tape is especially sensitive to weak sounds. It is also much less likely to overload and distort when subjected to unexpected and sudden loud sounds. Thus, high-output tape provides an extra margin of safety, freeing the operator from the necessity of constantly riding the gain control.

Binder Formulations

The binder is an adhesive that is blended into the magnetic dispersion, making the iron-oxide particles adhere to the backing. Also incorporated in the binder are a number of other elements such as lubricants, preservatives,and plasticizers.

The binder is designed so that it will not be too hard or brittle. If it is too brittle, when the tape rounds a sharp corner,the coating will actually crack and the oxide will chip off. However, the binder should also age well withstanding changes in temperature and humidity, retaining its bond to the backing.

It is equally important that the oxide not be too soft so that the oxide will easily rub off during recording or playback.

Certain types of binders at high temperature become tacky, causing the tape to stick and squeal as it is propelled past the record head. The result is serious high-frequency flutter.

Other tape binders tend to become stiff and hard, curling with temperature changes. Still other binders have a different expansion rate than the backing material, again causing the tape to cup and curl with a change in temperature or humidity. Therefore, it can be seen that the binder as well as the tape backing plays a critical role as to whether or not a tape will cup and curl. The tape must, of course, lie flat against the head, conforming readily at all times, for satisfactory frequency response and uniformity of amplitude.

Tape Lubrication

The tape should be lubricated to improve head wear and reduce frictional vibrations in the tape, causing high-frequency flutter. Lubrication will prolong the life of both the tape and the record heads and guides, as well as giving better recording results.

The lubrication is incorporated in the tape binder itself so that it will last the life of the tape, not wearing off as it would if only the tape surface were lubricated. Included in the binder are a number of other properties such as plasticizers that are employed to keep the tape soft and flexible throughout its life. While binder chemical formulations are closely held trade secrets, also included in the binder are agents which permit tape operation at high and low temperatures and improve the physical performance of the tape. One tape manufacturer uses a silicone lubricating process which actually coats the record head with a thin film of protective lubricant.

Life of Magnetic Tape

Despite universal acceptance of magnetic recording tape in the professional field and its increasing popularity among home users, considerable folklore and unfounded rumor exists even among informed groups.

Confusion is particularly rampant regarding the life of magnetic properties of recording tape. Statements that there is a slow loss of magnetism are without foundation in fact. There is a vast reservoir of references in technical literature relating to the permanency of magnetic materials similar to those used in recording tape. Geological investigations have uncovered natural fields of magnetite which have been magnetized since the formation of the earth. From these and other evidences it may be concluded that the magnetic retentivity of recording tape is infinite unless altered by magnetic means.

On typical broadcast recorders, magnetic tape has been played thousands of times with perfect results. Despite the number of times played, the noise level does not rise as does the surface noise on disc recording or on a film because of clouding. Clean, well adjusted heads and tape guides will assure almost indefinite tape wearing life. Although the magnetic recording medium is much too new to predict the life of tape in actual years, accelerated aging tests have indicated a useful life of at least one hundred years. Broadcasts that typify our contemporary society have been recorded on magnetic tape and sealed

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in time capsules for posterity, to be opened several hundred years hence.

Storage Precautions

While the magnetic properties of recording tape are very stable over long periods of time, care must be exercised to avoid accidental erasure by exposure to strong magnetic fields

Permanent magnets and strong electromagnets will very likely cause erasure if placed within a few inches of the tape. This is the principle used in the so-called bulk erasure process in which an entire reel of tape is demagnetized without unwinding. Since the field necessary to produce erasure must be so intense, it is unlikely that accidental erasure would occur from close proximity to ordinary electric house wiring. Erasure will not take place unless the field is strong enough to exert a noticeable attraction for the tape, or to induce vibration in the tape.

All manufacturers state that, ideally, magnetic tape should be stored in a room with relative humidity being maintained between 40 and 60 per cent with a room temperature of 70^{o} Fahrenheit. However, tape storage under these carefully controlled humidity limits is a ridiculous condition for magnetic tape users to meet. An air conditioning unit that could control room humidity within such a range would cost many thousands of dollars and very few such units exist in the world today.

Realistically, storage of tape at moderate temperatures such as maintained in the home is desirable. Tape that is subjected to extremes of temperature for short periods of time such as in shipment is generally not affected. The same precautions exercised in storage of safety-base film can be applied to magnetic tape. If the tape was subjected to extreme temperature, allow the tape to return to room temperature before using.

High temperature plus high humidities, however, tend to rapidly deteriorate the cellulose-acetate backing of magnetic tape.

The worst condition is high temperature with low humidities. The backing will tend to dry out and become brittle. Embrittlement of tape will result from exposure to prolonged low humidity which exists in heated areas during cold winter months. Just as woodwork shrinks in winter and swells in summer, the same principle applies to magnetic tape. In winter low temperature is forced into a room and is heated. It can hold more moisture and consequently draws moisture from all objects in the room. Subsequent storage at normal humidities completely restores the desired tape properties, the tape picking up its original moisture and becoming limp again.

If the relative humidity is subject to large variations, magnetic tape can be safely stored in sealed metal cans. Seal the cans with a

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pressure sensitive plastic or cloth-backed tape if long time storage is anticipated. The use of desiccants or humidifying agents is not recommended because of the difficulty in controlling the results.

The tape should be stored, wound loosely on its reels. Many professional recorders wind the tape far too tightly on the reel during rewind or in the normal forward position. Thus, when the tape goes through several humidity cycles, expanding and contracting, the pressure and tensions built up severely stretch and deform the tape. To avoid this condition, the tape, before being stored, should be rewound with very low tension. Before using a tape that has been stored for any appreciable length of time, the tape should be rewound through a recorder to relieve any tensions that may have set in while the tape was wound on the reel.

Print-Through Problems

When tape is wound on a reel, the magnetic field from one layer tends to somewhat magnetize the adjacent layers of tape, causing a signal transfer. This is called print through or cross-talk. The signal transfer can be heard either ahead or behind the recorder signal, depending on which layer the transfer came from. Often both the pre-print and the post-print signal can be heard.

Print occurs mostly in staccato-type recordings in the middle frequencies such as when, suddenly, a voice is heard, then stops, and all is quiet. Consequently, the print is then heard as either a pre-or post-echo of the voice.

Print-through has been considered an inherent disadvantage of magnetic recording. However, generally the print is far enough below the sound level on the tape to cause no trouble. In fact, in nearly all home-type recorders, the noise level in the reproducing amplifier alone is far higher than the print. However, by contrast, on professional machines that employ excellent amplifiers with very little background noise, the print is sometimes audible.

One theory advanced concerning the cause of print is that in every magnetic material there are many "soft" particles. As we have already seen, "soft" magnetic materials are easily magnetized. The normal "hard" iron-oxide particles that are coated on a tape coating require a strong magnetic field before they become magnetized. The bias and record signals are many times stronger than the field that is left on the tape. Consequently, any "soft" particles in the tape are weak enough to become magnetized from the recorded signals on the adjoining tape layers.

According to one school of theorists, the weak "soft" particles line themselves up with the magnetic field on the next tape layer on the reel. It is obvious that any shaking field such as a bias or magnetic field will aid the "soft" particles in lining up. So, therefore, a stored reel of magnetic tape should be kept away from any magnetic fields. Also, a high temperature will aid "soft" magnetic particles in lining up.

It is also believed the strong bias used during the record process makes the particles susceptible to print. That is, when the tape is being recorded, the particles are sensitized and, more or less shaken up, are left in a random position out of their normal field. As a result, they are highly susceptible to magnetism from adjacent fields. Then when wound on a reel next to a turn of tape that has a highly recorded signal, the weak particles will very easily line up with the adjacent layer.

Despite lack of agreement regarding the cause of print, considerable information about print has already been accumulated. It is interesting to note that during print the magnetic particles line up very rapidly at first because of their highly sensitized position. But, as time goes on, the rate of print becomes progressively less.

The signal-to-print ratio is the ratio of the maximum recorded signal, often assumed to be that signal which produces 3% harmonic distortion, compared to the print or echo level.

If one were to make a recording, then play it back in a matter of several seconds after it was recorded, let us assume a 50 db signal-to-print ratio would be noted. However, if five minutes were allowed to lapse before playing the tape, a 48 db signal-to-print ratio would be present. If one were to wait an hour, the signal-to-print ratio would be 47 db and, after 5 hours, 46 db. Following 8 hours, very little more happens to the signal-to-print ratio. Typically, it would settle down to a value of approximately 45 db and never become worse.

However, if the reel is played several times through a recorder, it is obvious that the print layers will not line up in precisely the same pattern. That is, with each tape winding, the area which has received the print will not line up exactly adjacent to the tape area that first made the print. Then, each time the tape is played, the same signal source will print in a slightly different area. Consequently, the print will eventually become noise. Although obvious, few people realize that if a tape with a high signal-to-print ratio is played several times, print no longer remains print but turns into noise and is heard as hiss.

Splicing Problems and Techniques

One of the most appealing and useful characteristics of magnetic tape is the ease with which it may be cut, edited, and re-spliced without impairing the quality of the recorded information on the tape. The fact that tape ends can be joined so easily has led to careless techniques which have resulted, inevitably, in considerable trouble in recorder operation.

At least six months is required to properly train a good tape editor. Considerable skill is demanded in professional recording studios for which there is no substitute for experience. Many professional tape editors prefer to splice without the use of either a mechanical splicer or splicing block. However, this does not mean the rank amateur cannot make acceptable splices. Provided a few simple rules and precautions are followed, the novice can make splices which will be as strong as the magnetic tape itself — splices which will wear without fraying or loosening and which can be detected insofar as magnetic performance is concerned only by the most sensitive computer-type recorders.

Most pressure-sensitive tapes now on the market have adhesives which are unsatisfactory for use in splicing magnetic tape. Splices in the wound roll of tape are subject to considerable pressure and temperature variations, and the adhesive used in ordinary pressure-sensitive tapes will "creep" or "bleed" around the splice. This is a particularly serious condition, since not only the strength of the splice is impaired but also the adhesive invariably contaminates the magnetic side of the tape, causing adjacent layers to adhere, one to the other, resulting in the loss of the recorded information in the contaminated area due to poor head contact. The adhesive can also transfer to the heads and guides of a recorder, and thus ruin a considerable amount of tape.

To prevent trouble from the adhesive of the tape, a specially formulated splicing tape is available, guaranteeing trouble-free performance if properly used.

Translucent white in color, this acetate-backed, pressure-sensitive tape for splicing is universally used with quarter-inch magnetic tape. Its mil and a half thickness provides thin yet strong splices. Its pressure-sensitive adhesive has these thermosetting characteristics: The bond with the magnetic tape increases under the effects of time and temperatures. Also, the adhesive will not ooze or bleed around the edges of the splice. The splicing tape eliminates any tendency to gum up recording heads or cause adjacent layers of tape to stick together on the reel. This standard splicing tape is available in standard rolls 7/32", 1/2", 3/4" in width by 66 feet, or by 150 inches in length.

Apart from considerations of strength, the excellence of a splice in magnetic tape editing can best be judged by the degree of disturbance it causes upon playback. The use of the right splicing tape material, together with proper splicing methods, can produce splices which are essentially "acoustically invisible."

In the quarter-inch magnetic tape field the diagonal butt splice is by now a tradition. Such splices, properly made, wear without fraying or loosening. To make a perfect splice the ends of the tape to be joined should be held in some rigid fashion to prevent displacement while the splice is being made. There are three ways of doing this:

A. The most common method, even among professional tape editors, is to hold the tape securely between fingers, cutting with a pair of scissors.

B. By laying on a flat surface (example, soft wood block or sheet of rubber) and cutting with a razor blade. This technique can be further improved by placing a straight edge along one side to position both tapes.

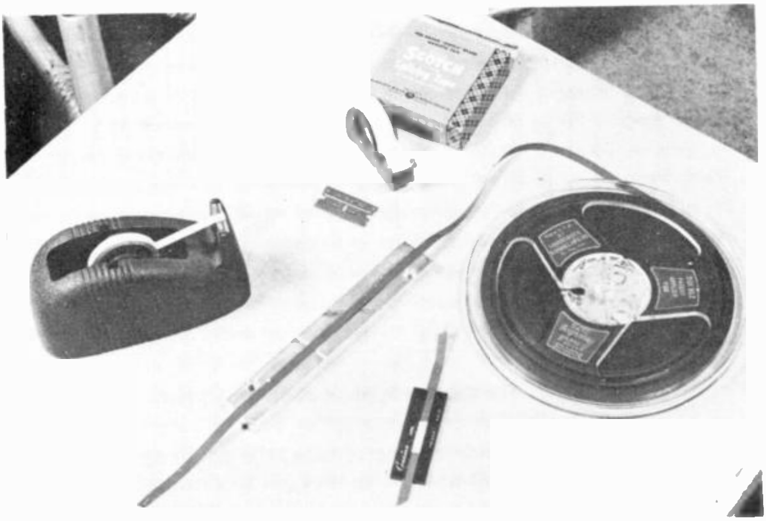

Fig. 10-5. Standard Splicing Blocks for Use by Home Hobbyists.

C. By using a commercially available splicing block. Fig. 10-5 shows one for use by home hobbyists. A professional-type splicer for magnetic tape is shown in Fig. 10-6.

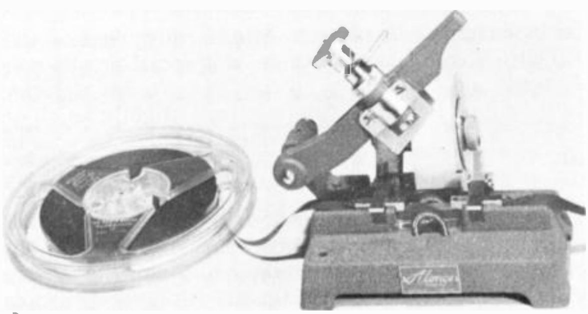

Fig. 10-6. Professional Splicer for Magnetic Tape Manufactured by Alonge Products.

The two ends of the magnetic tape to be spliced should be overlapped sufficiently to enable easy cutting and true alignment of both tape ends, as shown in Fig. 10-7A , providing the recorded information will allow this much tape to be removed. Naturally, no

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cutting will be done at all if a break in the tape is being repaired. Line up the ends of the tape so both sections are butted and are in alignment with each other (see Fig. 10-7B). The splicing tape must always be placed on the backing (or "shiny") side of the magnetic tape.

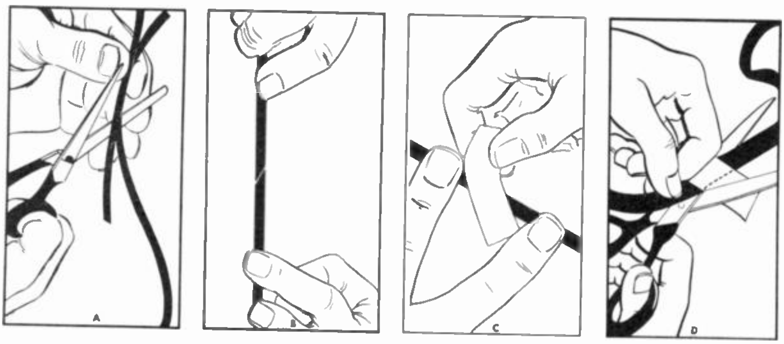

Fig. 10-7. The Correct Method of Splicing Tape.

For quarter-inch wide magnetic tape, the angle of the cut ends is not critical but one must use a diagonal cut to avoid a "pop" at the splice point. All angles are measured from the edge of the tape. A 90° cut is to be avoided always. As the angle of the cut edge becomes smaller, the strength, flexibility, and magnetic invisibility of the splice becomes greater. A 45° angle is satisfactory although a 30° splice is approximately as strong and flexible.

A piece of standard splicing tape is centered over the butted ends parallel to the splice as shown in Fig. 10-7C. The width of the splicing tape used should never exceed 3/4" for general work, since wider tapes impair flexibility. After firmly pressing the splicing tape into position, rub firmly with the fingernail or other semi-hard object to press out all air bubbles. The excess splicing tape is trimmed by cutting into the magnetic tape slightly as shown in Fig. 10-7D. Thus danger of exposed adhesive from the splicing tape is eliminated.

The techniques of splicing magnetic film in the motion-picture industry differ widely from the procedures followed in editing 1/4" magnetic tape. Because of sprocket holes and the stiffer backing employed in the manufacture of magnetic film, rigidity is increased. Consequently, the edges of the splice have a tendency not to conform as readily when passing through the head, tending to lift at the edges of the splice.

A different type of splicing tape is employed in editing magnetic film. While identical in adhesive characteristics to standard splicing tape, the tape is cut to 35 mm, 17.5 mm, and 16 mm widths. Also translucent white, it is available with either double or single perforations for standard sprocket holes. No thicker than regular splicing tape, it is made with a tough polyester backing.

Reel Design and Construction

Reels for magnetic tape also play an important role in the recording process. Reels for magnetic tape must meet a variety of exacting requirements. First, the reel must not in any way distort the tape. Reels with large openings in their hubs in which the tape can become deformed are undesirable. As tape is wound on a reel, tremendous pressures are built up within the inner turns. Any threading slot, especially if it is large, will tend to deform the tape at that point.

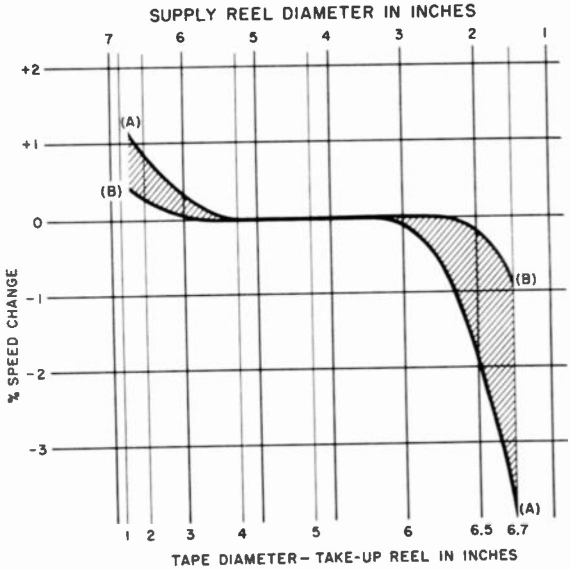

Fig. 10-8. Chart Showing Per Cent of Speed Change as the Reel Hub Diameter Changes.

In addition, the 7-inch plastic reel, the most common reel size, should have a 2 1/4 inch minimum hub diameter to avoid timing errors as we have seen in the chapter on motorboards. The timing error problem is perhaps the most serious consideration. Fig. 10-8 shows typical speed changes for a number of recording machines. It can be seen that recorders tend to speed up at the beginning of a reel due to high tension on the wind up side, and tend to slow down at the end due to high tension on the supply reel. Referring to Fig. 10-8, the per cent of speed change for the 2 1/4-inch hub diameter (curve B) is much less than that of the 1 3/4-inch hub diameter (curve A). At the 2 1/4-inch hub diameter, most of the timing error occurring on the 1 3/4-inch hub reel will be corrected. A 2 3/4-inch hub gives still closer timing results and is used in applications demanding precision programming.

A comparison of the three hub diameters used for 7-inch reels is shown in Fig. 10-9.

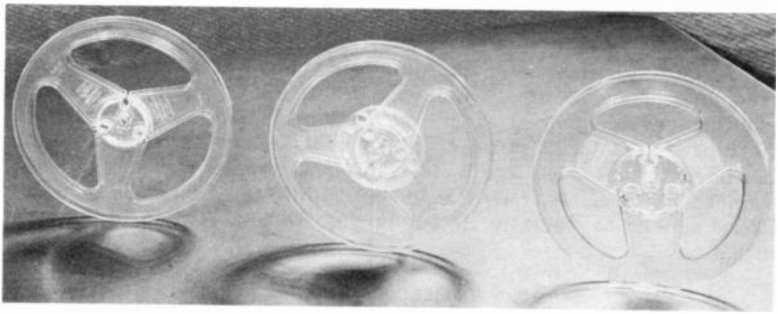

Fig. 10-9. Three Types of 7-Inch Reels with the Three Hub Diameters.

However, earlier standard magnetic tape wound on the 1 3/4-inch hub reel averaged .0022 inches in thickness. Since the thickness of new present-day standard tape is 2 mils, it was often difficult to place 1200 feet of older-type tape on the 2 3/4-inch hub reel without the tape spilling over the edge.

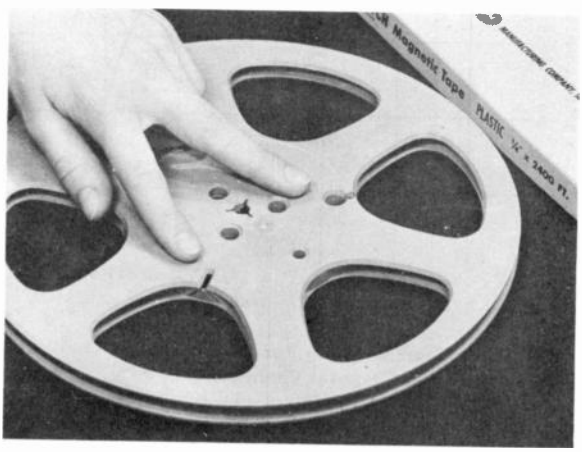

Fig. 10-10. The 10½-Inch Plastic Reel Which Can Be Adapted for Use with Various Recording Machines.

In addition, the reel flanges should be straight and true so that they will not rub either edge of the tape. There should also be a method of locking one end of the magnetic tape to the reel and securing it with several turns on the reel so that it will not pull free. The tape should lay flat against the thread-up device and not leave a hump on subsequent turns. The NARTB 10 1/2-inch plastic reel, for example, provides a unique post thread-up device.

On the large size NARTB 10 1/2-inch and 14-inch reel, the tape is supplied on either a metal hub or on a metal hub with flanges. Also, a plastic replacement for the 10 1/2-inch metal hub with flanges with its large center hole is available. The major change is the reduction of distance between the flanges to a value of .270 inches. This reel is manufactured from glass-filled plastic. With the changes in the distance between flanges, the winding characteristics have been greatly improved. A large center hole is used for those professional recorders that use a hold-down clamp to secure the reel to the pedestal. A supplemental 10 1/2-inch plastic reel has also recently been developed. This reel has a small center hole, corresponding to the 7-inch reel, and contains other drive holes to adapt it to the recording machines of various manufacturers. This reel also contains both conventional and V-type thread-up slots as shown in Fig. 10-10.

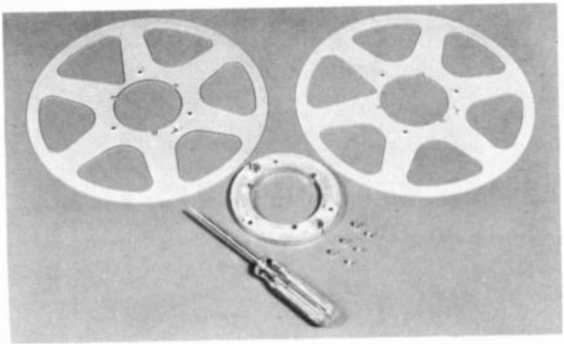

Fig. 10-11A. The NARTB 10½-Inch Reel Shown Disassembled.

Unless care in storage is exercised, this type of glass-filled plastic reel is subject to a certain amount of warpage, thus minimizing its improved winding advantages.

Because there is a cost saving in ordering 2400 or 4800 feet of tape on a NARTB hub without flanges, some recording engineers prefer to screw on their own flanges as illustrated in Figs. 10-11A and B. Also, several recorders operate using only a hub without flanges to eliminate any possibility of the edge of the tape scraping on the reel flanges, causing wow and flutter. However, on a properly designed tape recorder, the tape should ride between the flanges and at no time scrape on them.

A number of evolutions have been made in the metal NARTB hub which have greatly improved it. One improvement is that the surface of all good present-day metal hubs has been ground. Since the hub is made from a die-cast mould, the surface of an unground hub is mottled, resulting in tape distortion near the center of the reel. Also, the grinding of a metal hub leaves the surface exactly the same diameter across the hub's entire width. Because the hub has exactly the same diameter, the tape will not be distorted through receiving a long edge.

A new development in 10-1/2-inch hubs and reels is the narrowing down of the hub. The hub was originally designed to be

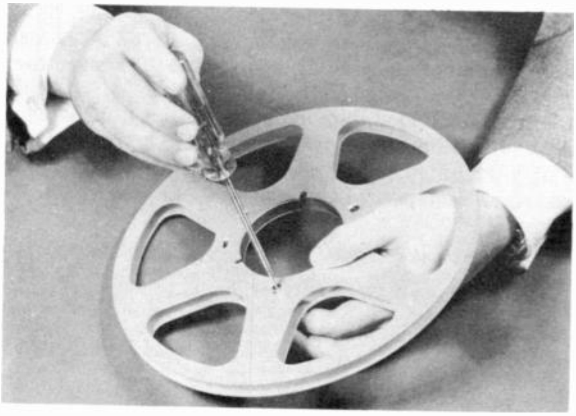

Fig. 10-11B. The NARTB 10½-Inch Reel Assembled.

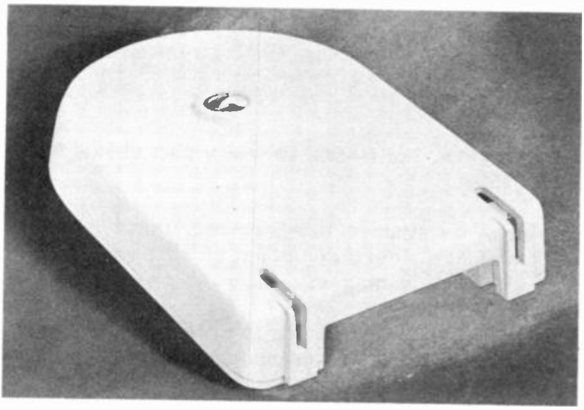

Fig. 10-12. A Self-Loading Cartridge for Use in Pre-Recorded Tape.

350 mils thick. This left ample room between the tape edges and each flange. The purpose, of course, was to prevent scraping and rubbing on the flanges. However, during the fast forward and rewind on professional machines, the tape would wind in a sloppy manner, causing some turns of the tape to be higher than other turns. During storage, when the flanges of the reel would be slightly compressed, the higher turns would be crushed. Consequently, there has been a recent trend to narrow the metal hub down to .260 from .270 inches.

The reduction of the metal hub thickness can be accomplished in two ways. One, the thickness of the hub can be milled down and ordinary flanges installed. While this provides a good solution, the center line of the reel is now in the wrong position for the recorder. This can be solved by readjusting the pedestal heights of the recorder, however, throwing them out of adjustment for other reels. A second solution is to place spacers, such as screws with a large head or washers, outside the flange area to raise the reel to the right height when using the narrowed down hub.

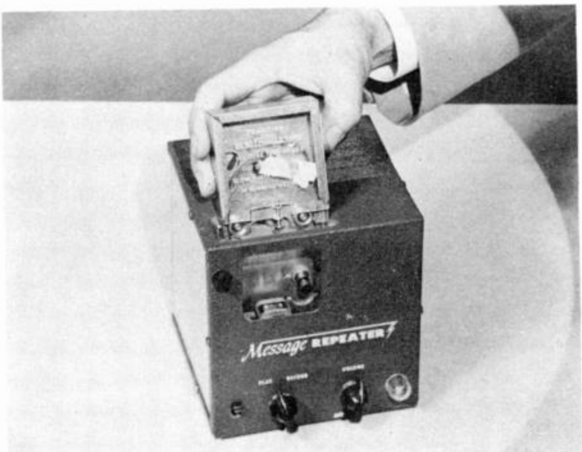

Fig. 10-13. A Variation of the Cartridge Mechanism for Magnetic Tape Used in this Message Repeater Manufactured by the Mohawk Business Machines Corp.

As previously mentioned, the new plastic 10 1/2-inch plastic reel has automatically incorporated a narrowed down hub in the plastic mould, requiring no further attention. Since the distance between flanges has been reduced to .270 inches, the reduction in distance was accomplished by moulding a thicker plastic flange. While the 10 1/2-inch plastic reel is subject to warpage, it is expected that with the solution of this problem, the reels will soon be perfected.

A new development in pre-recorded magnetic tape eliminates the need for reel threading. A plastic self-loading cartridge such as shown in Fig. 10-12 is used. Another variation of the cartridge method, which is used in a message repeater, is shown in Fig. 10-13.

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CHAPTER 11

Test Procedures

In order to evaluate new equipment and to localize and run down bothersome recording defects, a knowledge of testing techniques is essential. To properly test magnetic tape and tape recorders, a series of test instruments is required.

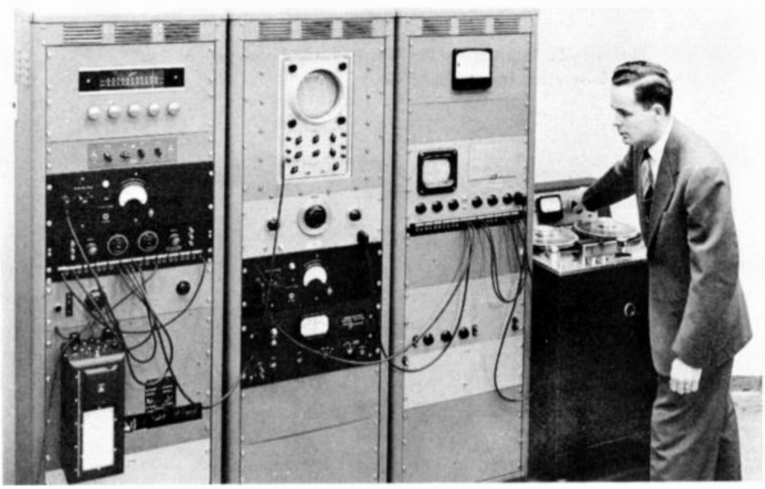

Fig. 11-1. A Typical Commercial Testing Installation.

The equipment need not be of expensive laboratory caliber as shown in Fig. 11-1. All test instruments required are relatively inexpensive and can conveniently be kept on hand in recording studios and broadcast stations. In addition, the advanced high fidelity enthusiast would do well to consider the addition of several test instruments to his gear in order to keep his recorder in peak operating condition.

Useful Test Instruments

Among the most useful test instruments is an audio oscillator capable of reproducing the audio range of frequencies. (See Fig. 11-2.) A good quality audio oscillator is not expensive. There are audio oscillators available, in kit form, for as low as $25.

Fig. 11-2. Typical Audio Oscillator. (Courtesy of Jackson Electrical Instrument Co.)

Fig. 11-3. An AC VTVM with a Db Scale. (Courtesy of Hickok Electrical Instrument Co.)

An output meter such as shown in Fig. 11-3 is also on the "must" list of necessary test instruments. Most volt-ohmmeters have a db scale which serves satisfactorily. The output meter should read essentially flat over the audio range and can be calibrated against the audio oscillator. If the output meter reads 2 db higher at 10,000 cycles than at one thousand cycles, the 2 db should be subtracted in frequency runs. The error in the meter must also be taken into consideration when making measurements.

In addition to an audio oscillator and an AC meter for reading output, a measuring device is needed to determine distortion. There are available several excellent inter-modulation distortion measuring devices selling in kit form for slightly under $50. Other precision inter-modulation measuring instruments of laboratory quality sell upwards of $500. However, it is possible to make highly accurate harmonic distortion measurements with a filter selling for approximately $20.

In the distortion tests to be discussed later in the chapter, it is assumed that the filter method of measurement will be used. A filter can be used in two ways. First, the filter can be used to reject the signal being recorded, thus passing only the harmonic products. Or, second, the filter can be used to pass only the desired harmonic product, rejecting all other frequencies. In other words, one may use a filter as a rejection device, rejecting the signal being recorded and passing all harmonics, thus reading total harmonic distortion. Or, a filter may serve as a pass filter, used to pass only the harmonics being measured, enabling one to check 2nd and 3rd harmonic distortion independently.

Testing Magnetic Tape

In testing a Magnetic tape recorder, one is, in reality, testing two things: the magnetic recording tape and the recorder itself. Magnetic tape is an inseparable part of the recording process. Therefore, in order to realistically test a recorder, it is essential to understand and evaluate certain important characteristics of the tape.

The backing, the magnetic oxide coating, the binder, the plasticizer, the lubrication, when combined in finished form, produce a magnetic tape. In testing a magnetic tape, all tape properties can be divided into two main classifications: (1) physical properties of the tape; and (2) magnetic properties of the tape.

In properly evaluating the performance of magnetic tape, all physical and magnetic properties must be considered since each affects performance of a tape.

Physical Characteristics of Magnetic Tape

The physical characteristics of magnetic recording tape must be evaluated in any testing procedure. Of a tape's physical properties, it is important to know what is the strength of a particular backing material. Under a given tensile force, what is its break point? What it its yield point?

Tape should have a reasonable strength so that it will not break easily. However, practically all tape breakage is caused by nicks on the tape edges rather than the tape being pulled apart. The tensile strength of most acetate-backed tapes is approximately 5.5 pounds, while the operating tension exerted by a recorder is seldom more than a few ounces. However, since the strength of acetate is equivalent to its edge strength, any nick or tear on the tape's edge represents a potential break point. The nicks generally occur during thread-up of the recorder. Care should be taken to place the tape in the recording mechanism properly.

Another important property of magnetic tape is that the oxide adhere firmly to the base, not rubbing or flaking off. Some tape constructions have been known to become brittle and flake off with the passage of time. Most present-day tapes, however, have been greatly improved in this respect.

Other factors that affect a tape's performance are cupping and curling. When the tape is subjected to high temperature and humidity, will the tape remain flat or will it tend to curl or cup? Poor tape, under high humidity conditions will tend to curl, thus making poor contact with the record head. Poor head contact results in the loss of high frequencies and serious amplitude variations.

What is the layer-to-layer adhesion of a tape? Can one turn of the tape be freely pulled from the next or will the layers tend to stick, indicating an adhesive, sticky binder material or excessive smoothness of the surface? Squealing will occur when the tape actually becomes gummy, sticking to the magnetic head intermittently with a staccato effect. The squeal is picked up and reproduced in the record and playback process with a very disconcerting effect. Most present-day tapes are especially lubricated, a treatment designed to prevent squealing.

Tests of Physical Properties

The following tests are typical of those used in testing laboratories in evaluating tape constructions. Each test is but one method (although in all cases not necessarily the best way) of measuring a specific tape property.

The backing material: The backing material is determined by visual inspection and chemical analysis. The strength of the material, stability, and smoothness are then determined.

Tensile strength: The tensile properties are measured with a Scott inclined-plane tensile tester. (See Fig. 11-4.) The result is the tensile stress in pounds required to break the tape.

Blocking: The test for layer-to-layer adhesion (blocking) consists of tightly winding several layers of tape on a stainless-steel mandrel and subjecting this sample to a 16-hour conditioning at 130° F., 90% relative humidity. The tape is then subjected to a 4 hour cycle at 130° F., and 0% relative humidity, and finally allowed to return to room conditions. When cooled, the tape is unwound and inspected for adhesion between layers and transfer of the oxide coating to adjacent layers. This test simulates the effect of natural aging and humidity cycling on layer-to-layer adhesion.

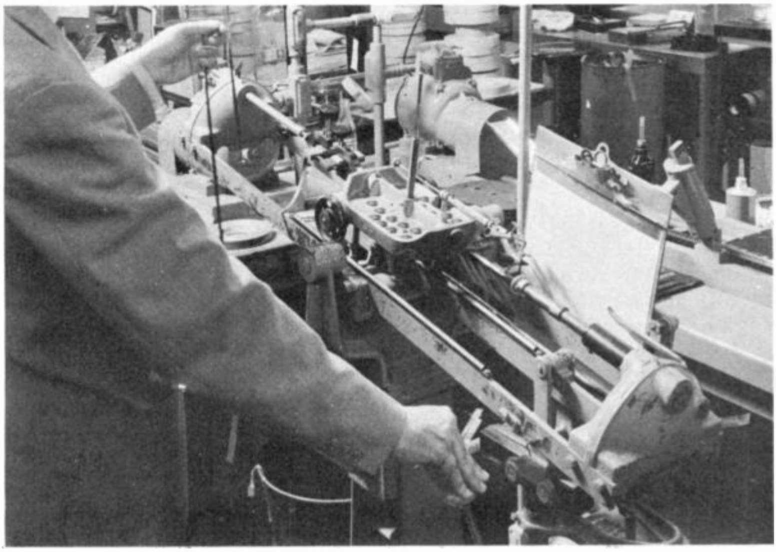

Fig. 11-4. The Scott Inclined-Plane Tester Shown Here Is Used to Test the Tensil Strength of the Tape Backing.

Curling: In the curling test, small samples of the tape are placed in each of two chambers having relative humidities of 0% and 85%. The samples are viewed "end on" and the angle of curvature is accurately measured.

Anchorage: To test for coating anchorage to the base, the oxide coating is stripped off with pressure-sensitive adhesive tape. The degree of removal indicates the firmness of the bond between the coating and the backing. Another simple test for oxide anchorage is to pinch the tape between the figures and roll it sharply, indicating whether the oxide has good adhesion to the base.

Caliper: Tape thickness is measured on special calipering devices which measure accurately to the hundred-thousandth of an inch.

Evaluation of Magnetic Properties

Here are the magnetic properties of a tape and how they can be measured and evaluated:

Output for 1% distortion: The output of a magnetic tape is generally determined by the coating thickness or, through newly perfected techniques in magnetic tape construction, by improved formulations which increase the density of the oxide coating without adding to tape thickness.

The output test for 1% third-harmonic distortion is made on a professional recorder adjusted at peak bias for the tape under test. A 1000-cps signal is recorded on the tape. The input signal strength is increased until the output signal is 1% distorted (3rd harmonic). This output is the maximum obtainable before seriously overloading the tape. A high output for a given distortion is essential in obtaining a good signal-to-noise ratio.

Sensitivity: The sensitivity of a tape is a measure of how much output or signal is obtained from the tape for a given input. This is generally measured on a comparative basis. For example, tape of two manufacturers are spliced end for end. A given signal at low or middle frequencies is applied, well below the distortion or overload region of the tape.

After measuring output at 1% third-harmonic distortion, the 1000-cps input signal strength is reduced to a standard value, fixed at a point well below 1% distortion for all tapes. The output of a given tape for this fixed input is, then, a measure of the tape's sensitivity. A tape with high sensitivity is desirable since it requires a minimum of recording signal power to obtain full output.

The output is observed for each of the tapes. If one tape has 2 db more output then the other tape, then that tape is said to be 2 db more sensitive.

It is vital that tapes have the same sensitivity, especially when the tapes are spliced together. To cite an example of the seriousness of the problem, let us assume two tapes of varying sensitivity are spliced together. One tape may be 4 db less sensitive than the other. When recording at full band, suddenly there will be a drop of 4 db in the volume when the less-sensitive tape passes the magnetic record-reproduce head.

Tape distortion: Another measure of a tape's performance is its output for a given distortion. As explained in the chapter on amplifiers, the tape itself introduces only third-harmonic distortion. The amplifier, however, will introduce both even and odd harmonic components. Generally, second and third harmonics are the strongest. However, if there are any magnetized regions on the recorder such as magnetized heads, the tape will introduce second-harmonic distortion.

Using a filter measuring device, the measure of a tape's output for a given distortion is determined as follows: A middle or low frequency signal (between 500 to 1000 cycles) is recorded on the tape. The amplitude of the signal is slowly increased until its distortion reads a fixed value, 3%. Then the output from the tape is observed at this point.

Frequency response: Still another test of a tape's magnetic properties is its frequency response. This is, in reality, a measurement of a tape's sensitivity at different frequencies. For example, on a given recording mechanism one tape reproduces the same output at a high frequency, say 10,000 cycles, as at 1,000 cycles. A second tape may reproduce 2 db less output at 10,000 cycles as at 1,000 cycles. The second tape is said to have 2 db less output at 10,000 cycles when compared to the standard reference test tape.

With the input signal level set below the 1% distortion point by the amount of pre-equalization used in the recorder (input at least 15 db below "0" level for most recorders at 15 ips), the output for a 1000 cps and a 15,000 cps signal is noted. When the low-frequency output in db is subtracted from the high-frequency output the result represents either the loss or gain in output of the tape at high frequencies. A good output at high frequencies is a "must" for high fidelity recordings and for machines operating at slow tape speeds.

Noise level: Generally the easiest method of reading noise is to hold a strong permanent magnet against the tape. By playing the tape at a fixed gain setting of the playback amplifier, the overall DC noise is measured. The noise figure indicates the amount of modulation noise contributed by non-uniformities on the coated surface of the tape.

Uniformity: To test for uniformity, again using a 1000-cps input signal which is held at a constant level, the recorder's output is observed on a meter. Careful watch should be kept for the maximum output deviations. On present-day recording tape, the sensitivity should not vary more than a quarter of a db within a reel and not more than a half of a db from reel to reel. A more exact measurement may be made by feeding the recorder's output to a magnetic pen-motor with good response up to 50 or 100 cps. The uniformity is then taken as the average output variation in db over the length of tape wound on the reel.

Coercive force and remanent flux: The magnetic tests for coercive force and remanent flux are made on a dynamic hysteresis curve tracer, a laboratory instrument. The coercive force largely determines the signal strength required to record or erase the tape. The tape's remanent flux indicates the approximate signal output.

Testing a Recorder

Frequency response: The most common measurement made of a recorder's performance is the frequency response test. This is the most common test of a recorder, perhaps, because it is the easiest test to make and is generally indicative of a recorder's over-all performance.

A good recorder will have what is known as a reasonably flat response. That is, over a given range of frequencies, the output will vary only a small amount. There will be no sudden drops of output at certain frequencies or rises in output at other frequencies. Professional recording equipment is often flat to within one or two db over the entire audio range from 30 to 15,000 cycles. In contrast, some home recorders may vary as much as 6 to 10 db over the range of 70 to 8,000 cycles.

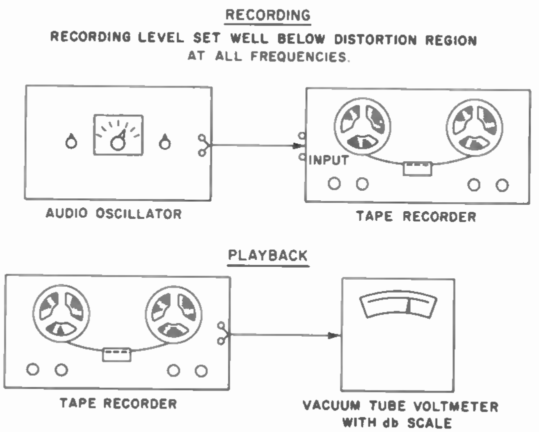

Fig. 11-5. Method of Measuring Frequency Response of a Tape Recorder.

To measure frequency response, the audio oscillator is connected to the input of the recorder as shown in Fig. 11-5. Its amplitude is set so that the signal level recorded on the tape is down by at least the amount of pre-equalization used in the recorder (generally 15 db below the normal record level).

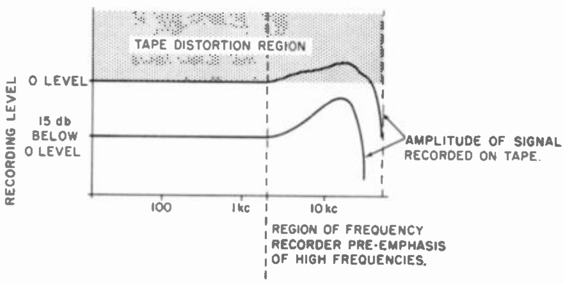

Fig. 11-6. Disadvantage of Taking Frequency Response Checks at a High Volume Setting.

Magnetic tape overloads at approximately the same amplitude regardless of frequency. Since most recorders often boost the high frequencies during recording, the frequency run must be made at a low enough level so that the high frequencies will not be boosted to a point where they will overload the tape. If, when making a frequency response measurement, the record level is set too high, the high frequencies in the region of pre-emphasis will overload the tape and will not be reproduced properly. A tape recorder with normally excellent frequency response would then appear to have very low output at high frequencies. As shown in Fig. 11-6, the record level for frequency response checks should be made at least 15 db below "0" level for most machines. That is, if in the equalization process the high frequencies are boosted by 15 db, when making a frequency response test, one must record at 15 db below the normal recording level. This must be done to avoid overloading the tape at high frequencies. The audio oscillator is then varied over the frequency band, and the output is noted and recorded on the AC voltmeter or output meter. It is necessary that the output meter be calibrated in terms of db since this is the unit of measure generally used in specifying recorder performance.

Signal-to-noise ratio: Another important test of a recorder's performance is the determination of the signal-to-noise ratio. This is generally a test of the maximum distorted output, taken as 3 per cent total harmonic distortion, compared to the noise from the amplifier with erased tape. To perform this test, one should have a rejection filter. The filter should be calibrated in terms of number of db rejected at a certain frequency. Generally, a rejection filter of 400 cycles is satisfactory.

The audio oscillator is again connected to the input and a 400 cycle tone is fed to the recorder. The signal from the recorder is then fed into the filter, thus rejecting the 400 cycle or fundamental. The output from the filter then represents the harmonic products. However, care should be taken to subtract any fundamental that is passed by the filter.

The tape output is then set to give 3 per cent harmonic distortion. The output at this point is then observed. Next, cleanly erased tape is played back on the same machine, and the noise is noted.

The difference in output between the 3 per cent point and the noise level is the signal-to-noise ratio of the recorder.

Professional recording equipment often has a 60 db or better signal-to-noise ratio. On home-type recorders, a figure of 40 db is often considered good.

Flutter and wow: Still another test of a recorder is for flutter and wow. To accurately express the amount of flutter and wow in a percentile generally requires an expensive flutter and wow meter. However, one can get along without this costly laboratory measurement device. The human ear is most sensitive to flutter and wow around three thousand cycles. Therefore, to measure flutter and wow, it is well to record a signal of approximately 3,000 cycles and then to play it back, listening carefully. Any flutter and wow at 3,000 cycles can be easily discerned. With a little practice, one can quickly judge what is acceptable and unacceptable. Generally, if only a slight amount of flutter and wow can be discerned the recorder is operating properly. If the amount is noticeable or irritating, chances are that the recorder has an excessive amount of flutter and wow.

Distortion: To measure Distortion in a recorder, the output is passed through a rejection filter, and the distortion products are read for a given output level.

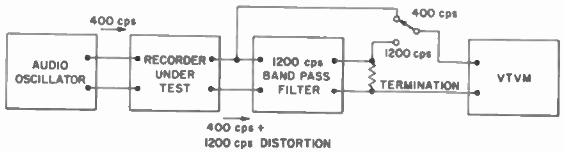

Fig. 11-7. Block Diagram of a Distortion-Measuring System.

The equipment required for distortion measurement is an audio oscillator with good waveshape, a vacuum tube voltmeter capable of reading over a fairly wide range of voltage, and a bandpass filter. A block diagram of this method is shown in Fig. 11-7. Since it is customary to measure distortion at 400 cps, a 1200 cps bandpass filter is ideal for measuring third harmonic distortion. The filter should have a rejection of at least 60 db at the fundamental test frequency (400 cps) if highest accuracy is to be obtained.

Before making the test it is necessary to calibrate the system to take into account the insertion loss of the filter. Since the input determination will affect this value, it is best to calibrate the filter from the actual recorder under test. To do this, the filter is disconnected and the output level of the recorder checked at 400 cps and 1200 cps to determine if it is the same at these frequencies. If not,

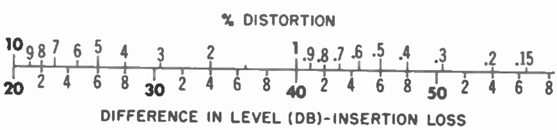

Fig. 11-8. An Alignment Chart for Converting Decibels to % Distortion.

the input to the recorder must be readjusted at one of the frequencies to compensate for this discrepancy. The filter is then connected to the recorder, and a level reading taken at 400 cps at the input to the filter. The oscillator is then set at 1200 cps and the level is read at the output of the filter. (The input level to the recorder must be readjusted if necessary as previously determined.) The difference between these readings in decibels is the insertion loss of the filter.

In making a distortion measurement test, a 400 cps signal is fed through the recorder and level readings taken at both the input and output of the filter. The difference between these readings in db minus the insertion loss of the filter is the true ratio between the signal and the third audio harmonic component. This can be converted to percent by reference to the alignment chart given in Fig. 11-8.

Other recorder tests: In addition to the performance tests of a recorder, care should be taken to see that the mechanism functions smoothly. Tape must not spill off the reel during fast forward and rewind. The drives must engage smoothly and evenly. The recorder must be relatively quiet in respect to mechanical noise.

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