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THE SERRASOID FM MODULATOR

by James R. Day

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PROCEEDINGS
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RADIO CLUB OF AMERICA

Volume 26 1949 No. 1

THE SERRASOID FM MODULATOR

By

James R. Day*

Presented before the Radio Club, September 23, 1948

Before describing the subject in detail, I believe it will be helpful first briefly to talk in general terms about the matter of generating a frequency modulated current, particularly for broadcasting purposes. This will be familiar ground to you, and I hope that you will pardon the lack of novelty in such an approach. The general success and high performance of FM broadcasting could lead to a belief by some not working directly on its problems that, for example, the design of modulators is in a satisfactory state. Such a belief is, of course, neither wholly right nor wrong. For the day to day purposes of ordinary FM broadcasting, and at the moment, most designs are adequate, but by a not very comfortable margin. The widening of this margin, among other reasons, was an object in the development of the Serrasoid Modulator.

The two general classes of circuits for the generation of frequency modulated currents are the reactance modulated oscillator and the constant frequency oscillator phase shift type. In the former the frequency of an oscillating circuit is caused to vary as linearly as possible by means of a modulated reactance. In order to be readily and linearly modulated, the average frequency of such a combination is very far from stable enough for broadcasting purposes. The average carrier frequency is therefore stabilized by an error force derived from the comparison of the carrier frequency or a submultiple of it with that of a crystal oscillator. In the phase shift type the frequency of the controlling oscillator is not varied during modulation, and may therefore be stabilized to any practical degree by means of a quartz crystal, the entire circuit being completely independent of the modulating means. The reactance method is capable of much greater initial frequency deviation than the phase shift method, and hence requires correspondingly less subsequent multiplication. Thus, other things being equal, - they aren't - it would appear that the elaboration of automatic frequency control in the reactance method is balanced by the additional frequency multipliers used in the phase shift type. Such a balance is superficial, and does not negative the fact that in the reactance type the carrier frequency control is basically indeterminate in that it cannot be effective at rates lying in the range of modulating frequencies. It has been said, in the course of the competitive wrangle, that failure in the automatic frequency control branch would still not take the transmitter off the air, and that therefore the tubes and circuits involved cannot properly be counted as essential. With equal logic and fairness, however, we can be reminded that "the air" is a big place. Well prior to his public disclosure of the wide-band FM system in 1935, Major Armstrong had gone over this ground carefully, and had decided in favor of the phase shift system. To those of us who learned our FM from him the interval since then has not produced anything to alter this choice, and development work has centered mainly around improving the phase shift system. The original phase shift type modulators, in use from 1936 to 1940, were not quite up to par in the matters of inherent noise, distortion at the low modulating frequencies, and average carrier frequency stability. Nevertheless they were quite up to the job of launching the development of FM broadcasting, and its numerous offshoots. The invention, by Major Armstrong, of the double channel phase shift modulator, first placed in service in 1940, disposed of the shortcomings just mentioned. These units to date have probably furnished more hours of trouble-free high performance broadcasting, than have the units of any other system, under conditions of real field maintenance - or lack of it.

The Serrasoid Modulator is of the phase shift type and represents an improvement on the double channel method in simplicity, cost and performance, secured with no lessening of the great reliability of the latter. Let us now

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Long Island City, N.Y.

quickly review how a phase shift type modulator works and what a good one should do. All such modulators have in common a device which, in effect selects some fixed event in the oscillation cycle, causes this event to be advanced and retarded in phase, and which then recreates a new wave timed in accordance with the advance and retard. For instance, consider a sine wave. If we imagine an amplitude gate that selects out a small portion of the wave on the axis and which is sensitive only to say the positive going parts of the wave, such a gate can conceivably be modulated in amplitude so that the aperture slides up and down the wave. The passage of the wave through the gate will then be modulated in time or phase in accordance with the amplitude variation of the gate. By various means a new sine wave may be recreated that is timed by the gating action; such a wave will be then phase modulated. In the original phase shift type modulators the amplitude variations of the gate were secured by varying the amplitude of one of two sine waves that were displaced in phase by ninety degrees. The phase of the resultant when they were recombined than varied in accordance with the amplitude of the one that was changed. Thinking of this in terms of vectors it is evident that while the phase is advancing the rotational speed and therefore the instantaneous frequency of the resultant is greater than the fixed frequency of its two components; the converse obtains while the amplitude is decreasing. I've always been more than a little puzzled that such a simple and straightforward way of varying the frequency of an alternating current should have been dubbed the "indirect" method of frequency modulation. There is nothing the least indirect about it when it occurs inadvertently in an amplitude modulation system. A little more stroboscopic clairvoyance and the vector picture yields the information that not only does the frequency of the resultant change only while the phase is changing, but that the amount of the change, the frequency deviation, is proportional to the rate at which the phase is changing. If the rate of change of phase is doubled, as for example by doubling the frequency of a modulating sine wave, the resulting frequency deviations are doubled. In order, therefore, that the deviations be independent of modulating frequency and proportional to amplitude, all phase shift type frequency modulators include a network that makes the applied modulating force inversely proportional to its frequency. This network is generally called the corrector. If we stick to the case of sine wave modulation, the vector picture alluded to before gives the simple relation or rule that the peak frequency deviation is equal to the product of the modulating frequency and of the peak phase shift in radians; from which it is evident that the maximum phase shifting capabilities of such systems are only called upon for the lowest modulating frequencies.

In the original Armstrong modulators where the gating or timing was secured by the amplitude modulation of a sine wave, the process is linear to the extent that sine of an angle is equal to the angle. Expressed in terms of distortion of a frequency modulated wave it amounts to about one percent for a peak phase shift of one fifth of a radian or eleven degrees. Setting a limit of one percent distortion and using a figure of fifty cycles for the lowest modulating frequency, the frequency deviation is about ten cycles. To reach the standardized value then for 100% modulation of 75,000 cycles requires a subsequent frequency multiplication of 7500 times. The refinement of this method is attested by the fact that in commercial models the measured distortion at the indicated peak phase shift equals within very close experimental limits that computed from the departure of the sine function from the angle. At modulating frequencies higher than fifty cycles and corresponding phase shifts of less than one fifth of a radian the distortion falls off very rapidly until at a few hundred cycles it is limited by other factors than the phase shifting process, and at a value that evokes a whole new problem in that of an absolute measurement of the distortion of a frequency modulated wave. Under the stated conditions and with the practical circuit constants employed the random noise generated in the course of the modulating process is about 73 db below 100% modulation. This all adds up to pretty superlative performance, and it may reasonably be asked why anything better is needed at the moment. Apart from a very good reason that I'll mention in a moment, this all was secured with some twenty-three receiving type tubes coupled by relatively non-critical circuits. Any reduction in the number of tubes would of course be welcome, although I for one, in the course of time, had acquired more confidence in the twenty three tubes than I could ever work up for a lesser number plus a tuning motor.

The very good reason I just referred to is the imminent prevalence of radio broadcast relaying. In such relaying modulator noise and distortion is cumulative, and requires that the noise background and distortion be very low in the individual links so that the final signal may still meet the relatively high standards required for any FM broadcasting system. The history of such relaying including measurements thereon since 1940 when the Yankee Networks studio link from Boston to Mt. Asnebumskit was brought through to New York, has led to the conclusion that a modulator with an inherent signal to noise ratio of better than 80 db and distortion of less than one quarter of one percent would fill the bill for a while. Such a modulator would immediately pass the buck to the receivers involved in the chain and, of course, to the microphone and its associated amplifiers. These were the general design objectives in the work on the Serrasoid Modulator, and with the surpassing of same the burden of signal to noise ratio in aural broadcasting had reverted to the microphone. The principle reason for the improved performance of the Serrasoid is its greater permissible phase shift.

Going back to the picture of the gate sliding up and down a sine wave, the limitation is evidently its curvature at values off the axis. Obviously a straight line wave shape through the axis removes this limitation. This is the ordinary sawtooth and is the gating wave shape used in the Serrasoid. Incidently, such an elegant wave form deserves a better name than sawtooth - pity the poor sine function if there were a "sinetooth". C.R. Runyon, III therefore coined "serrasoid" based on the Latin word "serra" for saw. We hope it will pass into the language as a fit and euphonious companion to the sinusoid and others. The maximum phase shift allowable in the elementary form of the Serrasoid is about plus and minus 150 degrees, and a value of plus and minus ninety degrees has been standardized for 100% modulation, leaving the excess as a margin for overmodulation. By simple means not involving tube linearity the sawtooth and the gating mechanism can be contrived to involve less than one tenth percent FM distortion at the maximum deviation. The inherent random noise of the elementary commercial unit is 84 db below 100% modulation, and the limitation is imposed by the requirements of simplicity.

The essential parts of a Serrasoid Modulator are as follows. A source of stable oscillations at the required submultiple of the carrier frequency. A circuit for generating a serrasoid wave form of the same period. A gating circuit that is modulated or slid up and down the serrasoid. And finally a circuit that recreates a sinusoid - or more properly a continuous current - the phase of which is determined by the instant of gating. It is worth pointing out that a simple assemblage of the parts enumerated is by no means sufficient. After exhibiting a sample circuit I'll enumerate the more or less general rules we have found it necessary to follow simultaneously to secure low noise and distortion, and yet maintain simplicity.

The initial deviation being some eight times greater than for the double channel type, the required multiplication is correspondingly less. These modulators start with a crystal controlled frequency of about one one-thousandth of the final carrier frequency - the usual multiplication is 972. To make the necessary mental arithmetic easy we can use for illustration a modulator starting at 100 kilocycles and ending in a carrier of 97.2 megacycles.

V1 (Figure 1) is a pentode crystal controlled oscillator. The constants are adjusted so that the wave form shown in Figure 2A results at the plate. Such a form is secured by confining tube conduction to a small part of the cycle, the width of the negative portion of the wave. This form is differentiated by C5, R5 and the grid conductance of V2a (Figure 2) so that the wave form shown in 2B is applied to the grid. These negative pulses exceed cut off of V2a and pulses as in Figure 2C occur at the plate. V2b is an over-driven cathode follower used to clean out the base line and to give low driving point impedance during the positive going portion of the pulse. The wave form at the cathode of V2b is shown in Figure 2D.

V3a (Figure 3) is the serrasoid or sawtooth generator proper. Between pulses on its grid the tube is cut off by self bias and C10 charges exponentially through R11. By coupling this wave form via the cathode follower V3b to the supply voltage the drop across R11 and hence the charging current in C10 is held constant. The linear serrasoid is shown at Figure 2E. Later the significance of this bootstrap, or its low voltage low impedance equivalent will be noted.

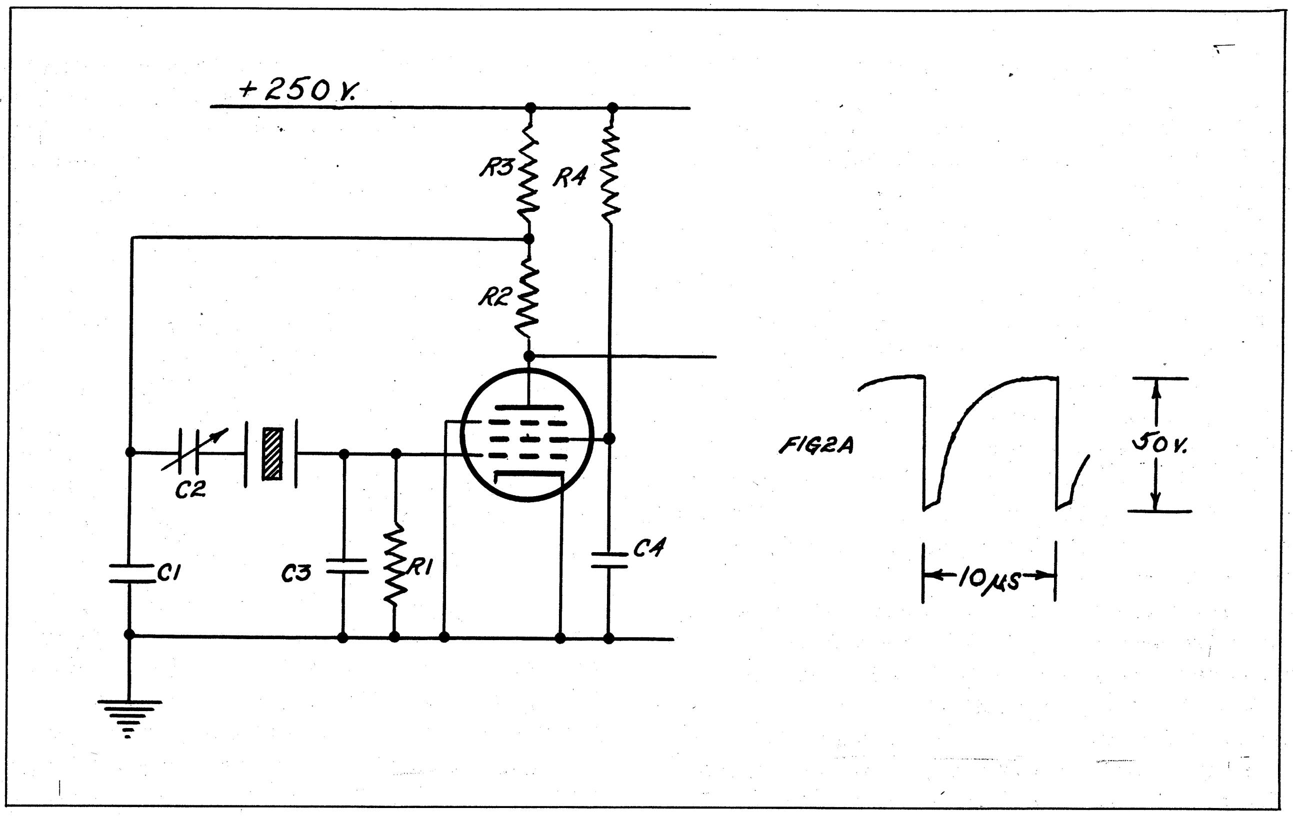


Figure 1

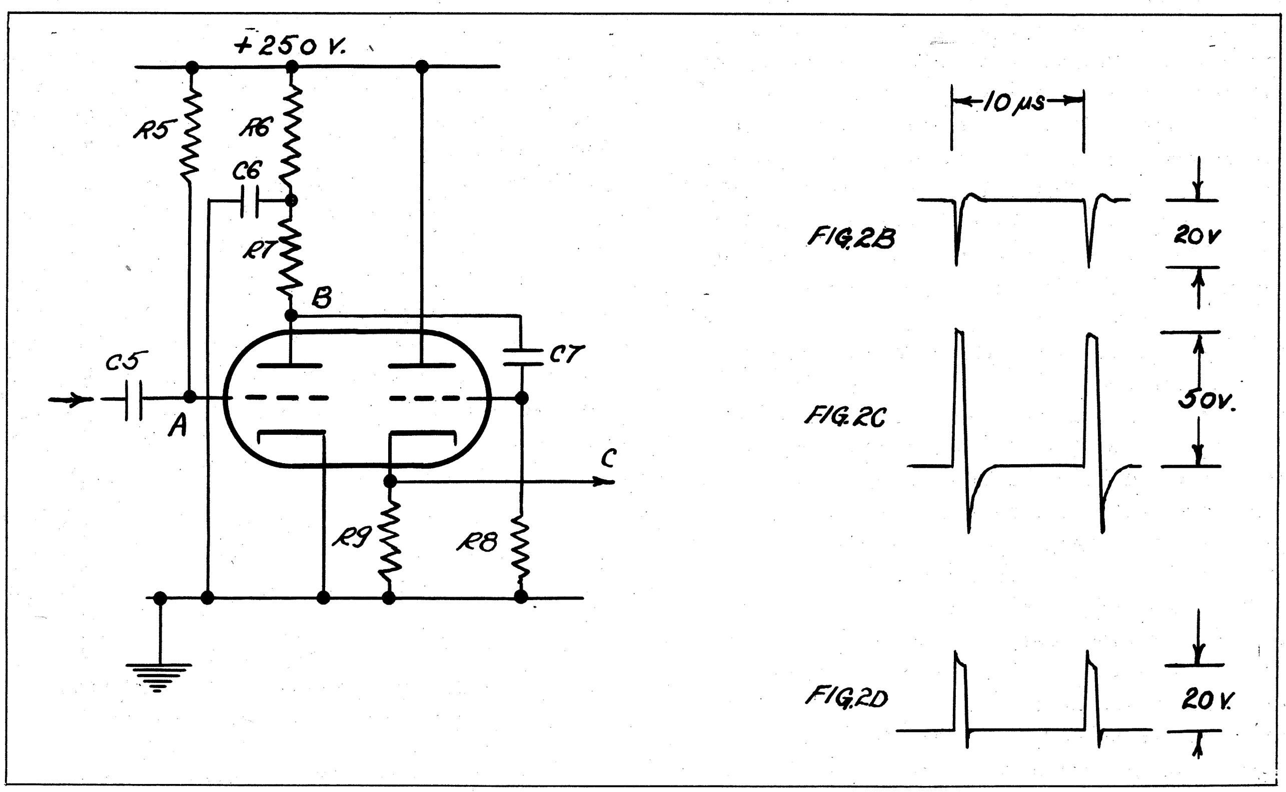


Figure 2

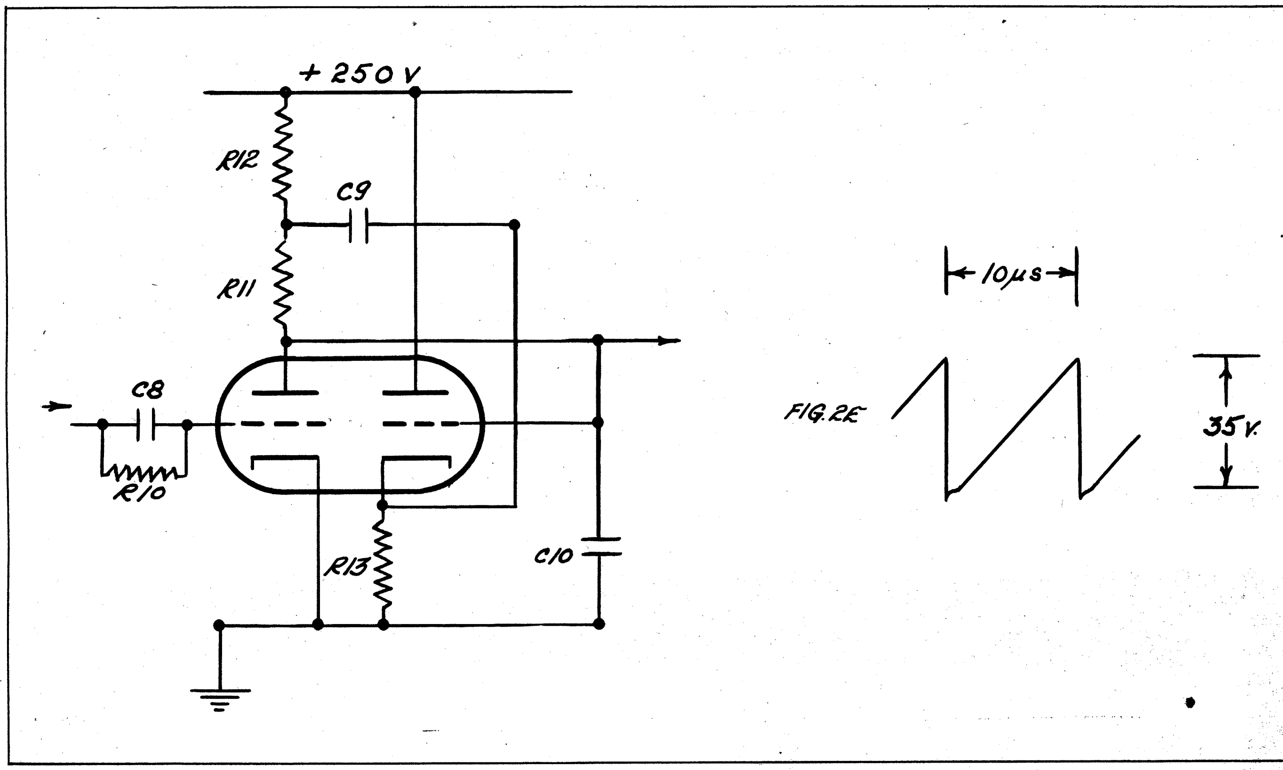


Figure 3

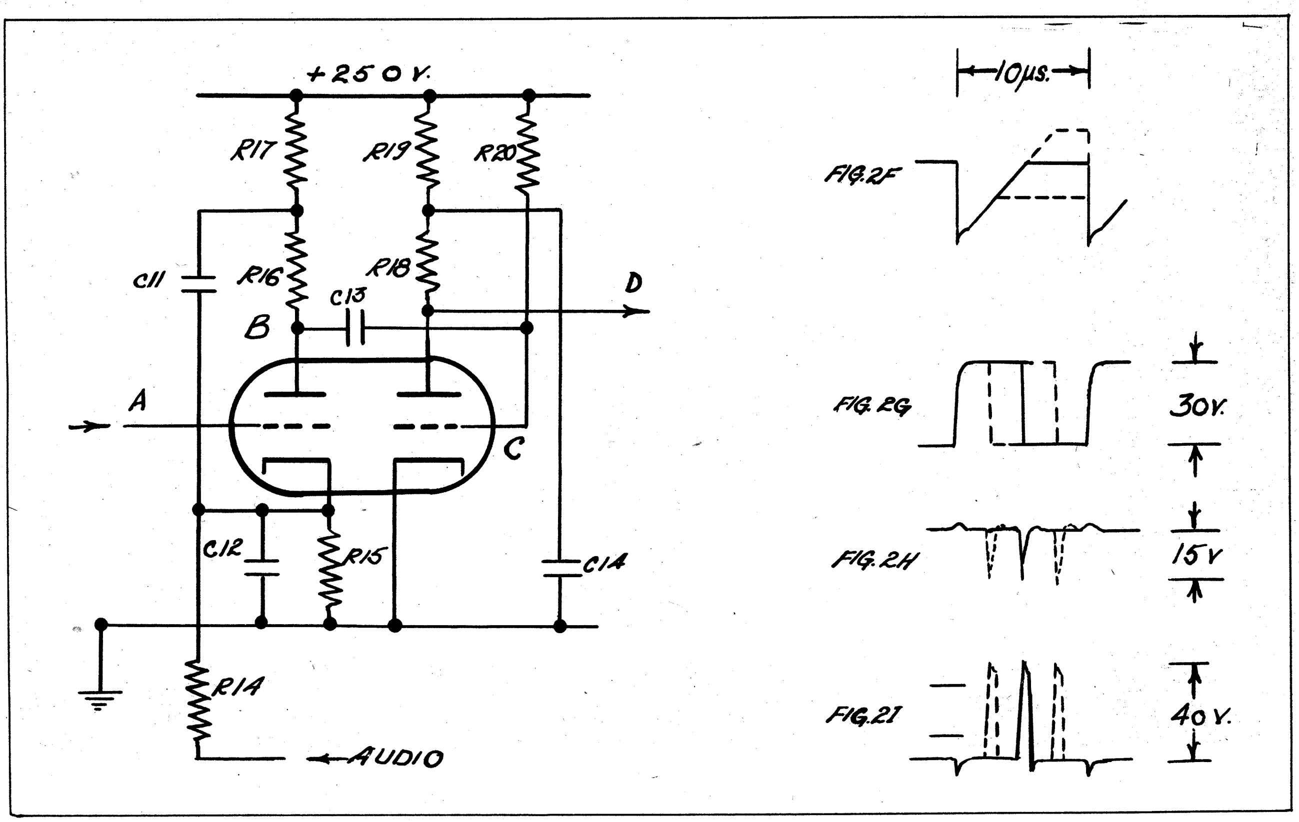
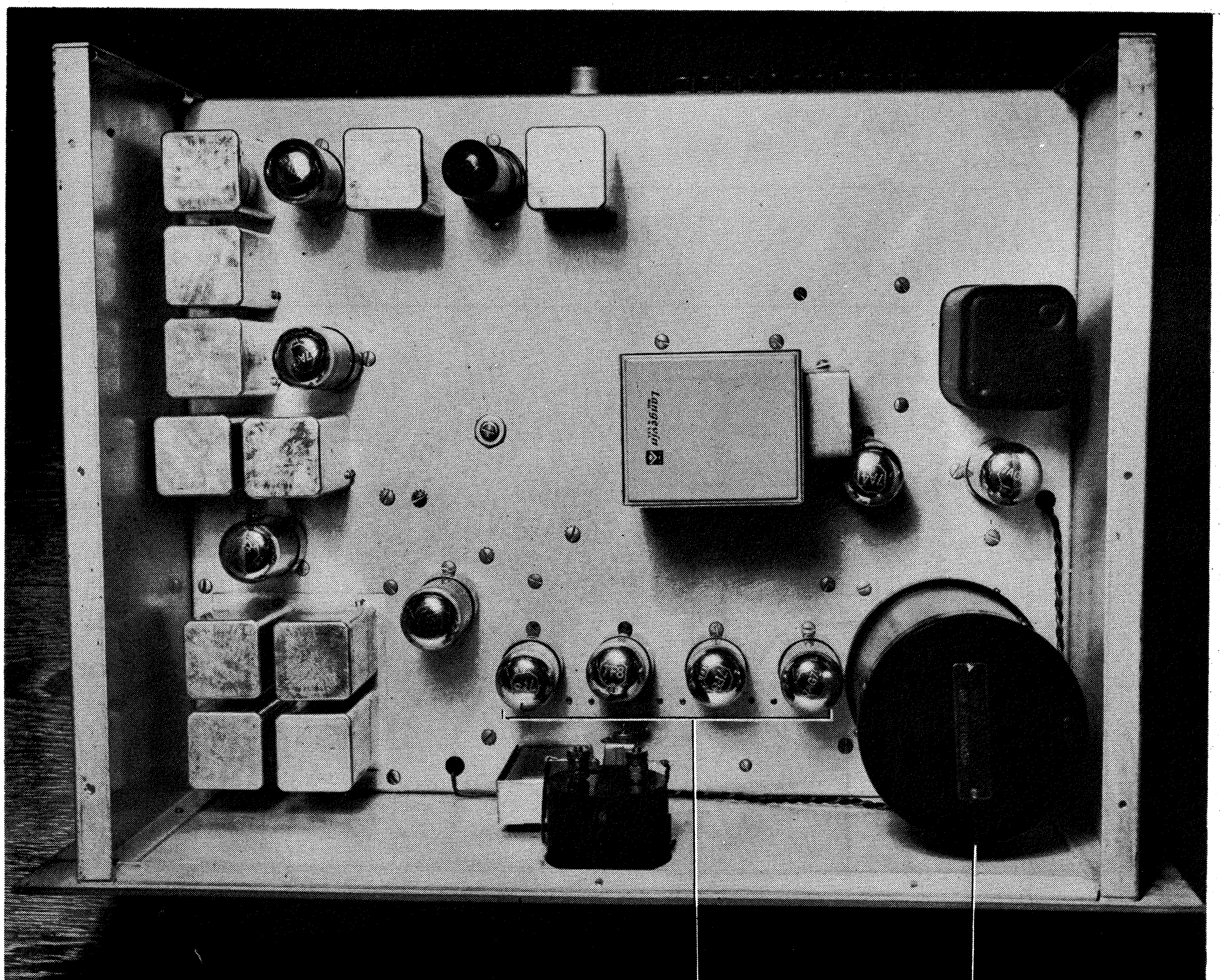


Figure 4

V4a (Figure 4) is the modulator tube proper. It functions as an amplitude gate. It is self biased in the cathode so that in the absence of modulation it begins to draw current at about half amplitude on the serrasoid. Because R17 and C11 are large the effective plate supply voltage is low, about 35 or 40 volts, yielding a sharp cut off. The gradient of the serrasoid is such that about .25 microsecond elapses between the beginning of conduction in V4a and grid current. At grid current charging of C10 stops and the wave shown by the solid line of Figure 2F results. The voltage wave at the plate of V4a is shown in Figure 2G, solid line. R14 and C12 are proportioned to perform the function of the corrector network common to phase shift tube frequency modulators, and the modulation is coupled to the cathode of V4a via these elements. During modulation the bias of V4a varies from the resting condition causing the time of intercept or gating to be advanced and retarded linearly in proportion to the modulating voltage. The dashed lines of Figures 2F and following illustrate extreme positions at 100% modulation.

The wave at the plate of V4a is differentiated by C13, R20 and the grid conductance of V4b giving rise to the voltage wave forms of Figures 2H and 2I at the grid and plate respectively of V4b. The final pulses are applied to the first of the frequency multipliers. By adjustment of the grid and plate operating conditions of this multiplier tube current flow is limited to a



SERRASOID TUBES

CYLINDRICAL
CRYSTAL OVEN

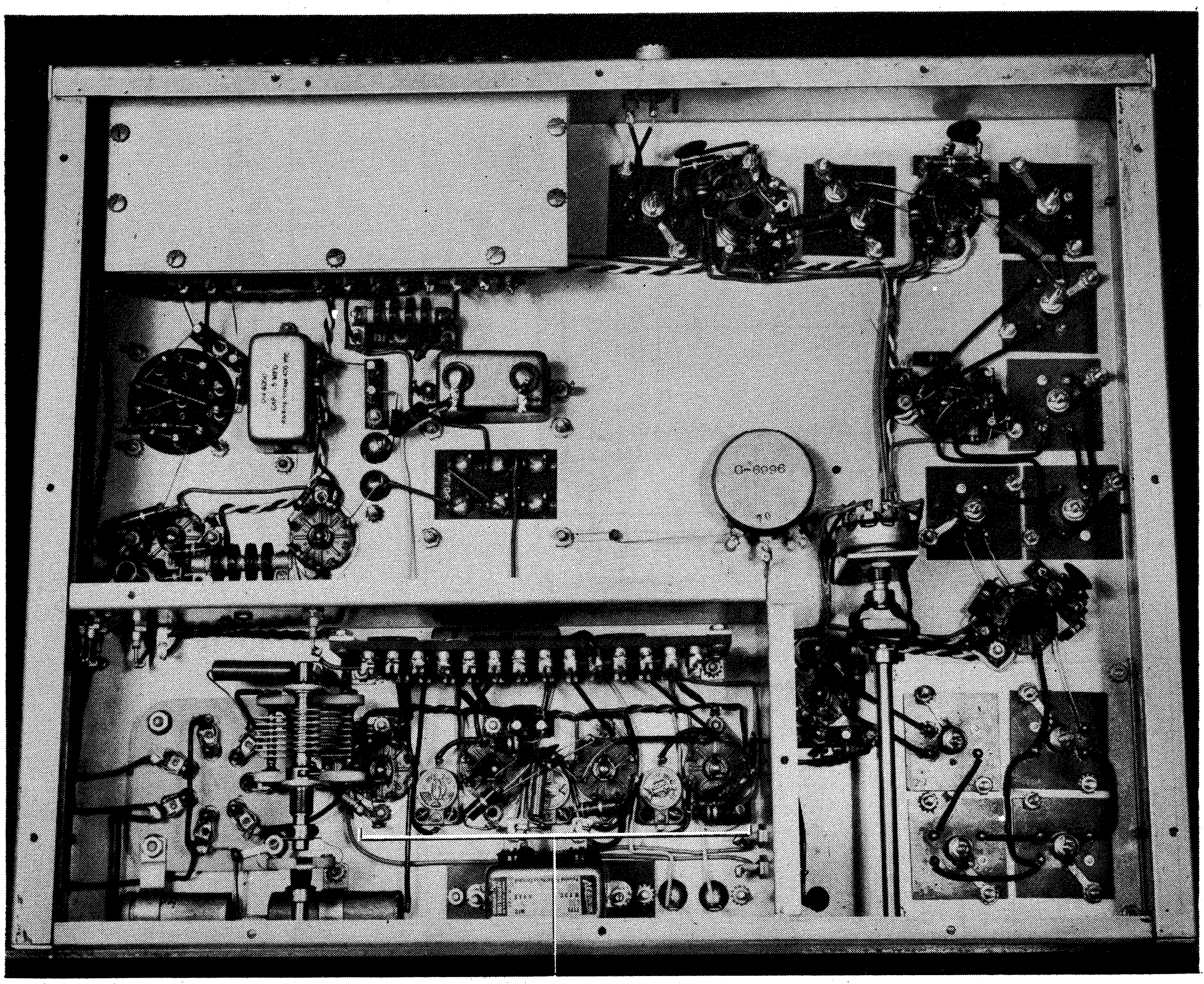
Figure 5

time corresponding to the middle of the pulse amplitude. Current flow is therefore in short square pulses and the resonant load selects the desired harmonic component.

The frequency modulated pulses finally developed are applied to the grid of a tube that saturates on their peaks and which is cut off between pulses. A resonant circuit at a harmonic of the base rate in the plate circuit of this tube recovers the continuous frequency modulated component at this frequency - in effect the tube is a multiplier, usually a tripler.

Figure 5, page 8, and Figure 6 illustrated below, show the innards of a Serrasoid Modulator.

The factors I mentioned before as bearing on the successful performance of a given design may be grouped roughly according to those that largely effect the noise alone, the distortion alone, and noise and distortion together. First of those relating to noise alone is that the oscillator tube current should flow in as short pulses as practical. This of course is to insure that the rate of change of output voltage be a maximum. The circuit illustrated (Figure 7) operates in this manner when used with a sharp cutoff pentode, and with moderate crystal currents. LC crystal oscillators are comparatively noisy, and class A or near class A oscillators are very bad when used for this service. Having provided thus that the oscillator have least practical noise, all circuits thereafter should be contrived with the greatest practicable pulse bandwidth, again in order that rise and decay times shall be short. An important corollary of this is that tubes handling steep front pulses be operated either cut off or current limited, and that the transition time be



SERRASOID TUBES

Figure 6

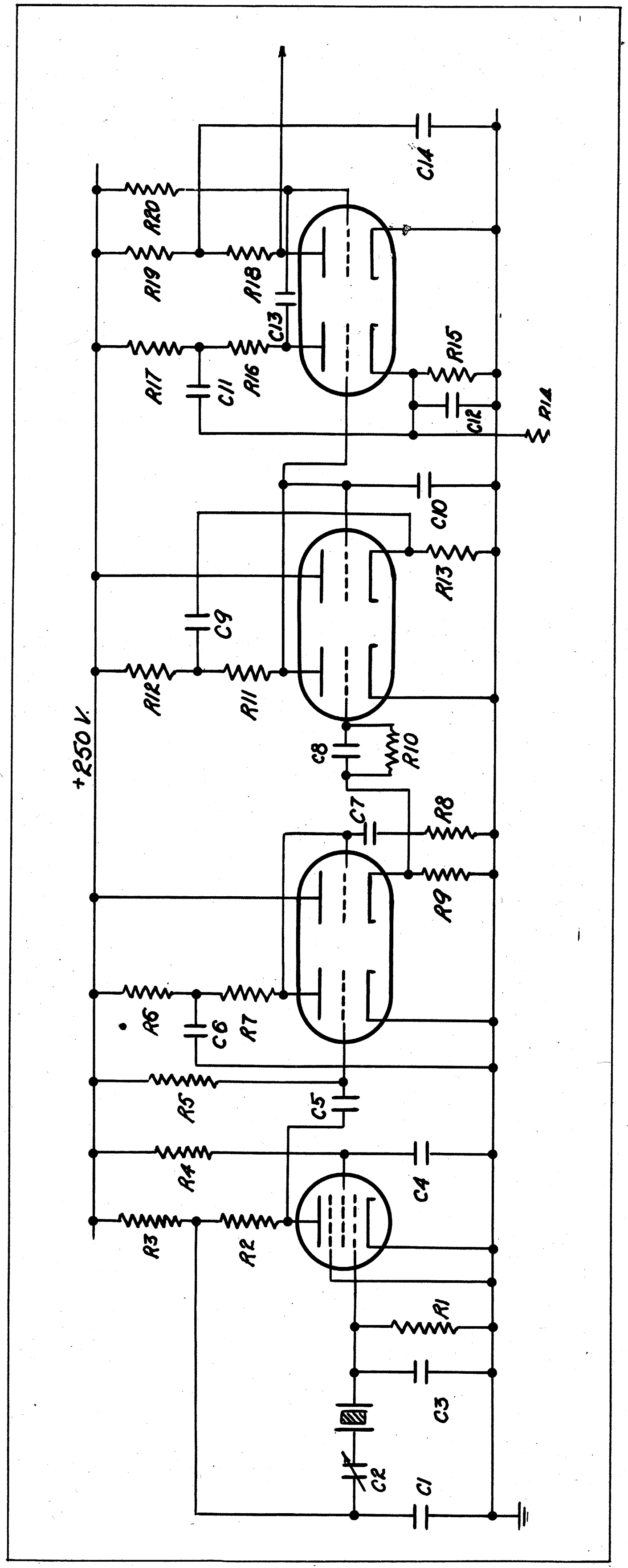


Figure 7
SCHEMATIC DIAGRAM, SERRASOID MODULATOR

short. All of this is of course related to the fact that noise originates in a system of this sort by the superposition on the desired waveform of random and unwanted amplitude variations which, when the pulses are not infinitely steep, cause lateral or time displacements appearing finally as noise modulation. It was found experimentally that multivibrators, one shot oscillators, or other regenerative means could not be employed as synchronized pulse forming circuits, without raising the background noise to prohibitive levels. The possibility of noise modulation arising in the plate circuit of the first tube following the generation of the frequency modulated pulses is minimized by making it a multiplier so that such components are multiplied by a smaller factor than those originating earlier, and which are by then ineradicable. The location of the corrector network capacitor directly at the cathode of the gating or modulating tube, is necessary for least noise. If this network is placed at a lower audio level then audio noise originating between it and the modulator goes on as pure phase noise with the typical triangular distribution. Counting the effect of 75 microsecond deemphasis the protection, so to speak, gained by placing the corrector at this point is about 31 db, which effectually puts it out of sight.

In the matter of factors affecting principally the distortion, these naturally have most significance at the lowest modulating frequencies where the phase shifts and the gating excursions are maximum. First, it was found by diligent experiments that the serrasoid waveform could not be amplified or caused to appear as such in the plate current variations of a plate loaded tube, without seriously impairing linearity. Distortion introduced by failure to follow this precept, can perhaps be cancelled or compensated, but only by reliance on the curvature of tube characteristics, which is not considered an admissible practice. Of equal importance, is that, starting with the gating action, pulses developed should be constant in amplitude over the modulating cycle. Failure to maintain such constant amplitude results eventually in width modulation of the pulses applied to the first multiplier and consequent distortion.

There is one functional part of the circuit where both noise and distortion may be seriously influenced. For once, however, the same medicine is good for both things. Without the so-called bootstrap the serrasoid would have an intolerable amount of ordinary exponential curvature. It might be supposed that by having a much higher supply voltage - say twenty times greater - and then using only one twentieth as much of the available rise the use of the straightener would be obviated. So far as linearity is concerned this would be satisfactory. But beside the inconvenience of a separate high voltage supply - and more important - Johnson noise in the necessary high value of charging resistor becomes a serious factor. The resistor cannot be reduced by making the capacitor greater because of the need for a fast discharge. So this boils down to the bootstrap, or its low voltage, low resistance equivalent, being a necessary as well as a sufficient condition for simultaneous low noise and low distortion.

These design factors have been mentioned because in the course of development many variations of the circuit shown operated with high performance, but it was found as a matter of experiment that the high performance was only secured after all the factors had been satisfactorily accounted for. The particular circuit shown is outstanding in its simplicity compared with others of the same performance.

There are some interesting elaborations of the scheme that it will be of interest to mention. First, the maximum phase shift can be increased by a particularly simple form of cascading. The modulated pulses applied to the first multiplier are similar in shape and amplitude to those used to discharge the serrasoid. If they are applied instead of to a multiplier, to a duplicate of the serrasoid generator, a new serrasoid already frequency modulated will be generated. This in turn can be gated by modulation of the same phase in a duplicate modulator stage. For the simplest case of one stage of cascading and where the same modulation is used, the peak phase shift and the peak deviation is doubled - 6 db - while the noise rises something less than 3 db. The noise rise is less than 3 db because the original carrier oscillation accounts for somewhat more noise than the modulation process per se. The cost of this 3 db improvement in signal to noise ratio and this increase in modulation capability - which could be of value in itself - is two and a half double triodes and twice the required audio power to modulate. The maximum phase shift may be increased in still another way. Starting with the original oscillations two or more interlaced serrasoids may be generated at sub-multiples of the crystal frequency by means of a step counter frequency divider. Each of these is then separately gated by the same modulation, but over a correspondingly greater advance and retard. The sets of modulated pulses thus derived are then combined into a single group. The submultiple frequency, of course, must be more than twice as great as the highest modulating frequency involved.

The circuit shown lends itself rather simply to the application of feedback for the reduction of noise and distortion. It will have been noted that the plate voltage variations at the gating tube are of the form of a width modulated square wave. If this is picked off and limited, and a current developed corresponding to the limited version, the average value of this current will vary linearly in accordance with the phase modulation, and in fact it will be a replica of the modulating voltage applied to the modulator cathode. The carrier term can be removed and the audio recovered by means of a simple low pass filter. The recovered audio is then available as a feedback voltage for insertion with degenerative polarity at any point after the corrector network. To make this practical it is necessary to provide audio amplification between the corrector and the modulator, which according to what was said previously may introduce audio noise with a phase modulation characteristic. By adjustment of this amplification, and the amount of feedback, however, it is possible to reduce this noise contribution to its former level while yet lowering contributions to noise and distortion made by the modulator tube itself. Such reductions in the order of 20 db have been made with simple practical circuits. In the complete circuit shown the modulator stage does not control the noise and distortion, so that applied to it the feedback improves overall figures by less than 20 db.

I'd like now to summarize the principle performance data for a regular commercial design. The particular unit I have here, and which you are most welcome to inspect, comprises the aperiodic circuits for frequency control and modulation, the necessary audio amplification from the standard input of ten milliwatts, and frequency multipliers up to one sixth of the final FM broadcast frequency, lying between 88 and 108 megacycles. The obvious features include the lack of resonant circuits and critical adjustments in the oscillator and modulator proper. Tubes may usually be changed without readjustment, and these in any case are small. The sideband problem sometimes encountered in units starting at low submultiple frequencies has been disposed of by making the first two multiplier plate loads as multisection band pass filters. Subsequent multiplier loads are conventional double tuned interstage transformers with appropriate coupling and loading.

The overall distortion for such a unit is less than one quarter percent at 100% modulation for any modulating frequency from 50 to 15,000 cycles. The phase shift process itself contributes something of the order of one tenth percent FM distortion at 50 cycles, and rapidly decreasing amounts at higher frequencies. This is a tough spot because phase shift distortion here due, say to serrasoid curvature, appears as FM distortion with the harmonic amplitudes multiplied by their order. Thus one percent third harmonic in the initial phase shift would appear as three percent FM distortion. The main contribution to distortion at 50 cycles is made by the included audio amplifier. At 140% modulation the outside limit is four tenths percent, again largely due to the audio. In the middle frequencies distortion is negligible. Distortion in the upper part of the modulating range is entirely controlled by the damping of the resonent circuits of the frequency multipliers, and ordinary care in design and alignment serves to meet the quarter percent limit, measured without deemphasis.

Noise in this unit is more than 80 db. below the level for 100% modulation, measured in the band up to 15,000 cycles, and with 75 microsecond deemphasis. The noise is entirely hiss, since the heaters in the serrasoid circuit and the first audio stage are operated with DC. AC operation throughout seldom results in poorer than 75 db, and then is invariably due to a tube with excessive heater cathode leakage. AC is used on the crystal oven heater. The practical limit for this unit appears to be about 84 db. Of the total noise power roughly two thirds is contributed by the crystal and the oscillator circuit, and one third by the modulator proper. There is a small contribution from the crystal itself that is not well understood. The noise limit encountered after employing all presently known design refinements we estimate to be about 94 db.

Measurements of FM noise and distortion in the ranges noted are not readily made. Available instruments, such as audio oscillators and noise and distortion analyzers while representing good designs admirably executed, are not adequate, and it is necessary to modify them in various ways. The question of a distortionless detector for FM signals is a very pertinent one. As a matter of incidental interest we have found the discriminator type to be the most useful to us. Counter type detectors used at high modulating frequencies and high deviation ratios exhibit anamolous performance not shown at low modulating frequencies. These are no doubt due to small departures from constant delay time that become increasingly important as the signal frequency sweeps more rapidly over the very great fractional range. Such detectors are, however, very useful as near standards at low modulating frequencies. What with one thing and another, including storage batteries for the heaters, we always do our best late at night when Long Island City relaxes electrically.

For the record, a modulator of the type I have here has operated satisfactorily for the past five months at Major Armstrong's Alpine station W2XEA, at 92.1 megacycles. Another unit of slightly different form has operated 24 hours a day since last February at KSBR, the FM station connected with the Eitel-McCullough Company, at San Bruno, California. It is used there as the modulator in a 940 megacycle studio to transmitter link to program the 50 kilowatt transmitter on Mount Diablo. The main transmitter there uses a regular double channel modulator, and the link circuit may be cut in and out with no audible change in noise.

I wish here sincerely to acknowledge the encouragement and stimulation provided during this development by Major Armstrong and C.R. Runyon, Jr.

EDITOR'S NOTE: The following letter was received from Dr. Zenneck. It will no doubt prove of interest to our members, particularly the early pioneers whose studies always included Dr. Zenneck's famous book, "Wireless Telegraphy", written in 1908 and published by the McGraw-Hill Book Company in 1915.

June 17, 1948.

The RADIO CLUB OF AMERICA
11 West 42nd Street
NEW YORK CITY

Gentlemen,

Thank you very much for the YEAR BOOK of the RADIO CLUB of America which you kindly sent me.

I was much impressed by the list of papers read before the club since 1913 and of their authors. The high standard of scientific activity of the club could not be better demonstrated than by this list.

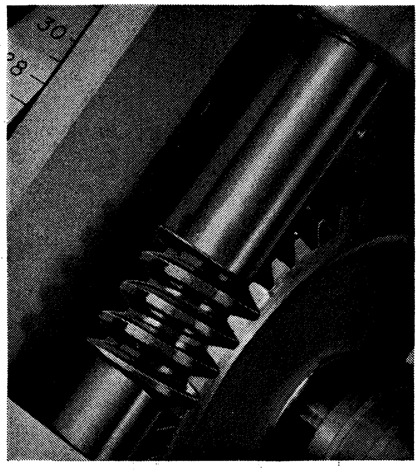
The list of the deceased members of the club contains quite a number of scientists and engineers I have known personally or by their publications. I am especially sorry to see from the list that John Stone Stone died. I used to know him very well and appreciated him very much. Up to the beginning of the last war I was in intermittent correspondance with him. He certainly was an outstanding pioneer during the early time of radio telegraphy.

Sincerely yours

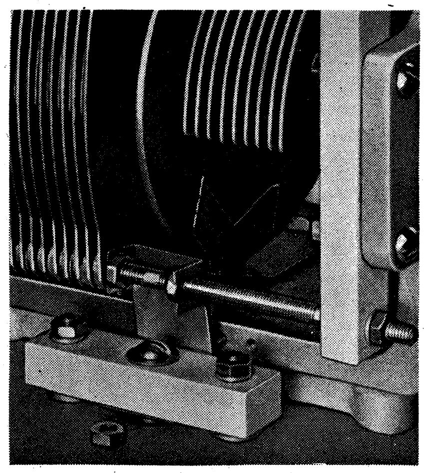
(Signed) J. Zenneck

Prof. Dr. J. Zenneck
Allhegenberg 67
Uber Mering (13b)
Bayern Deutschland
U.S. Zone

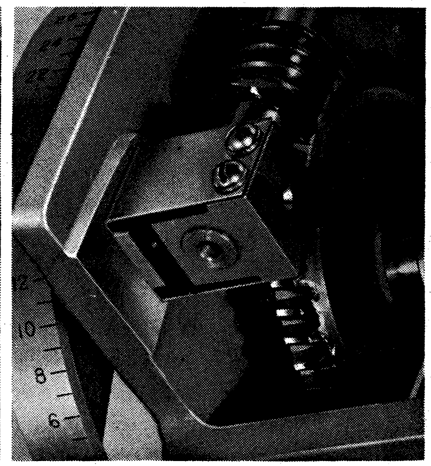
Correction; Page 3 of Vol. 25, No. 2 presenting the paper "Cost vs Quality in Audio" by John M. van Beuren should have carried the following footnote giving Mr. van Beuren's affiliation - Chief Research Engineer, Measurements Corporation, Boonton, N.J.



This 50-to-1 worm drive, equipped with a 3 ½ inch dial, is used for the fine setting adjustment. Backlash is kept very low by spring pressure on the worm shaft. Eccentricity from set screws and misfit is eliminated by cutting the worm and its shaft from an integral steel shafting.



Two small, waxed steatite bars insulate the stator plates. A Figure of Merit (Dissipation Factor x Capacitance) of 0.04 μμf is secured (0.003 μμf with quartz insulators). Connection to the rotor is through spring-tempered silver alloy brushes bearing on a silver-overlay brass disc.

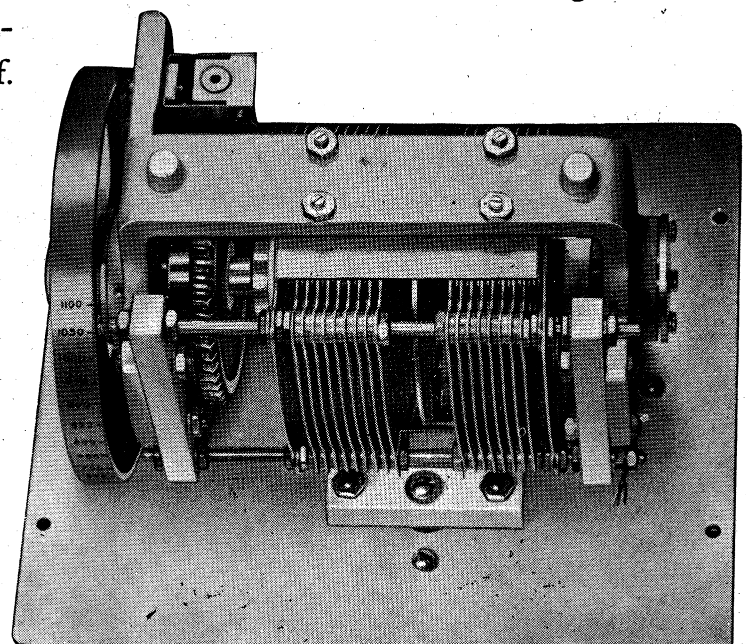


The worm shaft is held to a tolerance of 0.0004 inch; radial eccentricity of the worm gear is less than 0.002 inch. The main rotor shaft is held to a tolerance of 0.0005 inch and its bearing surfaces to 0.0002 inch. Ball bearings are used on worm and main rotor shafts.

The STANDARD of Variable Capacitance

Recently the accuracy of the well-known G-R Type 722 Precision Condensers has been increased, making these standards of variable capacitance of even greater use in the laboratory and as the variable element in many instruments such as oscillators and frequency meters.

Typical of the three different models of this condenser is the Type 722-N, with extra low metallic resistance and inductance. This condenser (illustrated) is direct reading to ± 1 μμf. When the corrections (charted on the front panel) are applied to the direct-reading settings the accuracy is increased to ± 0.1% or ± 0.4 μμf, whichever is greater, and the corresponding accuracy for capacitance differences is ± 0.1% or ± 0.5 μμf.



SPECIFICATIONS

- **CAPACITANCE RANGE:** 100 to 1100 μμf, direct reading
- **STANDARD CALIBRATION:** Direct reading in μμf at 1 kc to ± 1 μμf. Mounted correction chart gives corrections to 0.1 μμf at multiples of 100 μμf.
- **WORM CORRECTION:** For very precise measurements a worm correction calibration can be supplied. When these are applied capacitance can be determined within ± 0.1 μμf or ± 0.1%, whichever is greater, and capacitance differences to ± 0.2 μμf or ± 0.1%
- **METALLIC RESISTANCE:** Series resistance about 0.008 ohm at 1 Mc
- **SERIES INDUCTANCE:** Approximately 0.024 μh
- **TEMPERATURE COEFFICIENT:** Approximately 0.002% per deg. C.

- **TYPE 722-N PRECISION CONDENSER** **$160**
  Worm Correction Calibration **50**
  Quartz Insulation **85**

GENERAL RADIO COMPANY Cambridge 39, Massachusetts

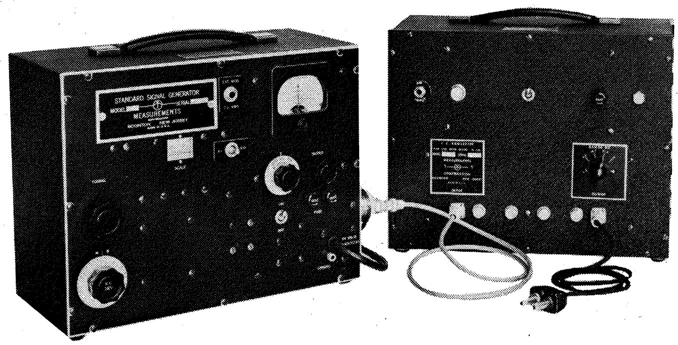
90 West St., New York 6 920 S. Michigan Ave., Chicago 5 1000 N. Seward St., Los Angeles 38

Laboratory Standards
MEASUREMENTS CORPORATION

MEASUREMENTS MODEL 78-FM

SPECIFICATIONS

FREQUENCY RANGE: 86 to 108 megacycles, individually calibrated dials. Accurate to ± .5%.
OUTPUT VOLTAGE: 1 to 100,000 microvolts.
LEAKAGE: Less than 1 microvolt.
MODULATION: Deviation continuously variable from 0 to 300 kc. Indicated on directly calibrated dial. 400 cycle internal audio oscillator can be modulated from an external source providing 6 volts across 5000 ohms.
FIDELITY: Flat within two db from DC to 15,000 cycles. Distortion is less than 1% at 75 kilocycles deviation. Transient response is excellent.
POWER SUPPLY: 117 volts, 50 to 60 cycles.
DIMENSIONS: 10" high x 13" wide x 7" deep, overall.
WEIGHT: Approximately 25 pounds.



MEASUREMENTS MODEL M-275 I.F. CONVERTER

This instrument is designed to be used with the Model 78-FM Standard Signal Generator to provide output frequencies in the I.F. range.

CARRIER FREQUENCIES: 4.5, 10.7, 21.7 Mc. plus provision for one extra frequency.

OUTPUT VOLTAGE: 10 microvolts to 1.0 v., variable with Model 78-FM attenuator.

BAND WIDTHS: 5% down, 250 Kc. from center frequency.

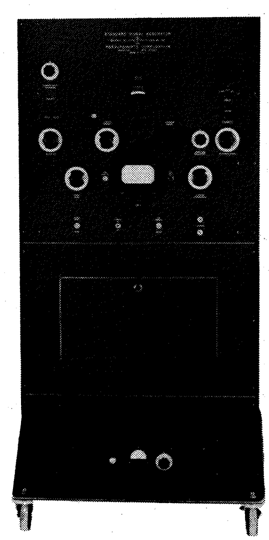
AMPLITUDE MODULATION: Provision for external AM up to approximately 80%, combined with, or exclusive of, FM. There is negligible spurious FM due to AM. The envelope distortion is less than 10% at 80% modulation.
DIMENSIONS: 10" x 13" x 7". 15 pounds.
POWER SUPPLY: 117 v., 50-60 cycles. 45 watts.

TELEVISION SIGNAL GENERATOR

MODEL 90

MANUFACTURERS OF
Standard Signal Generators
Pulse Generators
FM Signal Generators
Square Wave Generators
Vacuum Tube Voltmeters
UHF Radio Noise & Field Strength Meters
Capacity Bridges
Megohm Meters
Phase Sequence Indicators
Television and FM Test Equipment

This instrument is the first commercial wide-band, wide-range, standard signal generator ever to be developed. It is the master oscillator, buffer-amplifier, modulated power-amplifier type, and the output circuits are of the double-tuned, over-coupled, band-pass type, permitting modulation frequencies up to 5 megacycles. The excellent isolation between final amplifier and oscillator completely eliminates incidental frequency modulation.
The carrier range of 20 to 300 megacycles is covered in eight coil ranges. Video modulation is obtained from a built-in video modulator having a band width of 5 megacycles designed to operate from a standard R.M.A. television signal. Continuous monitoring is provided by a built-in oscilloscope. Audio modulation up to 100 percent may be obtained from a suitable external audio oscillator.
The Model 90 fills a long felt need for a real standard signal generator applicable to high definition television use.



MEASUREMENTS CORPORATION BOONTON · NEW JERSEY

REL

ENGINEERS AND MAKES

- **FM Broadcast Transmitters**
  From 10 to 50,000 Watts
- **Transmitter-Transmitter Links**
- **Antennas**
- **Point-To-Point FM Systems**
  For Multichannel and Studio-Transmitter Links
- **Tunable and Fixed FM Receivers**
- **Special Devices Involving FM**

All REL Transmitters employ

THE

SERRASOID FM MODULATOR

THIS UNIT represents the most advanced stage in the development of the phase shift principle for generating frequency modulated signals, and is of the widest possible application. It combines in one design the finest performance commercially attained, with the utmost in simplicity, freedom from critical features, and permanent reliability.

AS APPLIED in an FM broadcast exciter unit, four receiving type tubes plus a crystal comprise the SERRASOID proper, and insure the following performance:

- NOISE - 80 DB below 100% modulation •
- Distortion - Less than 0.25% at 100% modulation •
- Carrier Stability - Direct crystal control •

THESE same four tubes, with design details altered to fit the application, are the modulating heart of a widening group of other FM signalling and multiplexing systems, yielding again the highest order of performance.

WHEREVER a modulating peak phase shift of ±90°, with almost non-existent noise and distortion, is required, together with the ultimate in aperiodic simplicity and reliability, an application of the SERRASOID is the answer.

RADIO ENGINEERING LABORATORIES, INC.

35-54 36th STREET

LONG ISLAND CITY, N. Y.