GATES
ENGINEERING
REPORT

PREVENTING FM OVERMODULATION

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SUMMARY: With the advent of better broadcasting and recording systems, and the liberty enjoyed by today's recording artists, the high frequency signals programmed into the FM transmitter are often of sufficient amplitude (after pre-emphasis) to cause gross overmodulation. The optimum placement of the peak limiting amplifier and the use of auxiliary protective devices are discussed.

INTRODUCTION: Through the years there has been considerable controversy about the wisdom of pre-emphasizing the signal fed into the FM transmitter. The reason for the pre-emphasis was that the signal-to-noise figure was enhanced by the attenuation of the high frequency part of the audio spectrum in the receiver. Since there was appreciably less energy in the upper section of the 30 to 15,000 cps. region than in the part below 1,000 cps., a 75 microsecond pre-emphasis curve was adopted to take advantage of this distribution.

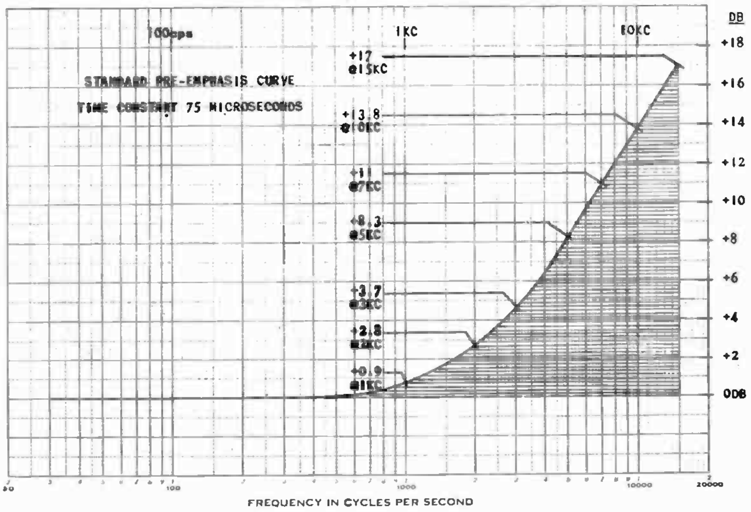

FIGURE 1

The standard 75 microsecond curve, shown in Fig. 1, is flat below 200 cps., rises to +0.9 db @ 1KC, +8.3 db @ 5KC, +13.8 db @ 10KC and +17 db @ 15KC. As the graph shows, this is quite a severe curve. When it was adopted, there must have been very little anticipation of the kind of effects that are programmed today. Also, the Broadcaster was expected to operate his FM transmitter with rather low values of average modulation to allow transmission of the full dynamic range of even classical music. Competition in FM Broadcasting was not too keen and programming was not stressed too highly in most areas. So, the low average modulation concept was generally practiced. In fact, many FM Stations did not employ a peak limiting amplifier, or any type of automatic levelling amplifier, due to the several reasons covered.

FM Broadcasting is becoming competitive. Programming is becoming commercial, and FM Stations are showing a profit. This is healthy for the general public and broadcaster alike, because it will permit better coverage of many areas and a wider choice of programs in every area.

Nearly all of the practices that helped prevent FM overmodulation in the past are being modified, in a direction that contributes to overmodulation, today. Peak limiting amplifiers are being used extensively today. Yet, more and more FM Stations are being cited for overmodulation.

This has caused many station engineers to believe that their limiting amplifiers are defective, or that the attack time is much too slow. However, their limiting amplifiers limited on a flat response curve, where the high frequencies did fall below the threshold of limiting, and the amplifiers were operating correctly. The problem was caused by the pre-emphasis of the signal after it was processed through the limiting amplifier. It was typical FM overmodulation.

ANALYSIS OF PROBLEM: If the high frequency content of any part of the day's programming never exceeds the curve shown in Fig. 2, the peak limiting amplifier could feed into the FM transmitter pre-emphasis filter (assuming a fast limiter attack time) and no overmodulation would occur. Good microphones, tape machines, phono cartridges and recordings make this very unlikely, however. This curve is complementary to the standard pre-emphasis curve, and is the one that should be used in the receiver to de-emphasize the signal to restore the original frequency response. However, if any of the high frequencies do exceed the limits of the curve shown in Fig. 2, and go into the shaded area - overmodulation will result.

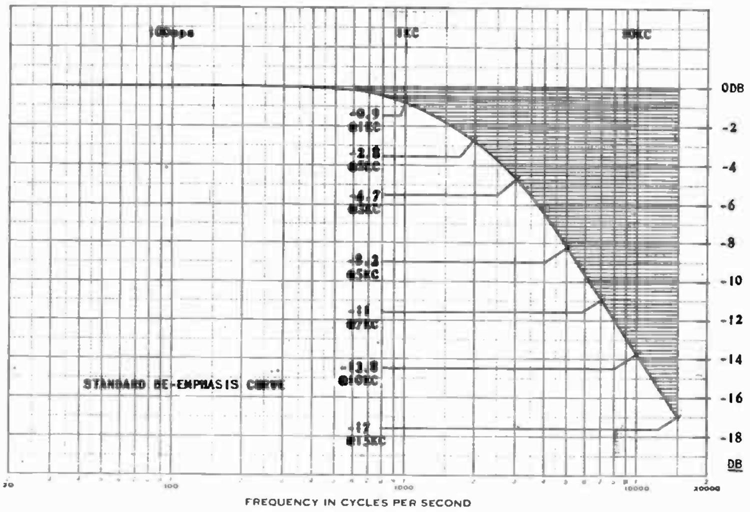

FIGURE 2

A good FM transmitter can tolerate extensive overmodulation without excessive distortion. The carrier swing is extended very rapidly from the maximum allowable ±75KC, however. A program peak of only 6 db will amplify the carrier swing to a very illegal ±150KC. We have reports of FCC citations with relatively low percentages of overmodulation. Many receivers and tuners cannot tolerate excessive overmodulation without serious distortion because of bandwidth and/or discriminator curve linearity restrictions. They frequently suffer from a type of base line shift that can cause perceptible distortion in the audible frequency range. Thus, the Broadcaster has a two-fold reason to stop overmodulating his FM transmitter.

An extensive search of current publications failed to reveal the distribution of spectral energy of modern recordings or of broadcast programs. After some reflection, this was readily understood. The extensive use of program equalizers, graphic equalizers and other frequency response shaping units, in not only the original programming - but in subsequent reproduction as well, eliminate any chance of two stations (or even one on a regular basis) having a typical curve. The limitations of recording media are even circumvented to a large extent by a judicious use of levels.

However, this study requires at least an arbitrary curve for an illustration. Various spectrum analyzers and wave analyzers were employed in approximating the typical peak power distribution curve shown here. This is a composite curve of the peaks observed in many types of programming over an appreciable portion of the broadcast day in a typical FM station. A conventional limiting amplifier maintained a constant mid-range level. The very high and very low frequency peaks occurred much less frequently than the intermediate high and low frequency peaks. Yet, they were frequent enough to fully understand why stations are being cited for overmodulation. It is safe to assume that nearly every FM Station will have a peak power distribution curve that will approach or exceed that shown, unless drastic preventive steps have been instituted.

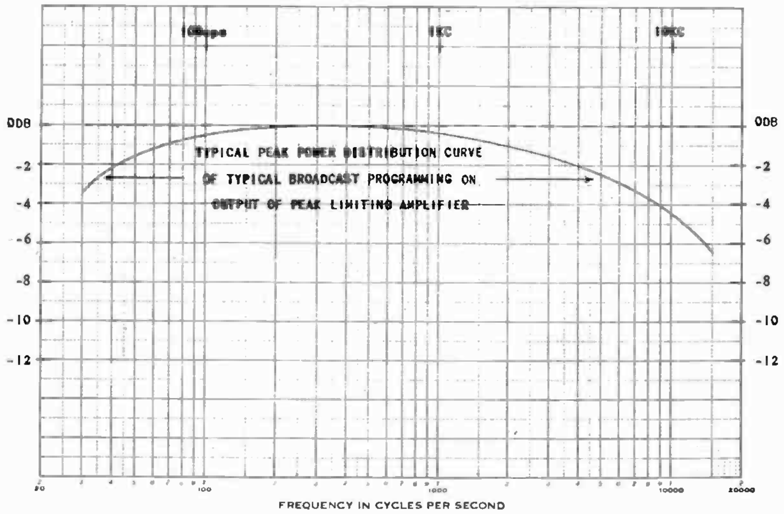

FIGURE 3

Perhaps the first step taken by many stations was to simply reduce the level of modulation to an average of 50%, effectively reducing the average program power to 1/4th the maximum allowable station power. Fig. 4 shows the result of 50% modulation of the low and mid frequencies. No overmodulation occurs below 5KC on the typical peak power distribution curve. It is possible, however, to overmodulate as much as 70% at 15KC — which constitutes an engraved invitation for a citation. The 10KC point shows up to 150% modulation under the conditions described. Obviously, an even lower level of mid-frequency modulation is necessary to prevent high frequency overmodulation. This is true, in spite of the fact that the mid-frequencies are controlled with a limiting amplifier.

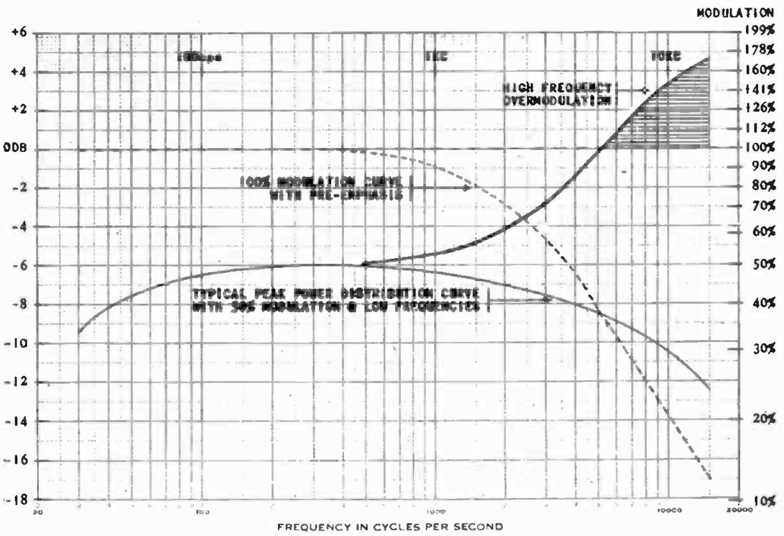

FIGURE 4

After this part of the study was completed and the levels shown in Fig. 5 were established, the manager of our engineering section responsible for FM transmitters was asked what mid-frequency modulation level was required to prevent high frequency overmodulation with average programming. His prompt reply was, " Around 30%". Fig. 5 shows that this study was in full agreement, as it resulted in a figure between 29% and 30% modulation. However, certain types of programming could still cause more than 100% modulation at high frequencies, even with 29% mid-frequency modulation. Thus, even lower levels of modulation are required to be sure that no overmodulation will occur.

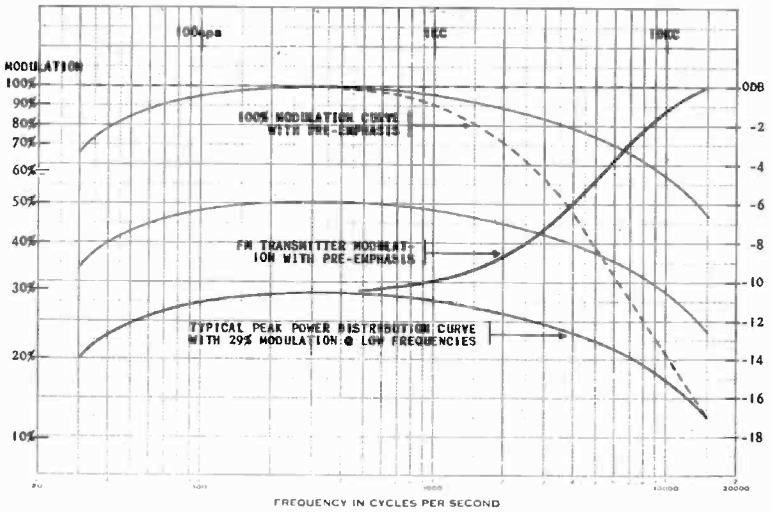

FIGURE 5

With 30% average modulation, the program power output of the station is approximately 1/10th of the maximum allowable power. Many of the program peaks that are causing the reduction in modulation are so high that some receivers will not even pass them, and some listeners are incapable of hearing them. Also, they are relatively very scarce in most programming, so the wisdom of using very low modulating levels is questionable.

PRE-EMPHASIS AHEAD OF LIMITING AMPLIFIER: The second step considered by many stations is to place the pre-emphasis before the limiting amplifier, so it can limit the high frequencies as well as the mid and low ones. If the program level is maintained carefully at a point that is generally well below the threshold of limiting, this method will produce fairly acceptable results. However, certain types of programming will still cause quite un-natural effects, as shown in Fig. 6.

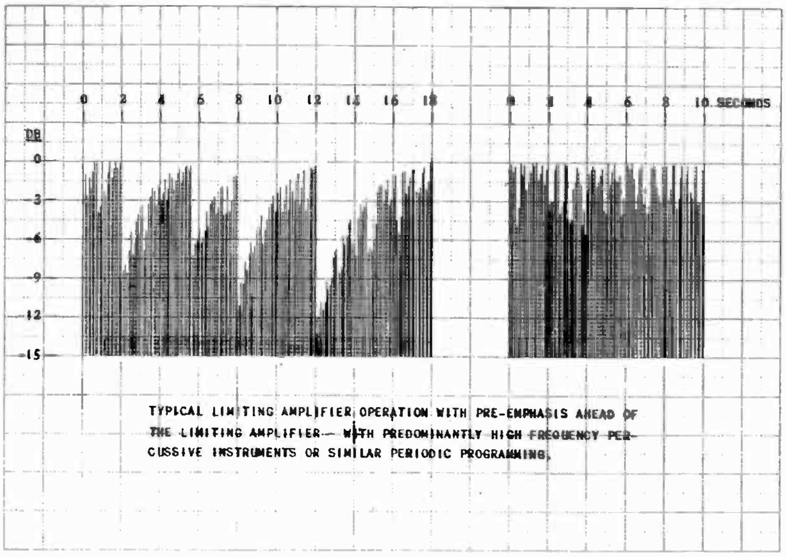

FIGURE 6

A conventional peak limiting amplifier with an attack time of approximately one millisecond and a 90% recovery time of around two seconds will have an output similar to that shown in

Fig. 6, with certain types of programming. This is a result of high pre-emphasized high-frequency peaks exceeding the threshold of limiting, causing the attendent gain reduction of mid-frequencies. When the resultant signal is de-emphasized it sounds like the limiting amplifier could be undergoing a blocking type of oscillation, where the gain suddenly drops for no audible reason, then recovers on the normal R-C slope. This is an excellent way to gain a large group of irate listeners, which will soon degenerate into a much smaller group of irate listeners.

The right hand portion of Fig. 6 shows the same type of programming without pre-emphasis ahead of the limiting amplifier. Only the upper half of the waveforms are represented in both portions, since this a sketched representation of the scope display observed under the two conditions covered.

METHODS OF CORRECTION: If the typical peak power distribution curve shown in Fig. 3 were never exceeded the problem could be eliminated by the installation of a low pass filter, such as shown in Fig. 7. A listening test of quite a few FM stations indicate that some must be using this method. Unfortunately, this performance is easily surpassed by the majority of the AM stations with modern transmitting and programming equipment.

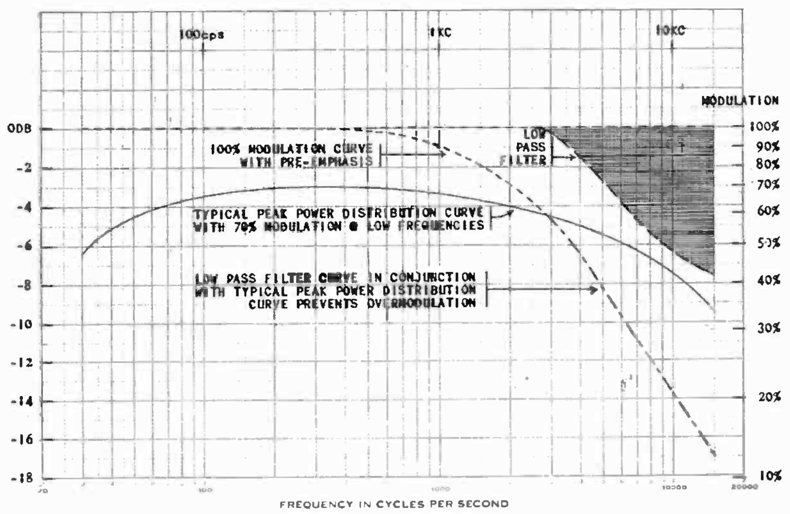

FIGURE 7

A low pass filter indiscriminately curtails all signals that fall on the filter slope — thus, degrading all programming just to protect the station from a relatively few overmodulation peaks. This "shotgun" approach cannot be considered as an effective cure for the FM overmodulation problem for many reasons.

One corrective method that does merit serious consideration is to simply repeal the decision to pre-emphasize FM signals in the transmitter. There have been many advances in the state of the art since the original decision and the original noise reduction requirement could probably be solved with modern components. With stereophonic operation becoming more prominent, with the unusually severe phase balance requirements from L+R to L–R, the injection of pre-emphasis and de-emphasis is a big handicap. It is the opinion of many in this field that a better overall system would result with the elimination of pre-emphasis.

Since so many existing receivers are involved in the proposed elimination of pre-emphasis, perhaps it would be best to consider a graduated reduction of pre-emphasis. For example, after July 1st. of this year, the pre-emphasis could be reduced from +17 db @ 15KC to +12 db @ 15KC. Nearly all of the decent existing FM systems have tone controls that could effectively compensate for the reduction of high frequency pre-emphasis.

In 1970 the 15KC peak could be reduced from +12 db to +6 db. The systems sold in the five year interim could compensate with their tone controls. Older systems (the majority of them would be more than ten years old) could have a simple and economical change in the de-emphasis circuit to make them compatible with the 6 db standard.

In 1975 the pre-emphasis could be completely eliminated. All of the FM systems sold in the preceeding five years, and all of the older systems that had been modified to the 6 db standard, could again compensate with their tone controls. Only the sets manufactured to the 12 db standard would need a simple change to make them fully compatible with the new 0 db standard. Thus, in a controlled ten year program the pre-emphasis problem can be wiped out without causing anyone a great hardship. The Broadcaster should have no real objection to buying a new pre-emphasis filter every five years. In fact, the old one could probably be modified by simply installing a factory specified shunt resistor.

ACTION WHILE AWAITING THE DOCTOR: It is somewhat doubtful that the proposal outlined above will be adopted soon enough to immediately solve the FM overmodulation problem. There surely must be a method of controlling the high frequency peaks, yet permitting decent levels of modulation with full quality. This problem is not unique in the FM broadcasting industry. Disc recorders have been faced with an almost identical problem, and a product has been marketed that certainly has the correct approach to the problem. It essentially pre-emphasizes the signal along a slope that corresponds to the problem area of the device that it eventually feeds, wipes out any peak that exceeds this slope, de-emphasizes in a complementary slope to give an overall flat response. Fig. 8 shows the advertised curves in solid lines, plotted in the same scale as all of the previous figures in this study. This graph is advertised for use with a 75 microsecond pre-emphasis curve in FM transmitters. The standard 75 microsecond pre-emphasis curve is shown in the dotted line on the graph. One of the curves falls

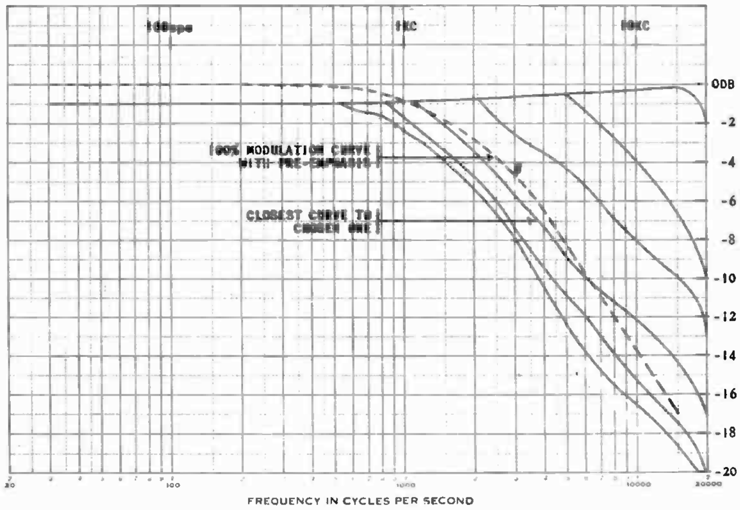

FIGURE 8

remarkably close to the standard 75 microsecond curve and would eliminate FM overmodulation with much of the standard programming. Selecting one of the two more severe curves would surely eliminate the problem. However, they would cause unnecessary reduction of all frequencies above 600 to 900 cps. with some resultant degradation of signal.

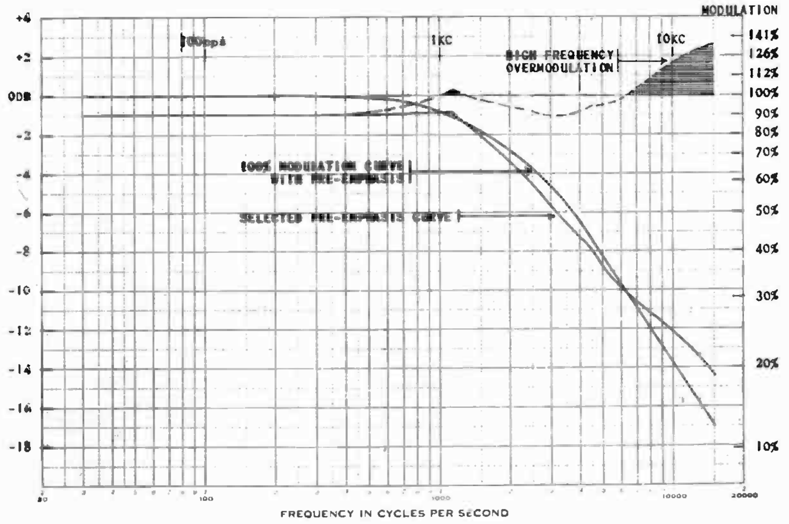

FIGURE 9

Fig. 9 shows the amount of overmodulation possible with the curve that falls closest to the 75 microsecond curve. With the low frequencies held to approximately 90% modulation by the peak limiting amplifier (which should preceed this unit for best control), it is possible to get a small amount of overmodulation in the 1100 to 1200 cps. area. Then, it is possible to get a serious amount above 6500 cps, with up to 130% @ 15KC. Another apparent deficiency occurs in the 2KC to 5KC region, where the Networks and larger stations generally install circuitry to give the system a gentle hump for " presence effect". The curves shown will give an almost opposite effect.

The system that would apparently give the least degradation of signal, yet yield full protection against FM overmodulation is shown in Fig. 10. The signal is pre-emphasized with a standard 75 microsecond curve and any random program peak that exceeds this curve is clipped off. Then, the signal is fed through a standard 75 microsecond de-emphasis curve to give an overall flat response.

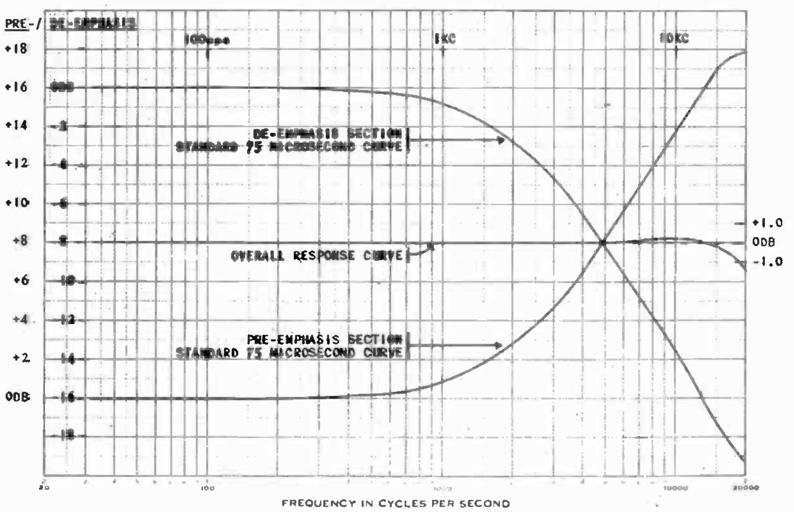

FIGURE 10

Actually, the three curves shown are carefully plotted from the test data on the new FM Top-Level Unit that was developed specifically to eliminate FM overmodulation. The pre-emphasis filter measured within 0.1 db of the standard curve. The overall response measured +0.2 db @ 10KC and –0.2 db @ 15KC, it was essentially flat below these frequencies. The M6467 FM Top-Level has two identical sections with essentially complete separation. Thus, it may be used for Left and Right stereo processing, main channel and sub channel processing, etc. It may even be used for FM in one channel and TV on the other.

The same problem that has been discussed for FM does exist on the aural portion of TV Stations. It needs the same method of correction.

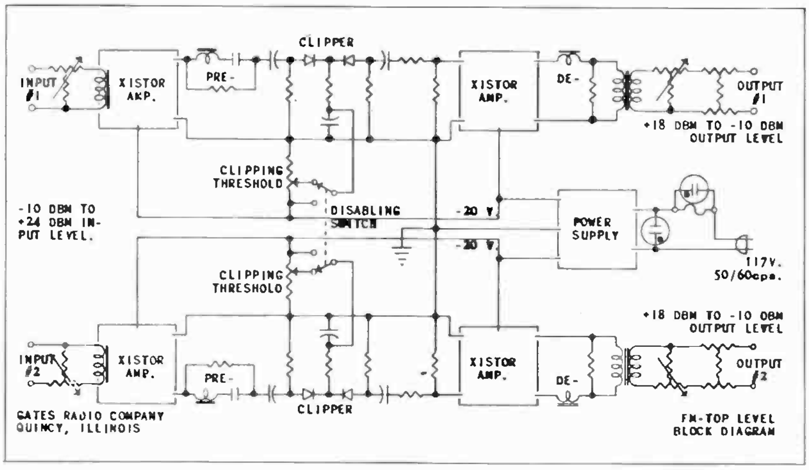

FIGURE 11

Fig. 11 shows the block diagram of the FM Top-Level. After the variable input gain control a transistor amplifier boosts the gain to the proper processing level. This is followed by a precision pre-emphasis filter, a balanced series clipper with its output matching section. This feeds into another transistor amplifier to recover the circuit losses of the preceeding components; then into a precision de-emphasis filter, isolation transformer, variable output gain control, and finally into a 6 db isolation pad.

The unit has 28 db gain, guaranteed ±1 db frequency response, 0.5% maximum distortion (below the clipping point), 75 db or better noise, instantaneous attack and release time, an input level range from –10 dbm to +24 dbm, and an output level range from +18 dbm to –10 dbm after the 6 db line isolation pad.

The unit does not cause deterioration of the programming when properly used because it does not act until the offending program peak tries to exceed 100% modulation. Then it neatly and instantaneously clips the excessive portion of the peak only, without affecting any of the associated signal. The harmonics generated by this clipping are greatly attenuated by the following de-emphasis filter so the action of the unit is extremely difficult to detect by critical listening tests.

IN SUMMARY: Pre-emphasized FM overmodulation presents a very complex problem that requires custom designed equipment to correct. With properly installed and operating corrective equipment, the FM system is actually enhanced since gross overmodulation and associated distortion are completely eliminated.

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