Amplitude Modulation—1973

Ronald Graiff
Allocations and RF Systems Engineer
American Broadcasting Company
New York, New York

Amplitude modulation is, perhaps, one of the oldest forms of information transmission in broadcasting, yet for many years, those connected with broadcasting were concerned only that the transmitter did modulate and sounded good. Concern was not placed on high peak modulation nor consistently high average-to-peak ratios. But as competition increased for radio audiences, it was realized that the higher the modulation averages, the more likely the audience was to hear the station in weak signal areas, in cars, or on transistor radios. As a result, averages and peaks of modulation went up. New equipment allowed higher modulation, but not many broadcasters were really breaking any modulation records.

Then, in late 1972, the Commission ruled that the present requirement for modulation to be limited only in the negative direction at 100 percent be amended to require that modulation in the positive direction also be limited, but to 125 percent. Now, the broadcasters had a limit. Just like a motorist on a superhighway with a posted speed limit of 70 miles per hour will tend to push that limit, whereas, if no limit were posted, he would probably drive at a comfortable speed, the broadcaster now wants to push the 125 percent positive peak limit whether he or his equipment is capable at that limit.

In the following, I will describe high peak modulation and its effects on the broadcast system, and present some of the techniques which may be employed to achieve and control higher and more consistent modulation averages. With these improved techniques, I will also describe methods of monitoring which may be employed to insure that the consistently high levels have no adverse affect on the broadcast system.

In a discussion of modulation, it might be enlightening and, perhaps, useful to begin with the derivation of amplitude modulation and its form with a periodic modulation signal. If we assume a carrier of:

$$\cos \omega_c t$$

and a modulating signal of:

$$\cos \omega_m t$$

which is a periodic signal with zero average value, and ω_m is much less than ω_c, the amplitude modulated carrier can be expressed,

$$f_c(t) = P\ (1 + m\cos \omega_m t\ ) \cos \omega_c t$$

where P is carrier amplitude and $m\text{Cos}\,\omega_m t$ is less than or equal to 1 for an undistorted signal.

By using the trigonometric sum and difference formulas, the previous expression now becomes:

$$P \cos \omega_c t + \frac{P}{2} m \cos (\omega_c + \omega_m) t + \frac{P}{2} m \cos (\omega_c - \omega_m) t$$

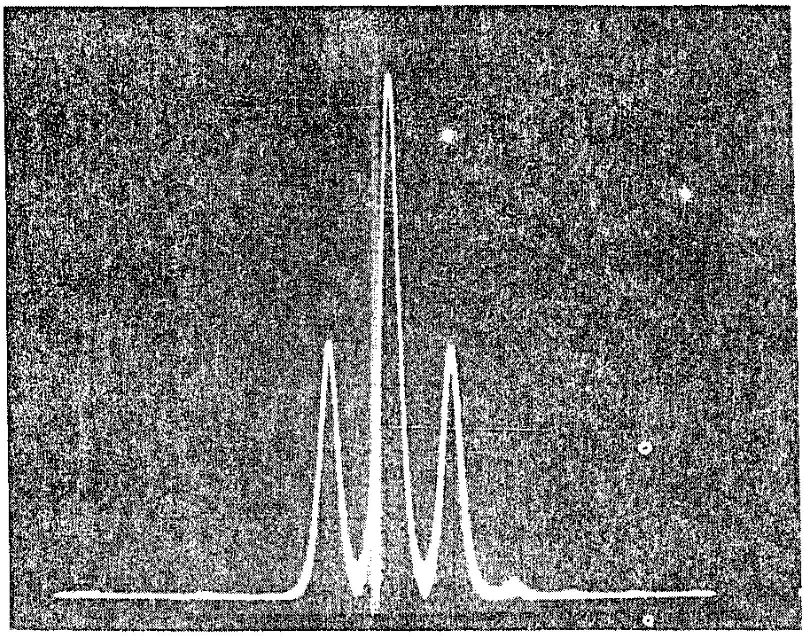


Fig. 1. Waveform showing relationship between carrier power and sideband power.

CONVENTIONAL HIGH LEVEL AM TRANSMITTER

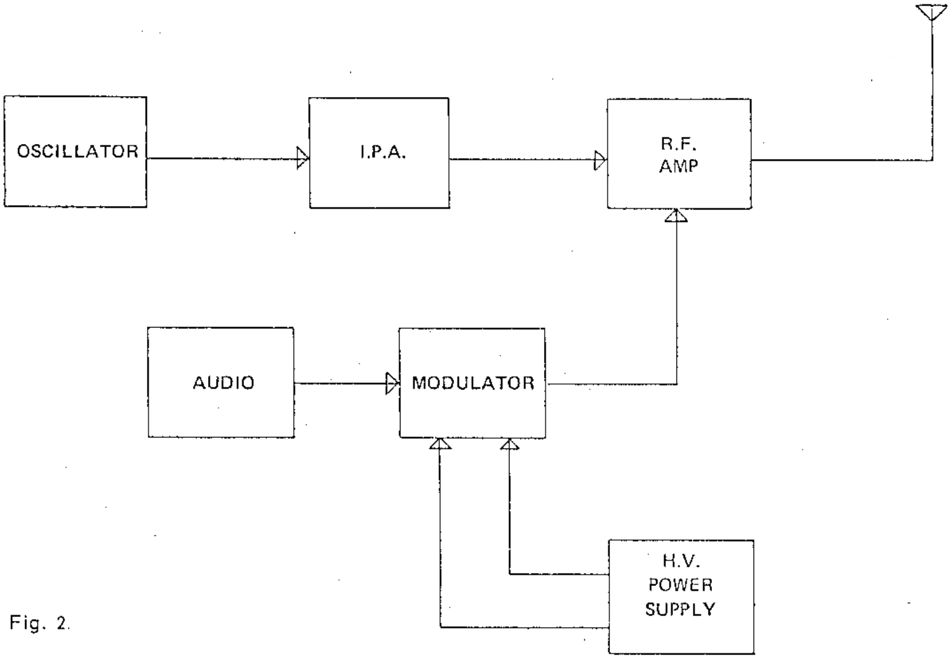


Fig. 2.

Examining the expression, it is apparent that a carrier is present at $\omega_c t$, plus side bands at $(\omega_c + \omega_m)t$ and $(\omega_c - \omega_m)t$. It is easily seen that the total average power in the sidebands is one-half that of the total carrier power at 100 percent modulation, as can be seen in Fig. 1.

The derivation shown above is for some type of periodic symmetric modulation, in this case a cosine function. The derivation works well, and many have approached modulation analysis from this point of view. In broadcasting, though, sine waves are not considered normal program (although, in some cases, it might help the ratings). The complex waveforms that are a part of the music and speech are asymmetrical and the transmission systems should be designed to handle this program, and processing equipment adjusted to provide the highest average-to-peak ratio while maintaining peak excursions at legal limits.

The transmitter is the method of delivering the audio from studio to the radio at home. As it is a method or a medium, the transmitter should have no affect on the signals put in to it, or, in other words, it should be transparent. No method of amplitude modulation, whether it be high-level, class B linear-amplifier, screen, class D, cathanode, phase-to-amplitude, or any other method in practice now, is totally transparent. If audio peaks go beyond the normal excursion, will the transmitter pass it? That is a question with which we must concern ourselves with on a discussion of high positive-peak modulation.

The majority of transmitters in use today employ a high-powered audio amplifier to modulate a class C rf amplifier. In most of these transmitters, a single high-voltage power supply is employed to power both the audio modulator and the rf amplifier. Figure 2 is a simplified block diagram of this type of transmitter. It is in this single high-voltage power supply that the peak modulation problems of the transmitter develop. For as the modulator is drawing increased current to follow the excursion of the peak, the rf amplifier is also demanding more current to supply the increased rf demand. In this type of conventional transmitter under 125 percent positive peak modulation, the instantaneous plate voltage can vary as much as 20 percent. As the voltage drops, so does the rf level and the modulated B+ from the modulator itself. What happens, then, is a rounding off of the peak excursion and carrier shift.

Now that I have mentioned it, and before proceeding, let us make certain we understand carrier shift. Carrier shift can be defined as a change in the average value of current produced by the carrier, whether modulated or not. This change can be measured by rectifying the carrier and measuring the average current (thanks to a meter movement) in a load, as can be noted in Fig. 3. Under symmetrical, ideal modulation, the value of the carrier decreases at the trough of modulation as much as it increases at the peak of modulation; therefore, there is no change in the average value of carrier.

Consider now a transmitter that is not capable of symmetrical modulation below 100 percent; that is, a transmitter that does not have sufficient rf to make the crest of modulation or one that does not have enough modulator power to close the carrier. In the first case, as the modulator calls for rf to supply the additional energy for the production of the crest, the rf runs out and the crest is rounded or flattened, as in Fig. 4. Assuming sufficient modulator power to close the carrier, the average value of carrier has decreased due to the fact that peak power was not attained. The result: negative carrier shift.

The second case is exactly opposite to the previous one. As there is sufficient rf to make the peak, but not enough modulator power to close the carrier, the average value of carrier has increased. The result: positive carrier shift, as can be noted in Fig. 5.

Now, passing either of these two signals through a low-pass filter, as in Fig. 6, we detect audio, but this audio is distorted because it is not identical to the modulating wave. Something has happened in the process of modulation that has affected the waveform; notice I said modulation and not carrier.

Perhaps carrier instability or shift is a misnomer. Assume a carrier in Fig. 7 and a modulator capable of modulating that carrier as much as desired. As modulation is increased, what happens to the carrier? Nothing. The carrier power is not unstable, nor does it shift, as is indicated in Fig. 8. Its only function in life is to move the audio spectra up to some frequency.

The origin of the specification for carrier shift is uncertain. Perhaps 35 years ago, when linear amplifiers were extensively used for broadcast transmitters, variations in the average power of the carrier indicated improper tuning of the linear amplifier, i.e., distorted modulation.

SIMPLIFIED CARRIER SHIFT DETECTOR

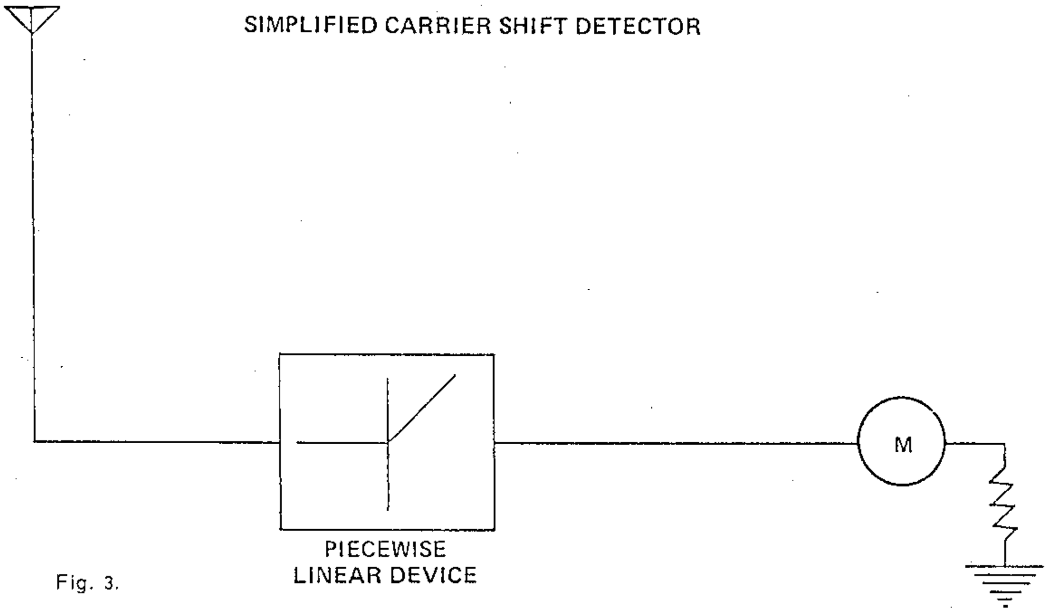
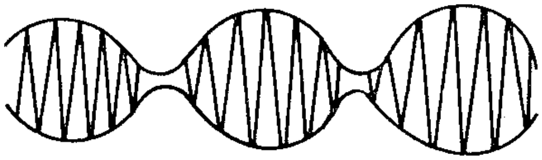


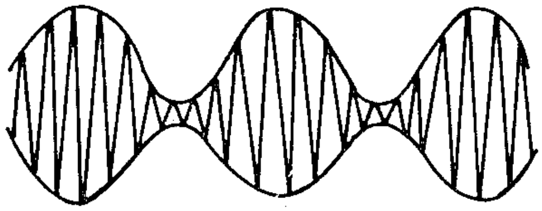
Fig. 3.

ASYMMETRICAL MODULATION LESS THAN 100%



NEGATIVE CARRIER SHIFT Fig. 4.

ASYMMETRICAL MODULATION LESS THAN 100%



POSITIVE CARRIER SHIFT Fig. 5.

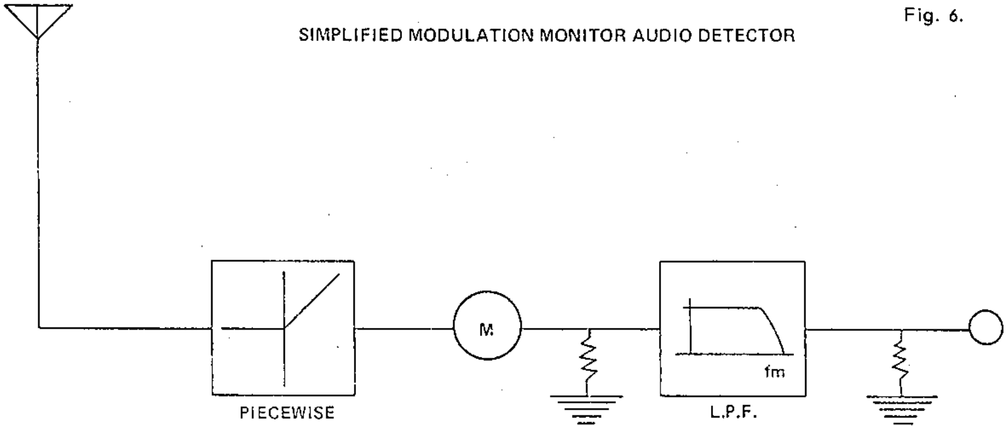
Even in our method for detecting carrier instability there are problems. The time constant of the piecewise linear detector, resistor load, and capacitor are not defined. The longer the time constant, the less sensitive to changes is the meter in measuring the average current produced by the carrier.

Another point that might be worth mentioning: What affect does this carrier instability or shift as defined have on the AM receiver? The process of detection strips away the carrier and throws it away. If an audio peak causes the transmitter to be severely modulated in the positive direction, and the carrier is caused to shift, by our definition, what happens? The receiver reproduces that audio peak in the manner that it left the studio. The average value of carrier current has no affect on the process of demodulation. Examining carrier instability from this point of view suggests that a specification on it limits the transparency of the broadcast system.

By our definition of carrier shift, that is, "a change in the average level of the modulated carrier as received," we must also state the modulating waveform is symmetric. At values less than 100 percent positive and negative modulation, an asymmetric waveform will, by not having a zero average value, produce carrier shift. If a symmetric waveform is applied to the transmitter, and the modulation process is linear up to 100 percent modulation, there is no carrier shift, as in Fig. 9.

Fig. 6.

SIMPLIFIED MODULATION MONITOR AUDIO DETECTOR



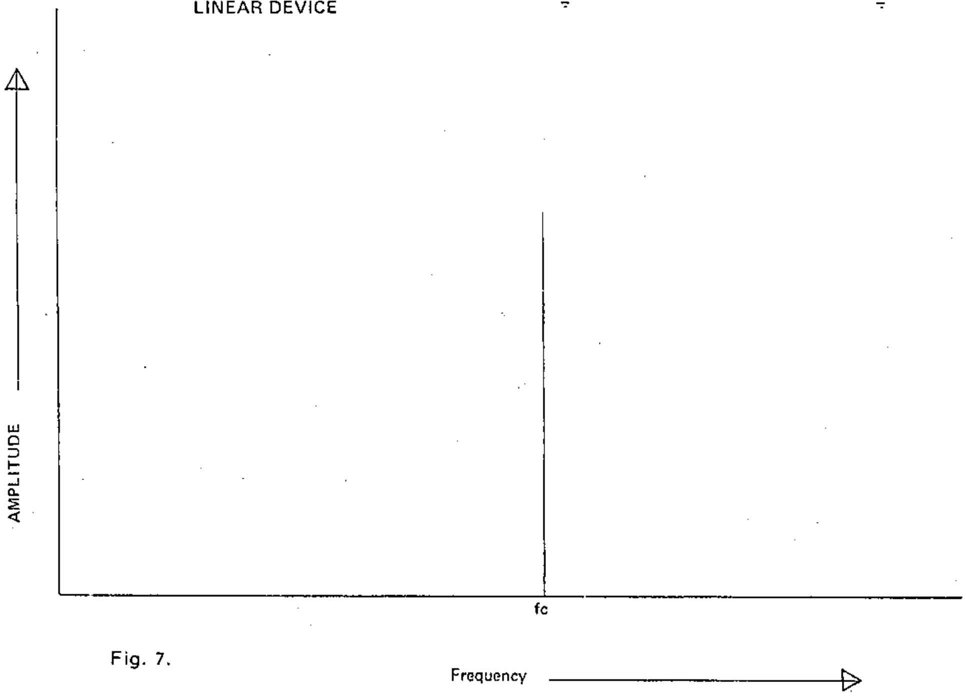


Fig. 7.

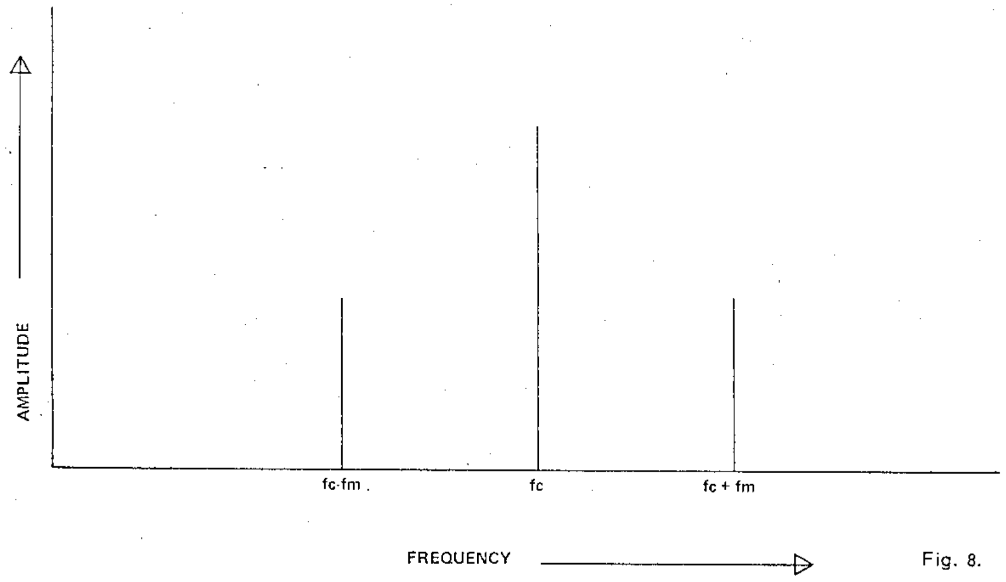
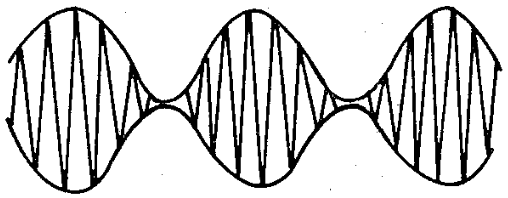


Fig. 8.

SYMMETRICAL MODULATION 100%



NO CARRIER SHIFT

Fig. 9.

IMPROVED HIGH LEVEL AM TRANSMITTER

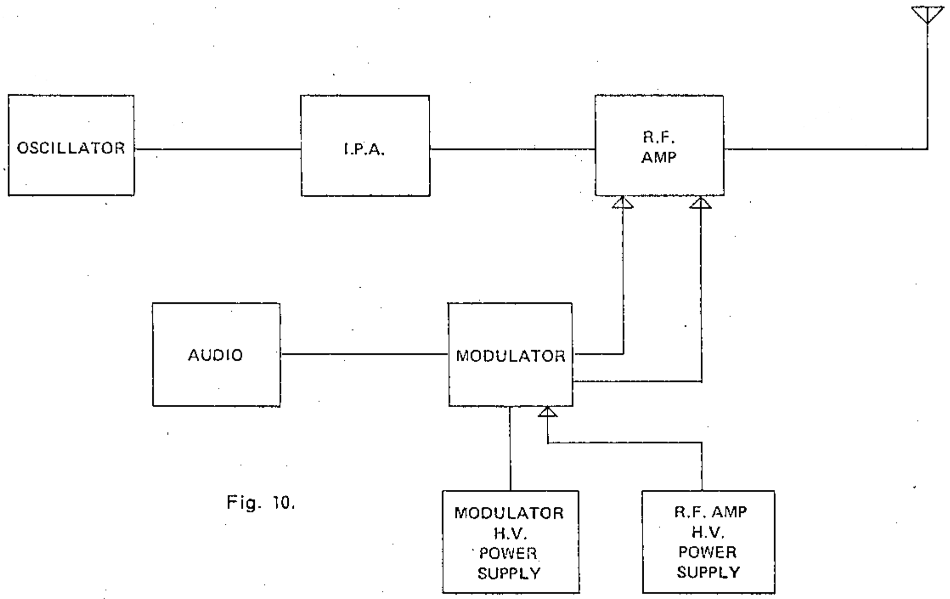


Fig. 10.

Assume a waveform that produces 125 percent positive peak and 100 percent negative peak modulation. Can this waveform be symmetric? I don't believe so. So now, how can we apply a limitation of carrier shift that is intended to be used with symmetric modulation?

What is needed is a test signal and a method of measuring the peak positive modulating capability of a transmitter. Hopefully, this measurement method could take over at 100 percent modulation, where sinusoidal distortion and carrier shift leave off. At ABC, we are working on such a signal and a measurement technique.

Figure 10 is a simplified block diagram of an improved high-level AM transmitter similar to one that ABC has in operation. Note that in this transmitter, the rf amplifier and the modulator are powered by separate power supplies. This allows both stages to act independently and not be tied to a common supply.

This approach to transmitters allows the previously used model of a carrier and modulated sidebands existing as a function of level and frequency of the modulating waveform. The only relationship existing between the carrier and the modulating frequency is the frequency translation from baseband.

In order to see how two different transmitters responded to high positive-peak modulation, a spectrum analyzer was utilized to look at a spectrum of both. Only one transmitter was capable of modulating in excess of 100 percent; the other transmitter had difficulty at the 100 percent level.

Complex audio in the form of top 40 music was applied to the transmitters with and without asymmetrical limiting. In order to make more consistent measurements, the audio was derived from a 10-second continuous loop. Measurements were endeavored to be taken at the exact portion of the program from which all the measurements were taken in an attempt to insure identical spectral content. The transmitters were applied to a dummy load, with identical characteristics as the main antenna.

Figure 11 is a spectrum of transmitter 1; that is, the transmitter not able to modulate highly, with no processing, but overmodulated to produce some peak information. The faint light line in the center of the photo is the center frequency reference as produced by the spectrum analyzer. Carrier amplitude is referenced to the top of the photo and was maintained at this point for all the photographs.

Note that the sidebands do not appear coherent. This is correct, as it requires the analyzer a finite amount of time to sweep the frequency range selected. This isn't a problem, however, as the sets of sidebands produced are identical; thus, we need concern ourselves only with one set. The lower sideband in this photo at one point has an amplitude of approximately 72 percent of that of the carrier, which corresponds to a peak of modulation of approximately 144 percent. In order to obtain the above peak

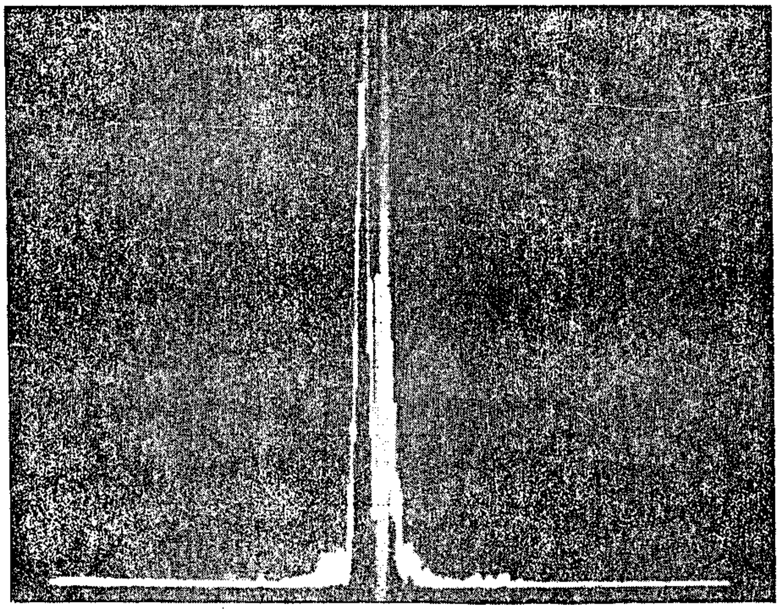


Fig. 11. Spectrum of transmitter 1.

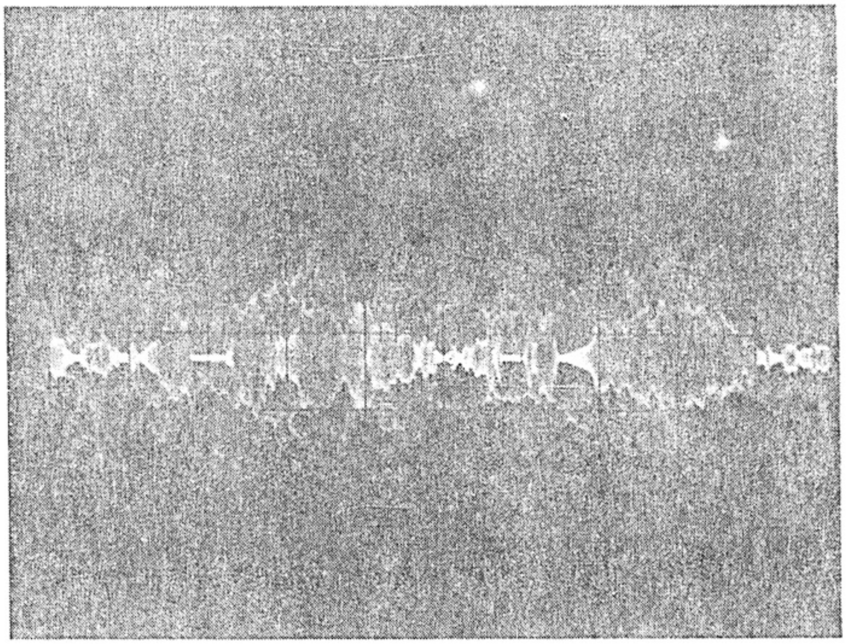


Fig. 12. Display showing severe overmodulation.

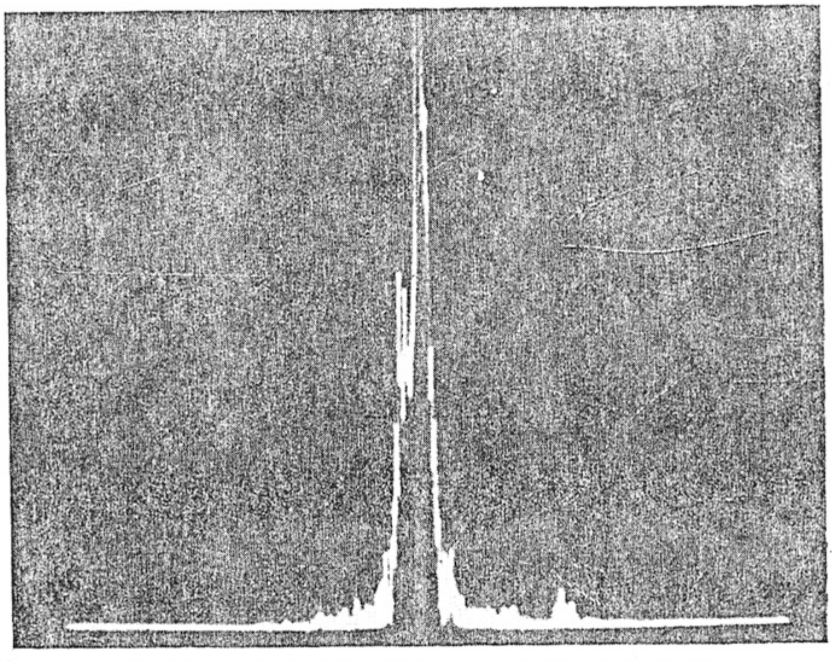


Fig. 13. Number 1 transmitter, asymmetrically processed.

percentage of modulation, the transmitter was severely overmodulated, as one can see in Fig. 12, which is an envelope or time-domain presentation of the modulated carrier. This photograph was triggered with the spectral display in Fig. 11. Notice the severe negative overmodulation; and, although it is not apparent from this photograph, the rounding and even flat-topping of the peaks of modulation, while this was happening, the modulation monitor, while indicating many negative peaks, was indicating high positive peaks. Were these peaks really there? Undoubtedly not, as the monitor was probably measuring the fundamentals and all other products of the complex waves.

Figure 13 is the display when the number 1 transmitter was asymmetrically processed. Notice the upper sideband, with a peak of approximately 70 percent of carrier. In this instance, however, severe negative modulation was not noticed, as the asymmetrical limiting tended to do its job.

Figure 14 is a spectrum of transmitter number 2 (the one that handles high positive-peak modulation) modulated by the same complex audio as was used in the preceding tests. Note in this photograph that the upper sideband has a peak of approximately 95 percent of carrier which corresponds to 195 percent positive peak modulation. No asymmetrical processing was used, and greater than 100 percent negative overmodulation was indicated by the modulation monitor at the time-domain display. I will say, however, that the carrier shift was horrendous; but, as I pointed out before, it is irrelevant. Whatever that assymetric peak of complex audio was, the transmitter passed it.

Figure 15 is the same transmitter as before, but this time asymmetrical limiting was employed. Note again the peak of about 95 percent carrier in the upper sideband. The spectrum also appears to be full and higher than in other photographs. I wish I could say that was true of asymmetrical processing. The full spectrum is undoubtedly due to the modulating signal at the instant the photograph was taken. The conditions of this photograph produced no negative overmodulation.

I believe the preceding photographs tend to show that the positive-peak-handling capability of a transmitter is important with complex waveforms. The transmitter becomes a transparent medium. Does this high-peak capability make one sound louder on the radio? Not really. As the speaker in the radio responds mostly to average level, it is the average level of all audio that will make one transmitter louder than another. Consequently, high average-to-peak levels must be maintained by some type of audio processing.

We at ABC employ two devices to process audio to the transmitter—an average-level-controlling device or AGC, and a limiting device or limiter. I don't propose to make statements about the setup of audio processing devices, as I imagine everyone has a different idea on what to do. I would like to, however, explain some ideas which we use when adjusting our processing equipment.

The AGC has one purpose in the chain and that is to improve the average level of program material. Basically, we use the AGC in a medium fast portion of attack and release times, on the order of tens of milliseconds for attack and hundreds of milliseconds for release. In this manner, we hope to have the gain of the amplifier change almost at an audio rate so that the program tends to become leveled in an average range of 7 dB. The AGC, however, won't catch the peaks of program or level changes that are beyond its dynamic range, so the limiter comes into play.

The limiter is of classic design, which up to a predetermined value, is basically a linear amplifier. After that point, however, any increase in input produces little or no increase in the output. The limiters we employ use a fast attack time on the order of microseconds and release times in the range of milliseconds. This combination of time constants allows the limiter to quickly do its work and then get out.

Another important feature of the limiter is its ability to see a highly negative asymmetric peak and flip it over. As I imagine you are all aware, the male voice has a content which is highly rich in negative peak information. Under these instances with normal processing, the male voice would be more likely to overmodulate the transmitter in the negative direction, which is limited to 100 percent, and not in the positive direction.

With conventional limiters, this audio would cause them to limit at 100 percent negative; and, since the amplitude of the negative is greater than the positive, the transmitter would not be fully modulated in the positive direction. By employing this flip-type of limiter, the high-amplitude negative peaks are inverted so that they go positive, and with the high positive-peak capability of the transmitter, the average value of the audio transmitted is increased.

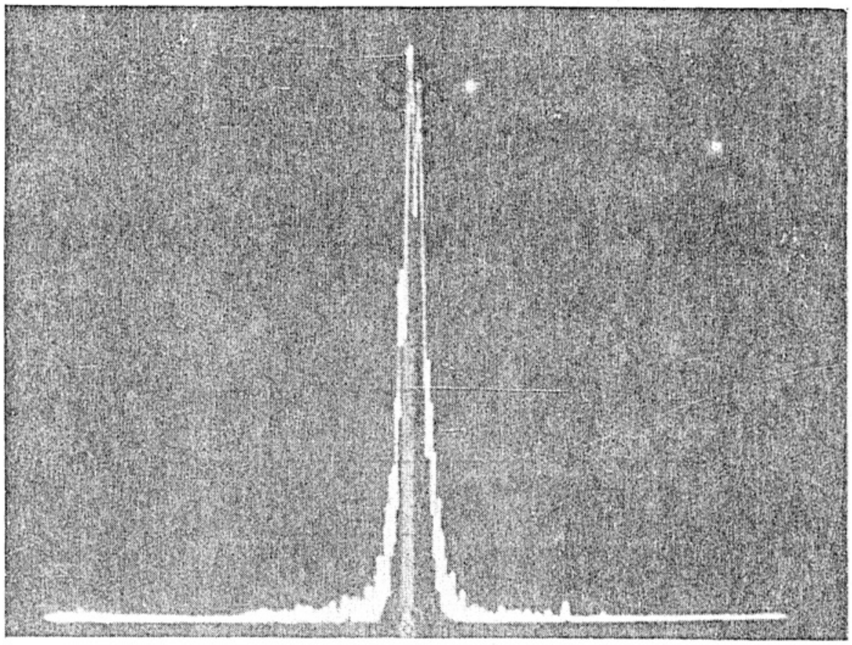


Fig. 14. Number 2 transmitter modulated by same complex wave.

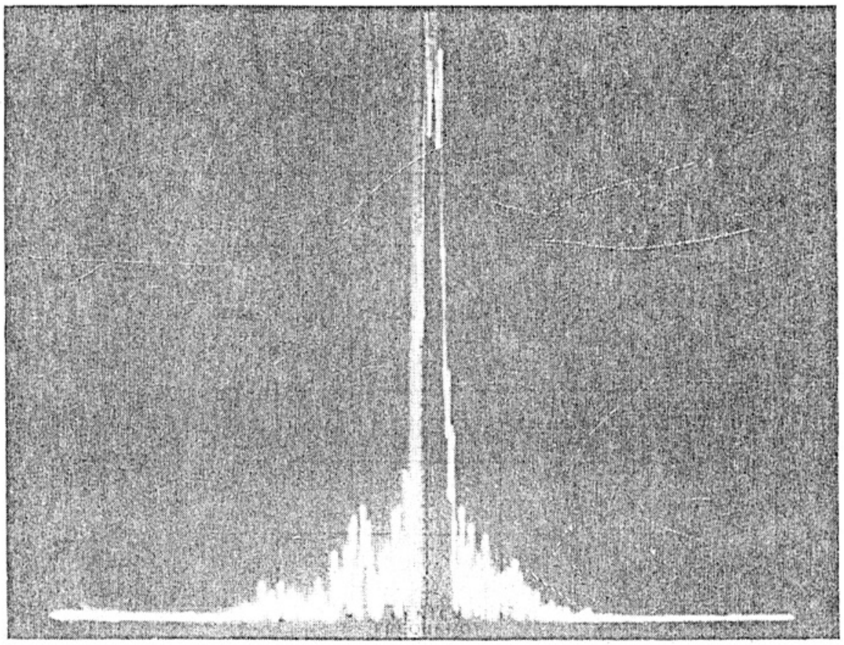


Fig. 15. Display showing effect of limiting.

As I mentioned before, the processing of audio is a personal approach in which one has to tune for the sound that he wants. It is this processing that will determine the amplitude modulation characteristics of the transmitter. But with some of the basics discussed here, and an awareness of what happens during that modulation process, perhaps your task of attaining that sound will be made more logical, and 1973 will be a very good year for AM.

The author wishes to extend his deepest appreciation to Fred Zellner and John Toth of the American Broadcasting Company's Engineering Department for the many hours of consultation they provided and without whose assistance this paper would not have been possible.