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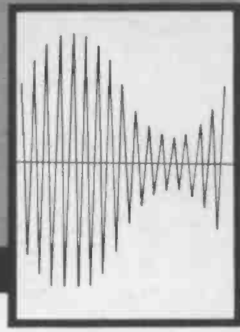

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WHICH IS WHAT?

A Review of Some Modern Amplitude-Modulation Systems

by Kenneth W. Uhler*

Single sideband, synchronous detection, compatible single sideband! These and many other similar phrases appear in many of today's publications. But too often the advantages claimed for one of these systems in the article you are currently reading conflict with the claims made for another system featured in the article you read last week. This seeming confusion leaves the reader with the question: "Which is what?" Hence, this article — intended as a review of the basic systems in the hope that it will lead to a better understanding of the published material.

Before a comparison of amplitude-modulation systems is made, however, some of the terms used in this article should be defined. The symbols are derived from the terms used and refer to frequencies, not magnitudes.

The radio frequency to be modulated is referred to as the carrier and the symbol is f_c. Similarly, this article is concerned with radiotelephony, where the modulating signal is the voice, and the symbol used is f_v.

Amplitude modulation can be defined as the process of varying the amplitude of a carrier at an audio rate. The result is that two new frequencies, (f_c+f_v) and (f_c-f_v), are produced.

For example, if the carrier frequency is 14 Mc, and it is modulated by an audio frequency of 1000 cycles:

14,000,000 modulated with 1000 will give:
(f_c) (f_v)

14,001,000 and 14,000,000 and 13,999,000
(f_c+f_v) (f_c) (f_c-f_v)

The sum of the two frequencies (f_c+f_v) is referred to as the upper sideband and the difference between the two frequencies (f_c-f_v) is referred to as the lower sideband.

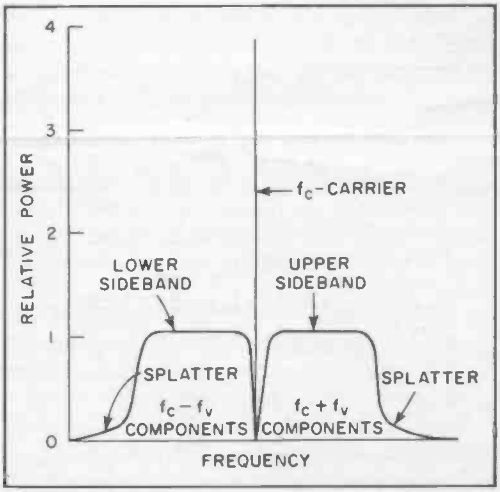

Figure 1: amplitude modulation.

AM (Both Sidebands and Carrier)

In the example of amplitude modulation given above, the modulated signal consists of

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three frequencies: the lower sideband (f_c—f_v), the carrier (f_c), and the upper sideband (f_c+f_v). Figure 1 illustrates a frequency versus power curve for AM. The width of the sideband is dependent on the highest audio frequency used to modulate the carrier.

One of the common methods of obtaining amplitude modulation utilizes the fact that a power tube when operated Class C has a generally linear output for wide variations in plate voltage. Modulation is accomplished by inserting the audio signal in series with the plate of the tube.

No practical modulating system is without some non-linearity, and non-linearity, however small, leads to the generation of some unwanted frequencies. Because the plate tank has a relatively low Q when loaded and, therefore, relatively poor selectivity, all the unwanted frequencies generated are not filtered out. When these unwanted signals appear outside of the desired band, they can create very undesirable interference.

The AM system is not complete until we consider how the modulated wave can be translated back into intelligence at the receiver. The process by which the audio is recovered from the radiated wave is known as demodulation or detection. In the process of modulation, the audio frequencies produce sidebands which are centered about the carrier frequency. In demodulation, the carrier frequency is mixed or intermodulated with the sidebands to produce an audio frequency signal. Most receivers employ a local oscillator to heterodyne with the incoming rf and produce an intermediate frequency (if). The fixed-tuned if stages provide easier control of both bandwidth and gain.

One of the most common methods of demodulation utilizes the unidirectional characteristics of a diode which provide the non-linearity needed to intermodulate the carrier with the sidebands. One product of the intermodulation is the audio frequency. The unwanted sideband, carrier, and higher-frequency products are filtered out in simple RC circuits.

The diode demodulator has two distinct disadvantages. First, it has no gain, and the desired signal is usually attenuated 10% to 20% because rf filtering is required. Second, the desired modulation component becomes distorted at low signal levels and high percentages of modulation.

The complete AM system is subject to another commonly experienced phenomenon known as selective fading. Briefly, selective fading is a reduction in signal strength of a part of the band of frequencies transmitted. It can affect the amplitude and/or phase relationship between the carrier and either or both of the sidebands. This distortion in ordinary receivers often results in a significant loss of intelligibility.

The primary advantages of AM systems, as described, lie in their simplicity and low cost. Moreover, many practical techniques have been developed which greatly enhance the usefulness of AM. Improved bandwidth control and oscillator stability, better noise limiting and blanking circuits, and heterodyne detectors are all widely used in new receiver designs. The heterodyne detector, for example, produces much lower-order distortion for small-signal inputs than any of the simpler diode circuits, and can handle high percentages of modulation. This detector mixes a local oscillator signal with the radio frequency or intermediate frequency to produce an amplified audio signal.

Speech clipper and modulator design in the transmitter also can be greatly improved, and at only small additional cost and complexity. In comparing "new" systems to "ordinary" AM, one should be careful to determine how much of the advantage offered by the system comes from improvements that could be added to any system.

DSB (Both Sidebands, No Carrier)

"Double sideband" is also referred to as synchronous AM. The term "synchronous AM" comes from a method used to detect amplitude modulation. Basically, this method uses a heterodyne detector which demodulates directly to audio by mixing the modulated rf with a local oscillator signal. The local oscillator signal must be synchronized (in phase) with the original carrier to prevent unwanted phase distortion.

One such proposed system demodulates in two simultaneous heterodyne detectors. The local oscillator signal fed to one of them is phase shifted 90 degrees, so that the audio-output signal from this detector is zero.

When the local oscillator is phase locked (exactly in phase) to the original carrier frequency, the phase-shifted heterodyne output will remain zero. If the local oscillator is not in exact phase with the original carrier, the shifted detector will have an audio output proportional to the phase difference. This signal is used to provide a correction voltage for an automatic-frequency-control circuit. The frequency of the local oscillator is con-

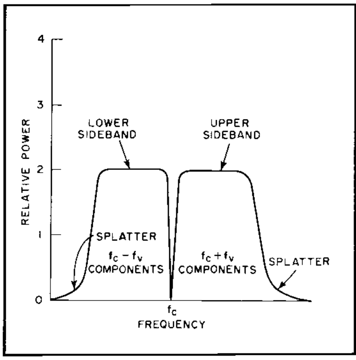

Figure 2: double sideband.

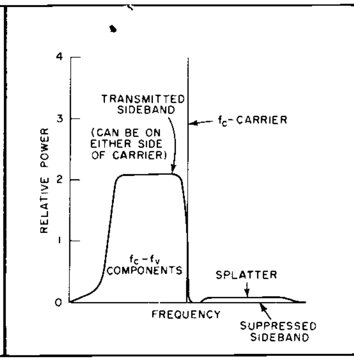

Figure 3: compatible SSB.

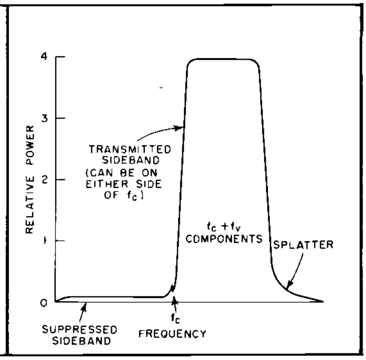

Figure 4: single sideband.

trolled at the apparent carrier frequency, reducing the effect of any selective fading present.

The principal advantages of this system come from the fact that no carrier is needed and the single receiver oscillator is frequency controlled. Of all the systems, synchronous AM is the least affected by selective fading.

Figure 2, drawn to the same scale as the AM diagram in Figure 1, points out the increased sideband power available for DSB operation without taking into account possible transmitter redesign. Balanced modulation in the transmitter will reduce the carrier level at least 30 db without special circuits of any kind. Balanced modulation is usually accomplished by using a push-pull final, which retains one of the advantages of AM in that it allows plate modulation of the final.

Two distinct advantages are inherent in the double-sideband system: 1) Reduction of the carrier eliminates the most annoying source of a continuous beat-frequency whistle interference produced by a co-channel station which reduces signal intelligibility and produces operator fatigue to a far greater degree than the "monkey chatter" of sideband cross-modulation products. 2) The final power amplifier is generally operated Class C in a balanced circuit so that rf power is produced only when modulation is present.

Compatible SSB (Single Sideband With Carrier)

The compatible single sideband system—currently being used by the "Voice of America" and WMGM—can be received on the present ordinary diode detector receivers. Balanced modulation is used to suppress the carrier, as in synchronous AM. One sideband is then filtered out and a controlled amount of carrier reinserted.

Compatible SSB can be represented as shown in Figure 3. Either sideband can be used. This system is subject to selective fading much in the same manner as conventional amplitude modulation, and is somewhat more susceptible to fading than AM and synchronous AM because the single sideband does not afford the redundancy of the double sideband. The advantages of this system are very important in applications like the "Voice of America" and other ground-to-fixed-station systems because of the following characteristics:

(1) Half the normal AM bandwidth.

(2) Compatible with existing receiving equipment.

(3) Allows increased efficiency in high-power transmitter design.

SSB (Single Sideband, No Carrier)

SSB goes all the way and transmits only one sideband, as shown in Figure 4. The lack of a carrier eliminates the whistle type of co-channel interference.

The bandwidth is the same as the bandwidth of the modulating frequency. The signals handled in the transmitter final are entirely modulation components. RMS power ratings become somewhat meaningless because voice modulation has such a complex waveform. For this reason, SSB finals are usually rated in terms of peak power capability. Balanced modulators are used to reduce the carrier at least 30 db. Phase networks, or filters, can be used to remove the unwanted sideband and further reduce the carrier.

Somewhat more complexity results from the low frequency used. Heterodyne circuits must be used to bring the signal frequency up to the rf region. Non-linear frequency multipliers, such as harmonic generator and doublers, are not suitable because they would produce a high percentage of unwanted signals and distortion. Such circuits would also multiply the voice frequencies. This result would require complex frequency-divider circuits in the receiver.

The driver stages and final amplifier must be linear for the same reason. Efficiency of the final amplifier is considerably higher due to the fact that no carrier power is involved and the final can be designed to handle much greater peak power without exceeding the dissipation ratings. Because the zero signal condition exists until modulation is present, two-way single-channel communications are simplified (simplex operation).

The main disadvantages of the SSB system stem from the fact that demodulation must be accomplished by the addition of a demodulating signal at the receiver (often referred to as reinserting the carrier). Variations in the frequency of this injected signal will cause distortion of the voice frequencies that sound like a variable-speed phonograph. It is my personal opinion—through listening—that although this distortion is objectionable from a theoretical standpoint, it actually results in very little loss in intelligibility over a ±150 cycle range. Critical applications are usually governed by a ±50 cps maximum. The interference from an adjacent channel results in variable-pitch "monkey chatter" which can be tolerated even at quite high levels.

Selective fading becomes just plain fading in the case of only one sideband. The ability to select sidebands could provide the necessary redundancy to overcome this effect, but it would double the bandwidth.

The disadvantages of SSB are: (1) increased complexity, (2) tight frequency-drift specifications, (3) non-compatibility with existing equipment, and (4) both the transmitter and the receiver have tight linearity requirements. Cost is not always a factor. For equipments designed to produce the same degree of intelligibility between any two points, savings in power supply and tube cost make it entirely possible to build SSB equipment in the same price range as the comparable AM equipment.

The advantages of SSB, other than those associated with the improved circuitry, are: (1) narrow bandwidth and (2) improved co-channel and adjacent channel operation (elimination of carrier whistle). Although these advantages are small in number, they are large in their importance to commercial and military communications.

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Harvey Slovik Editor

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