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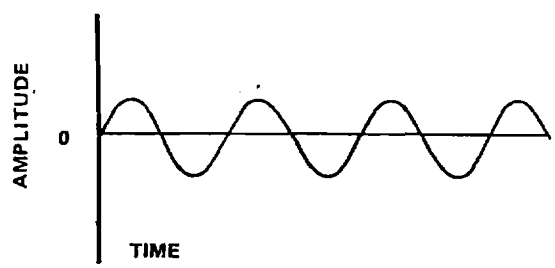
Sigint Technical Primer—II Modulation

The radio signal analyzed

It is certainly possible to get through life without knowing that AM and FM stand for amplitude modulation and frequency modulation. One may even know these terms, not be able to explain the difference between them, and still enjoy listening to the radio and watching some of the better TV programs. Here at the Agency it is possible to survive quite nicely, thank you, without understanding the terms *modulation* and its opposite, *demodulation*, even though they occur very often, both in their spoken and written forms, in the conduct of our business. But if modulation is such a basic concept in radio communications, perhaps it would be useful to improve one's grip on its meaning.

For a simple, if slightly ridiculous, explanation of modulation, one could imagine a drummer in a village in the jungle being briefed on the technique of communicating a message by tomtom. He is told to keep a steady, unaccented rhythm on the drum until a sign is given by the chief, and then to accent every other beat, a signal to the next village that something big is about to happen. Until he puts the accents in his drumming, he is conveying no information, but then he *modulates* his beat. Obviously he could send a number of messages this way by varying the pattern of his drumming. He could modulate the rhythm by striking three beats and skipping the fourth, and this pattern could by pre-arrangement mean "We need help (rest)! We need help (rest)! We need help (rest)!" By modulating the basic rhythm, which by itself carries no information, he can send quite a range of messages.

In radio communications, the *carrier wave* takes the place of the steady, unaccented rhythm of the tomtom. The carrier wave just hums along without saying anything other than that it is there. It is the carrier wave which must be altered in some way (modulated) in order to get a message across. Usually the carrier wave is a *sine wave*, whose familiar form is pictured below, although another increasingly useful form is the *pulse*. The sine wave is recognizable by the regularity of its appearance. Note the consistency in both amplitude and frequency.



SINE WAVE

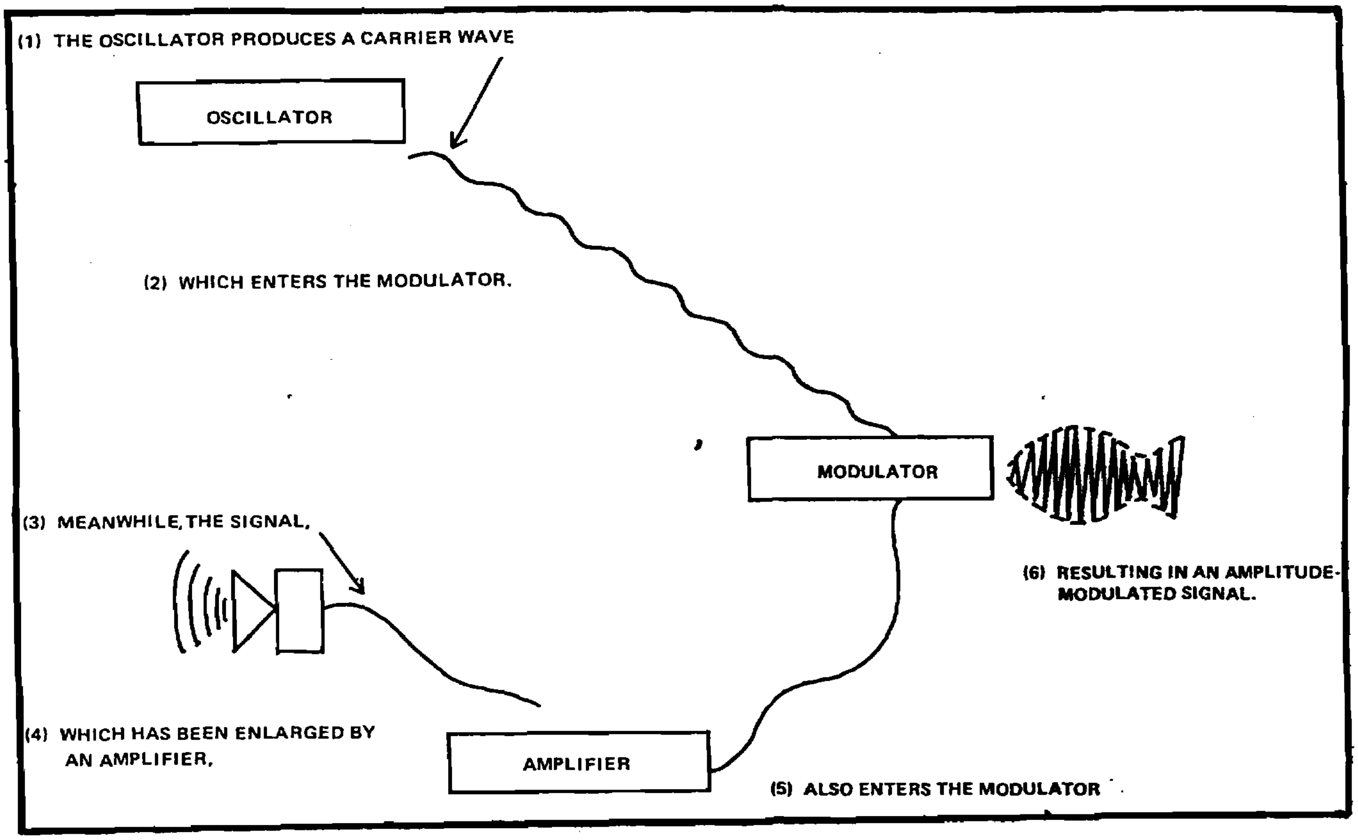
Note: Since we are dealing here with alternating current, the amplitude (or voltage) goes back and forth across the zero lines, representing the changes in direction of the current.

It is the carrier wave, then, which is going to be modulated so that it does more than just hum along without any useful purpose.

Amplitude Modulation

This is the oldest form of modulation and the one most easily produced. Amplitude is simply a name for the strength of a current at any time, and up to now our carrier has had a regular peaking of amplitude, as has been illustrated. Now this amplitude is going to be varied in accordance with the voltages of the signal it is to carry. It is as though our jungle drummer were to modulate his pattern, without changing the tempo, by accenting some beats and not others, and accenting some more strongly than others.

Perhaps the best way to illustrate amplitude modulation is by portraying the functioning of a simple AM transmitter system.



AM Transmitter System

Amplitude Modulation and Noise

AM is relatively simple and cheap. But it is troubled by noise, which, like the signal, is primarily an amplitude effect and therefore interferes with the communication process. (Was that a signal or a burst of static?)

Sideband Operation

While we speak of an AM signal as operating at a certain frequency, this is not really so. As a result of the modulation process, two additional bands of frequency, called sidebands, are generated, one above the assigned carrier frequency and one below.

Upper sideband	{ 1005 kHz 1000.1 kHz
Carrier frequency	1000 kHz
Lower sideband	{ 999.9 kHz 995 kHz

Sideband Formation

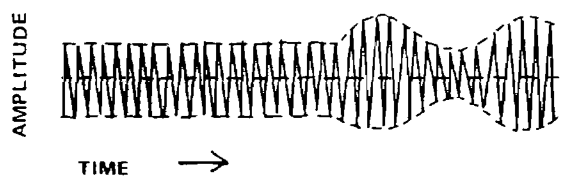
In the above example, the carrier, at 1000 kHz is modulated by a wave with the range of .1 to 5 kHz. This phenomenon is used to good advantage in single sideband operation (SSB). After the modulation process, the carrier (old faithful tomtom) and one of the two sidebands are suppressed, and only one sideband is actually transmitted. This sideband carries the signal quite effectively, uses less of the frequency spectrum, and consumes only a fraction of the power which the entire signal would have required. Thus, single sideband operation permits either a saving in power output or, if all the power is put into just the one sideband, an increase in effective transmitting power. It is even possible to operate a double single sideband (DSSB) system, in which the two sidebands are transmitting two entirely independent canals of information. As in the SSB operation, the carrier may be suppressed, and the power saved can be added to the sidebands.

Frequency Modulation

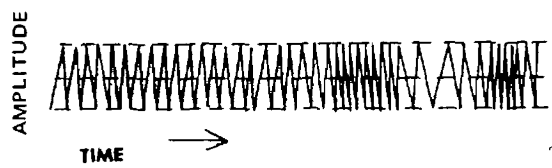
As might be expected, frequency modulation involves varying the frequency rather than the amplitude of the carrier wave in order to convey the intelligence in the signal. To go back to our jungle drummer, he is asked to play each beat as loudly as the others, but he will have to vary the rhythm to convey the message, now providing a slow cadence and now a rapid tattoo, plus all the variations in between.

Your FM radio sounds better than the AM because the receiver reacts to changes in frequency rather than amplitude and the problem of static, which is amplitude-related, is almost eliminated.

While the AM signal looks like this:



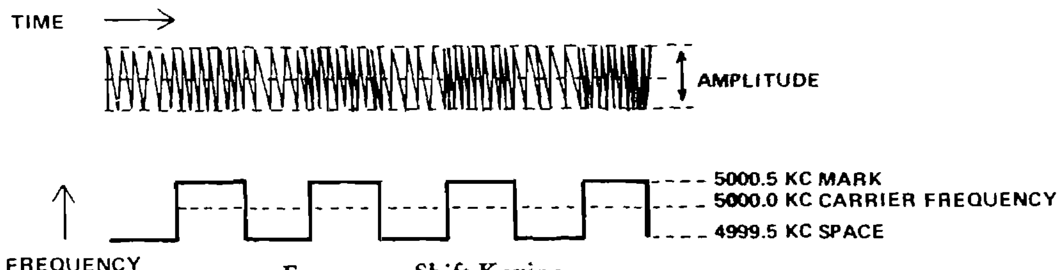
The FM signal looks like this:



Frequency Shift Keying (FSK)

FSK is a form of frequency modulation in which two frequencies are used, one indicating "on," the other "off." If our jungle drummer may be dragged in again to illustrate the point, let us suppose that he has been taking lessons and now can execute a drum roll. He is told that he must now drum at two speeds: his old steady beat and his new drum roll. The roll will mean "on" and the old beat will mean "off." Now he can be used to send messages in Morse code, for a short roll can stand for a dot, a long one for a dash, and the slow beat for a space.

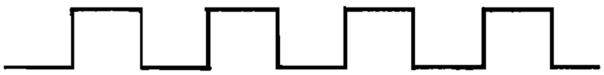
The illustration below shows how FSK is used for teletype transmission. The upper frequency stands for a mark and the lower for a space.



Frequency Shift Keying

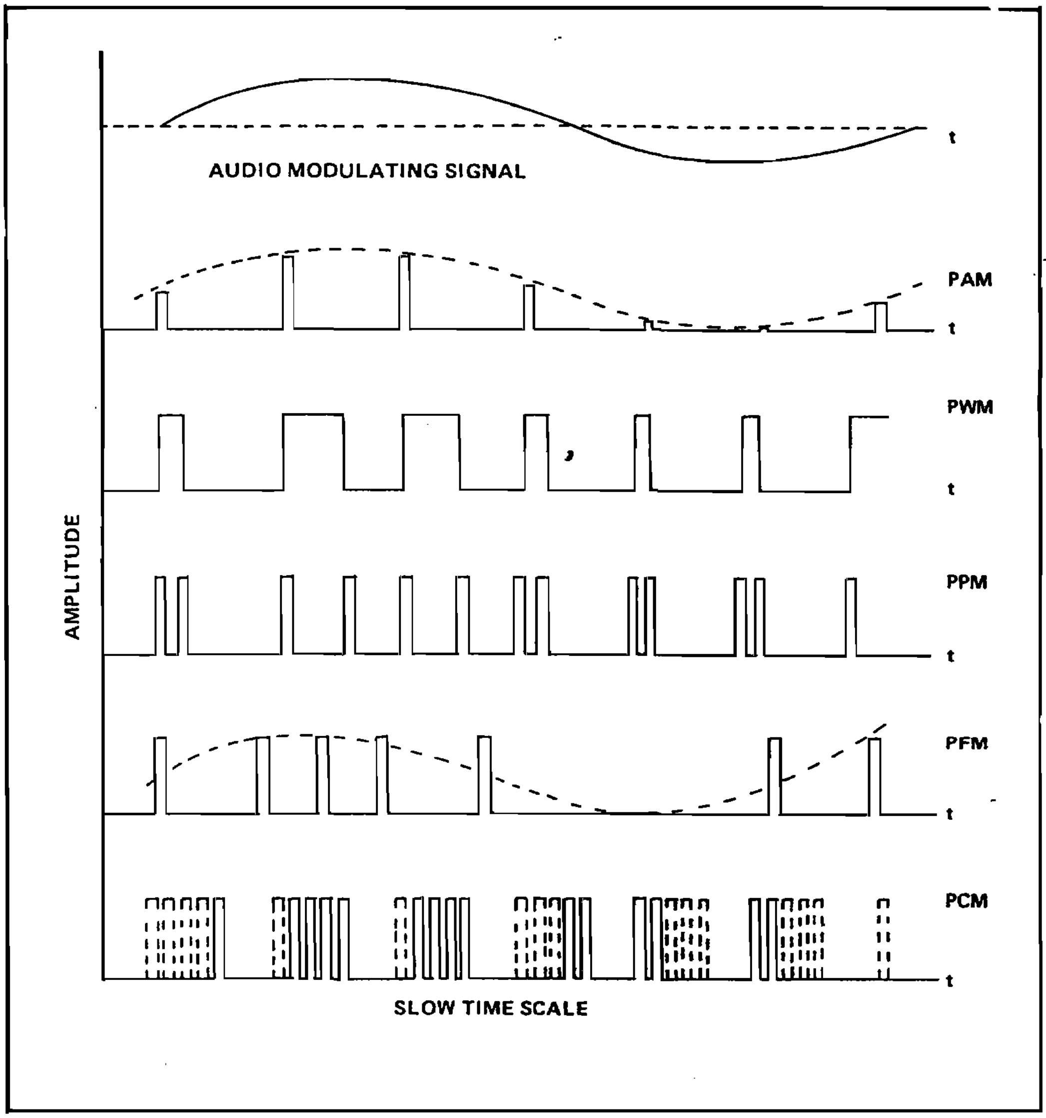
Pulse Modulation

Up to this point, our carrier has been a sine wave, but an increasingly popular communication technique employs regularly recurrent pulses instead. Pulses are bursts of energy produced by turning a transmitter on and off in quick succession. Until modulated, this train of pulses bears no information except the announcement of its presence and looks like this:



As you might imagine after seeing what happened to the sine wave, the pulse train can be modified in a number of ways in order to transmit information. The amplitude of the pulses may be varied in accordance with the amplitude of the modulating signal (pulse amplitude modulation); or the width of each pulse may be varied (pulse width modulation); or the position of the pulse may be changed (pulse position modulation); or the repetition rate of the pulse train may be caused to vary (pulse frequency modulation). In pulse code modulation the pulses are actually coded groups, and these groups are changed in accordance with the modulating signal.

Examples of different types of pulse modulation are shown below:



PULSE MODULATION METHODS.

Multiplexing

Although it is not properly a part of the subject of modulation, it may be appropriate to take a quick look at multiplexing, which is such an important technique in radio communication today. Multiplexing is the sending of several independent signals out on the same carrier wave, an economy measure made essential by the volume of radio communication.

By multiplexing several channels, a single uhf transmitter could, for example, send out the following:

Channel 1 AM radiotelephone traffic
Channel 2 Frequency-shift-keyed teletypewriter
Channel 3 Several sub-channels of teletype and Morse signals

It quickly becomes apparent that, through multiplexing, we can make efficient use of both the transmitting equipment and the allotted portion of the frequency spectrum.

The two methods of multiplexing you may encounter are frequency division and time division.

Frequency Division Multiplex

In FDM, the allowed portion of the frequency spectrum is cut up into smaller, separated bands, and these are used to transmit separate channels of information. Each of these channels may have employed AM, FM, or pulse modulation before being combined into the multiplexed signal conveyed by the carrier.

Time Division Multiplex

TDM is particularly useful with teletypewriter and pulse systems. All channels to be transmitted are sandwiched together by a timing device which takes out and sends a bit of the first channel, then a bit of the second, and so on until the cycle is completed. This process is repeated until the last bit of the last channel has been sent out.

Jack Gurin served as a Japanese linguist with Military Intelligence in World War II and entered Sigint with ASA in 1946. He has held a great variety of line, staff and technical positions and also managed to contribute frequently to cryptologic literature—as well as the NSA Men's Chorus, the Jazz Band and the Phoenix Society.