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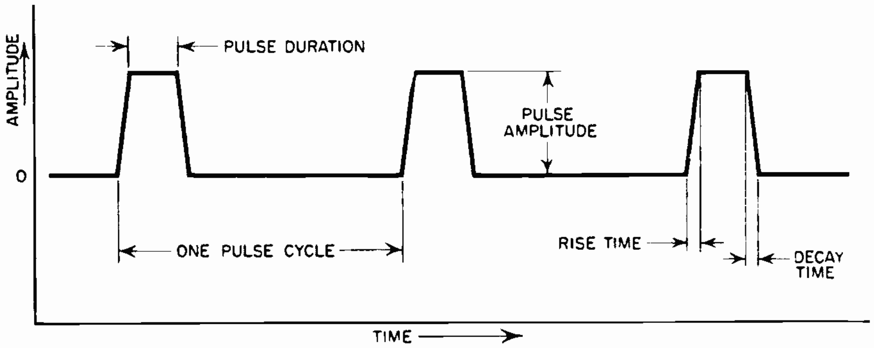
Introduction to Pulse Modutation

By the Engineering Department, Aerovox Corporation

The use of *pulses*, or short bursts of radio-frequency energy, is well known in connection with the transmission of television synchronizing signals and in radar practice. Pulse signals of this type have also been applied to microwave radio-relay systems, resulting in the revolutionary new techniques of voice communication known as "pulse modulation". Cross-country, point-to-point radio-relay circuits utilizing these techniques have many practical advantages and are rapidly replacing older types of wire, cable, and relay-link equipment in both commercial and military applications. This issue of the AEROVOX RESEARCH WORKER presents the fundamental concepts of pulse modulation and discusses typical applications.

The advantages of pulse modulation include economy of equipment size and weight, good speech quality, adaptability to multiplex operation with low inter-channel cross-talk, enhanced signal-to-noise ratios, and ideal utilization of the special microwave tubes such as the magnetron and klystron. Microwave frequencies are used in most radio-relay systems employing pulse modulation since relatively wide bandwidths are required, and because the shorter wavelengths permit the greater antenna directivity required to maintain privacy in point-to-point radio telephony.



PULSE CHARACTERISTICS
FIG.1

There are four general kinds of pulse modulation:

- Pulse Amplitude Modulation (PAM)
- Pulse Time Modulation (PTM)
- Pulse Code Modulation (PCM)
- Composite Pulse Modulation (CPM)

In addition to these basic types, there are over forty methods of pulse modulation using combinations of the above types impressed as pulsed subcarriers on either amplitude modulated or frequency modulated r.f. carriers. Since most of these systems are highly complex, and in some cases quite impractical, the purpose of this paper will be more aptly served by confining this discussion to the more basic types of pulse modulation.

Pulse Fundamentals

A *pulse* may be defined as a single electrical disturbance of short duration. As used in radar, television, and communications, pulses usually have rectangular or trapezoidal wave-forms. Such wave-forms represent the abrupt rise of a d.c. voltage from zero to a constant value, the maintenance of that value for a short period of time, and an abrupt decrease to zero again. A recurrent series of such pulses, and the standard terms used to define pulse characteristics, are shown in Fig. 1. The frequency of occurrance of the pulses is called the *pulse repetition frequency* and is commonly abbreviated PRF.

The duration of the pulses employed in pulse modulation is usually measured in *microseconds*. The product of the pulse duration in seconds and the pulse repetition rate in pulses-per-second is called the "duty factor" or "duty cycle". It represents the ratio of the time that a pulse is present to the time of one complete pulse cycle. As an example, if the pulse duration is one microsecond (.000001 second) and the PRF is 10,000 p.p.s., the duty cycle is .01, or 1/100th. This means that the pulse occupies only 1/100th of the period of one pulse cycle. In other words, there are 99 microseconds between each one-microsecond pulse.

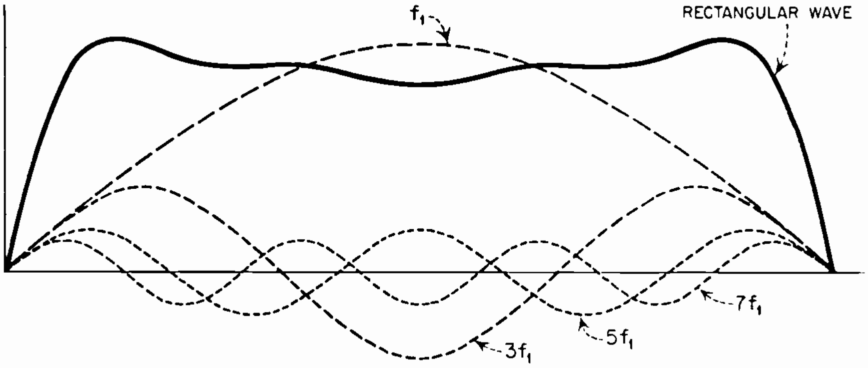
Although the pulse repetition frequencies employed in pulse modulation are usually less than 100 kilocycles, frequency components much higher than this are required to form essentially rectangular pulses. In other words, if the pulse is broken down into its sine wave components, it is found to consist of a *Fourier series* made up of a fundamental and its odd harmonics, as depicted in Fig. 2. The steepness of the sides of the pulse determines the number of harmonic frequencies required to form it. Theoretically, if the pulse were perfectly rectangular, it would contain an infinite number of sine wave harmonic components. Under these conditions, an infinitely wide band of frequencies would be required to transmit it without distortion. In practice, frequencies up to several megacycles are usually present, necessitating the use of video frequency circuits for the handling of pulses. The actual video bandwidth required depends on the rise or decay time of the pulse in accordance with the approximate relationship:

(1)

$$F = \frac{1}{2t_r} \text{ megacycles}$$

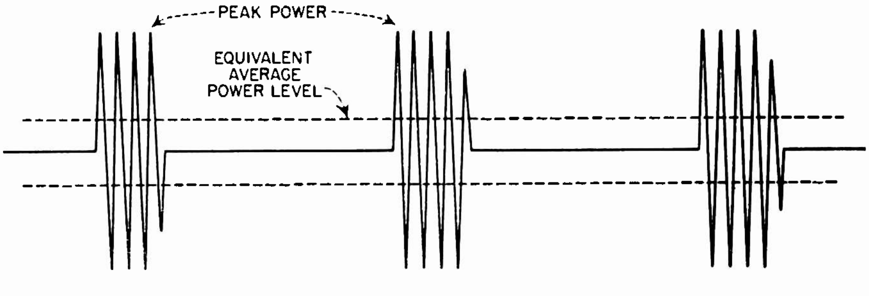
Where: F is the required video bandwidth.
t_r is the pulse rise or decay time, whichever is shorter. (Microseconds)

Thus, a pulse having a rise time of .2 microseconds would require a video bandwidth of 2.5 megacycles for undistorted transmission.



FORMATION OF PULSE BY FOURIER COMPONENTS
FIG. 2

When pulses of this type are used to modulate an r.f. carrier, the result is a train of r.f. pulses like those of Fig. 3, having wave envelopes essentially like those of the modulating video pulses. The r.f. bandwidth required to faithfully transmit the pulses is twice as large as the video bandwidth given in Eq. 1, however, since an amplitude modulated carrier has side-bands on either side which are removed in frequency by the amount of the highest frequency components present. The distribution of transmitted energy within this bandwidth would be approximately as shown in Fig. 4, which is the .rf. *spectrum* of a typical pulsed carrier. For extremely short pulses having very fast rise times, the r.f. bandwidth may be many megacycles. For this reason, pulse modulated systems usually require considerably greater bandwidths than is needed for other communication systems having equal rates of intelligence transmission.



PULSE-MODULATED R.F. CARRIER
FIG. 3

When a transmitter is pulse modulated, it is possible to obtain instantaneous r.f. power outputs which are very high compared to the continuous wave power obtainable from the same transmitter. These high "peak" powers are achieved because it is possible to apply very high voltages to the transmitting tubes and to allow them to draw very high anode currents during the short pulses without exceeding the *average* power dissipation ratings of the tubes. Thus, tubes rated for a few watts *average* power output when operated c.w. may be capable of delivering kilowatts of instantaneous or *peak* power when pulsed. The average power contained in a pulse train is related to the peak power by the duty cycle, in the following manner:

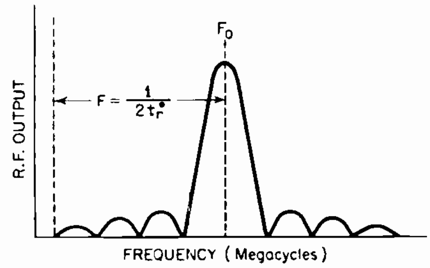
(2)

$$\text{Average Power } (P_{ave}) = \text{Peak Power X Pulse Duration X PRF}$$
$$= \text{Peak Power X Duty Cycle}$$

In the r.f. pulse train of Fig. 3, the average power level is shown by the dotted lines. It represents the power level which would be present if the pulse peaks were smoothed out to form a continuous signal containing equal average energy.

Modulation Systems

Most of the simple systems of pulse communication function by causing the average power of the pulse train to vary in accordance with the modulating signal. As shown by Eq. 2, this may be accomplished by varying either the peak power, the pulse duration, or the pulse repetition frequency. These systems are classified as pulse *amplitude* modulation (PAM), pulse *duration* modulation (PDM), and pulse *frequency* modulation (PFM), respectively. Figure 5 illustrates how pulse sequences of these three types would appear when modulated by a sine-wave signal. The dotted lines represent the average power variations of the pulse train. This is the



SPECTRUM OF PULSED TRANSMITTER

FIG.4

wave which is reproduced in the receiver when the pulse carrier is demodulated.

The process whereby the characteristics of the pulse train are modulated by the instantaneous value of the modulating signal is known as "sampling." In other words, the modulating wave is sampled at intervals determined by the PRF. To reproduce the modulating wave without appreciable distortion, the sampling frequency must be 2.5 or 3 times higher than the highest modulating frequency. Thus, to effectively reproduce voice frequencies up to 3000 c.p.s., a sampling PRF of about 9000 p.p.s. would be required.

Another form of pulse modulation which has been used to some extent is called *pulse position modulation*, abbreviated PPM. In this system, the transmitter pulse duration and amplitude are held constant, and the average repetition rate and average power nearly so. Modulation is accomplished by varying the time interval between successive pairs of pulses. These varying intervals are then converted to pulse duration modulation at the receiver by a "flip-flop" multivibrator. The first pulse of each pair triggers the multivibrator to start a locally generated pulse, which continues until the second pulse arrives to turn the circuit off.

Time-division Multiplexing

Multiplexing is the technique of impressing two or more communications channels on a single circuit, so that each can be operated simultaneously without interference with the others. This may be done by separating the individual channels on either a frequency or a time basis. Pulse modulation is particularly adaptable to time-division multiplexing because of the long intervals between pulses during which no signal is being transmitted. This makes it possible to send other pulse signals during these intervals which may be separated at the receiver by their time of occurence.

The basic principle of time-division multiplexing is illustrated in the hypothetical telephone circuit of Fig. 6. Here four pairs of telephone transmitters and receivers are connected to corresponding segments of a pair of commutators which have brushes or "wipers" rotating in speed and phase synchronism. A single telephone line circuit connects the brushes so that correspondingly numbered transmitters and receivers are connected together in rapid sequence. If the commutation frequency, or sampling rate, is several times as high as the highest voice frequency used, the speech output of each microphone will appear at the matching receiver. A low pass filter is used in each receiver circuit to separate the speech frequencies from the sampling frequency.

In this system of multiplexing, each voice channel uses the wire circuit for a short period of each commutation cycle. Thus, the time of each cycle is divided among the four channels — hence the term *time-division* multiplex. It will be apparent that this principle will work equally well if the wire circuit is replaced by a radio circuit.

In practical systems of time-division multiplexing, commutation is accomplished electronically, rather than mechanically. A synchronizing pulse, which is distinguishable from the channel pulses because it is of longer duration, is sent out by the transmitter before each sampling cycle to actuate timing circuits at the receiver. These timing circuits disable the input circuits of all receiver channels except the one which should receive a pulse at that time. Thus, the receiver "commutator" is automatically synchronized with the transmitter. As many as eight voice channels may be conveniently multiplexed on a single radio frequency circuit by this method.

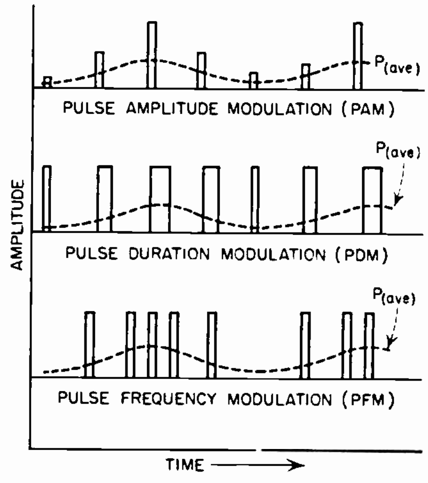
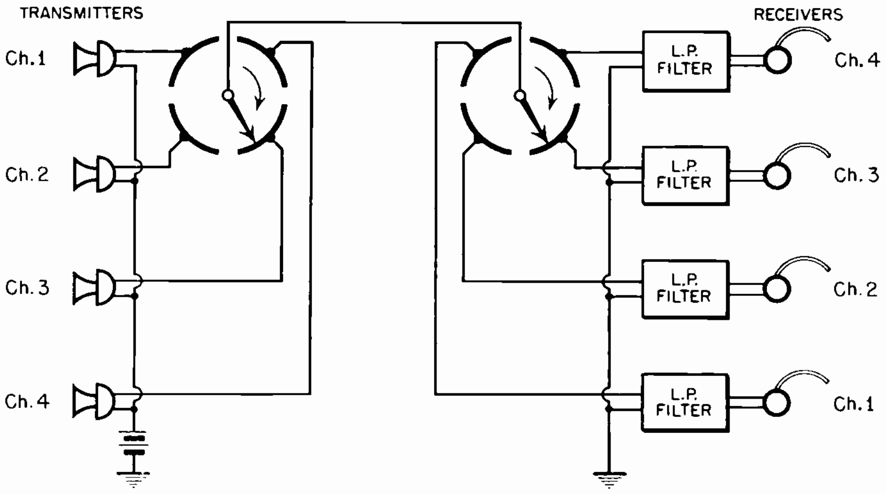


FIG.5

Systems of pulse modulation which make use of pulses of constant amplitude have signal-to-noise ratios comparable to FM systems. This is because noise modulation variations in the pulse amplitudes can be removed by limiting or clippipng circuits such as are used in FM practice, without impairing the signal modulation.

Another advantage incidental to the use of pulse modulation lies in the fact that it enables the use of vacuum tubes at frequencies considerably higher than the c.w. limit for the same type. The very high pulse voltages applied reduce the frequency limiting effects of electron transit time. In applications where the duty cycle is sufficiently low, the upper frequency limit for a given tube type may be more than doubled.



ILLUSTRATING TIME-DIVISION PULSE MULTIPLEXING

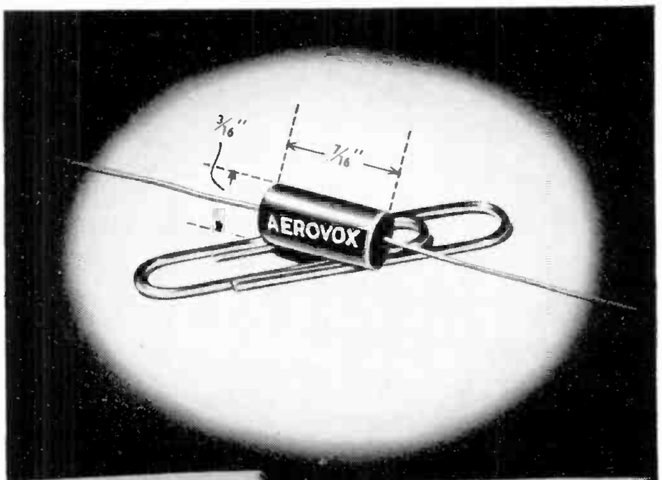
FIG.6

SMALLER THAN PREVIOUS "SMALLEST"...

PREDETERMINED ACCURACY...

REMARKABLE STABILITY...

EXCEPTIONAL CHARACTERISTICS...



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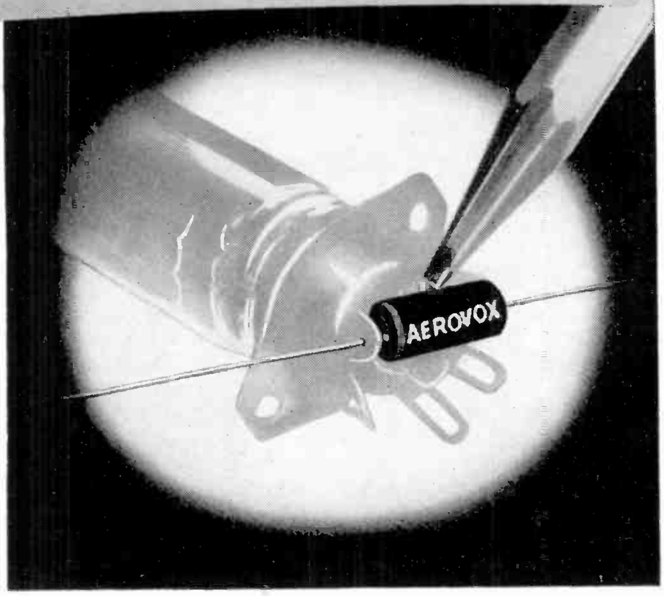

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