FREQUENCY SHIFT KEYING

FREQUENCY MODULATION PRINCIPLES APPLIED TO RADIO TELEGRAPHY

Lieut. Myron E. Beard, USN

■ Practically everyone has read or heard of the new radio technique known as "FM" (frequency modulation), and the vast improvement expected when FM stations supplement or eventually supersede the present amplitude-modulated broadcasting stations.

Radio technicians also are aware of the fact that FM systems of voice communication have been in use on fleet circuits and amphibious-force circuits for some time. Their opinion of this new technique is invariably highly colored by their own experiences with such equipment, its performance, reliability, and ease of maintenance. Unfortunately, the reliability and performance are a direct function of the ease of maintenance, and easy maintenance is only possible when the technical personnel have a thorough understanding of the principles involved. This is not a common case, since the visualization of FM principles is usually difficult.

Although this new development in radio communication applies basic FM principles to radio telegraphy, it is as easy to understand as ordinary CW telegraphy. In fact, its principal features are most clearly illustrated by a direct comparison of the signals with conventional CW signals.

Using as a basis of comparison the Morse letter S (three dots) the graphic representation is shown in figure 1. A third dimension, that of frequency, has been added in this illustration. But, since CW signals are of constant frequency, there is no variation along the frequency axis. In order to receive the intelligence carried by such a signal, the receiving equipment must be able to scan the signal along the time axis, plus the axis which carries the intelligence (the amplitude axis in this case). This is shown graphically in figure 2. When scanned along the amplitude and time axes, figure 2 (l), the intelligence appears as large changes in signal amplitude. In a theoretically perfect circuit, this variation would be from zero amplitude for the intervals when the key is open, to a maximum value when the key is closed. But extraneous components of energy due to atmospherics, interfering stations, etc., appear as additional variations along the amplitude axis, and when these extraneous components of energy approach or exceed the value of signal variation, the signal is "blanked out by interference." Figure 2 (r) represents the same signal as scanned along the frequency and time axis. Variations in signal amplitude have no effect on this figure, so no intelligence can be received, but neither is the effect of noise and interference apparent.

This leads to a logical conclusion that if the intelligence variations could be made to appear as changes along the *frequency* axis, and the receiving equipment designed to respond to this type of signal, the variations in amplitude due to noise and interference would be eliminated as a factor affecting communications, since these components cause amplitude variations only.

Frequency-shift keying accomplishes the first of these conditions; that is, a shift of the signal frequency between key-closed and key-open intervals, with signal amplitude remaining essentially constant. In addition, the constant-amplitude carrier permits the use of AVC and other refinements in the receiver.

New terms are used in conjunction with frequency-shift keying, and in order to make them familiar they will be defined here. The intervals when the key is open are referred to as spacing intervals, while the in-
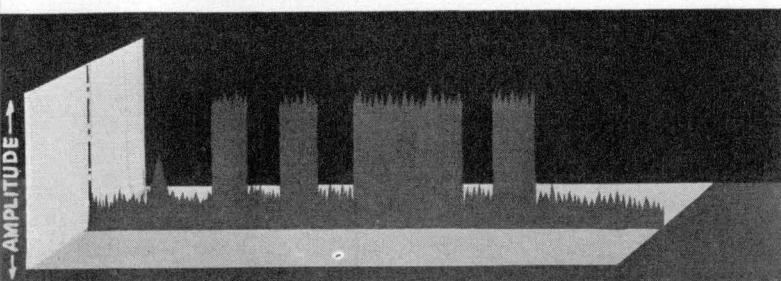
FIGURE 1.—*Three-dimensional representation of a conventional telegraph signal.*

FIGURE 2.—*Receiver response to on-off keyed signals when converted by (left) a conventional detector and (right) by an FM discriminator.*

tervals during which the key is closed are called marking intervals. Thus, in the letter S there are three dots, and it may be referred to as "mark-space-mark-space-mark" preceded and followed by a continuous space signal to separate it from other letters. Letters containing dashes, such as A could be designated as "mark-space-long mark" or, more correctly, "mark-space-mark-mark-mark," since a dash is equivalent on the time axis to three dots. The shift of amplitude or frequency from space to mark condition is known as a space-to-mark *transition* and, similarly, the return shift is called a mark-to-space transition. These transitions occur almost instantaneously, and are usually considered instantaneous for practical purposes.

Frequency-shift keying systems (abbreviated FSK) impress the desired intelligence on the radio wave as a change in the radiated *frequency*. This is illustrated in figure 3, and again the letter S is used as an example.

Note that the normal circuit condition is the space-frequency (key-up) condition. When the key is closed the frequency changes instantly and remains during the dot or marking interval, returns to the space frequency when the key is opened, etc. Midway between these two frequencies is the assigned channel frequency, but the only time the transmitter radiates the assigned frequency is during the initial tuning of the equipment. Also shown in figure 3 is the variation along the amplitude axis caused by noise and interference, but this is eliminated on a portion of the drawing to illustrate its actual elimination by the limiter-amplifier in the receiving equipment.

A look at figure 3 makes it apparent that if the signal is scanned along the amplitude and time axes, the amplitude variations due to the signal intelligence will be zero, as illustrated in figure 4 (l). However, if the scanning is accomplished along the frequency and time axes, the intelligence is reproduced as shown in figure 4 (r). By this system, then, the intelligence can be reproduced at the receiving station exactly in its original form and will be largely unaffected by conditions in the radio path other than the complete loss of signal due to ionospheric variations. This condition, of course, also eliminates ordinary CW signals. As a matter of fact FSK, because of its characteristics, considerably reduces the effects of fading, and will often maintain a usable channel on frequencies long after CW communications would have been impossible due to a low signal-to-noise ratio.

Several questions regarding frequency-shift keying present themselves:

1. How is the signal generated and received?
2. What improvement in circuit merit may be expected?
3. If this improvement is sufficient, how many Navy circuits will be changed over, and how soon may the change be expected?
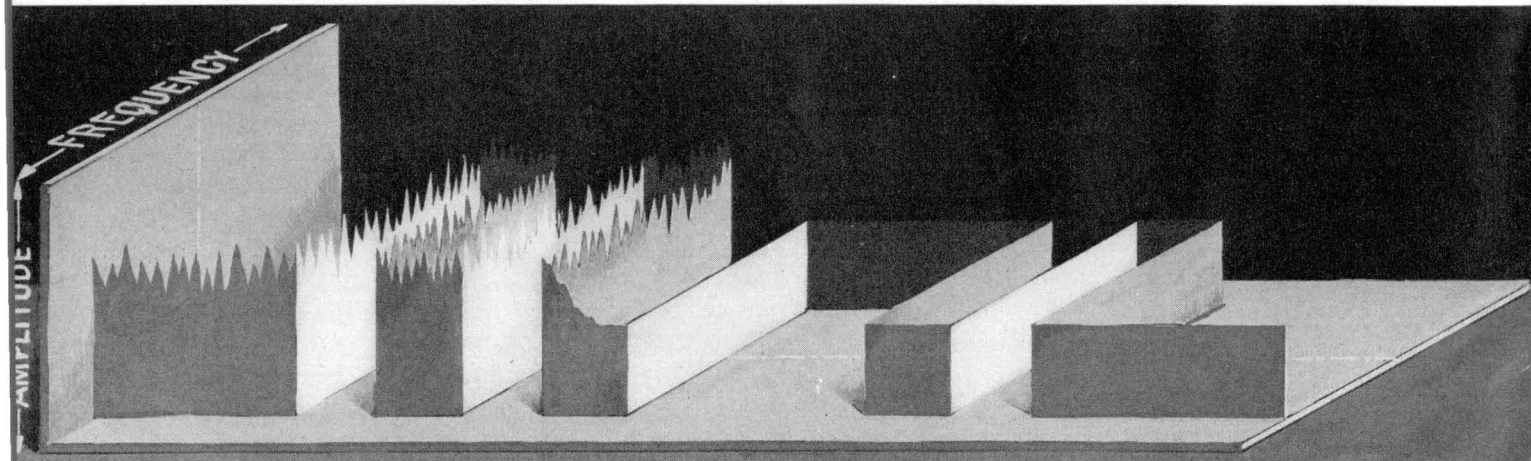4. What new electronic equipment is necessary?

FIGURE 3.—*Three-dimensional representation of a frequency-shift keyed telegraph signal.*
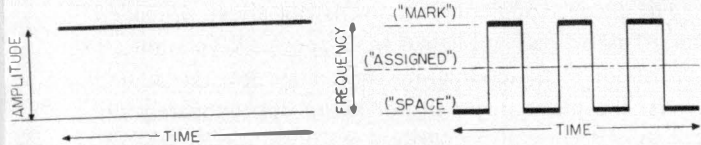
FIGURE 4.—*Receiver response to FSK telegraph signals converted by (left) a conventional detector and (right) by an FSK receiver-converter.*
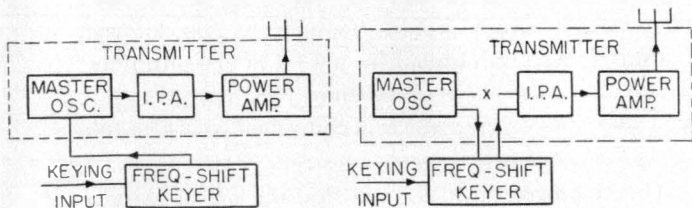

FIGURE 5.—*Two arrangements for frequency-shift keying a transmitter.*

5. How complicated is the new equipment?

Although this article will make no attempt to give detailed information on equipment, these questions are answered in the following paragraphs.

In its simplest form, frequency-shift keying of a transmitter could be accomplished merely by shunting a capacitor and key in series across the oscillator tank circuit, locking the normal key of the transmitter, and operating oscillator-circuit key. The shift in frequency between mark (key-closed) and space conditions would be determined by the effect of the additional capacity on the oscillator frequency, and the multiplication factor in the transmitter amplifiers. Thus, if the desired shift is the conventional 850 cycles at the radiated frequency, and this frequency is four times the oscillator frequency (doubled in two stages), the effect of the additional capacity on the oscillator would have to be limited to 212.5 cycles. Frequency-shift keyers are, of course, more elaborate than this simple illustration, but the basic principles are the same. That is, the keyer operates to change the oscillator frequency by a certain number of cycles, and this change must be correlated with the multiplication factor of the transmitter and the desired shift in the transmitter output frequency. Some keyers also include a phase-modulation feature which minimizes undesirable effects caused by selective fading of the received signal.

All medium- and high-frequency transmitters now being designed and procured will contain FSK features as an integral part of the equipment, but a number of existing transmitters have been and will be converted for FSK operation by the use of an external unit. Transmitters such as the TBA, TBK, TBM, TCK and others lend themselves readily to such conversion.

In general, the units may operate on either of two principles. First, the keyer may take the transmitter master-oscillator frequency and, by modulating it with the output of an additional oscillator which is frequency-shift keyed, obtain two frequencies which are fed into the intermediate power amplifier stage of the transmitter and so up to the output circuit. One of these is the mark frequency and the other is the space frequency. This system is illustrated in the block diagram, figure 5 (right).

Figure 5 (l) illustrates the second method in which the master oscillator of the transmitter is itself shifted in frequency by the keyer or, in some instances, is replaced entirely as the frequency determinant by an oscillator in the keyer unit. In addition to the FSK units proper, necessary coupling systems are provided to make the complete conversion. These units employ strictly conventional modulation and filter circuits, and are therefore easily serviced and maintained.

At the Receiving end, the additional electronic equipment necessary for FSK reception is a little more complicated because it is here that the principle advantages of the system are derived. There are two methods by which the intelligence of an FSK signal may be used and, since either method may be encountered, both will be discussed briefly. Standard communication receivers are used, plus an additional unit called a Receiver Converter, it being the adaptor which determines the method employed.

Figure 6 is a block representation of one method, which utilizes the audio output of the receiver. Here the mark and space carrier frequencies are received in the conventional manner, the CW oscillator in the receiver causing separate mark and space audio frequencies to appear in the output. The receiver is normally adjusted in such a manner as to produce a mark frequency of 2125 cycles, and a space frequency of 2975 cycles. It is this two-tone audio signal that drives the converter. The signal is first fed through a band-pass filter to remove
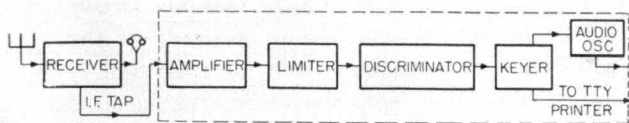

FIGURE 7.—*Arrangement of FSK receiver-converter for operation direct from the IF amplifier of a receiver which has been modified for the purpose.*
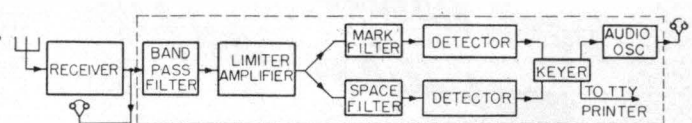

FIGURE 6.—*FSK receiver-converter for operation from two-tone audio output of a conventional receiver.*

interferance from adjacent frequencies, and then through a limiter-amplifier to eliminate amplitude variations in the signal. From the limiter output the signal passes through a pair of filters which separate the mark and space components. These frequencies are then separately detected, amplified and rectified, the resulting DC being used to operate a keyer. The keyer may then operate a high-speed recorder, an audio oscillator for manual reception, a relay for further transmission to a remote point, or the relay of a teletypewriter.

The second type of receiver converter is shown in figure 7. In this case the signal energy is taken from the receiver at the IF amplifier output. This energy enters the converter through an additional amplifier, a limiter and, in some cases, an additional frequency-conversion stage. It then passes into a discriminator, the output current of which varies in proportion to the frequency of the applied signal. This variation in current is used to operate a keyer to furnish the same services as above.

The advantage of frequency-shift keying may be summarized by its effect on the various factors which determine the merit of a circuit. A preliminary estimate of these effects is shown below, using conventional on-off keying as a standard.

Keying Method	Signal-to-noise	Selective Fading	Flat Fading	Total Improvement
(a) on-off	0	0	0	0
(b) on-off, with phase modulation	−5	+8	0	+3
(c) FSK	+4	0	+13	+17
(d) FSK, with phase modulation	+1	+8	+13	+20

The phase modulation feature is not always included, but if used is accomplished by a special keyer unit. It consists of phase-modulating the carrier at a rate of 200 cycles, the phase displacement being approximately one radian. Its effect is primarily a minimization of selective fading effects. No additional equipment is required at the receiving end.

It is apparent that FSK plus phase modulation may result in circuit improvement up to 20 db, or the same improvement which would result if a 100 kilowatt transmitter were substituted for a 1 kilowatt transmitter! Even without the phase modulation, FSK may give up to a 17 db improvement, which is equivalent to a fifty-fold increase in transmitted power.

This improvement makes practical the use of automatic printers on radio circuits, and for this reason radio teletype circuits are almost always frequency-shift keyed. It should be pointed out, however, that if a keyed circuit has a high signal-to-noise ratio and is free from selective or flat fading, perfect operation of a teletypewriter is possible, and FSK would offer no improvement. Its advantage is important only when the circuit deteriorates to marginal or near marginal conditions due to fading, noise or interference. In other words, FSK makes possible the use of a given channel for many more hours per day on otherwise difficult long-haul circuits.

Much FSK equipment has already been installed at Navy shore radio stations and in Naval vessels; more is being installed as rapidly as it can be produced, and within a year much of the Navy's long-haul communications will probably be carried on FSK circuits.

Don't hoard it — pass it around!

VG PROJECTION LAMPS

■ Whenever the erase time of a VG is too long, changing the projection lamp may remedy the condition. Tests made by the General Electric Company and by the Radiation Laboratory have shown that after 200 hours of life a deposit forms on the inside of the bulb. This deposit decreases the heat output to such an extent that the temperature on the face of the 4AP10 tube is lowered by as much as 30° C without decreasing the visible light output.

The resistance of the 4AP10 tube depends largely upon the temperature at which it is operated. If the heat controls are set at maximum and the erase time is too long, the projection lamp should be replaced as a possible solution.