GTE LENKURT

DEMODULATOR

SEPTEMBER/OCTOBER 1977

Advances in

2-GHz

RADIO TECHNOLOGY

Also in this issue:

DIFFERENTIAL ABSOLUTE DELAY EQUALIZATION

Designers of microwave radios are continually advancing the state of the art. Some of the more recent advances in microwave radio technology are being applied for the first time to a new 2-GHz radio.

Since the first commercial microwave radio systems were put into service over a quarter century ago, microwave radio technology has made some amazing changes in the state of the art. Solid-state devices have replaced vacuum tubes resulting in a major reduction in the physical size and power consumption of the equipment. As the noise performance and frequency response of the transistor improved, the channel capacity of the radio steadily increased. The more recent introduction of integrated circuit packages into the radio has resulted in another significant reduction in the space and power requirements of the equipment. These more recent advances in technology have been incorporated in a new 2-GHz radio designed to handle from 120 to 600 frequency division multiplex voice channels or similar baseband signals.

An examination of the block diagram of the circuit functions in this radio (see Figure 1) reveals that certain circuits typically used to control transmitter frequency are missing. A radio-frequency divider circuit has replaced the crystal-controlled reference oscillator and mixer circuits traditional to other radio transmitters. Also, though it is not apparent in the block diagram, the automatic frequency control (afc) unit is a programmable digital afc instead of the usual analog type. The rf divider and digital afc in combination maintain the frequency of the frequency modulated oscillator (fmo) within limits rarely attained by other techniques.

Another unique feature of this radio is its built-in deviation-test circuit. Again, the function as such does not appear in the block diagram because it is a circuit that loops through several of the functional blocks. The advantage of having this circuit built into the radio itself is that it eliminates the need for external test equipment to set or check deviation of the transmitted carrier.

Other features of this radio such as optional transmitter output power levels, receiver threshold extension, transistorized local oscillator (lo), digital receiver afc, and multiple baseband input and output ports combine to make the 79F1 2-GHz radio representative of the current state of the art in microwave radio. But it is the rf divider, the digital programmable afc, and the built-in deviation check circuits that present a notable advance in circuit technology.

rf Divider Circuit

Microwave radios make use of automatic frequency control to keep the frequency of the transmitted carrier within permissible limits. One way often used to accomplish this is to mix a sample of the carrier frequency from the fmo with a sample of the multiplied frequency from a crystal-controlled reference oscillator (see Figure 2). The reference oscillator is tuned to some frequency above or below the carrier frequency to produce a difference frequency — in this example, 70 MHz — at the output of the mixer. This signal is amplified and fed to a digital afc circuit in which the frequency is divided and compared to another crystal-controlled reference frequency. The result of this frequency comparison is a dc voltage at the output of the afc that is fed to the varactor diode in the fmo to control its frequency.

Use of an rf divider instead of a reference oscillator and mixer greatly simplifies the afc loop (see Figure 3). This rf divider operates according to a phenomenon whereby a lower frequency oscillator is made to follow the frequency change of a higher frequency signal if the higher frequency is an integral multiple of the lower frequency. As an example, if the oscillator is tuned to 500 MHz or reasonably close to it, it will lock to a 2-GHz signal injected through an isolator into the emitter of the transistor oscillator (see Figure 4). The oscillator will continue to lock on the injected signal even as it varies over approximately a ±70-MHz range.

The frequency-determining elements in the oscillator are capacitor C1 and printed inductor L1. Varying C1 allows the oscillator to be tuned to any frequency from 400 MHz to 600 MHz. This means the oscillator can be made to lock on any fmo frequency from 1.6 GHz to 2.4 GHz that is four times (the integral multiple) higher than the oscillator frequency. Since 2-GHz microwave radio channel assignments lie between 1.7 GHz and 2.3 GHz, the entire band falls well within the tuning range of this oscillator.

Even though this rf analog divider is quite elementary, it works over the 200 MHz tuning range only if it is properly built. It is essential that the physical dimensions of the circuit and its connections be kept small and well grounded. For this reason the oscillator is mounted on a printed wiring board that in turn is mounted within a brass enclosure. Such construction assures that the level of the 2-GHz injection signal is relatively constant and that the oscillator locks at all frequencies over its tuning range. It is also important that the isolator present a constant impedance to the oscillator over the operating temperature range of the radio.

The output of the analog divider feeds two digital frequency dividers connected in tandem, each of which divides the signal by four. Therefore, the frequency of the signal at the output of the rf divider is the carrier frequency divided by 64. In the example of a 2-GHz carrier, the output frequency of the divider is 31.25 MHz.

Programmable Digital afc

The basic functions of the circuits in the afc unit are to compare the frequencies of two signals, to generate a dc control voltage proportional to the frequency difference of the two signals, and to produce an alarm indication whenever the dc control voltage or the open-loop center frequency of the fmo, referenced to the programmed center frequency, exceed preset limits. Other circuits within the unit convert the logic level of the signal making it compatible with the various types of logic circuits used in the unit (see Figure 5). There are also a metering circuit and deviation test circuit that are described later.

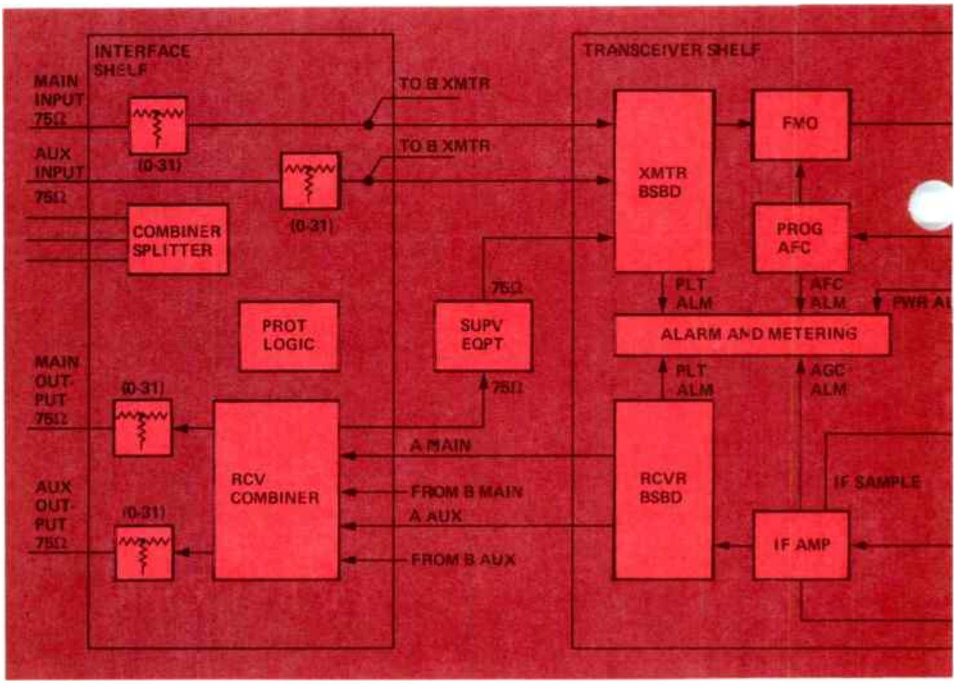
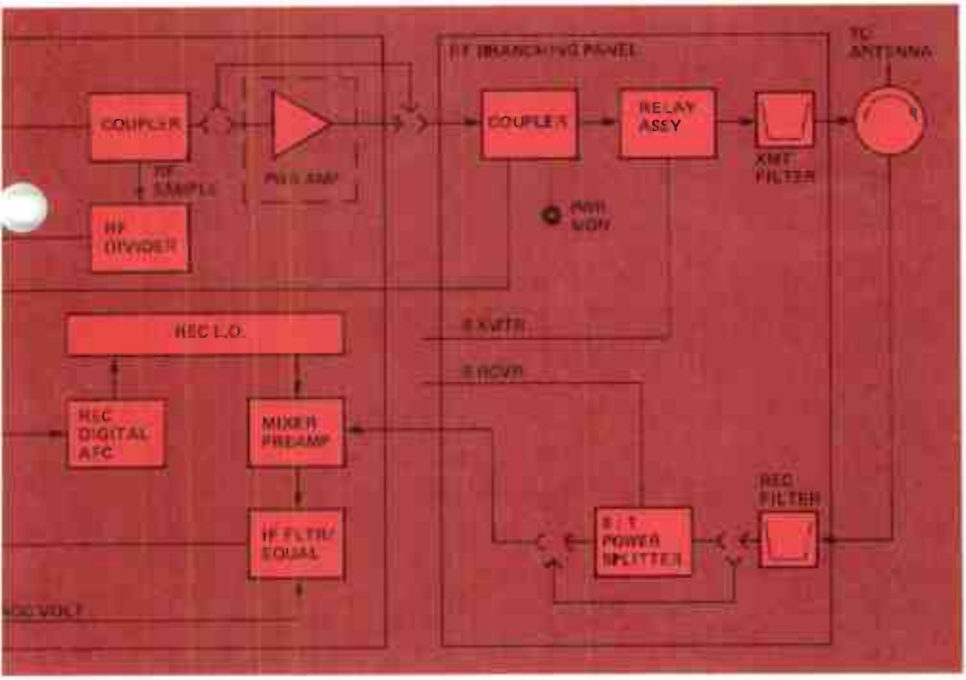


Figure 1. A typical hot-standby arrangement of the 2-GHz 79F1 radio is composed of an interface shelf, two transceiver shelves and an rf branching panel. The second transceiver shelf is not shown, but the interconnections between it, the interface shelf, and the rf branching panel are indicated.

This digital afc unit differs from others in that it is programmable. Programming of the unit is accomplished by setting each of eighteen miniature strapping plugs in one of two positions (see Figure 6). The positions are arranged in five groups. Each group except the first contains four plugs; the first group (X 1 GHz) contains two plugs. Each plug position represents a binary value of 1 or 0. Each group of positions represents a four-bit binary-coded-decimal digit of the desired transmitter frequency in powers of ten from 100 kHz to 1 GHz. If, as sometimes happens, the frequency of the transmitter must be changed, neither the afc unit itself nor the reference crystal in it need be changed. It is only necessary to reprogram it, or any spare unit, to the new frequency. Of course, the transmit filter in the rf branching panel must be retuned or exchanged.

The signal fed into the afc unit from the rf divider is a digital signal whose frequency is the frequency of the fmo divided by 64. The afc unit first converts the logic level of the signal, then divides the frequency of the signal by sixteen, and, after another logic level conversion, feeds the signal into the program counter. At this point the frequency of the signal is the carrier frequency divided by 1024 ($f_c/1024$).

The program counter is a programmable five-decade synchronous down-



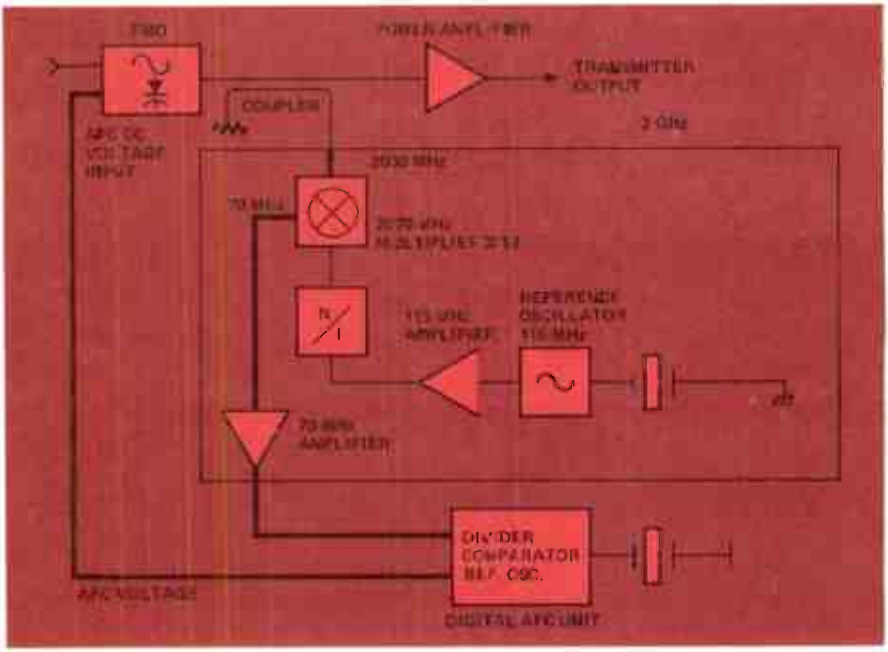


Figure 2. The typical afc loop requires a crystal-controlled reference oscillator, a frequency multiplier and a mixer.

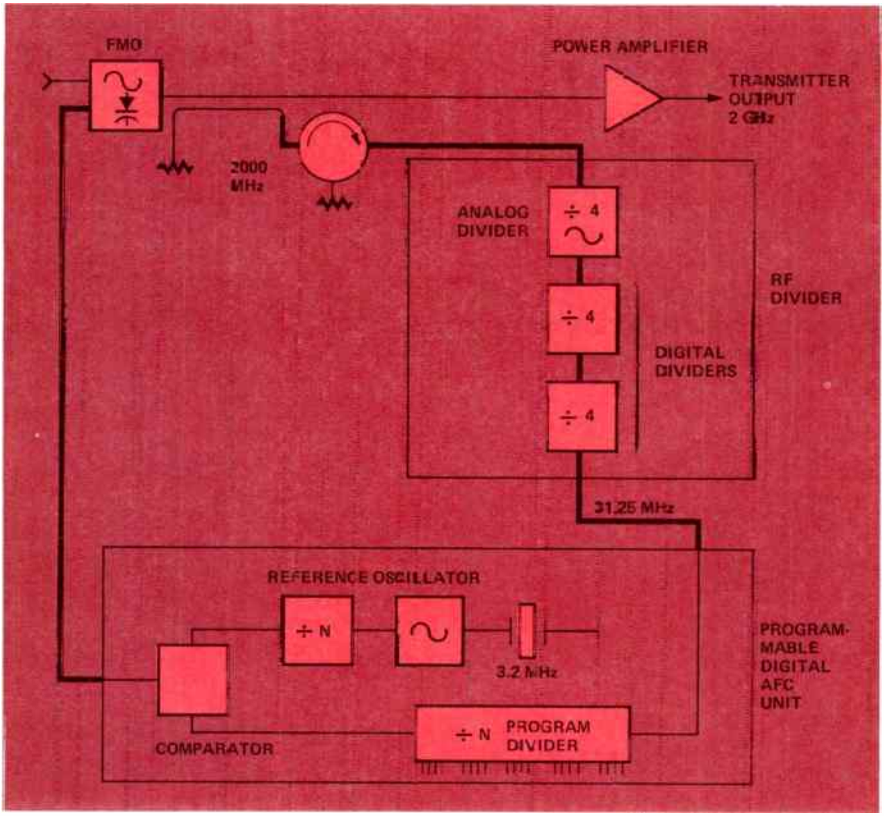


Figure 3. The new 2-GHz radio uses an rf divider instead of a reference oscillator, multiplier and mixer in the afc loop.

counter into which, as already noted, the five most significant digits of the carrier frequency are programmed. Associated with the program counter is a reference counter that down-counts the frequency of a very stable crystal-controlled oscillator tuned to 3.199886 MHz. The reference counter divides this oscillator frequency by 2^{16} (65,536) to obtain a frequency of 48.83 Hz, the sample frequency.

This reference counter has two outputs: a negative-going load pulse and the 48.83 Hz square-wave sample signal. The load pulse occurs just prior to the beginning of each sample period which starts at the negative-going edge of the sample signal. The load pulse parallel-loads the programmed carrier frequency into the program counter and presets the program counter prescaler to help synchronize the $f_c/1024$ frequency to the reference frequency. The negative- and positive-going edges of the square-wave sample signal mark the beginning and end, respectively, of the sample period, which is approximately 10.2 milliseconds in length. During the sample period both the program counter and reference counter are counting down to zero.

At the end of the sample period the sample signal at the output of the reference counter rises to a logic high

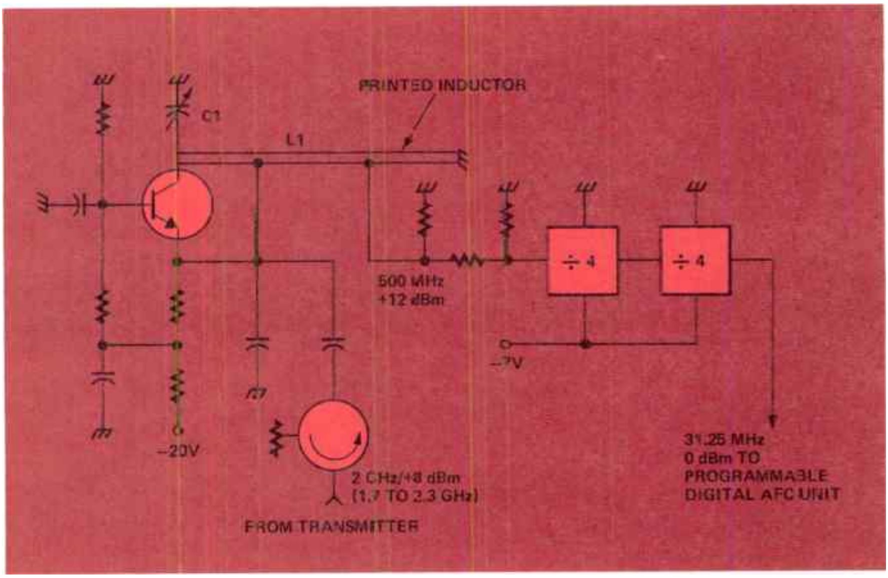


Figure 4. The injection-locked oscillator in the rf divider can be tuned by adjusting capacitor C1 to lock on any transmitter frequency in the 2-GHz band. The transmitter frequency is four times higher than the oscillator frequency.

level. At the same moment the output of the program counter will also go to a logic high only if the frequency of the fmo is exactly at the programmed value. If the carrier frequency is too high, the output of the program counter will go high prior to the output of the reference counter. If the carrier frequency is too low, the output of the reference counter will go high first.

These outputs of the two counters feed a comparator circuit that has two outputs. The comparator generates at one output a positive-going pulse, if the carrier frequency is too low, or a negative-going pulse at the other output, if the carrier frequency is too high. The width of the output pulse is proportional to the carrier frequency error.

The output pulses are rectified and integrated to produce a dc control voltage applied to the varactor diode in the fmo. It is this control voltage that keeps the fmo operating at the desired frequency. If the open loop center frequency of the fmo varies by more than 4.5 MHz from the programmed frequency, the afc will generate a system alarm. Also the unit will prevent non-linear modulation of the fmo by clamping the dc control voltage to a value proportional to ±5 MHz from the programmed carrier frequency.

Deviation-Test Function

The function of the deviation-test circuitry is to precisely adjust (within ±0.1 dB) the modulation sensitivity of the transmit modulation amplifier/fmo unit combination. To make or check this adjustment, traffic must be removed from the baseband or switched onto the standby radio. During this check the 48.83 Hz sample signal from the reference counter, instead of the baseband signal, modulates the fmo. Correct setting of deviation sensitivity

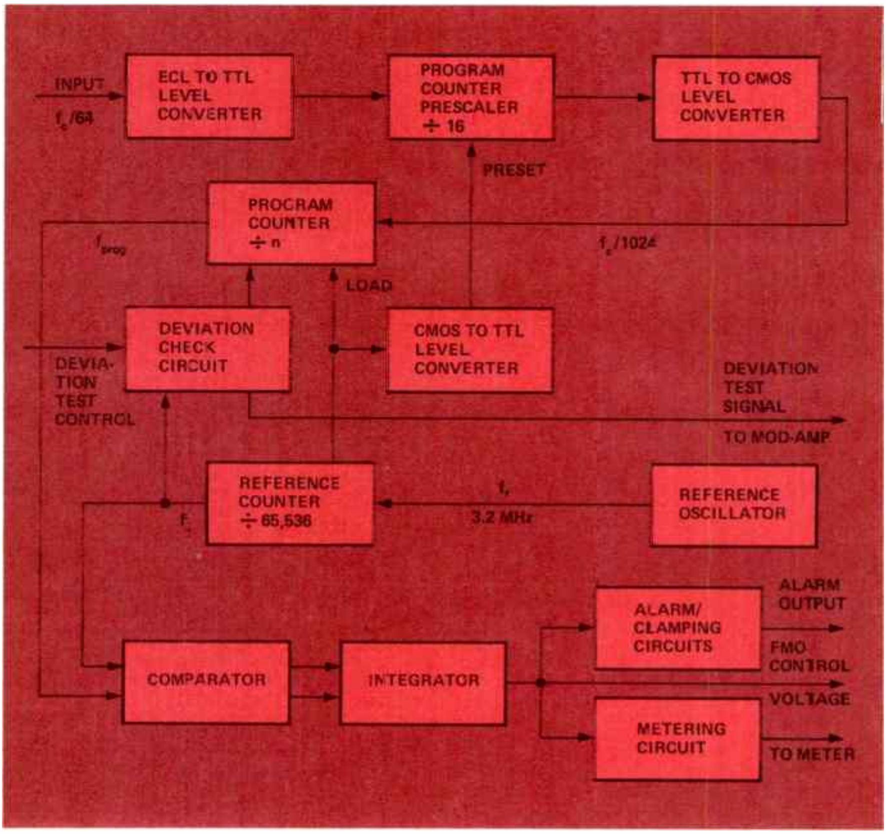


Figure 5. The primary function of the afc unit is to compare the divided frequency of the fmo to a very stable reference frequency and generate a dc control voltage proportional to the frequency error of the fmo.

is determined by observing the position of the pointer on the afc meter (see Figure 7).

The afc meter is calibrated so that the meter pointer will center on zero on the meter face when the open loop frequency of the fmo is equal to the programmed frequency. When the open loop frequency of the fmo is higher than the programmed frequency, the pointer will be to the right of zero; when lower, to the left of zero.

The measurement and adjustment of deviation sensitivity begins by tuning the fmo, if necessary, to bring the afc meter pointer near center scale. The deviation-test switch in the transmit baseband unit is then activated. One contact of the switch places a ground on the deviation-check-control lead. This changes the programmed frequency in the program counter 1 MHz above or below—determined by the position of one of the strapping plugs—the strapped-in frequency. The result is a difference of 1 MHz between the programmed frequency and the desired fmo frequency.

A second switch contact connects the 48.83 Hz sample signal from the

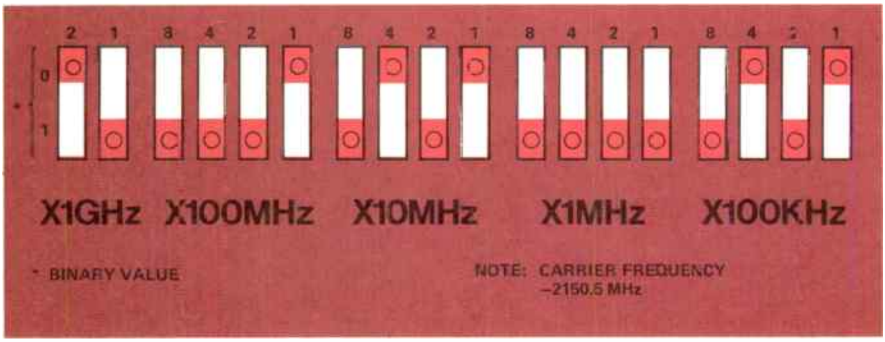


Figure 6. The positions of eighteen miniature strapping plugs are assigned binary values that represent the five most significant digits of the carrier frequency in binary-coded-decimal format. This is the program loaded into the program counter of the afc unit. The positions of the plugs in this figure represent a carrier frequency of 2150.5 MHz.

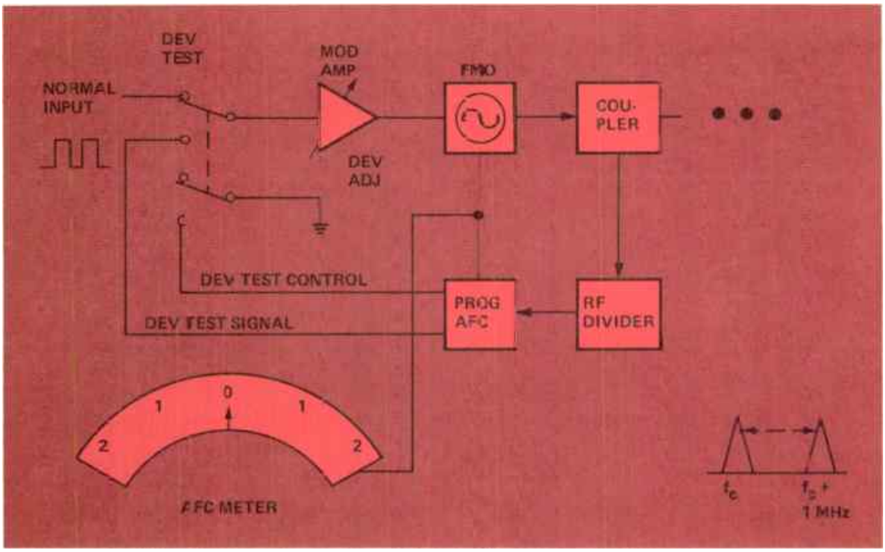


Figure 7. The deviation test circuit built into the transceiver shelf eliminates the need for external test equipment to set the deviation sensitivity of the radio.

reference counter to the modulation amplifier in the transmit baseband unit. The voltage level of the sample signal at the input of the modulation amplifier is precisely set, so that when the deviation sensitivity is properly adjusted, this sample signal, since it is a square wave, causes the frequency of the fmo to shift a certain amount in one direction during one-half of the square-wave cycle, and the same amount in the opposite direction during the other half. Recall that the afc unit only samples the frequency of the fmo during the negative half of the sample signal cycle. During this sample period the same half-cycle of sample signal is modulating the fmo, thus causing the frequency of the fmo to shift. The deviation-test circuit is arranged so that if the frequency shift of the fmo is exactly 1 MHz, the fmo will appear to the program counter to be on frequency, since the programmed frequency of the counter has also been precisely shifted 1 MHz. As a result there will be no change in the dc control voltage from the afc unit. Also, the position of the afc meter pointer will be the same as it was prior to activating the deviation-test switch.

If, on the other hand, the sample signal deviates the frequency of the fmo more or less than 1 MHz, the fmo will appear to be off frequency, and the control voltage and the position of the pointer will change. The deviation sensitivity control in the transmit baseband unit is then adjusted until the position of the meter pointer remains unchanged as the deviation-test switch is alternately depressed and released. The deviation sensitivity is then correctly set.

Although these new circuits are first appearing in a 2-GHz radio, their application is not limited to this band. Rapidly evolving solid-state technology is extending the operating frequency range of the transistor so that in the very near future these circuits can be used in radios operating in the higher frequency bands. Improved performance and reliability at significantly lower cost can then be realized in these radios as well.

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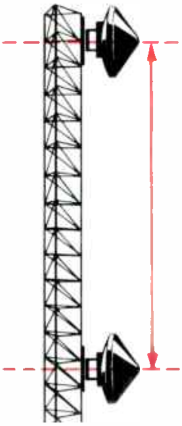

Differential Absolute Delay Equalization

Hot standby and space diversity configurations of equipment in a line-of-sight microwave radio system decidely improve the system's reliability. But there is an inherent problem in these configurations that, unless corrected, can degrade the system's performance to the point that it is unacceptable. The problem is differential absolute delay; the correction is equalization.

Reliability is one measure of the quality of a microwave radio system. It is that percentage of a definite period of time, usually several thousand hours, that the system probably will be, or actually is, usable. The two basic elements that enter into the determination of a system's reliability are the equipment and the propagation path. There is seldom a system outage that cannot be attributed to either equipment failure or path deterioration. Any method devised to reduce system outages caused by either or both of these elements obviously will improve the reliability of the system.

Failures in modern radio equipment are not nearly so frequent as they have been in the recent past. This is chiefly due to major improvements made in components and in the design of the circuits in which they are used. Nevertheless, failures still occur. Other means, therefore, continue to be used to safeguard against system outages due to equipment failures. Equipment redundancy in the form of hot-standby or protection channel switching continues to be an economical method of improving system reliability.

The two chief schemes devised to decrease the number of system outages due to the changes in the characteristics of the propagation path are space diversity and frequency diversity transmission. The FCC, in its efforts to conserve the frequency spectrum, now rarely permits the use of frequency diversity. Space diversity, on the other hand, is gaining widespread acceptance as an alternative to frequency diversity. Both techniques reduce the number of system outages caused by multipath fading. More information on the use of diversity techniques in microwave systems is provided in the March, 1961 and May, 1973 issues of the *Demodulator*.

Differential Absolute Delay

While hot standby and space diversity configurations of microwave radio enhance system reliability, they introduce into the system a signal transmission impairment commonly referred to as differential absolute delay. What differential absolute delay is and what causes it in these radio configurations can be more easily understood by referring to Figure 1. The figure represents a typical one-way space-diversity radio hop. At the receive end of the hop are two antennas vertically separated on the tower by a distance of 40 feet. A separate transmission line connects each antenna to separate radio

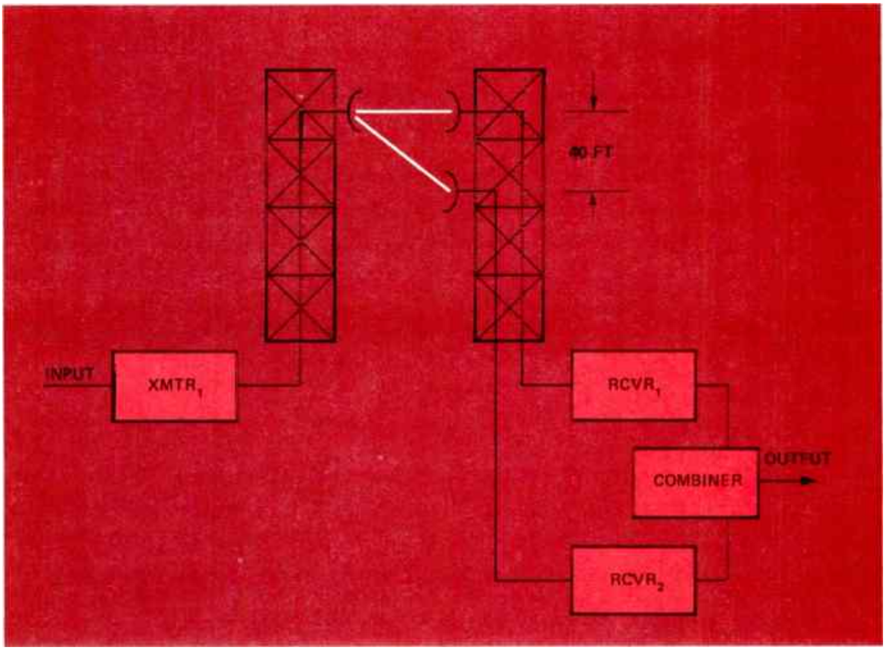

Figure 1. In a typical space diversity arrangement of a radio hop, the transmitted signal propagates over two separate paths to the receiving antennas.

receivers. The outputs of the two receivers are then combined into one signal path.

It is evident from the figure that once the signal is transmitted, it travels over two distinct paths before it is combined. All other elements and distances in the transmission path being considered equal, the signal arriving at the top antenna must travel through 40 more feet of transmission line than the signal at the lower antenna. Assume in this case that the transmitted signal arrives at the two receive antennas at precisely the same moment. Since electromagnetic waves require a finite period of time to travel through any medium from one point to another, the signal component from the upper antenna will appear at the output of the combiner later than the signal component from the lower antenna, because the distance it must travel is 40 feet greater. The difference in time between the appearance of the two signal components at the output of the combiner is differential absolute delay. The amount of differential absolute delay depends on the difference in the path length of the transmission medium and the velocity of propagation through it. If, in this example, the frequency of the transmitted signal is 6700 MHz and the transmission line is WR-137 waveguide, the signal will traverse about nine inches of waveguide every nanosecond (10^{-9} second). The difference in absolute delay of the two signal components then is approximately 53 nanoseconds.

In this example the difference in path lengths of the signal is attributed only to the difference in the lengths of the two transmission lines. Over a real space diversity hop of line-of-sight microwave radio, that difference is the major cause of differential absolute delay, but it is to be noted that other elements of equipment also contribute to it.

Effects of Delay

Previously when channel capacities of the baseband were less than 240 channels, little attention was given to differences in absolute delay. Its presence had very little impact on system performance. As the bandwidth of the baseband began to increase, however, concern over the detrimental effects of delay increased.

Basically, any difference in the delay time of corresponding signal components propagated over two separate paths creates a phase difference between the two signal components at the point where the two paths again become one. The amount of phase difference in the two signal components due to this delay depends on their frequency. Phase difference increases linearly as frequency increases. Although a few nanoseconds of delay at rf and IF frequencies result in several hundred degrees in phase shift, the shift is relatively small at baseband frequencies. Since it is only the effect that delay has on the message content of the signal that is of interest, attention is focused primarily on the amount of phase shift that differential delay produces in a signal near the top of the baseband spectrum. Figure 2 reveals the amount of phase shift that varying amounts of delay will produce in a signal at several baseband frequencies.

What effect this phase difference in signal components has on the signal itself depends on whether the two signal paths are combined or switched onto the single path, and whether the signal of interest is a voice or data signal. When the two signal components at the inputs to the baseband combiner are in phase and at the same level, their combined level at the output of the combiner is the same as the uncombined level of either at the input of the combiner. If there is a difference in their phase, and the difference is less than 360 electrical degrees, their combined level is less than the uncombined level of either. Theoretically, if the difference is precisely 180 degrees, the two combined signal components cancel one another and there is no signal at the output. Thus, difference in absolute delay affects baseband signal level. The amount of delay and the frequency of the baseband signal determine the amount of signal degradation.

If, on the other hand, the two signals are not combined, but alternately switched onto a common path, any difference in their phase has no effect on their respective levels at the output of the switch. Neither does phase difference have any perceptible effect on the message content of a voice signal as the two paths are switched back and forth. However, error-free transmission of data requires that the sequence and relative separation of data bits remain the same throughout their transmission. Synchronization of the data clocks must also be maintained. A phase difference in the two signals, as they are switched, can upset these characteristics of the data stream and cause data errors. If the phase difference is sufficiently large, the data channel can become totally useless for several minutes during those periods when active atmospheric conditions produce moments of very rapid switching between the two paths.

It is to be noted that the switch in this discussion is a high-speed switch that may be located in either the rf,

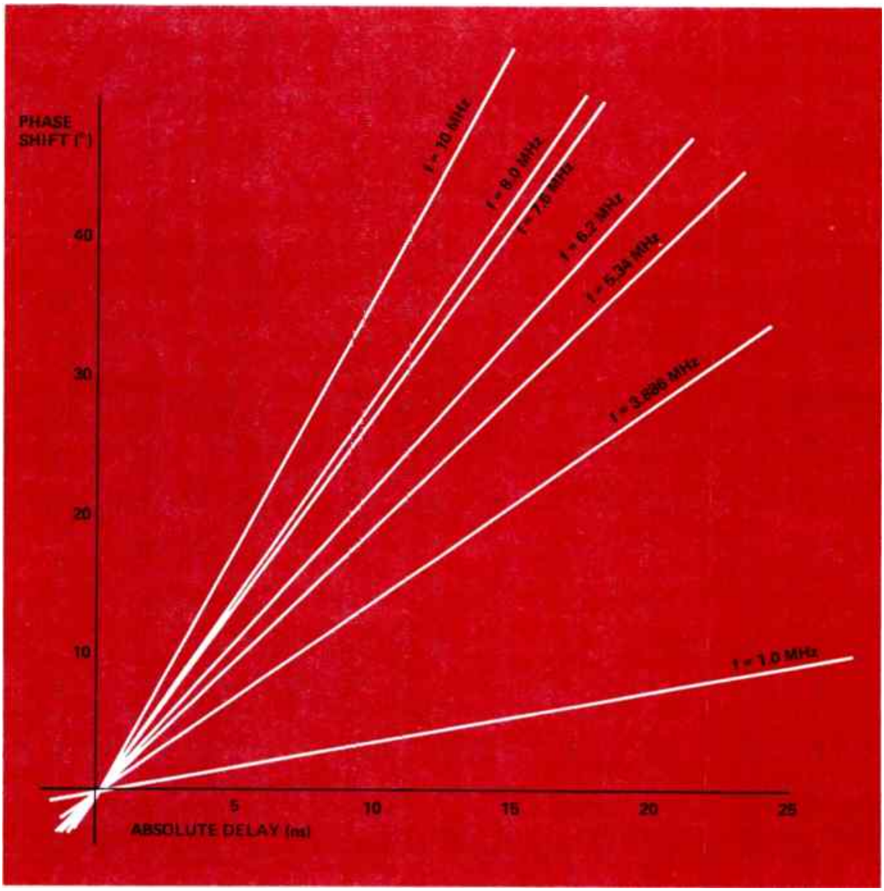

Figure 2. The phase shift between two signals increases linearly as the difference in their absolute delay and their frequency increase.

IF, or baseband section of the equipment. Operation of the switch itself may or may not cause data errors. But when this does happen, any phase difference in the switched signals is very likely to increase significantly the recovery time of the data signal.

Equalization

The solution to the problem of differential absolute delay in space diversity or hot standby radio configurations is to make the lengths of the two paths electrically the same. This procedure is called differential absolute delay equalization (dade).

The procedure is quite simple. It basically consists of determining the difference in absolute delay of the two signal paths and inserting additional delay in the shorter path to make its total delay equal that of the longer path. The absolute delay time of a signal is increased by increasing the amount of reactance in its path. This reactance added to the shorter path is sometimes in the form of a lumped constant type equalizer in which varying amounts of delay are inserted into the path by way of optional strapping. A more economical and usually more accurate method of adding delay is to increase the length of cable between the rf and IF sections of the equipment, or between the IF and baseband equipment. Where possible, lengthening of the cable between the rf and IF is preferred, since at baseband frequencies any increase in cable length adds slope to the frequency response of the baseband. No matter what means is used to add delay to the shorter path, it must first be determined which of the two paths is electrically shorter and by how much.

There are several methods of measuring the difference in absolute delay. Generally it is the type of radio and its configuration that dictate the method of measurement. These various methods of measuring the difference in absolute delay between two radio paths will be the topic of a future *Demodulator* article.

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Corrections: In the July, 1977 issue, Figure 1, a ground symbol instead of battery should appear on the M-lead relay in both signaling circuits. In Figure 3, the grounded contact on the M-lead in trunk circuit A was omitted in error. On page 8, the first sentence of the second paragraph should read, "Private branch exchanges (PBX's) and. . .are connected *together* by dual repeating tie trunks. . . . In the August, 1977 issue, Figure 8 is a typical AR0-type converter instead of an AR1-type.

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