The Lenkurt® Demodulator

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DATA TIMING

For HF Radio Transmission

Data transmission, by its very nature, involves a compromise between speed and error rate. Higher speed demands a shorter time interval for each information bit; and reduced bit length usually means more errors, particularly in high-frequency radio transmission, where path conditions may vary from moment to moment. This article discusses some of the problems inherent in the transmission of data over HF (3 to 30 Mc) radio, and describes how high transmission speed can be attained while maintaining the relatively long bit length necessary for a low error rate.

The transmission of information in digital form has grown tremendously in recent years, due in large part to the increased use of computers, but also stimulated by the increase in communications between people. Part of this additional communication goes over telephone circuits as analog signals; but a large portion is transmitted in digital form. This includes various types of printed messages, as well as facsimile. Furthermore, digital voice transmission is being used more widely, particularly for "secure" communications. where privacy is vital.

The result is increased demand for transmission facilities for long-distance digital data communication. For overland links, there is likely to be a variety of facilities available, but when an ocean must be spanned the present choice is either submarine cable or HF radio. Submarine cables are usually both crowded and expensive, but often their biggest disadvantage is that they don't go where the prospective user needs them. If no transmission facilities exist between the points to be linked, and new ones must be installed, radio is almost certain to be the choice, whether it is judged by cost or by installation time. Thus, radio is quite attractive.

Historically, data transmission on HF radio has been either slow or unreliable. Often it has been both. Recent efforts aimed at increasing both the speed and reliability of HF data transmission have shown considerable success, but many problems which are unique to HF radio have been encountered.

The HF Transmission Problem

For distances longer than about a hundred miles, HF radio transmission depends entirely upon the ionosphere, a region of charged particles high in the earth's atmosphere. Unless the radio beam is refracted (bent) by the ionosphere, little or no propagation path exists beyond the earth's curvature and the signal will not reach a distant receiver. For this reason, the quality of HF radio transmission is intimately involved with the behavior of the ionosphere.

The ability of the ionosphere to refract or absorb radio waves is directly dependent on the density of the negatively charged particles, the free electrons. The free electron density is controlled by several factors, but by far the most important is solar activity. In fact, the action of the sunlight in ionizing the rarified air is primarily responsible for the existence of the ionosphere. Hence, the free electron density is much greater during daylight than it is at night.

Although the return of radio energy to the earth by the ionosphere is commonly called "reflection," it is actually a form of refraction which is controlled by both the frequency of the signal and the density of the electrons. At higher frequencies the radio wave is refracted less than at lower frequencies. For any given frequency, the greater the electron density the greater the refraction or bending of the wave. In other words, the *index of refraction* of the ionized medium, which determines the amount of deflection of the ray, is a function of both the electron density and the operating frequency. The operating frequency is important because if the frequency is too high, the radiated energy goes right on through the ionosphere. Conversely, if the frequency is too low, the beam is effectively absorbed by the ionized layer, and little or no energy reaches the receiver.

One of the main complications in using the ionosphere for radio transmission is the fact that it is nonhomogeneous. In some places the electrons are grouped together in bunches, while in other places there are "holes" in the ionosphere. The effect is much like a layer of broken or scattered clouds. To further complicate matters, the whole ionosphere is constantly shifting. Thus, where at one moment the free electron density is high in a given spot, at the next moment the density may be so low that a radio signal can pass straight through and be lost in space.

This erratic behavior of the ionosphere has several important effects on HF radio transmission. One of the more important of these is called the "multipath effect." Multipath effects occur when two transmitted signals take a slightly different path from the transmitter to the receiver. The result, of course, is that the two signals arrive at the receiver in a slightly different time relationship, due to the different lengths of their propagation paths. One of the most common ways for this to happen is for one signal to take a "one-hop"

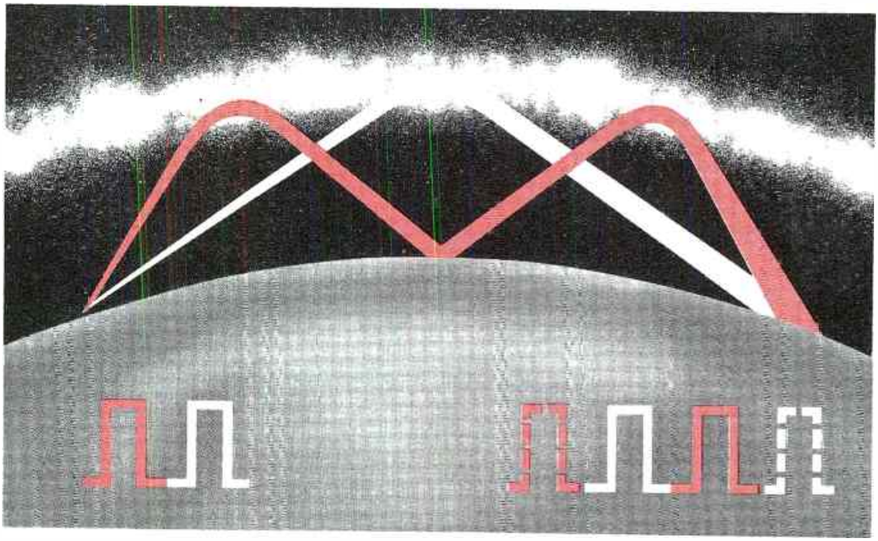

Figure 1. Multipath effect occurs when signals take different paths from transmitter to receiver, arriving in a different time relationship.

path while the other signal takes a "two-hop path" as illustrated in Figure 1.

This simply means that one signal is deflected only once by the ionosphere while the other signal is deflected three times—twice by the ionosphere and once by the earth. In the illustration, pulse two is transmitted after pulse one, but because of the difference in path length, pulse two arrives before pulse one. Or, if the difference in transmission time is not so great, the two pulses may arrive simultaneously. When this effect occurs in a high-speed data stream, several pulses may be overlapped or "smeared." The same effect may occur when the same pulse takes both paths simultaneously. The difference in propagation time makes the receiver see two pulses, often overlapped. This smearing effect is what limits the minimum acceptable pulse length for data transmission on HF radio.

Solving the Bit-Length Problem

From a qualitative viewpoint, reducing the speed of data transmission can be likened to introducing redundancy. Holding a mark or a space for a longer period of time has somewhat the same effect as sending the same information bit more than once. In either case there is a better chance that it will be correctly identified.

To avoid the garbling caused by the smearing which occurs in the HF path, however, it is often necessary to use such a long bit length that transmission speed is severely restricted. For example, consider an HF path of 4,000 miles, with a propagation time of about 22 milliseconds. A bit length of perhaps 2 to 4 milliseconds would be required to counteract the multipath effects. Thus, the data transmission speed over a single channel is limited to 250 to 500 bits per second, *regardless of the bandwidth* *of the channel*. The same channel on cable (assuming a 3-kc voice channel) would have a data capacity of perhaps 2,000 to 3,000 bps (probably 2,400 bps, a common data-transmission speed over a 3-kc channel).

One solution to this problem is to divide the single serial data stream into several parallel streams which together provide the same total transmission capacity. This way, bit length can be increased without reducing speed or using more bandwidth. For example, suppose that a standard 3-kc HF radio channel is available for the transmission of 2,400 bits per second. The bit length at this speed is 0.42 millisecond. If, however, the 2,400-bps serial stream is split into 16 150-bps channels, the bit length in each of these slower channels is 6.67 milliseconds — 16 times as long as it would be in the single channel. Since these 16 channels operate at much lower speeds, they require less bandwidth, and can be frequency-division multiplexed into the single 3-kc voice channel.

This arrangement effectively solves the bit-length problem, but it introduces another complication. In order to reconstruct the 2,400-bps serial data stream, the 16 parallel channels must be recombined at the receiver. If the information bits which make up a single word are distributed among several channels, it is apparent that they must be rearranged in the same order at the receiving end.

But because of the nature of HF radio transmission, each of the sixteen channels is likely to have a slightly different propagation path. The channels are also likely to have different fading characteristics because they are at slightly different frequencies, and are not affected identically by the ionosphere. The usual practice in HF radio is to use *space-diversity reception* to counteract fading. In such a diversity arrangement, two receivers are used with antennas separated by several wavelengths. This minimizes the possibility that the signals received by the two receivers will fade simultaneously. The signals from the two receivers are put together in a combiner.

Because the sixteen channels are all at different frequencies and have different fading characteristics, it is entirely possible that at a single instant some channels will be stronger at receiver A,

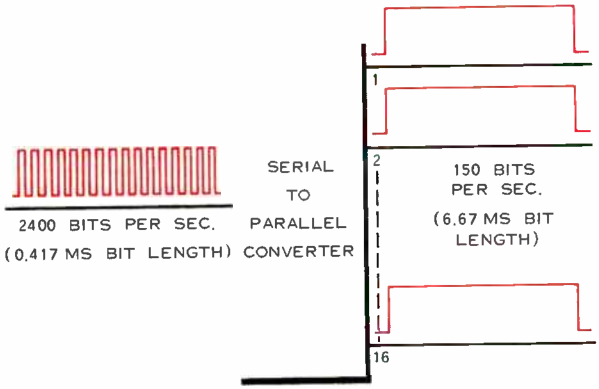

Figure 2. Use of 16 150-bps channels rather than one 2400-bps channel permits bit length 16 times as long while requiring no more bandwidth.

while the other channels will produce a stronger signal at receiver B. This further complicates the recombination because the filters used in the two receivers may have different delay characteristics. This delay variation, added to the difference in propagation time between the various channels, produces a real timing

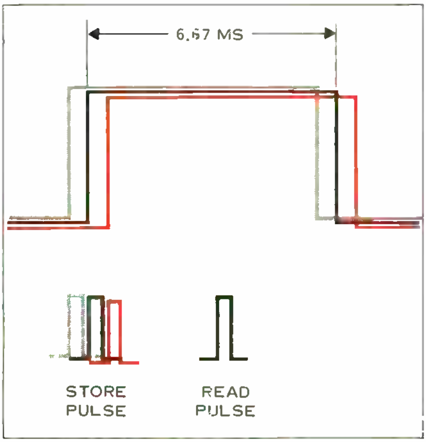

Figure 3. Optional synchronizer has 6.67-millisecond storage capacity. Read-out rate is fixed, while storage is controlled by phase-corrected pulses from phase resolver.

problem at the receiving end. The channels cannot simply be brought together and combined into a serial stream, because it is likely that the information from one channel would be placed "on top of" the information from another channel. In effect, this would be multipath smearing again.

Furthermore, because of rapid shifts in the ionosphere, the total path length changes with time. The result is that the number of information bits "in the air" at any instant varies. In other words, even though the data is being transmitted at a constant rate, it is received in bunches or groups of information bits. The long-term output rate is equal to the transmisison rate, but the short-term output rate varies. For some purposes, this non-uniform data stream is perfectly acceptable, while for other uses it must be retimed. For example, if the equipment is being used with vocoders for digital voice transmission, the non-uniformity of the data stream will probably have little effect. On the other hand, for some computer applications the data stream must be phase locked to a highly stable clock.

Retiming

A good example of how the serial stream may be reconstructed is provided by Lenkurt's Type 27A Data Terminal. Since the 27A uses Lenkurt's Duobinary Coding technique (see THE LENKURT DEMODULATOR, February, 1963), which effectively halves the required bandwidth for a particular bit rate, its operation at 2,400 bps is much like that of conventional binary equipment operating at 1,200 bps. The retiming problems, however, are similar regardless of the coding techniques used.

The receive timing system of the 27A has two automatic adjustments. One follows the short-term (fractions of a second) phase variations between the 16 channels to provide a single sampling instant for all channels. The other varies the long-term (several minutes) data read-out rate to match the transmission rate.

Figure 4 is a simplified block diagram of the data timing system used in the 27A receiver. An adjustable crystal oscillator generates a timing signal at the same frequency (nominally 2400 cps) as the data-transmission rate. This "clock" signal is fed to a phase resolver which adjusts the phase of the clock signal to follow the short-term phase variations in the received data. The phase-corrected output from the phase resolver goes to the sampling circuits for the 16 150-bps channels (after being counted down to 150 cps), causing them all to sample their incoming signals at the same instant.

This phase-corrected signal also goes to the phase detector, where it is compared to a composite signal from the 16 incoming channels. This composite signal indicates the *mean* phase of the channels, thus providing a reference for correcting the clock signal. The phase detector produces an output which is proportional to the phase difference between the corrected clock signal and the composite received-data signal. The error signal goes to a servo which reduces the error signal to zero by adjusting the phase resolver.

The servo is also connected to the crystal oscillator. The oscillator, however, has a long response time, and is unaffected by rapid fluctuations. Its function is to adjust slowly to long-term variations in the transmitted data rate.

The oscillator output may also be used to control the read-out rate from an optional synchronizer, which provides a completely uniform data stream for some applications. The synchronization is accomplished by a "buffer" shift register in each of the 16 channels. Its purpose is to store extra data when the input is temporarily too fast, and to provide a "reservoir" for the read-out to draw on when the input is temporarily too slow.

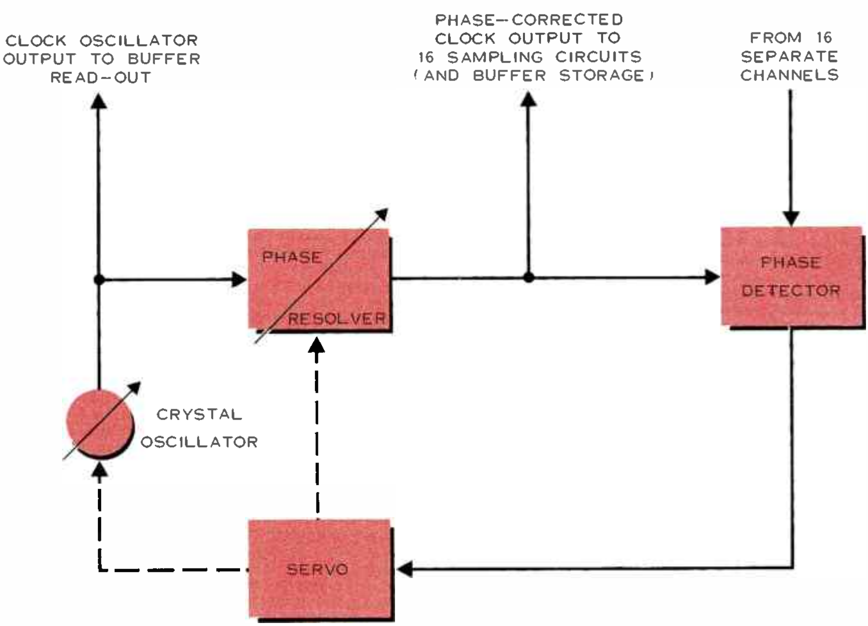

Figure 4. Simplified block diagram of timing system used in Lenkurt's Type 27A Data Terminal. Dotted lines indicate mechanical links from servo to phase resolver and oscillator.

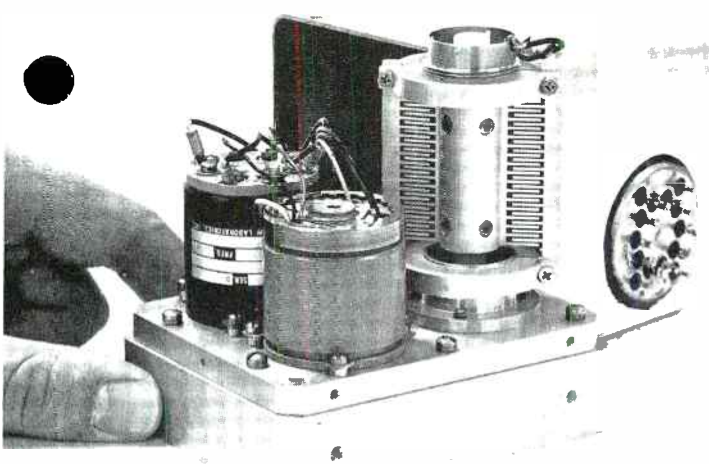

Figure 5. Mechanical action in 27A timing system is provided by motor (left) which drives phase resolver and variable capacitor. Phase resolver follows short-term variations in data rate, while capacitor permits oscillator frequency adjustment up to plus or minus 20 parts per million.

The shift register has a storage capacity of one bit length — 6.67 milliseconds. (The same effect could be obtained by putting a shift register with a 16-bit capacity in the serial stream. Again, the storage capacity would be 6.67 milliseconds.)

Figure 3 illustrates the operation of the synchronizer The read-out rate is fixed, controlled by regular pulses from the oscillator. However, the input rate to the shift register is controlled by a non-uniform series of phase-corrected "store" pulses from the phase resolver. The nominal read-out point is the center of the pulse, but it can vary across the whole width of the pulse. This provides a tolerance of plus or minus 3.33 milliseconds to allow for rapid variations in path length, and hence in propagation time. In the highly unlikely event that the read-out were to "run off the end," it is automatically reset to the center with a loss of only 8 serial bits.

Conclusion

The problems posed by the transmission of data over HF radio are somewhat different from those encountered in transmitting voice over similar facilities. One of the main differences is the lack of redundancy in data, whereas speech may include 75 percent redundant information. When a bit is lost from a data stream, an error results. But when a portion of a word is lost from a sentence, the meaning is usually clear from the context. This is one reason why data transmission puts more severe requirements on HF radio than does voice transmission.

One of the more pressing of the problems has been that of timing the data to achieve both speed and reliability. The solution has not been simple, but it has proven practical. The result is that HF radio is now taking its place as a reliable, as well as economical, medium for high-speed data transmission. •

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Data Terminal for HF Radio

The recently introduced 27A DUOBINARY-DATATEL* applies Lenkurt's exclusive Duobinary coding technique to HF radio transmission. The 27A transmits serial binary data at 2400 bits per second over a single 3-kc voice channel on HF radio. Equipment features and performance are described in a new publication, Form 27A-P4, available on request from Lenkurt or any Lenkurt field office.

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