# The Lenkurt® DEMODULATOR

1969
ISSUES

The Lenkurt®

# DEMODULATOR

# 1969
# ISSUES

LENKURT ELECTRIC
GENERAL TELEPHONE & ELECTRONICS

**LIMITED EDITION**
**Price $3.00**

Printed in the United States of America

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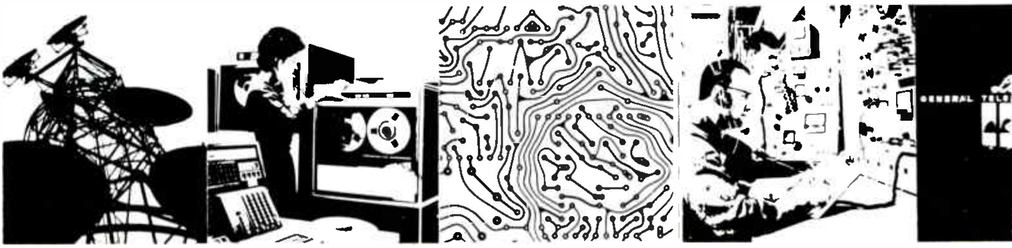

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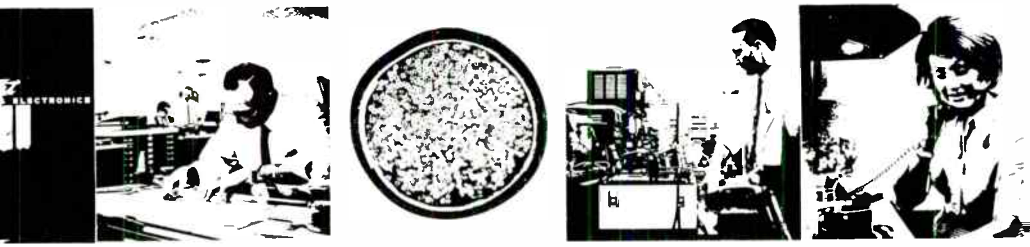

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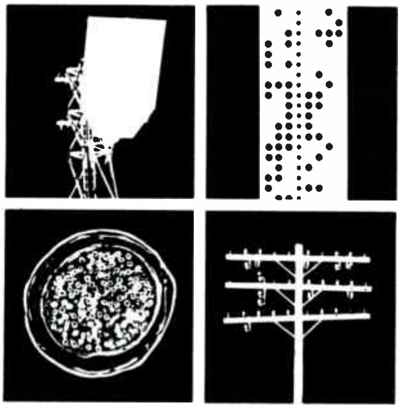

The **Lenkurt Demodulator** is a technical periodical published monthly and circulated without charge within the telecommunications industry and to educational institutions.

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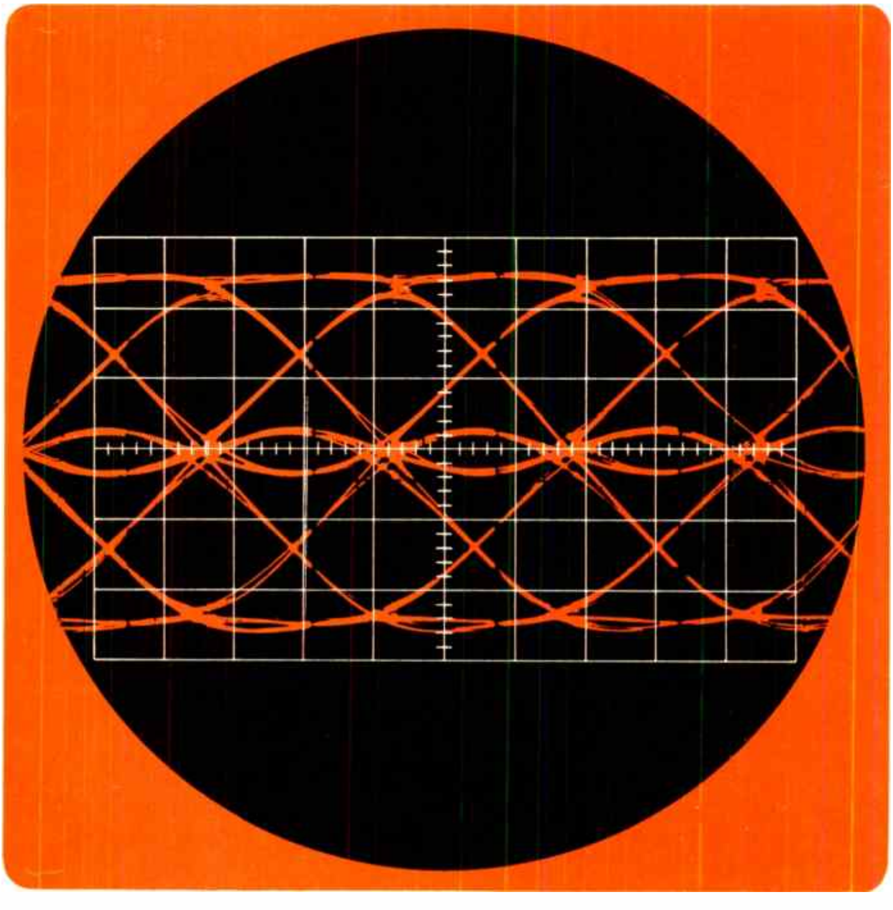
JANUARY 1969

DEMODULATOR

# Circuit Conditioning Part 1



## Data transmission speeds go higher and higher and line quality requirements increase correspondingly.

Quality, in a communications circuit, is relative. The same circuit may perform flawlessly for voice communications and not handle data traffic at all satisfactorily. Before the recent upsurge in the amount of digital traffic being handled by common carriers, this was not an especially serious problem. But nowadays, data is demanding an increasing amount of the telephone industry's attention. They are faced with the pressing requirement to improve their networks to more efficiently handle digital type traffic.

Since it is not feasible to replace all existing voice-grade circuits or to install whole new networks dedicated to data transmission, the obvious solution is to upgrade existing circuitry.

Two phenomena cause most of the difficulties encountered in attempting to send digital data over voice circuits. They are delay distortion and amplitude distortion. But both can be overcome by proper conditioning of the circuit. The Lenkurt 971B Adjustable Equalizer is designed specifically to cope with problems of distortion in voice circuits intended for data traffic. It corrects for both amplitude and envelope delay distortion, and conditions circuits to meet C–1, C–2, C–3 and C–4 standards.

### Delay Distortion

Delay distortion of electrical signals is a type of distortion caused by the non-linear phase delay-versus-frequency characteristics of a communications circuit.

In voice-frequency transmission facilities, such distortion is caused mainly by the capacitive and inductive effects of transformers and amplifiers at the low frequencies. At the higher frequencies it is caused by loading coils and line capacitance. In carrier transmission facilities, channel bank, group, supergroup, and mastergroup transformers and filters are the main causes of delay distortion.

Delay distortion is not a problem until it begins to interfere with the ability of the communications receiver to understand the information contained in the signal. In the case of speech transmission, delay distortion has not been a problem, since the human ear is relatively insensitive to variations in phase-versus-frequency relationships.

However, digital signals are quite vulnerable to the effects of delay distortion. Data bits usually originate as rectangular-shaped pulses which are used to modulate a carrier at a particular keying rate for transmission over a communications circuit. The analagous AM or FM signals resulting from this modulation process are composed of many frequencies.

The envelope of these signals results from energy at the fundamental and harmonic frequencies adding together vectorially. If such a signal passes through a circuit with non-linear phase-versus-frequency characteristics, it becomes severely distorted. In fact, the signal energy may "spread out" to the point where adjacent pulses begin to interfere with one another. Under such conditions, the data receiver may not be able to properly detect the information content of each bit, (for example, a binary 1 may be detected as a binary 0, or vice versa).

When considering the cause of delay distortion, it should be noted that an appreciable impedance mismatch between line sections or between the line and office apparatus will influence the distortion characteristics of the facility. The presence of reflected currents sometimes causes an overall distortion much different from that which is indicated by analyzing the individual facility components. This is particularly noticeable at low frequencies or with short lengths of line, where the loss is relatively low, and reflection and interaction effects are consequently greater. In the case of long loaded cable circuits, manufacturing tolerances and subsequent treatment of cables can cause appreciable variation from the delay determined by formula or from typical curves. Another problem is the spacing of load coils which varies from the ideal because of the necessity for spacing coils according to the location of manholes or telephone poles.

## Measurement Techniques

There are two common techniques used to measure delay distortion in communications circuits. One consists of measuring phase shift, either with a phase meter or by means of an oscilloscope Lissajous pattern – a method mainly used in the laboratory. It is a tedious procedure because phase shift-versus-frequency must first be computed and then point-by-point slope measurements made to derive the delay curve.

This method requires accurate frequency measurement and is suitable only when both terminals of the circuit are available at the same location. The method is also occasionally used for transmission circuits where two similar circuits exist so they can be "looped back" to the measuring point. Figure 1 is a curve of frequency-

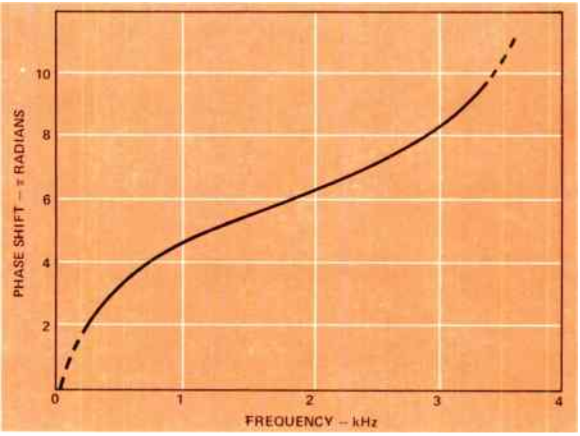


*Figure 1. Frequency/ Phase Shift Characteristic's of Typical Communications Channel.*

versus-phase for a typical communications channel.

The second technique consists of measuring the envelope delay characteristics of a circuit rather than the frequency/phase-shift characteristics and is relatively easy to accomplish.

Envelope delay of a particular frequency is equal to the slope of the phase-frequency curve at the specific frequency. Therefore, envelope delay can be determined by measuring the phase shift of two incremental frequencies and then computing the slope. The degree of resolution of the measurement depends upon the incremental spacing of the two frequencies used to determine the slope characteristics. The closer the spacing the greater the resolution of the measurement.

Measuring the slope at various points throughout the passband of a circuit provides an indirect indication of the phase-versus-frequency characteristics of the circuit.

However, it is not necessary to use two incremental frequencies to make such a measurement. The usual practice is to transmit an amplitude modulated carrier through the circuit under test, and measure the resulting phase shift of the modulation envelope. The result is the same as measuring the slope of two incremental frequencies, and the measurement concept employs much simpler computational techniques.

When transmitting an amplitude modulated carrier through a circuit, energy at the carrier and upper and lower sideband frequencies will be displaced in time according to the frequency/phase characteristics of the circuit. This is illustrated in Figure 2. It means that the envelope of the signal will shift in phase from the carrier by an amount equal to the mean value of the slopes of the two sidebands (assuming both sidebands are equal in amplitude). The amount of this phase shift is called *envelop delay.*

As a rule, the lower the modulating frequency, the more the envelope phase shift approaches the actual value of the slope of the phase shift at the carrier frequency. It can be assumed in practice that the envelope phase shift of the amplitude modulated carrier is equal to the slope of the frequency/

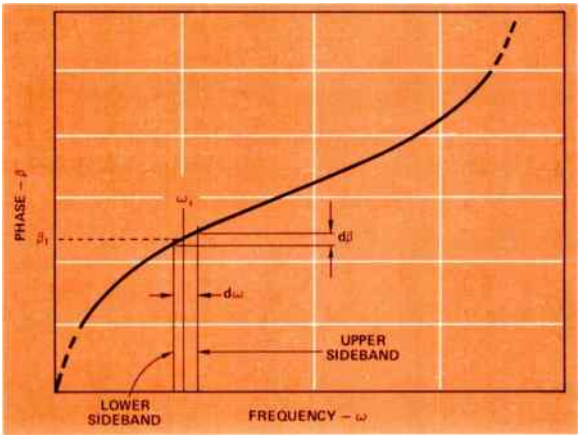


*Figure 2. Envelope Delay at Amplitude Modulated Carrier Frequency* $\omega_1$.

phase curve describing the circuit at the carrier frequency. (See Figure 2). This means that if the amplitude modulated test signal is tuned or swept across the band of interest, the envelope phase shift detected at the receiving end of the circuit provides an indirect measurement of the frequency/phase shift characteristics of the circuit. A curve of envelope delay-versus-frequency for a typical communications circuit is shown in Figure 3.

Delay measuring test sets have been developed to measure envelope delay in communications circuits. An example of such a set is the Sierra Model 340B, shown in Figure 4. The set generates an amplitude modulated carrier that can be manually adjusted or electronically swept over a frequency range corresponding to voice band, standard group and supergroup circuits. The carrier is usually 50 percent amplitude modulated with one of three frequencies.

As mentioned previously, the lower the modulating frequency the more meaningful the measurement. However, variations in envelope delay are difficult to measure accurately if the frequency is too low and a compromise is usually reached. Three modulating frequencies, 25 Hz, 83-1/3 Hz, and 250 Hz, have become somewhat standard throughout the communications industry and are employed in most delay measuring test sets.

The test set also processes the modulated signal after it has traveled through the communications circuit. The phase shift encountered by the envelope with respect to the carrier is measured by a zero-crossing detector. The difference in phase is read directly on a digital display or meter as delay in microseconds. Typically, these test sets are capable of measuring delays as great as 20 milliseconds.

It is important to realize that the absolute envelope delay at a particular frequency is of no immediate concern in equalizing a circuit. It is only the *relative* delay that is important. This is the term used to express delay distortion performance requirements in communications standards. Relative delay is the difference between the envelope delay (in microseconds) measured at some frequency within

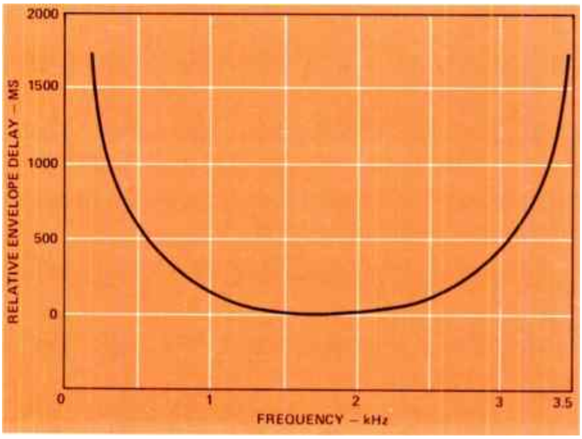


*Figure 3. Typical Relative Envelope Delay — 46A Channel Equipment (Measured With Channel Units Back-To-Back).*

*Figure 4. Envelope Delay Test Set*

(Courtesy Sierra Electronic Operation, Philco–Ford Corp.)

the band of interest and a reference delay and frequency established within the same band.

In performance standards, envelope delay distortion is usually expressed as a maximum difference in envelope delay (in microseconds) between two frequencies within the passband of the circuit. For example, the envelope delay standards for a telephone trunk circuit might read:

> "Envelope delay distortion shall not exceed:
> 80 microseconds between 1000 and 2600 Hz.
> 250 microseconds between 600 and 2600 Hz.
> 500 microseconds between 500 and 2800 Hz."

This means that the difference in envelope delay (in microseconds) between any two frequencies between 1000 and 2600 Hz cannot exceed 80 microseconds, and so on. Using a delay measuring test set, the envelope delay characteristics of a circuit can be determined very quickly to see if they meet these requirements.

Such a test can be accomplished by tuning the amplitude modulated carrier to a series of discrete frequencies across the band of interest (i.e. 1000 to 2600 Hertz), and manually recording the relative envelope delay reading at each frequency on the receiver of the test set.

Alternatively, the carrier can be electronically or manually swept across the band of interest and the envelope delay information recorded on an X–Y recorder or viewed on an oscilloscope.

Subtracting the minimum delay reading from the maximum delay reading provides a measure of the envelope delay distortion for the particular passband. If the difference between 1000 and 2600 Hz is greater than 80 microseconds, then the delay performance of the circuit will not meet the standards described in the example and the circuit must be equalized.

## Delay Equalization

It is not always necessary to measure the delay characteristics of a circuit to equalize it for data. There is a technique for equalizing a circuit known as the "eye pattern" method which is useful when conditioning a circuit for a particular data modem.

With this method, a data modem such as the Lenkurt 26C which has its own test pattern generator is placed in the circuit with the modulator generating a random data pattern. An oscilloscope is connected to the data receiver (or demodulator) and synchronized with the receiver clock. The overlapping traces viewed on the oscilloscope provide an indication of the amount of phase distortion present in the signal.

Equalizers can be added to the circuit and adjusted until the distorted eye pattern improves. This technique, although it does not assure that the circuit is equalized to certain specified limits, does provide the fastest adjustment to optimum setting for the particular data modem involved.

The job of equalizing a telephone circuit for data transmission has been greatly improved through the use of delay measuring test sets and variable equalizers. Most of the delay measuring test sets provide analog output voltages that are proportional to the carrier frequency and envelope delay detected in the receiver. These voltages are used to drive an oscilloscope or an X–Y recorder to provide a visual display of the relative envelope delay-versus-frequency characterisitics of a circuit. Such visual information is extremely helpful when attempting to equalize a circuit.

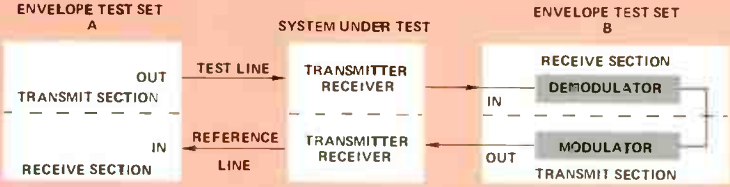
There are several methods of setting up delay test sets to measure the envelope delay characteristics of a circuit such as *loop back*, *end-to-end with return reference*, and *end-to-end*, as shown in Figure 5.

The loop-back method is used primarily in the laboratory or in factory tests to measure the envelope delay characteristics of a circuit when both ends are available at the same location. The end-to-end with return reference method generally provides the most accurate measurement of a circuit because of better synchronization between the transmitter and receiver of the test set.

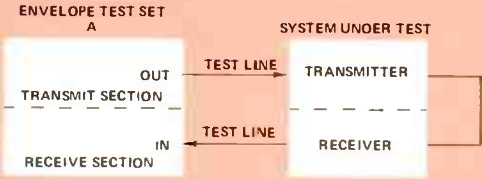
The first step in equalizing a circuit with a delay measuring test set is to establish the test arrangement. The end-to-end method is generally the most convenient.

In such an arrangement, an operator is required at each end of the circuit with an order wire facility so that the operators can talk to each other. At the transmit end of the circuit the terminal equipment is removed and the delay test set transmitter connected in its place. The test set receiver is then connected to the opposite end of the circuit. An X–Y recorder can be connected to the receiver to facilitate equalizing the circuit.

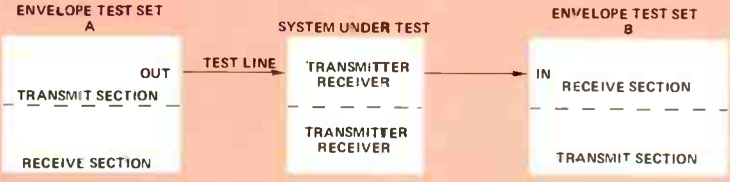
It is important to understand that the absolute delay within a circuit cannot be reduced. Equalizers correct,



A. END–TO–END WITH RETURN REFERENCE



B. LOOP BACK



C. END–TO–END

*Figure 5. Envelope Delay Test Sets, Test Arrangements*

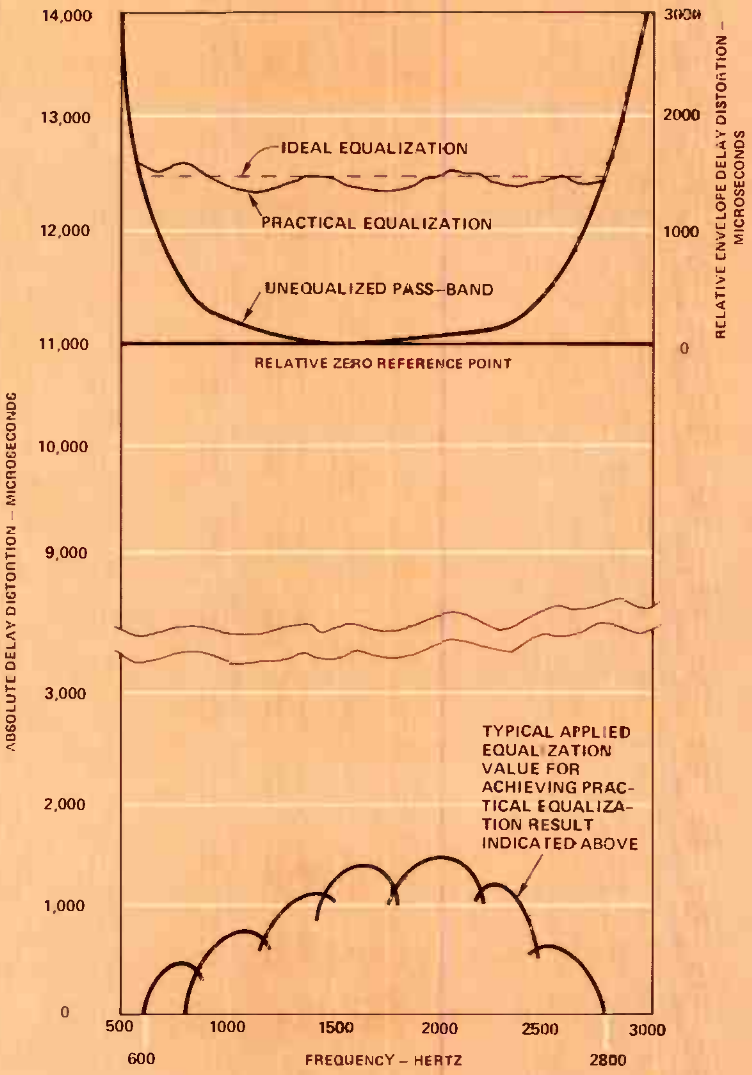


*Figure 6. Relationship of Relative Envelope Delay Distortion To Absolute Delay Distortion.*

at a specific point in the circuit, for relative values of delay (and associated amplitude) distortion across the passband. This point is usually at the receiving end of the circuit. Fundamentally, relative delay distortion is corrected by adding extra delay to those areas in frequency where the signal distortion value is low. This effectively flattens the passband by setting the overall distortion levels, across the band, at the value of the worst (highest) condition. Even though system end-to-end absolute (total) delay has been increased slightly for certain frequencies, the conditioned signal will display very little effect from these forms of distortion.

Relative delay distortion is usually determined by establishing, individually, the lowest respective delay value and corresponding frequency within the passband as the reference point and comparing the values at other frequencies with this point of reference. For most applications, the reference point is arbitrarily set at zero microseconds of delay. In this way, measurements made at discrete frequencies within the passband of the circuit will all read as positive numbers. Occasionally, the point of zero reference is set at a specific frequency, such as 1500 Hz. In this event, values of distortion throughout the passband may appear both as positive and negative numbers with respect to the reference point. Figure 6 shows the relationship between relative and absolute delay distortion.

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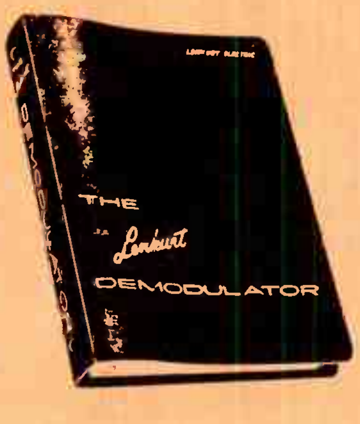
The February, 1969 DEMODULATOR, Circuit Conditioning, Part 2, will discuss amplitude distortion and the means for coping with it.



# To Our Readers...

Regrettably, increased costs force us to change the price of the *Demodulator* three-ring binder. In an effort to make the price equitable to *all* of our subscribers, we have decided to set the new price at $1.00 each to both domestic and overseas readers. This will cover both the higher cost to us as well as the increase in mailing and handling charges.

New subscribers will be interested to know that one binder will handily accommodate two full years' issues of the *Demodulator.*

**The Editor**

**LENKURT ELECTRIC CO., INC.**
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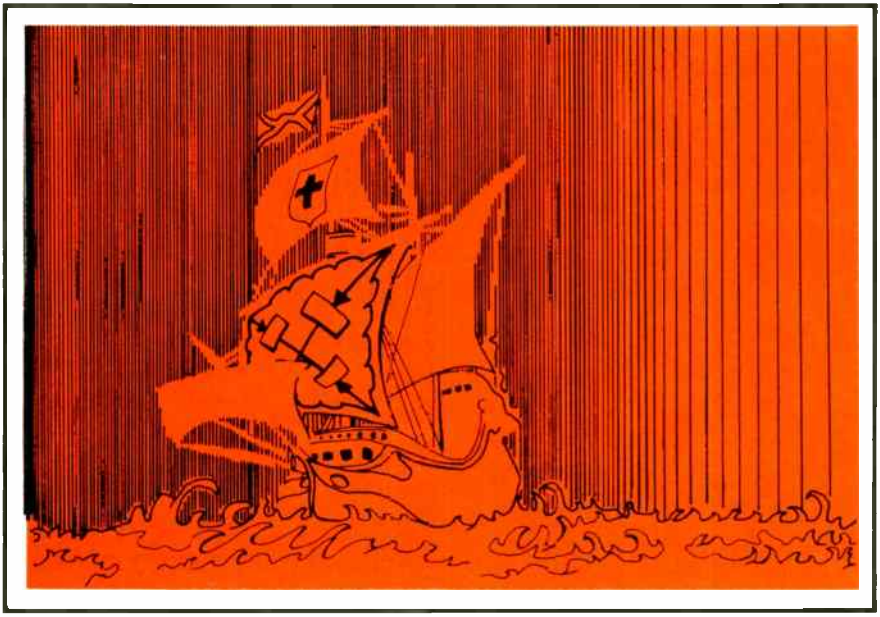
# OUR SHIP IS IN



At long-last, the Demodulator reprint book, *Selected Articles from the Lenkurt Demodulator*, is available again. The quality and value are the same, and so is the price — $5.00 domestic and APO/FPO, $7.50 foreign. Reprint books and any other information about the "Demod" can be obtained by writing Lenkurt, Dept. A134.

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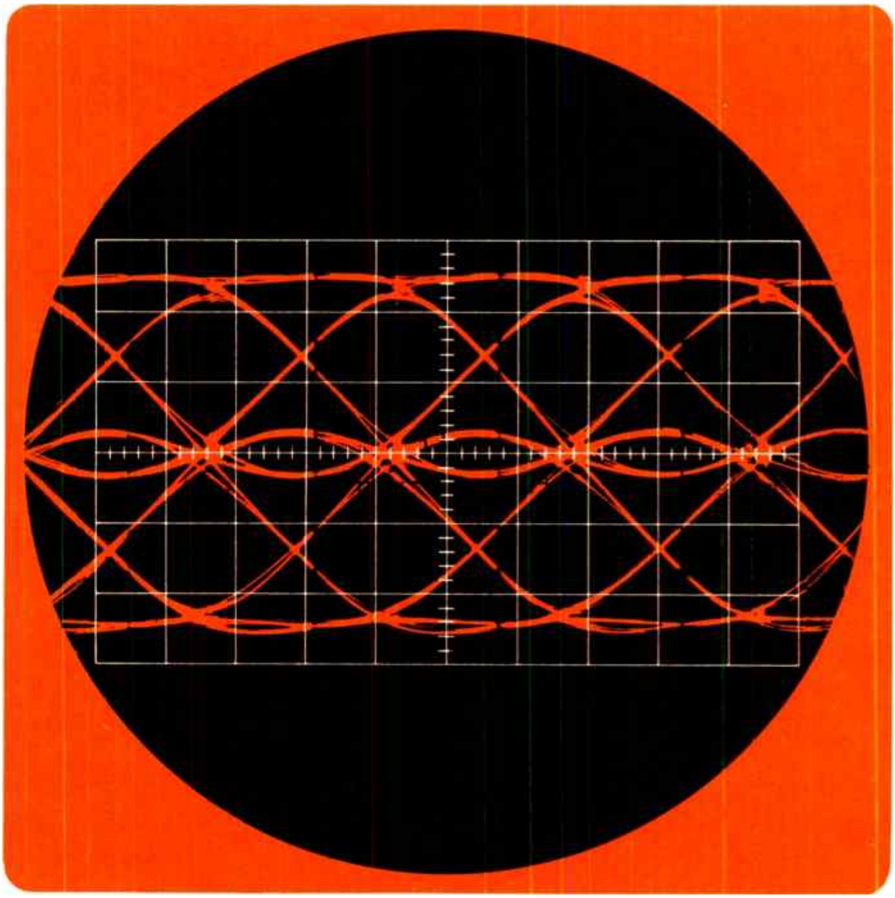
The Lenkurt® DEMODULATOR

FEBRUARY 1969

# Circuit Conditioning Part 2



# Amplitude distortion creates unique problems for data transmission over VF facilities.

Even though amplitude and delay distortion are not *necessarily* related and do not *always* appear in the same circuit, their causes are much the same. However, they are still two separate and distinct phenomena – consequently the means for correcting them will also differ.

By definition, amplitude distortion is a variation of loss or gain with frequency. It has two distinguishing characteristics – band edge roll-off and in-band ripple.

Band edge roll-off is usually caused by filters in a voice multiplexing system, or by loaded cable, or by high pass characteristics of transformers and series capacitors. In-band ripple is caused principally by impedance mismatches and their attendant reflection.

## Data Distortion

For frequency division multiplexing (FDM) equipment such as the Lenkurt 25B or other low speed data transmission systems, band edge distortion in the voice channel may be so severe that it is impracticable to obtain more data channels by equalization. In-band amplitude ripple or delay distortion, however, is seldom so severe as to affect these low-speed channels. Therefore, equalizers for frequency division multiplexing equipment need only correct the amplitude response at the corners of the channels.

For higher speed data transmission – 1200 bits per second or more – delay distortion usually is controlling, and only moderate amounts of amplitude correction are required. Usually, just enough to correct a general amplitude slope through the frequency band is sufficient.

However, in a switching network such as Autovon or Autodin, where high speed data is to be transmitted over several tandem switched sections, it is necessary that both amplitude and delay distortion be tightly controlled in each link of the switching system. This is so that the overall characteristics of several sections in tandem (which are the sum of the characteristics of the individual sections) will meet the requirements for data transmission.

In cases like this, the in-band ripple of the amplitude response becomes important and must be equalized. As previously mentioned, this ripple is caused by impedance mismatch; conceivably it could even be caused by imperfect impedance matching of delay distortion correction devices.

## Amplitude Equalization

Treatment for amplitude distortion usually accompanies delay equalization. As stated in Part 1 of this issue, the absolute delay within a system cannot be reduced from its total value at the point of origin. But, amplitude correction can be accomplished with gain devices.

The Lenkurt 971B Adjustable Equalizer is designed specifically for the correction of amplitude distortion as a function of frequency as well as delay distortion to enable VF circuits to meet stringent C3 and military DCA requirements for data transmission (as outlined in DCA Circular 330-185-1). See Table 1.

The 971B is usually operated from the receive end of the circuit. An exception would be in cases where intermediate switch locations occur in long-haul circuits that can be separated into shorter segments for switching. In such cases, for purposes of equalization, each segment is treated as a separate circuit.

Correction is accomplished by adding gain or loss in the areas of frequency where distortion exists to flatten the passband. Amplitude-versus-frequency distortion is reduced over a particular frequency range. This, in turn, decreases the distortion of the signals being transmitted in that range or, conversely, increases the data transmission rates.

A good adjustable equalizer system, such as the 971B, generally consists of independent delay and amplitude equalizers. Since the delay systems were described in Part 1 of this article, only the amplitude equalizer will be discussed here.

Basically, there are three methods of amplitude equalization. They involve the use of either "bump" sections, band edge booster sections or cosine sections.

The first method introduces variable compensation shapes (bumps) uniformly across the frequency range

*Table 1*

TYPE C3 CONDITIONING

Type C3 — For access lines and trunks associated with a Switched
Circuit Automatic Network or common control switching arrangement

Access Lines
- The envelope delay distortion shall not exceed:
  - Between 1000 and 2600 Hz, a maximum difference of 110 micro-seconds
  - Between 600 and 2600 Hz, a maximum difference of 300 micro-seconds
  - Between 500 and 2800 Hz, a maximum difference of 650 micro-seconds

- The loss deviation with frequency (from 1000 cps reference) shall not exceed
  - Between 500 and 2800, −0.5 dB to +1.5 dB
  - Between 300 and 3000, −0.8 dB to +3.0 dB
  - (+ means more loss)

Trunks
- The envelope delay distortion shall not exceed
  - Between 1000 and 2600 Hz, a maximum difference of 80 micro-seconds
  - Between 600 and 2600 Hz, a maximum difference of 260 micro-seconds
  - Between 500 and 2800 Hz, a maximum difference of 500 micro-seconds

- The loss deviation with frequency shall not exceed
  - Between 500 and 2800, −0.5 to +1.0 dB
  - Between 300 and 3000, −0.8 to +2.0 dB

NOTE: Conditioning in accordance with the above specifications is limited to:

Each Interexchange or local access line — between the customer's station and switching center

Each trunk — between switching centers

Extracted from Tariff F.C.C. No. 260 Page 143.2
— Effective August 7, 1967

to be equalized. It is effective for correcting moderate in-band distortion but has the problem of allowing too much interaction among the separate bumps in the line. However the bump method can deal with chosen subdivisions within the band on a one-by-one basis.

In facilities with steeply dropping band edges – such as loaded or submarine cable – equalization is aided by the use of a tuneable high and low frequency booster section with shape controls. Such devices (the Lenkurt 971B is one) are equipped for dealing with slope or band edge drop-off problems. But, unless another equalization technique is used, they cannot cope with mid-band ripples.

## Cosine Equalization

Bump section and band edge booster sections are fairly conventional techniques for equalizing data circuits. There is, however, a method used by the Lenkurt Adjustable Equalizer called cosine equalization which is not so common.

Cosine sections introduce a set of harmonically related cosine wave shapes of gain versus the log of the frequency. In general they are considerably more effective than bump shapes for equalizing severe in-band amplitude distortion, especially since they require fewer sections.

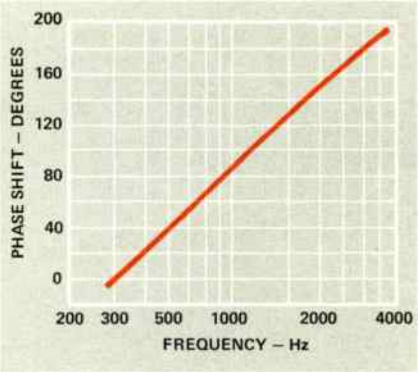


*Figure 1. Cosine section phase shift-versus-frequency characteristic – Amplitude Equalizer.*

In a conditioning system which employs cosine equalization techniques, the cosine equalizer consists of a number of identical phase-shifting networks connected in tandem. The networks are driven by compound transistors and unity-gain phase splitters the outputs of which are combined in a summing amplifier.

The 971B cosine equalizer provides five cosine shapes of amplitude versus logarithm of frequency. The shapes are continuously variable in amplitude and sign. Combinations of these shapes are used to cancel amplitude variations in the voice band of the circuit.

Figure 1 shows the phase shift/frequency relationship characteristic in a typical cosine stage. This relationship is almost linear. If the output voltage of the first phase shift stage is added linearly to the input voltage, the shift at 300 Hz will be zero and the summed voltage will be double that of the input voltage.

At 3000 Hz though, the phase shift is 180 degrees, and if the two voltages are added their sum will be zero. So, as the frequency is varied between 300 and 3000 Hz a half-cosine curve of the voltage-versus-log/frequency can be obtained. The curve will be on a logarithmic scale because of the logarithmic relationship between phase and frequency.

And, since the phase shift networks are in tandem, the output of the second stage (or section) will go from 0 to 360 degrees as frequency is varied between 300 and 3000 Hz. Output shifts of the next three stages will be 540, 720 and 900 degrees respectively. Consequently the five cosine stages will produce 1/2, 1, 1-1/2, 2 and 2-1/2 cosine curves. All five situations are represented in Figure 2.

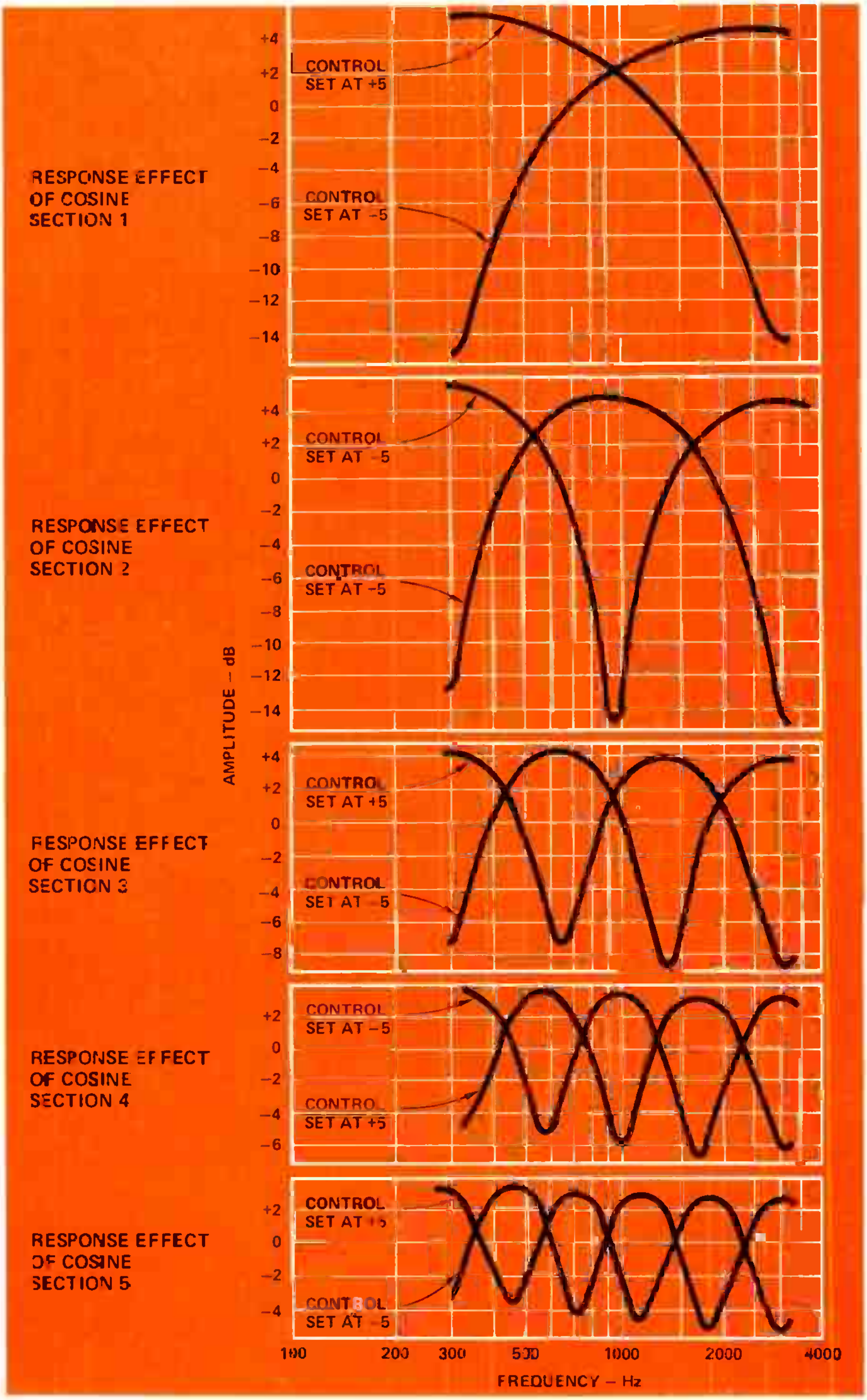
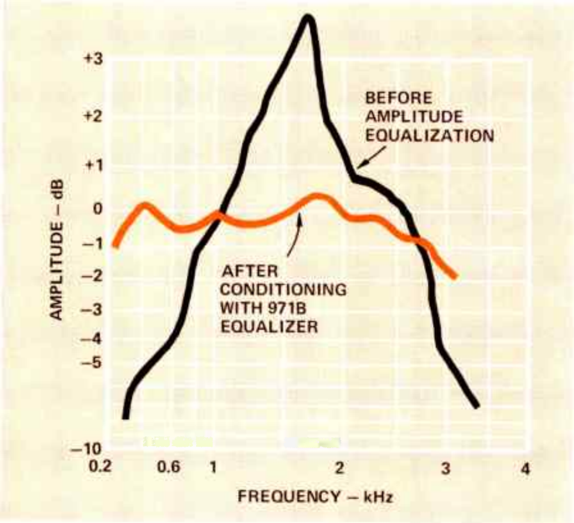


*Figure 2. Response effects of Lenkurt 971B's five cosine sections*

*Figure 3. Actual amplitude distortion condition – before and after equalization. End-to-end measurement of VF circuit consisting of four links of 46A Carrier and one link of 3-kHz submarine cable.*



## Measurement Techniques

Equipment for measuring amplitude distortion is basically an oscillator and a VTVM; whereas an envelope delay test set is used for determining delay distortion. There are also some differences in technique.

Whereas the reference point for delay measurements was arbitrarily set at zero microseconds on the test set, a specific frequency – usually 1 kHz with a 0 dB reference point – is chosen for amplitude measurements. Consequently, values of distortion throughout the passband may appear as both plus and minus figures with respect to the reference level. But just as with delay measurements, a reference point is provided to which distortion in other portions of the band may be compared. From this comparison, it can be determined whether or not equalization is feasible or even required.

Absolute values of minimum distortion and loss within a system are not directly related to the problem of correcting for relative distortion and its effect on a signal. Even though they may not be of immediate concern to the equalizer system, absolute values are important for purposes of comparison, particularly in parallel circuits. In such cases, the circuit with the lowest distortion and loss figures is "built out" of the network by the equalizer to the value of the circuit having the highest figures.

One of the most expedient methods of measuring amplitude distortion involves the use of level tracers such as the Siemen's REL 3 K 211G. A level tracer provides an oscilloscope trace pattern of the pass-band amplitude condition. Hence, the effects of adjustments made on the equalizer can be readily seen and adjustment results can be recorded for reference. In this method, one level tracer's generator is used at the transmitting end of the line as a sweep signal source. The receiving portion of a second level tracer is connected to the output of the equalizer at the line's receiving terminal. The tracer is then adjusted to track the sweep of the transmitting unit. The result is a calibrated amplitude-versus-frequency curve of the pass band.

By using a level tracer in conjunction with an adjustable equalizer such as the Lenkurt 971B, off-line amplitude equalization is possible. This is done by placing a mirror image of the trace (inverse tracing) before the cathode ray tube of the level tracer and matching to it the shape of the equalizer circuit. This technique is used when, for some reason or another, end-to-end alignment is not possible.

## Alignment for Amplitude Equalization

Just as with delay equalization, three basic pieces of equipment are required — an adjustable equalizer and two sweep level tracers.

The level tracers are connected to each end of the circuit and their controls are set for the desired transmit/receive levels as determined by the particular system requirements. Requirements differ widely depending upon the particular transmission facility being equalized.

To determine the system's general amplitude response characteristics, the line response should be first observed and recorded off the level tracer without the equalizer in the circuit.

The five cosine equalizer section controls are then adjusted to get the best possible (flat) response across the entire pass band. These controls are especially effective for minimizing in-band amplitude ripples. Each cosine section introduces a distinct positive or negative shape whose amplitude is directly proportional to the control knob setting.

At the start, each cosine control should be varied in both directions from its zero setting to determine the relative effect on the response for that particular section. Experimentation is usually necessary to determine the various combinations of cosine control settings which will best equalize the circuit.

From a simple operational point of view, it is not really necessary to know what each term is accomplishing except for a general understanding. This is because cosine shapes, up to the third or fourth terms, can be reckoned reasonably accurately from the gain/frequency response on the level tracer.

For higher terms, reduction of the total gain spread over the whole band usually provides sufficient adjustment standards. But when adjusting the cosine sections sequentially, if a point is reached where no appreciable reduction in gain spread is noted, this and all higher order sections should be left at zero. A new combination is then started by setting the first section at a new level.

In obtaining the desired amplitude response, it may be necessary to juggle the high and low booster sections and the 0 dB, 1000 Hz reference values during alignment since cosine adjustments can change the high and low end response.

But if all goes well, and the desired amplitude response is obtained, the line should then be ready and capable of carrying digital information as well as analog signals.

**LENKURT ELECTRIC CO., INC.**
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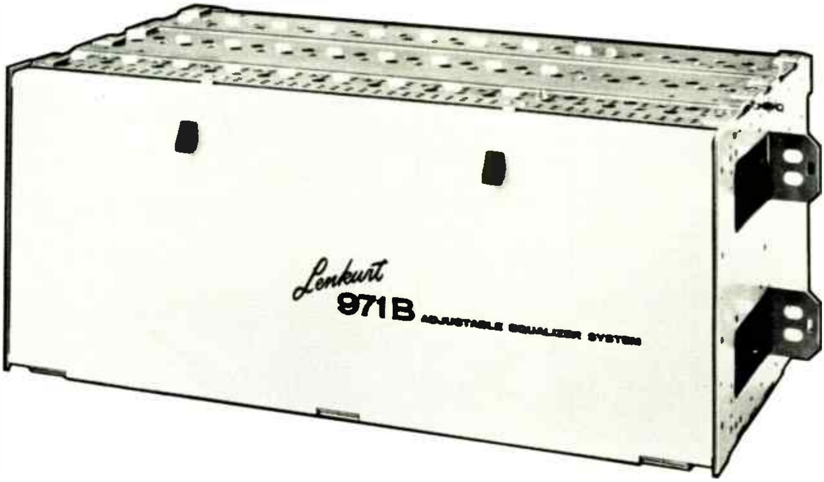

## DISTORTIONLESS DATA

To send digital data over voice circuits – error free – is a snap with the Lenkurt 971B Adjustable Equalizer.

This little system does a big job. It compensates for both delay and amplitude distortion – quickly and easily.

For more information on this or other Lenkurt communications systems, call or write Lenkurt, Dept. C720.

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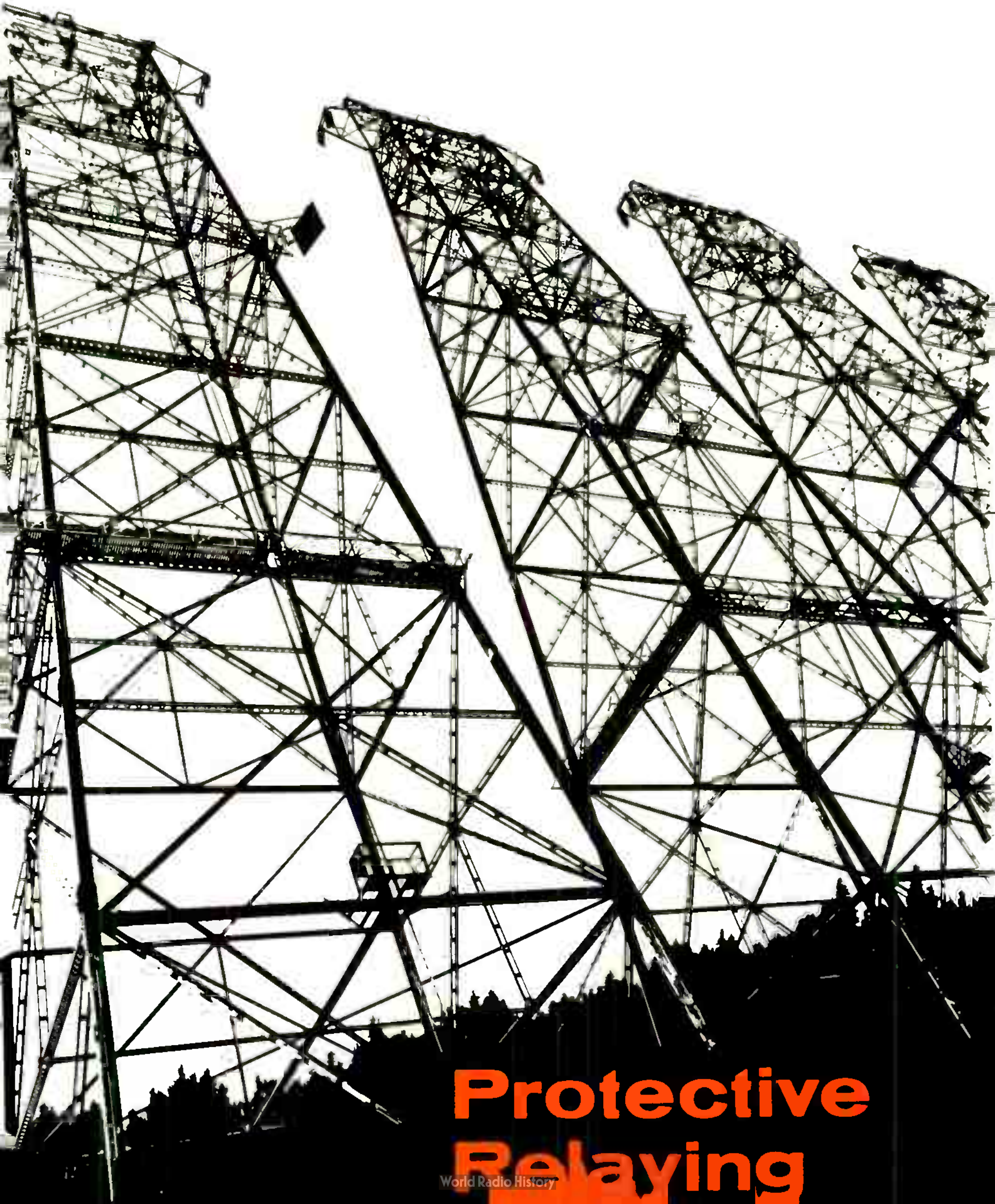
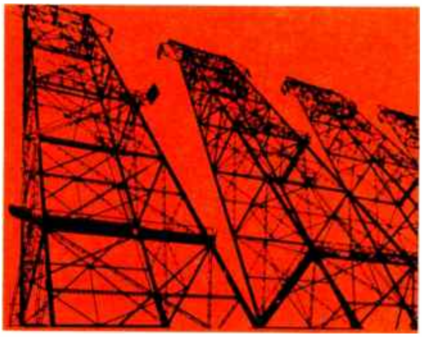
MARCH 1969



# Protective Relaying



# Vital Communications for Power Transmission

The unique nature of power transmission introduces communication problems not found in telephony and similar industrial communications. "Faults" or outages in a telephone network interrupt valuable and important communications, but neither the uses nor the communications network are otherwise affected; the loss of communication and information is the greatest harm that results.

In power transmission, however, a different type of commodity must be moved – raw power, electrical energy which may achieve an incredible magnitude. When power fails, almost everything around is affected. A breakdown in the power distribution system can literally paralyze any part of the country that is deprived of electricity. This was darkly evidenced by the outage that struck the American Northeast in 1965.

No less important is the effect of a transmission breakdown on the generation and distribution network itself. Modern power transmission is a finely balanced operation in which great amounts of energy are transformed by generators into electricity and moved efficiently through distribution networks to the consumers. The power that is generated and transmitted is carefully matched to consumer demand and the load-carrying capacity of the transmission network. Faults upset this balance, possibly releasing the load from a generator without warning, or maybe doubling it, in the case of short-circuited lines. Such faults can suddenly release millions of watts of power which, if unchecked, can severly damage or destroy generating and transmitting equipment worth hundreds of millions of dollars.

Because of the extreme importance of protecting equipment and maintaining service despite the almost inevitable occurrence of faults, many techniques have been developed for minimizing the effects of such occurrences. The most important of these is the organization of power "grids" or multi-terminal transmission networks which link many power sources and load centers.

Successful operation of the power grid requires a rather elaborate combination of sensing relays on each transmission line for detecting the presence of a fault on the line and swiftly triggering circuit breakers to isolate the fault before serious damage can occur.

## The Power Grid

In the earliest days of electric power, transmission was necessarily local. Generating stations were located

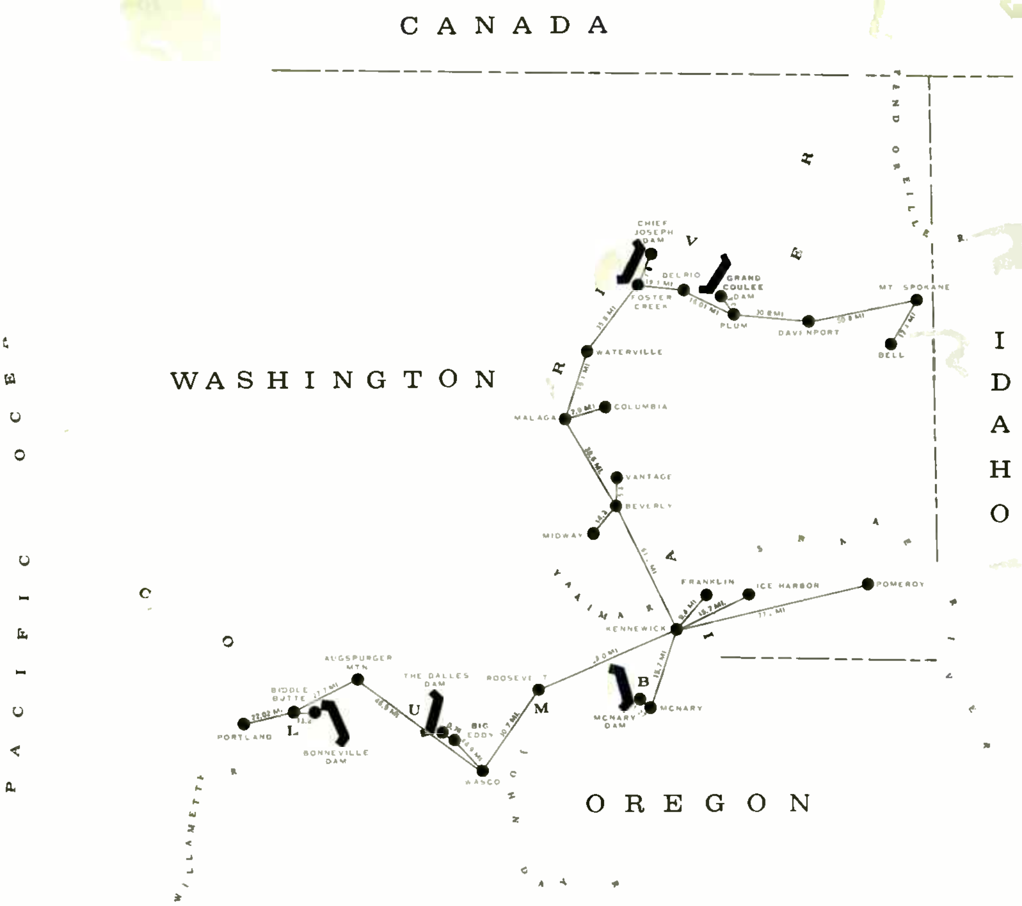


*Figure 1. The Bonneville Power Administration's EHV network in the Pacific Northwest is typical of modern extensive power transmission systems. Recently, consideration is being given to creating an intertie between this network and a similar one in the Southwest.*

close to the consumer, direct-current power was used, and voltage was low. Because of the low available voltage, current had to be high for a given amount of power. This limited the distance over which power could be transmitted, since transmission loss is proportional to $I^2R$, (where I is current and R is line resistance).

With power distribution restricted to short distances, standby generators capable of meeting peak loads were required to permit routine maintenance and to protect against failures. Naturally, this was very expensive.

Since then, the practice has changed. Alternating current permits transformers to be used to step the voltage up to very high values for transmission. By raising the voltage and lowering current, transmission loss is reduced, permitting power to be transmitted efficiently over great distances.

It soon became evident that widely spaced generators, each serving its own

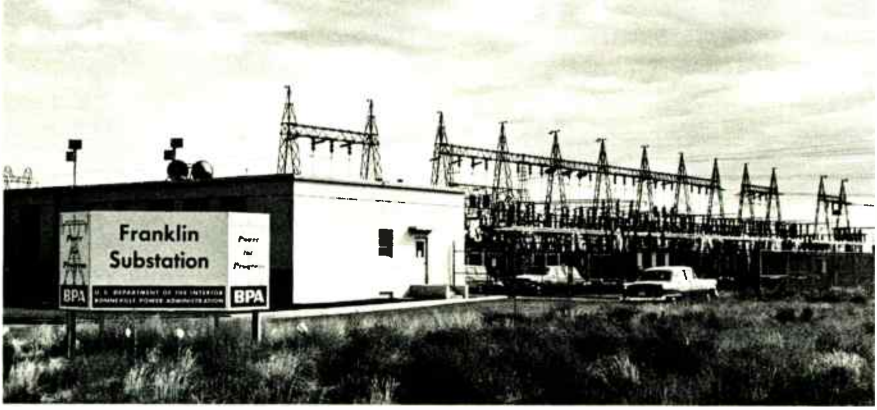


*Figure 2. Typical substation with adjacent switching yard.*

area, could be connected together to provide "mutual aid". If one generator or transmission line should fail, another could take on its load, thus maintaining service. As long-distance transmission became more efficient, it became possible to connect a greater number of widely separated power plants together in the network.

This capability has been further enhanced through a technique known as load shedding. Through the use of supervisory control systems, generator frequencies can be monitored. When overloads are indicated, portions of the power load can be transferred to other generators' networks. If a given generator's frequency falls below a predetermined rate – usually 58.5 Hz – it is shut down automatically and its entire load transferred to other parts of the facility.

Obviously power grids are more efficient and beneficial to all parties as they are increased in size and area. It is possible to adjust generating capacity to accept load changes more smoothly, since periods of peak demand in various parts of the grid may not necessarily coincide. For instance, daily peak load often comes at nightfall. This will obviously occur at different times in cities which are widely separated in longitude. Similarly, there may be a considerable seasonal load difference between cities of the far north where winter daylight hours are few, and in the far south where electricity is used in large quantities for summer air conditioning. The ability of each area to help the other permits more modest investment in generating plant.

A catastrophic fault in large power grids, however, can affect far more consumers and more actual power than in simpler systems. Without some means of rapidly isolating a serious fault, literally hundreds of millions of watts from the grid could be released, causing serious damage to the transmitting and generating equipment. Even individual generating sites may have a tremendous power capability. For instance, some large generating plants produce currents as high as 50,000 amperes at 250,000 volts if the main bus (uninsulated circuit junction) is short-circuited to ground. In this case, more than ten *billion* watts would be dissipated in the fault and equipment. At this rate, enough power would be liberated *in one second* to supply all the power requirements of a small town for a full year. A surge of this much power, if unchecked, can seriously damage transformers, generators, or transmission lines.

To guard against such damage, fast acting circuit breakers must be used to disconnect a "faulted" circuit as rapidly as possible. Speed of operation is essential in minimizing or preventing damage. Typically, modern high-power circuit breakers are built to break the flow of current within three cycles (1/20th second) of the occurrence of the fault. Even at this speed a major fault of the size mentioned above would still dissipate 150,000 kwh before the circuit could be broken.

Even where less power is involved, speed is very important in isolating a fault. This presents a problem since accurate discrimination between true faults and such natural occurrences as switching transients requires time. For instance, switching transients or momentary heavy loads (surges) which are within the capacity of the system should not cause circuit breakers to trip as if a fault were present. However, actual faults must be promptly recognized and isolated swiftly.

## Protective Relaying

To reduce uncertainty as much as possible, many special fault-sensing arrangements have been developed. Most employ sensitive relays which are able to distinguish between normal conditions and faults. One of the most basic types of protective devices is called an "overcurrent" relay. It protects against loads which are beyond the ability of the equipment to safely accommodate. Such loads may occur because of unusual peak demand, faults, or a combination of these. The overcurrent relay does not discriminate between faults and heavy demand.

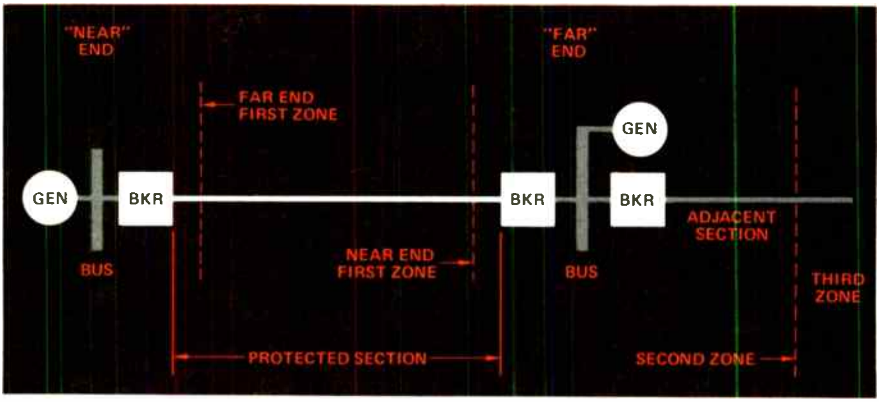


*Figure 3. Schematic representation of a typical transmission line. Distance relays must be adjusted to respond only to faults in "first zone," thus avoiding false trips due to ordinary switching transients in far-end switch yard. Different type of sensing arrangement is used to detect faults in second zone. Second zone includes portion of adjacent section, third zone includes everything beyond.*

*Figure 4. Microwave radio is fast becoming an indispensable adjunct to effective, reliable transmission of electric power.*

One of the basic types of protective relay which can distinguish between faults and normal overload is the "distance" relay. These devices monitor voltage and current on the line independently. Under normal conditions, increased voltage will result in increased current. In some fault conditions, however, (such as a ground fault or transmission line short-circuited to ground), line voltage will drop and current increase. The relay is sensitive to the relative values of current and voltage, and the resulting impedance. When a fault occurs, line impedance will change and the relay will trip if not prevented from doing so by other relays which guard against false trips. Because the transmission line is reactive, the impedance change varies with the distance from the fault. It thus becomes possible to adjust the relay to respond to faults which occur within a certain distance, but ignore those beyond.

Another way of sensing line faults is to compare the phase of the current at one end of the line with the phase at the other. Under normal conditions, the two ends will be in phase. If the line is short-circuited or grounded, however, the phase at one end will reverse with respect to the other. The phase reversal will be detected and cause circuit breakers at both ends of the line to trip.

In order to achieve reliable tripping, yet avoid false trips, conventional relay arrangements may be quite elaborate. Often two or three back-up relay arrangements are employed to provide high speed and supplementary protection as well as preventing false tripping because of faults in adjacent transmission sections.

Many different relaying methods may be used, according to circumstances and line characteristics. A typical basic arrangement for a two-terminal transmission section is diagrammed in Figure 3. High speed distance relays are used at each end of the line to provide fast "first zone" protection. The relays are adjusted to respond to faults occurring within 90% of the distance to the far end of the transmission line. It is necessary to adjust the relay for less than the full length of the line to avoid responding to momentary transients and surges caused by normal switching at a distant switchyard. At the distant end, a similar arrangement is used. Thus, faults occurring within the center 80% of the line will be detected at each end and quickly isolated by tripping the breakers at both ends.

If a fault occurs within the far 10% of the line, the distant breaker will immediately trip, thus disconnecting its end of the line. However, since the fault is beyond the reach of the near-end relay, it cannot respond. Consequently, the generator at the near end will still be feeding power to the fault.

To prevent this from continuing, an "overreach" relay (Figure 5) is used. It is a sensitive distance relay that is adjusted to respond to faults occurring not only on the protected transmission section, but also in the first 20% of the adjacent section.

In order to prevent this relay from tripping the near-end circuit breakers for faults in the next section, a blocking signal is transmitted, which, in effect, identifies the fault as lying in the next section and prevents breakers in the local section from operating. In order to allow the blocking signals "first priority," the overreach relay is normally made slightly slower acting than the first zone relays and the blocking signals. This time delay also may tend to prevent tripping in response to routine switching transients occurring at the far end.

Obviously, some sort of independent communications channel or so-called "pilot" circuit is required to link each end of a transmission line in order to trip the breakers at both ends of the line in case of a fault. Traditionally, these pilot channels have taken the form of wire or cable circuits, "power line carrier" channels, or channels transmitted by microwave.

Each of these methods has its own advantages and disadvantages. Physical circuits are generally limited to short distances, usually 10 or 15 miles, mostly because the shunt capacitance and series resistance of the line alter the currents which are put on the line to detect faults. This effect becomes excessive as distance increases.

Power line carrier is widely used for protective relaying, but is gradually giving way to microwave because of its limited information capacity, relatively high cost, and dubious reliability at the moment it is needed most — during a fault. Power line carrier systems transmit tones in the frequency range 30 to 200 Hz directly over the power lines themselves. Normally, the carrier transmitter and receiver are coupled to one phase wire of a three-phase transmission line. If the fault

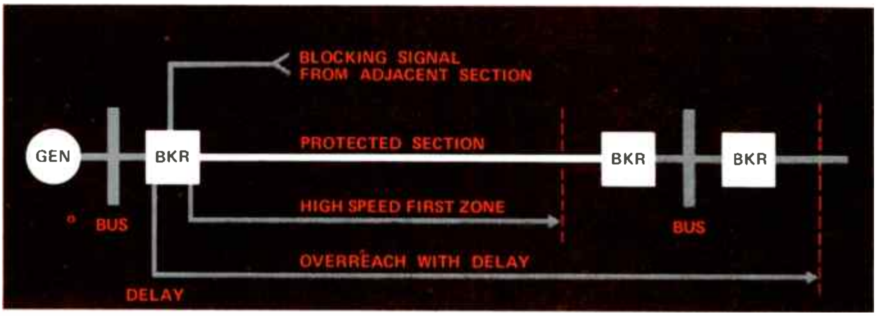


*Figure 5. Typical "overreach" arrangement with third zone blocking. High speed distance relays at both ends detect first zone faults. Sensitivie overreach relay detects second zone faults, but is blocked by signal from far end which indicates when the fault comes from the adjacent section. A slight delay is built into the overreach circuit to allow the blocking signal to have "first priority" in acting.*

occurs on the particular line carrying the signal, there is some chance that the signal still may be able to get through the fault by inductive and capacitive coupling to the adjacent phase wires.

During a fault (which may consist of a short circuit between phases or between one or more phases and ground), noise is extremely high, and this may obscure communication even if the phase wire carrying the signal is not involved. Because of these possible hazards to communication, many protective relaying arrangements which use power line carrier are arranged to prevent or *block* the tripping of a circuit breaker. Thus, it is not necessary to transmit through a fault. If a blocking signal continues to be received, it tends to confirm that the fault lies in another transmission section. Of course, many other blocking arrangements may be used to prevent a circuit breaker from tripping in error. These blocking arrangements are effective and dependable but are generally most suitable for simple two-terminal transmission lines.

As power grids grow more complex, there is greater use of multi-terminal transmission sections, that is, sections which have one or more branches. A fault in such a section is much harder to detect accurately than in a two terminal network since it may occur in a branch carrying some fraction of the energy appearing at the other terminals. Fault detecting techniques such as phase reversal are particularly difficult due to a substantial loss of sensitivity to the fault condition.

Multi-terminal sections also greatly increase the communication problem because it is necessary that each terminal be able to signal directly to each of the others. In the case of power line carrier, this uses up the limited signal bandwidth very rapidly. For example, a two-terminal line would require only two frequencies, one for each direction. A three terminal line requires six frequencies, while a four-terminal line must employ 12 frequencies. Once used, these frequencies should not be used again in nearby sections of the grid because of the difficulty of removing them from the power lines.

Although frequency traps are customarily used, they are necessarily simple devices (since they must operate at hundreds of thousands of volts), and are thus not completely effective in blocking carrier frequencies. Since most carrier tones are used as blocking signals, undesired tones from a distant transmission section, even though attenuated, might prevent a breaker from tripping during a fault. As a result, limited available bandwidth on power lines restricts the use of power line carrier in large or complex power grids.

## Transferred Trip

One solution to these problems is the use of remote tripping or *transferred trip* as it is often called. The principle of transferred trip is directly opposite that of conventional blocking schemes which prevent a circuit breaker from tripping. With transfer trip, distant breakers are tripped on command of a signal from a terminal where a fault has been identified. Thus, all breakers in a section – even where there are several branches – may be tripped rapidly to isolate the fault. It is necessary to arrange the fault detecting relays to overlap their areas of sensitivity so that a fault anywhere in the line will cause at least one terminal to trip and transmit a signal to the other terminals. Naturally each terminal is still free to trip at high speed if the fault is detected by that terminal's high speed relays.

A principal objection to transferred trip operation is that it lacks security. It may produce false trips as a result of noise or other interference – hence, it is not "fail safe". In the event that the communications channel over which the trip signal is sent should fail, protection of the grid would decline.

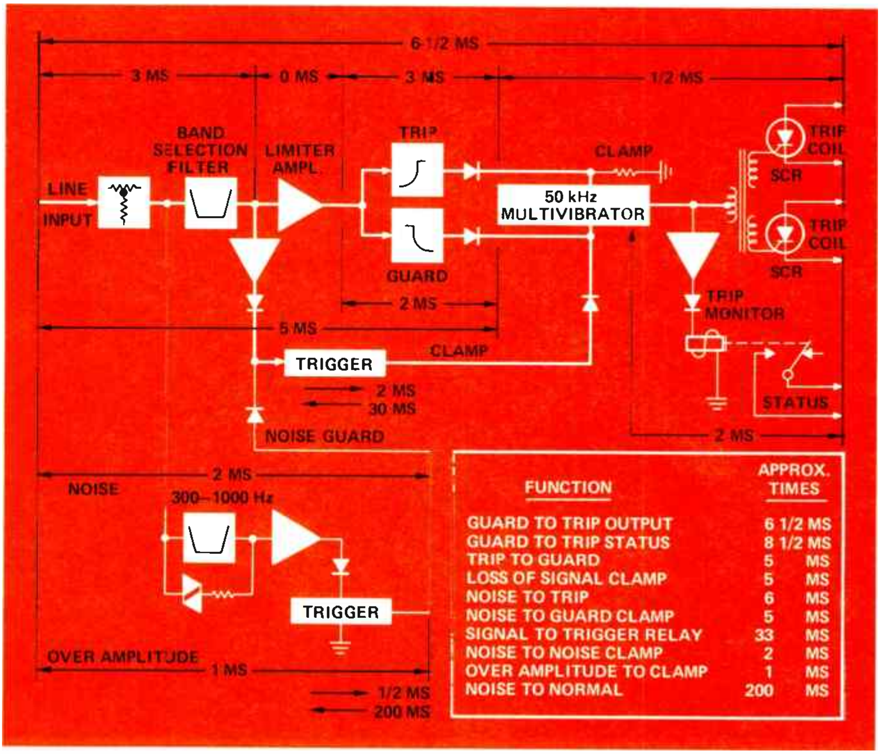
Offsetting this argument are the inherent simplicity and adaptability of the transferred trip method, and the fact that it provides 100% backup for the relaying methods on the transmission line itself.

## Security, Speed, and Reliability

Most faults consist of a short circuit between phases of the transmission line or between one or more phases and ground. Often these result in an arc. When this happens electrical noise is tremendous. Since a power line carrier channel must be assumed to be unreliable at the time of a fault, this is the basic reason that many conventional protection methods use the transmitted signals to *block* the tripping of breakers.

Installation of modern microwave systems relieves this problem by establishing reliable communication channels that are not associated with the line, and are therefore free from the interference caused by line faults. In the past, microwave seemed too costly and was considered unreliable. Two factors are changing this, however. Modern solid-state microwave systems are now able to operate directly from batteries, thus eliminating outages due to power failures. In addition, substantial improvements are achieved by increased use of transistors and by effective techniques for switching to standby equipment very rapidly in case of equipment failure. Furthermore, the cost of the coupling and frequency trapping equipment required for power line carrier has tended to increase greatly as higher and higher transmission voltages are used. This increased cost has not relieved the shortage of carrier frequencies or increased information capacity.

Although microwave provides communication channels that can be used for any of the conventional relaying methods which normally use a pilot wire or power line carrier, it is also



| FUNCTION | APPROX. TIMES |
|---|---|
| GUARD TO TRIP OUTPUT | 6 1/2 MS |
| GUARD TO TRIP STATUS | 8 1/2 MS |
| TRIP TO GUARD | 5 MS |
| LOSS OF SIGNAL CLAMP | 5 MS |
| NOISE TO TRIP | 6 MS |
| NOISE TO GUARD CLAMP | 5 MS |
| SIGNAL TO TRIGGER RELAY | 33 MS |
| NOISE TO NOISE CLAMP | 2 MS |
| OVER AMPLITUDE TO CLAMP | 1 MS |
| NOISE TO NORMAL | 200 MS |

*Figure 6. Lenkurt Type 937A achieves very high security against false trips due to noise by using overlapping and interlocking circuits which distinguish between noise and desired signals. Special care is devoted to time constant of filters used to separate noise and signals. Interposing relays are eliminated by SCR's.*

suitable for remote tripping. Accordingly, its use in power transmission is growing very rapidly.

With higher transmission voltages, a transmission line carries much more power than formerly. This makes it especially important to react to a fault with utmost speed. Modern relaying equipment and circuit breakers are able to isolate a line within about three cycles after a fault occurs. But additional time delay in responding to a fault may be introduced by the communications equipment and additional relays which may be used to trip the circuit breaker. Relays are often used in tone equipment of older design to control the fairly large amount of current required to trip the circuit breaker. However, with few exceptions, they contribute more delay and more unreliability than any other component in the system. In protective relaying the equipment may not be actuated even once a year, with the result that contacts may oxidize or become dusty, and fail to function when energized. In addition, relays add as much as 18 milliseconds further delay to the tripping of the breaker.

Both of these objections can be overcome by using modern solid-state components such as silicon controlled rectifiers (SCR's). These heavy-duty devices have no contacts or moving parts, and switch within a microsecond after being keyed, thus eliminating a major source of needless delay. Furthermore, the SCR is not subject to chatter or dropout. Once triggered, it goes on conducting, thus assuring that tripping will be completed.

One of the biggest problems encountered in transferred trip protection is to provide positive tripping on command, but avoid false trips caused by noise, hum, or other sources of interference. This is essentially a communications problem which yields readily to techniques developed for multichannel carrier equipment.

The highly successful approach taken in the Lenkurt 937A protective relaying equipment is diagrammed in simplified form in Figure 7. One of the unique features of this equipment is the careful attention give to the most critical factor in protective relaying, time – that is, the absolute time delay required for electrical energy to get through the various electrical filters used. The time delay imposed on a signal by a filter is inversely proportional to its bandwidth; the narrower the bandwidth of the filter, the slower the operation. In the 937A equipment, noise and signal tones follow separate paths having different time delays. The noise is given a "fast" path to a clamping circuit which overrides or blocks a multivibrator trigger circuit and prevents a false trip. Similarly, the guard tone filter is designed for a faster response time than the trip filter. This gives the guard signal "priority" and helps prevent spurious tripping. The circuit is arranged so that a trip signal can actuate the SCR output devices only if the trip signal is applied simultaneously with the removal of the guard tone. Several additional protective circuits are also incorporated to eliminate improper operation under various other conditions which might occur in service.

Total elapsed time between keying and the rise of current in the circuit breaker trip coil is 8 milliseconds in the 937A, almost all of it contributed by the filters. Although it is possible to reduce this delay by increasing the bandwidth of filters, this would impair the ability of the equipment to discriminate between noise and authentic tripping signals. In actual service, this design approach has proved more than adequate. Tripping signals never cause false trips, even if, during a major fault in an adjacent section, intense noise and heavy current surges occur in the switch yard.

As ever increasing power loads are handled by ever larger and more complex grids, tripping time becomes the most critical factor in protective relaying. Because of this, more emphasis will be placed on the faster solid-state devices such as SCR's. For the same reasons, microwave radio and protective relaying systems working in conjunction will also be subject to more attention in the future.

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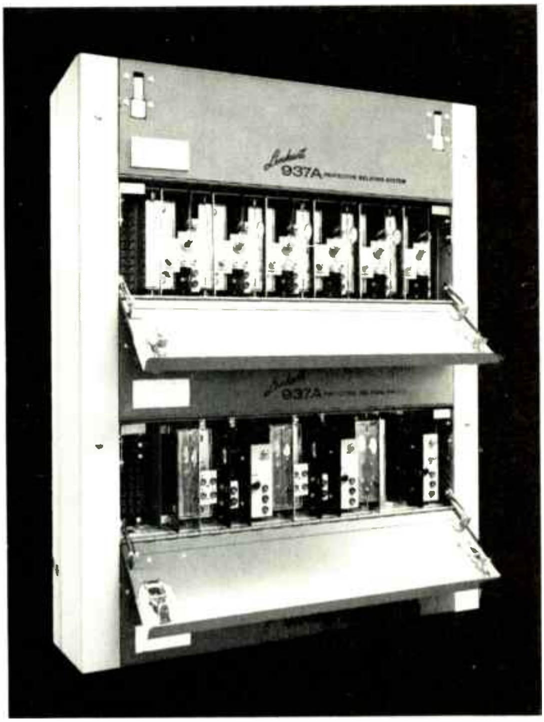

## EIGHT MILLISECOND PROTECTION

Three outstanding features distinguish the Lenkurt 937A Protective Relaying System — instantaneous reponse, high current output and maximum reliability. It is all solid-state with SCR's, transistor-controlled outputs and signal/noise monitoring circuits for preventing false trips. For more detailed information write Lenkurt, Dept. C720.

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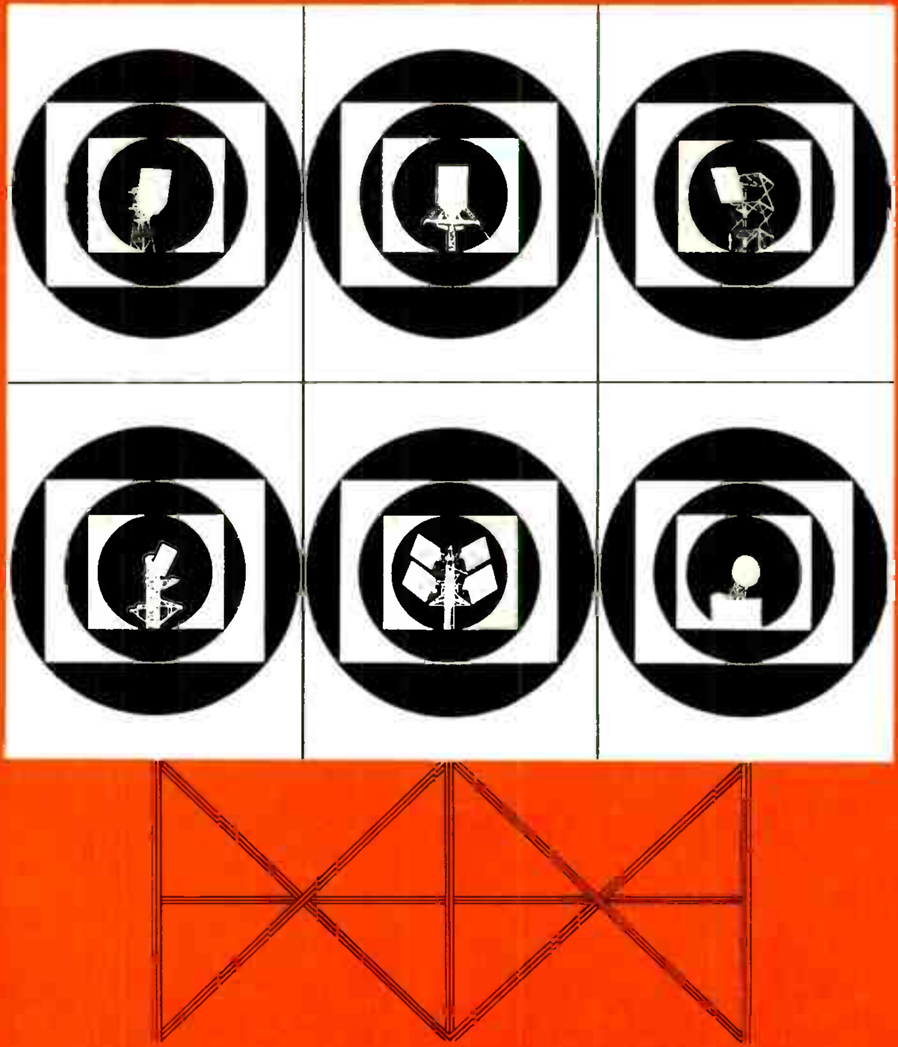
APRIL 1963

# DEMODULATOR

## Reflectors & Repeaters



**Radio-reflective surfaces offer design engineers an efficient and relatively inexpensive alternative to some path redirection problems.**

Because radio waves bounce off reflective surfaces in much the same way light is reflected by a mirror, radio reflectors can be thought of as radio mirrors.

In actual practice, the use of radio mirrors is dictated essentially by topographical conditions where the ruggedness of intervening terrain either makes a direct path impossible or requires that the antenna towers be extremely high.

Generally, speaking, radio mirrors fall into two categories – reflectors and passive repeaters. Those used in periscope antenna applications – rectangles, ellipticals, or "flyswatters" (Figure 1) are referred to as reflectors. The large "billboards", usually found on isolated hilltops, and certain "back-to-back" parabolic reflector arrangements are both classified as passive repeaters. (Figure 2).

In order to determine the relative advantages of one antenna reflector arrangement over another it is convenient to refer to some standard of measurement. In the case of microwave antennas, performance is measured in gain and expressed in decibels (dB). Using the isotropic antenna as a standard point of reference it is common practice to speak of an antenna's performance as the gain improvement (in dB) over what could be expected of an isotropic antenna.

An isotropic antenna would theoretically radiate or receive energy equally in all directions. (Figure 3). (A completely spherical radiation pattern is not really possible.) If an antenna could focus all its radiant energy into one-half a sphere, its gain (over isotropic) would be defined as 3 dB, since all the radiated energy would be concentrated in half the sphere and twice as much would appear on any given area of the half-sphere. Therefore, gain is 10 log 2 = 3 dB. Common beams run as small as 1 to 2 degrees and provide gains in the area of 40 dB.

The primary function of a good microwave antenna is to focus its radiant energy into the most concentrated and efficient beam possible.

## Reflectors

All periscope antenna systems require a reflector of some kind to redirect the transmitted beam from

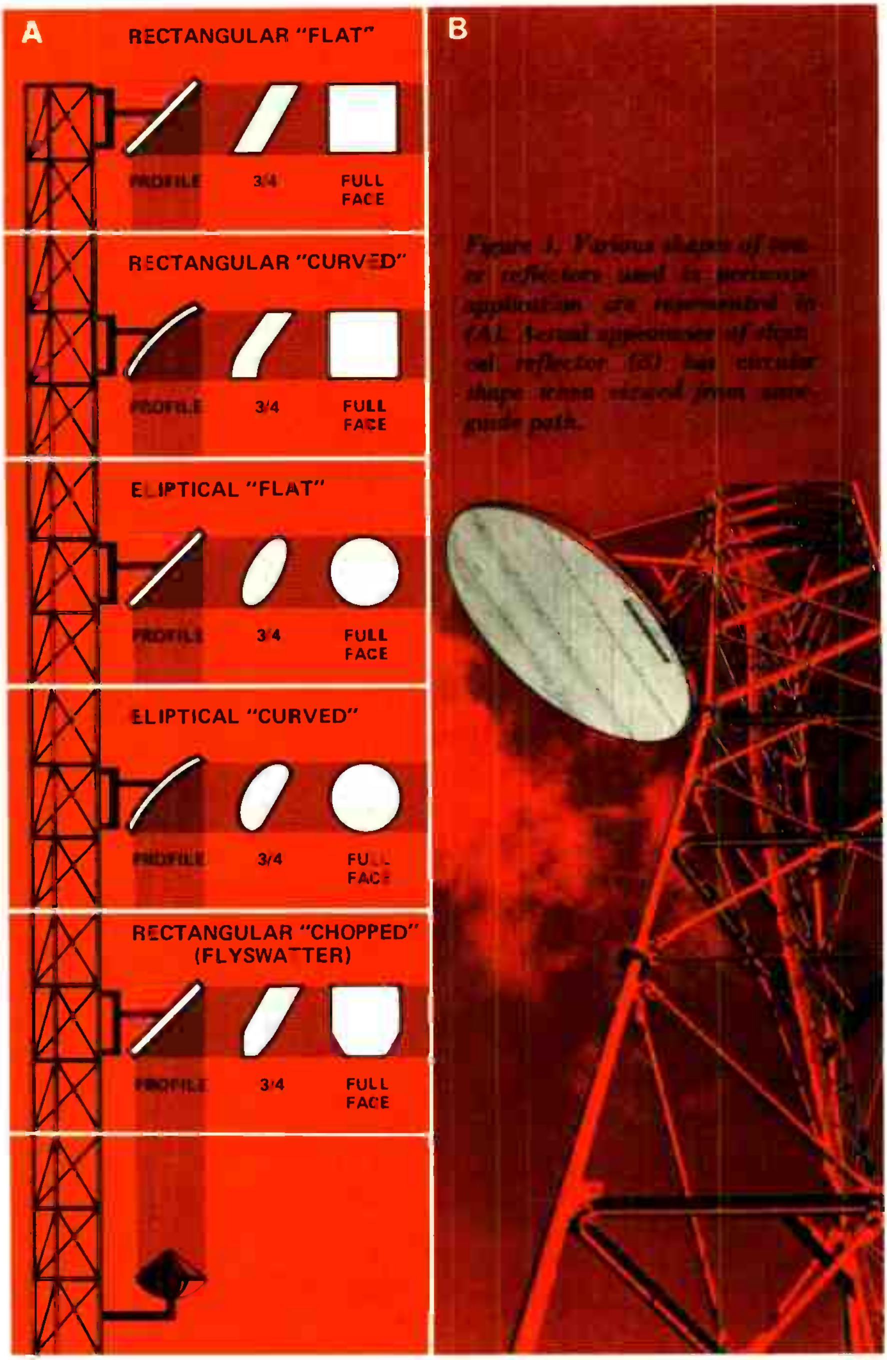


*Figure 1. Various shapes of tower reflectors used in microwave applications are represented in (A). Actual appearance of elliptical reflector (B) has circular shape when viewed from wave guide path.*

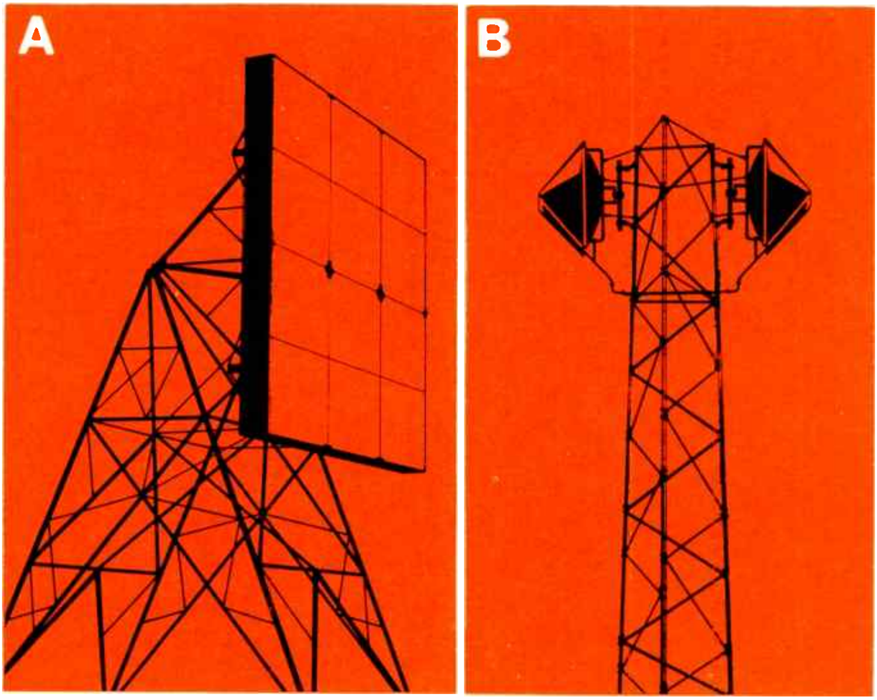


*Figure 2. Passive repeaters are of two basic types: the "billboard" (A), so labelled because of its appearance, and the parabolic "back-to-back" passive (B) which uses two standard antenna dishes directly joined by a short length of waveguide.*

the parabolic antenna to some distance receiver.

In most cases these reflectors are in close proximity to the transmitter-tower complex. There are some exceptions and because there is no absolute dividing line between what constitutes a periscope reflector and a passive repeater it is generally held that any system in which there is more than a few hundred feet of horizontal separation between reflector and illuminating dish is a passive repeater – not a periscope reflector.

The decision to use a periscope antenna arrangement is dependent on several considerations. Economic studies reveal that when the waveguide run to the parabolic antenna approaches distances of 150 feet and beyond, it is usually less expensive to use the periscope arrangement and beam the signal from the ground to the reflector atop the tower.

Tower height is not, however, the only consideration. Periscope antenna systems typically have somewhat higher side lobes and somewhat poorer

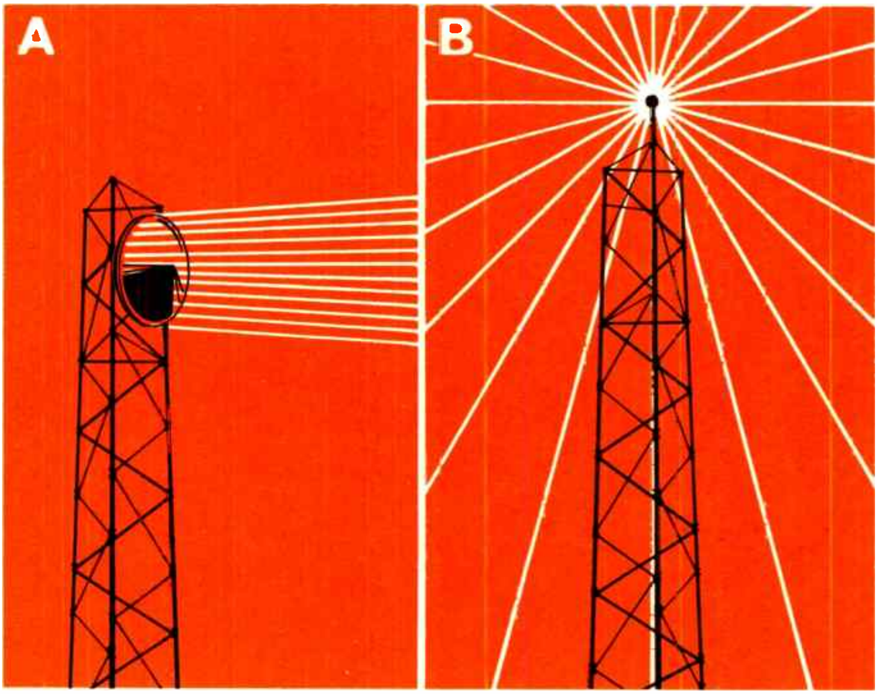


*Figure 3. Energy radiation is theoretically assumed to radiate isotropically in all directions (B). Parabolic antennas are used to focus radiant energy into a directional beam (A) which has an obviously high amplitude gain over the hypothetical isotropic antenna.*

discrimination patterns for radiation or reception at angles off the main beam than do direct-radiating antennas with comparable gains. They thus have a greater likelihood of creating interference to or receiving interference from other microwave systems operating in the same geographical area. This characteristic is probably the most negative aspect of periscope antennas. In areas of heavy microwave congestion it may be sufficiently important to preclude the use of periscope antenna systems, even though they might be advantageous from other points of view.

Another problem with the periscope setup is the "sneaking" of the signal from the illuminating dish to the distant receiver. (Figure 4). This bypassing of the reflector can occur when the direct path is not effectively blocked and allows a certain amount of the signal to reach the receiver ahead of the reflected main beam. This "sneaking" can produce troublesome noise levels requiring corrective engineering. In some instances, it has been

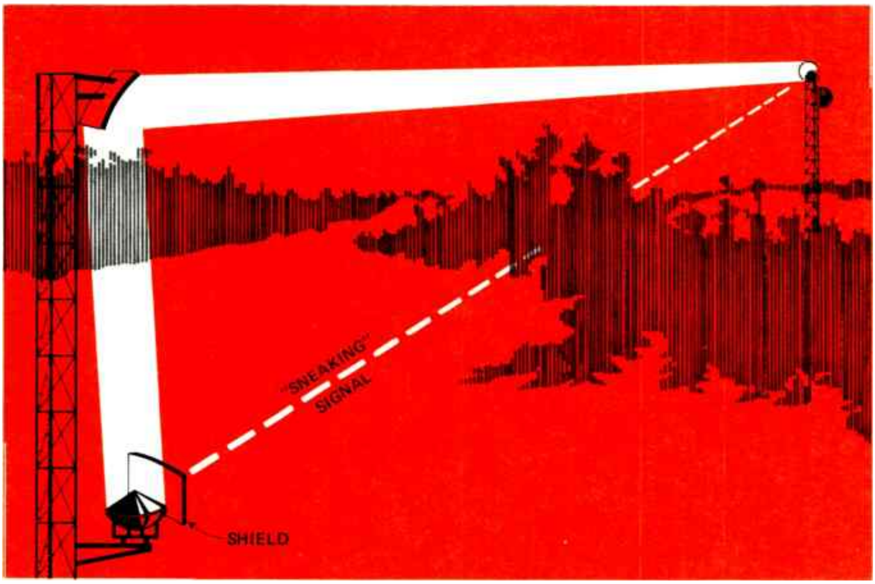


*Figure 4. In situations where the path is not effectively obstructed, the signal may sneak from the illuminating dish, directly to the distant receiver. This bypassing of the reflector causes noise at the receiver. Shielding is used to control this problem.*

necessary to place metal shields on the path sides of the illuminating dish in much the same manner blinders are used on race horses.

The periscope system has wide usage. Although the efficiency does not change with different frequencies, periscope application can nevertheless be more expensive at the lower frequencies (2 and 4 GHz) because the required dish sizes for these wave lengths are much larger.

One unique advantage of a properly laid-out periscope arrangement is the possible gain improvement over what can be expected from the parabolic antenna alone. This complex matter was clearly described in the July 1963 issue of the DEMODULATOR. By way of recapping, it is sufficient to say that the reflector's size, shape and its distance from the parabolic antenna can make it possible to reflect only first zone energy (Figure 6). When only first zone energy is reflected, the possibility of phase cancellation (caused by simultaneous reflection of the out-of-phase second zone energy) is almost completely eliminated. This arrangement produces sharper beams at distant points while giving net gains of from 2 to 3 dB for reflectors with flat faces.

Additional gain can be achieved by curving the face of the reflector to the approximate shape of a section of a paraboloid with the illuminating dish at its focus. (Figure 5) Actual practice has provided substantial evidence that a properly curved reflector can produce as much as 4 to 6 dB more gain than a flat uncurved reflector in the same application. This gain improvement results from the fact that the phase relationships of the various portions of a reflected beam are determined by the relative points at which the wavefront is intercepted by the reflective surface. It can be shown that because of this curving some of the second zone (out-of-phase) energy can be converted to in-phase energy thereby actually boosting the gain beyond anything possible with a flat reflector.

## Passive Repeaters

Erecting an active radio relay station where inaccessibility and severe weather changes can inflate construction and maintenance costs beyond desirable limits is a situation every engineer tries to avoid. This is precisely the kind of problem the engineer can resolve by using a passive repeater.

The two general types of passive repeaters in common use are shown in Figure 2. One consists of two parabolic antennas connected back-to-back through a short length of waveguide. Because the size requirements and the associated cost, this type of passive is rarely used except for very short paths where small dishes are sufficient. The efficiency of this arrangement is approximately 30% compared to a 98% efficiency rating for the "billboard".

"Billboard" passives range in size from 4' x 6' single panels to 40' x 60' connected panels. The reflective surfaces are generally made of aluminum

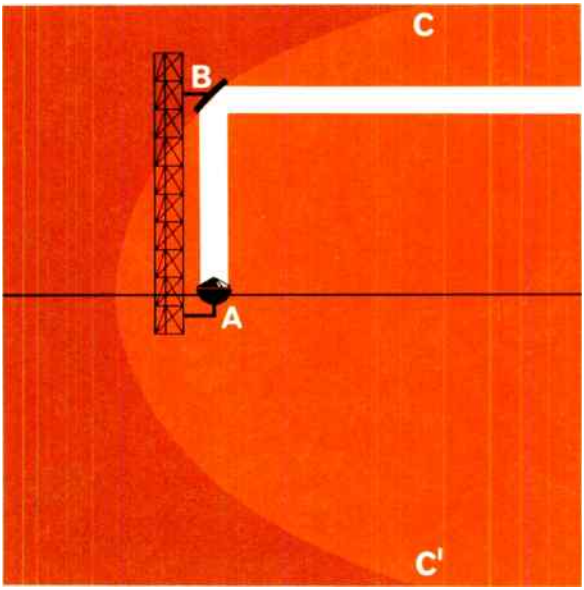


*Figure 5. To calculate the curve of a periscope reflector (B), it is convenient to consider the illuminating dish (A) as the focal point of the parabola represented by CC$^1$. The reflector (B) may simply be considered a solid segment of the imaginary parabolic shell.*

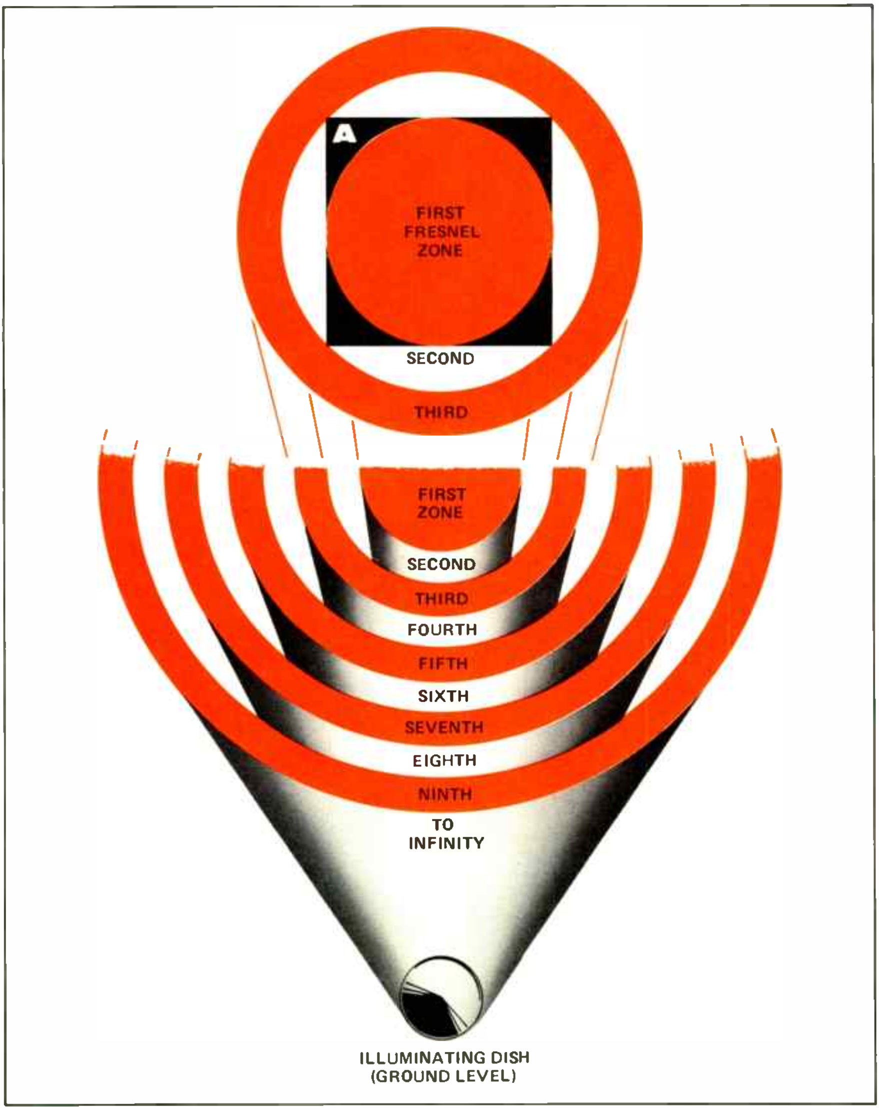


*Figure 6. Microwave signals are transmitted in concentric bands of energy (fresnel zones). Each zone is 180° out-of-phase with its adjacent zone. All even numbered zones are in phase with each other and out-of-phase with all odd numbered zones. The 2nd zone energy which is picked up by a flat reflector (A) will tend to cancel it equivalent in first zone energy. By using a curved periscope reflector which extends into the 2nd energy zone it is possible to actually convert the out-of-phase 2nd zone energy to an in-phase relationship with the first zone improving the overall gain.*

which has been treated to prevent corrosion. As a rule of thumb, face flatness should be within 1/8 the transmitted wavelength. It has been determined that the reflective surface of the passive must be flat to within 1/8" for 11-GHz transmissions, 1/4" for 6 GHz, and 3/4" for 2 GHz.

Once the existence of an obstruction makes it fairly certain that a passive must be used, it is then necessary to calculate the most efficient site available. The efficiency of any microwave path arrangement using a passive repeater has an inverse relationship to the product of the path distances.

Because of this it is obvious that any arrangement which reduces this product will improve the overall signal strength. It logically follows that those arrangements which place the passive nearest either of the path ends are therefore the most desirable. An additional benefit to this kind of site locating is the fact that the required surface area of the passive decreases as the distance to the path-end is shortened.

Some mention should be made of the fact that while certain topographical conditions appear to be well suited for passive repeater sites they may actually not be desirable at all. This has sometimes proved to be the case in heavily timbered areas immediately surrounding sites of small passive repeaters. Depending on their relationship to the passive and the signal beam, trees can produce serious inter-path noise problems. This is also the situation which is occasionally created by unwittingly placing a small passive in front of a rock wall or bluff. For these reasons it is advisable to determine passive sites only after acquiring a thorough awareness of the particular terrain involved. Once the most realistic sites have been selected it is then possible to estimate their relative efficiencies.

## Fields — Near and Far

One practical approach to determining antenna-reflector efficiency involves the calculated value of 1/K:

$$1/K = \frac{\pi \lambda}{4 a^2} d^1$$

Where:

$\lambda$ = *the wavelength in feet*

$d^1$ = *the path length in feet*

$a$ = *the effective area of the passive repeater*

When the value of 1/K is 2.5 or less, a near field condition exists. Once having determined a near-field condition it is then possible to decide the proper method to use in calculating the gain or loss of the proposed path arrangement.

If the passive is found to be in the far field, its gains and those of the end antennas are independent and the two-way gain of the passive repeater can be calculated by the following formula:

$$\text{Gain in dB} = 20 \log \frac{4 \pi A}{\lambda^2} \cos \alpha$$

Where:

$\alpha$ = *1/2 the horizontal included angle*

$\lambda$ = *wavelength in feet*

$A$ = *area in square feet*

To find the net loss between the two end points, it is only necessary to calculate the two path attenuations, add them together, then subtract from the result the two-way gain of the passive and the gains of the end antennas.

However, if the passive is found to be in the near field of either antenna then antenna and reflector gains are no longer independent but react with each other in such a way that the net gain would be reduced. In this case the above methods cannot be used, since they give overly optimistic results.

One way to evaluate gain where the passive is in the near-field is to consider the antenna and the nearby passive as a periscope antenna system. In this case a correction factor is calculated and applied to the gain of the antenna to obtain the net gain of the periscope combination. In these situations, the "path" is only taken to be the distance from the periscope reflector (passive in this case) to the far end – the distance between the antenna and reflector within this periscope arrangement is disregarded.

## Double Passive Repeaters

If the passive repeater location is behind or off to one side of the near end path, so that the included angle between the two paths at the repeater does not exceed about 120°, a single billboard reflector is most efficient. One reason the angle of the passive to the path should not exceed 120° is that the surface dimension requirements increase unrealistically beyond this angle. If, however, the passive location is more or less along the line between the two end points, it is possible to use a double passive installation. (Figure 7).

Such an arrangement, in which two closely spaced billboards are so situa-

*Figure 7. Double passive used to beam signal over a ridge.*

*Figure 8. An example of a "billboard" passive living up to its name.*

ted, can provide the desired beam displacement with only slightly less gain than a single reflector — it is also true that twice as much billboard surface is required.

## Reflections

The basic fact that microwave radio transmission is line-of-sight has imposed rather restrictive limitations on the methods microwave engineers can use in getting signals from one place to another. These limitations, like so many others, only serve to stimulate deeper investigations and more imaginative solutions to the problems which arise.

Although the use of radio mirrors in microwave path engineering is not a new development, it is indeed an excellent example of how imagination has provided a simple solution to a complex problem — both in terms of cost and performance. When viewed as simple components, these radio reflectors may be considered the only tool at the engineer's disposal whose efficiency approaches 100%.

It is important to point out that there is a wide distinction between reflective efficiency and overall path efficiency. Without exception, the reflective efficiency of periscope reflectors and passive repeaters is very close to 100%. Path efficiency is, however, a rather complex matter to determine and requires calculating whether or not a passive is in the near field or the far field. Additional figuring is then required to weigh the two-way antenna and passive repeater gains against the total path attenuation. To complicate matters further, in the case of periscope arrangements, it is customary to think of the reflector as simply an extension of the parabolic antenna and not a reflector as such.

These various approaches which experience has shown to be quite reliable, make it somewhat difficult to assess with a blanket statement the path efficiency of reflectors and passive repeaters, because it varies considerably with each application. It can be said without reservation, that the development of reflectors and passive repeaters has greatly increased the number of path engineering alternatives while measurably reducing installation and maintenance costs.

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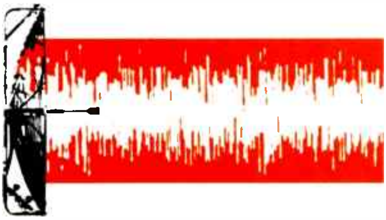
# The Lenkurt. DEMODULATOR

MAY 1969

## overloaded microwave systems — part 1



## Complicated voice and data loading requires special equations to calculate actual capacity.

Microwave communication systems, like most systems built for use in a constantly expanding consumer market, seem to reach their maximum capacity before they should. Even when extra capacity has been painstakingly engineered into a system, it is not at all uncommon to find that even this additional capacity has been consumed earlier than anticipated.

As an FM–FDM (microwave-multiplex) system expands to its maximum capacity, problems arise as more circuits or services are required. In general, these systems consist of several microwave hops in tandem between the end points of the system, with spur or sideleg hops often branching from the intermediate points.

### When is a System Overloaded?

In complex systems it is possible to have portions of the system operating at or near the overload point while the other portions are carrying much lighter loads. In determining an overload, it is only necessary to consider the single most heavily loaded microwave hop.

In an FM system there are several interrelated factors which limit maximum capacity. An overload exists when one or more of the following limits has been exceeded:

1) All of the available or usable baseband spectrum is in use.
2) The point at which total baseband signal power (system loading) if increased would cause unacceptable performance.
3) System usage is such that any increase in either the top baseband frequency or the system loading would cause emission bandwidth to exceed that legally allowed for the particular frequency band.

In FM systems, the first two of these limits often have some degree of elasticity. The third, however, is a legal limitation which cannot be exceeded without legal violation. Perhaps the best approach is to evaluate the nature of the emission, its limitations, a method by which it can be calculated, and how it is affected by various parameters of the microwave system.

### Legal Limitations of Capacity

The allowable maximum bandwidth (necessary or occupied, whichever is greater) for microwave systems under the Industrial Radio Services is established in Paragraph 91.111 of the Federal Communications Commission rules. It is:

*8 MHz in the 1850-1990 MHz band*
*800 kHz in the 2130-2150 and*
*2180-2200 MHz bands*
*10 MHz in the 6575-6875 MHz band*
*20 MHz in the 12,200-12,700 MHz*
*band*

Paragraph 2.202 of the FCC rules defines the various emission characteristics and provides formulas for calculating the "necessary bandwidth."

The type of service and the allowable bandwidth for a particular service is formalized in an "emission designator," which includes first the bandwidth in kHz, then a letter indicating the type of modulation (F for frequency modulated systems), then a code number indicating the type of transmission (usually "9" for composite transmission in case of FM systems with FDM multiplex). Thus the emission designators for the bands listed above would be 8000F9, 800F9, 10000F9 and 20000F9 respectively.

The formula given by FCC for calculating the necessary bandwidth of an F9 transmission is:

*(A)* $B_n = 2M + 2DK$

where:

$B_n$ = *necessary bandwidth in kHz*

$M$ = *maximum modulation frequency in kHz*

$D$ = *peak deviation in kHz, defined as half the difference between the maximum and minimum values of instantaneous frequency.*

$K$ = *a numerical factor depending upon the allowable distortion. A commonly used value for K in such systems is 0.9, though a value of 1.0 is sometimes used.*

The value of M for a particular system is easily established.[1] It is simply the frequency of the top modulating channel applied to the baseband. The value of D, however, is somewhat more elusive since the composite load applied to the baseband is a varying and complex quantity whose peak value can only be described statistically. The value of K is, as stated, very close to 1.0.

The multiplex used, except for systems of very low density, is almost exclusively of the single-sideband suppressed-carrier type (SSBSC).

Studies on operating systems have led to the following equations for calculating the rms (root mean square) value of white noise power, simulating the equivalent busy hour load of a given number of voice channels multiplexed into a baseband by SSBSC techniques (Fig. 1).

*(B)*

$P = (-15 + 10 \log N)$ dBm0

*(N is 240 or more)*

or:

*(C)*

$P = (-1 + 4 \log N)$ dBm0

*(N is 60 to 240)*

where:

$P$ = *equivalent rms white noise power applied over the same baseband spectrum as occupied by the multiplex channels.*

$N$ = *number of voice channels*

*dBm0* = *dB with respect to the power of a single channel test tone at zero relative level.*

These equations, originated by CCITT and CCIR, are almost universally accepted as a basis for the design and testing of multi-channel microwave systems and provide a basis for calculating peak deviation (Factor D in equation (A)).

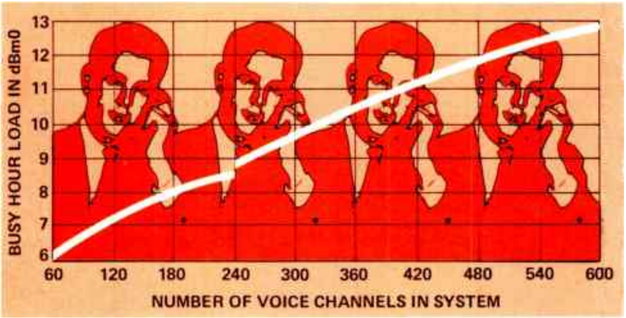
## Calculating D for Voice Systems

The starting point for the calculation of D (peak deviation) is the

---

[1] Electronics Industries Association (EIA) has submitted to FCC a proposal that a peak factor of 11.5 dB be used instead of the 13 dB which has been customary, and that a value of 1.0 be used for the factor K for the present. The result of these changes would reduce the calculated values of 2 DK by approximately 8%. This would allow a slight increase in channel capacity for the same necessary bandwidth. Industry's interpretation is that M should properly be taken as the frequency of the top information-bearing channel in the system, and that a sinusoidal continuity pilot located above the baseband should not be considered to be the "top modulation frequency" and should be excluded from the determination of M.

*Figure 1. This graph, based on equations (A) and (B), shows the busy hour load (in dBm0) for the various number of voice channels used in a particular system.*



known per-channel rms deviation and the known power of its signal. The per-channel deviation is a basic FM system parameter frequently chosen as 200 kHz rms. The baseband power of the test tone producing this deviation is 0 dBm0 rms.

The parenthetical expressions in (B) and (C), called the "noise loading ratio", express the dB ratio between the rms power of a white noise load whose peaks are equal to the peak values of the complex baseband signal during the busy hour, and the rms power of a test tone.

The peak value of white noise power is a statistical parameter with no specific value, but is commonly taken as 13 dB above the rms power. The use of two different equations for calculating the white noise load equivalent reflects the fact that the peak to rms factor of the complex signal from a number of voice channels is relatively constant at 13 dB for systems with more than 200 channels, but is variable and somewhat higher for systems with fewer channels (Fig. 2).

Deviation in an FM system has the dimension of voltage. Consequently, the effect of changes in deviation can be calculated as a 20 log function of changes in load power.

The following equations can be used to calculate the peak deviation for a multichannel SSBSC voice system:

*(D)*

$$D = 4.47d\left(\log^{-1} \frac{-15 + 10 \log N}{20}\right)$$

*(N is 240 or more)*

*(E)*

$$D = 4.47d\left(\log^{-1} \frac{-1 + 4 \log N}{20}\right)$$

*(N is 60 to 240)*

where:

$D$ = *peak deviation in kHz*

$d$ = *per-channel test tone deviation in kHz, rms*

$N$ = *number of SSBSC voice channels in system*

$$\text{Peak factor} = \log^{-1} \frac{13}{20} = 4.47$$

Example A:

A 300 channel radio system could typically have a 200 kHz per channel rms deviation.

$$\begin{aligned} D &= (4.47)\,(200)\left(\log^{-1} \frac{9.77}{20}\right) \\ &= (4.47)\,(200)\,(\log^{-1} .4885) \\ &= (4.47)\,(200)\,(3.08) \\ &= 2753 \text{ kHz} \end{aligned}$$

Equation (A) can be used to calculate $B_n$, noting that M = 1300 kHz (top channel of a 300 kHz system) and taking 0.9 for K. $B_n$ = 2 x 1300 + 2 x 2753 x 0.9 = 7555 kHz

For standard SSBSC multiplex configurations of 120 channels to about

960 channels, the frequency of the top channel in an N-channel system can be very closely approximated as (4.13 N + 60) kHz. By using this approximation for M, taking K as 0.9, and substituting the appropriate values of D from (D) and (E) respectively, the following equations for $B_n$ in terms of N and d can be derived. (It should be emphasized that they apply only to systems used primarily for voice):

*(F)*

$$B_n = 120 + 8.26N + 1.43d\,N^{0.5}$$

*(N is 240 or more)*

*(G)*

$$B_n = 120 + 8.26N + 7.17d\,N^{0.2}$$

*(N is 120 to 240)*

These equations provide insight into the complicated way the necessary bandwidth varies as a function of the number of channels and per channel deviation in voice operation.

The equations permit calculation of any one of the three variables ($B_n$, N, and d) provided the other two are known, and can be used to determine what combinations of number of channels and per channel deviation can be used without exceeding a specific value of $B_n$.

### Example B:

A typical microwave system in the 6 GHz industrial band has the limitation of 10000F9 emission. (From Example A, it is clear that there will be no problem with a 300 channel system using 200 kHz per channel deviation.)

But suppose 600 channels are desired in the same bandwidth.

What per channel deviation will allow staying within 10000F9?

By substituting 1000 for $B_n$ and 600 for N in (F) it can be easily calculated that the deviation must be reduced to 140 kHz.

If d is left at 200 kHz per channel, it can be shown that N cannot exceed about 450 channels if $B_n$ is not to exceed 10000 kHz.

Thus seven complete supergroups, or 420 channels, can be accommodated on a system using 200 kHz per channel deviation, within the 10000 kHz bandwidth limitation, but eight supergroups create an overload.

## Calculating Voice and Data

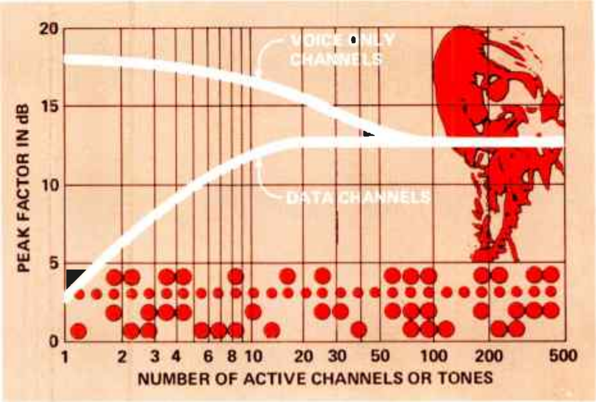
Present day systems have a significant percentage of the derived SSBSC channels devoted to the transmission of systems of submultiplexed tones carrying data or telegraph. The number of tones of this type in an SSBSC channel can vary from one to 25 or more. Their power represents a relatively constant rms load to the baseband, since the tones are on continuously. When the total number of individual data signals on the system exceeds about 15, the peak to rms factor for their complex summation approaches that of white noise.

If the levels chosen for each data or telegraph circuit are such that the total rms power of their tones submultiplexed in any SSBSC channel is 15 dBm0, the data loading per SSBSC channel will be the same as if it had been used for voice. In this case these equations can be used to calculate deviation and bandwidth.

The common practice of putting data at a somewhat higher level means the loading due to the number of channels devoted to data will be much greater than if they had been devoted to voice. This also means greater overall loading and deviation.

The necessary calculations for a mixture of voice and data channels are simple in theory. They can become complicated in practice, however, because there are so many possible combinations of voice and non-voice circuits. The following equation is a generalized form of (D) and (E):

*Figure 2. The patterns for the two peak factors – peak to rms ratios – of data and voice are essentially the same when the number of channels is large. However, restriction of data to low levels will affect the signal-to-noise ratios.*



*(H)*

$$D = 4.47\,d\left(\log^{-1}\frac{NLR_{tot}}{20}\right)\,\mathrm{kHz}$$

*which leads to a generalized form of (F) and (G):*

*(I)*

$$B_n = 120 + 8.26\,N + 8.05d \cdot \left(\log^{-1}\frac{NLR_{tot}}{20}\right)$$

where:

*$D$, $d$, $B_n$, and $N$ are all as before and $NLR_{tot}$ is the Noise Loading Ratio corresponding to the total equivalent voice channel power plus the equivalent power of all non-voice groups.*

*(Note: $N$ is the total number of SSBSC channels in the system, regardless of use. The function of $N$ is only to establish the top modulating frequency $M$).*

Before (H) and (I) can be used, a preliminary calculation must be made to determine the value of $NLR_{tot}$. The simplest way is to calculate separately the dBm0 equivalent noise power of the channels used for voice (using (B) or (C)), the equivalent dBm0 noise power of each non-voice group and then on a power summation basis, combine all the powers to obtain the equivalent total baseband load of white noise power. The $NLR_{tot}$ in dB is then numerically equal to the dBm0 value of the equivalent white noise load. Once $NLR_{tot}$ has been calculated, it can be used in (I) to obtain $B_n$, or with (H) and then (A) to determine both D and $B_n$.

The following example will illustrate the method.

Example C:

A 6 GHz system with 300 SSBSC channels, of which 200 channels are used for voice transmission, 40 channels are used for data at a power of −10 dBm0 per SSBSC channel, and 60 channels are used to carry submultiplex telegraph tones, each tone at a power level of −21 dBm0 and with each of the 60 SSBSC channels carrying 20 such tones. The per channel rms test tone deviation is 200 kHz. To calculate necessary bandwidth:

1. Calculate noise load power corresponding to 200 voice channels, using (C), as (−1 +4 log 200) = +8.2 dBm0.
2. Calculate noise power corresponding to 40 data channels at −10 dBm0 per channel as (−10 + 10 log 40) = +6.02 dBm0.
3. Calculate noise power corresponding to 20 tones in one SSBSC

channel as $(-21 + 10 \log 20) = -8$ dBm0 and the noise power corresponding to 60 such SSBSC channels as $(-8 + 10 \log 60) = m + 9.78$ dBm0.

4. Sum the three noise powers, +8.2 dBm0, +6.02 dBm0, and +9.78 dBm0 on a power basis, by using appropriate curves or by converting each value to its equivalent in milliwatts, adding, and reconverting to dBm0. The power sum will be found to be very close to +13 dBm0 or about 3.2 dB higher than the equivalent noise loading of 300 voice channels.
5. As indicated above, the NLR corresponding to +13 dBm0 of noise power is 13 dB. Substitute this value for $NLR_{tot}$ in (H), which gives the following:

$$\begin{aligned} D &= 4.47 \times 200 \times \left(\log^{-1} \frac{13}{20}\right) \\ &= 4.47 \times 200 \times 4.47 \\ &= 4000 \text{ kHz} \end{aligned}$$

(It is coincidental that the noise loading factor equals the peak factor. Generally, they will be different.)

6. With D known, use (A) to calculate the "necessary bandwidth". The value of M is still 1300 kHz, corresponding to the frequency of the top channel of a 300 channel SSBSC system, and the 0.9 value is still appropriate for K. This gives:

$$\begin{aligned} B_n &= 2 \times 1300 + 2 \times 4000 \times 0.9 \\ &= 9800 \text{ kHz} \end{aligned}$$

or:

Equation (I) could have been used to calculate $B_n$ directly.

The methods used in Example C can be extended to cover other situations provided the basic principles are followed.

To avoid possible confusion, these calculations of peak deviation are based on systems which do not have emphasis and whose per-channel test tone deviations have the same value regardless of the position of the channel in the baseband. When emphasis and deemphasis networks are used, per channel test tone deviation is not a constant but is a function of channel baseband frequency. Higher channels deviate more than lower channels, but systems are generally so arranged that the total deviation remains the same and the equations are still valid.

## Capacity Limitations

Microwave equipments are generally designed with some specific maximum capacity in mind, usually in some multiple of the standard 60-channel supergroup. In older systems, and in light route or spur legs, 120 channel and 240 channel systems were often used. Present usage tends toward systems with 300 channel capacity, even higher for backbone routes.

Selecting the proper equipment and employing the most effective field application necessarily requires some specific criterion of channel noise performance. Noise performance is an intricate function of the number of channels, the per channel deviation, the presence or absence of emphasis networks, the per channel loading, the receiver noise figure, the RF signal level, the fade margin needed to give the desired reliability, and the i-f bandwidth – to mention a few. There are many trade-offs and balances involved. The choices made when engineering a system for 300 channels would not be the same as those for 600 channels.

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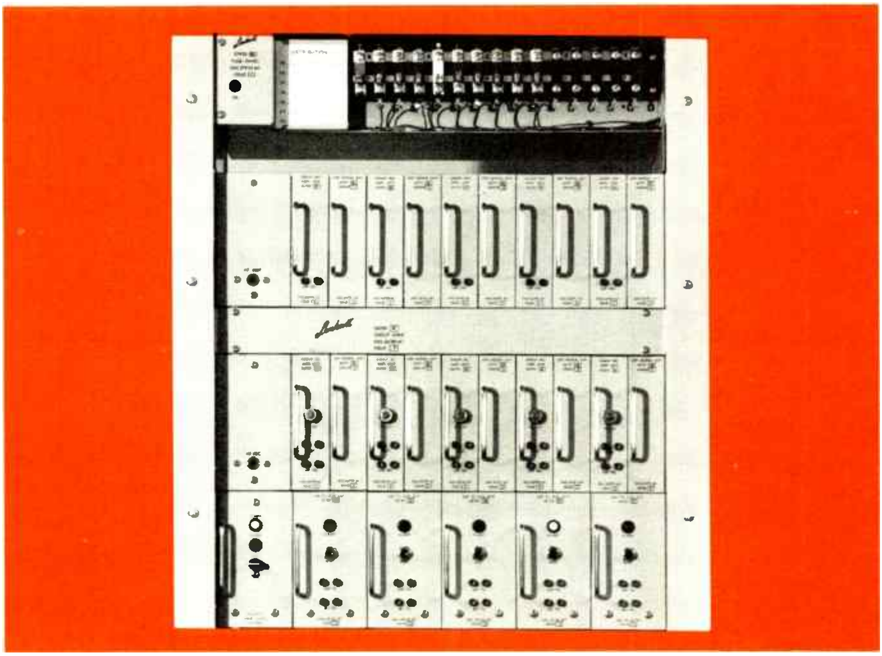
# RADIO MULTIPLEX SYSTEM



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# The Lenkurt DEMODULATOR

JUNE 1969

overloaded microwave systems — part 2

## Actual capacity often can be extended by several methods short of costly updating

When a microwave system reaches its capacity limitation and additional service is required, there are several practical alternatives which should be explored.

Probably the most fundamental consideration is the nature of the equipment being evaluated; older systems with relatively small channel cross-sections often use older multiplex types such as transmitted carrier or double sideband multiplex – both of which use more bandwidth and load the system more heavily than single-sideband suppressed-carrier (SSBSC) multiplex. In systems using these older multiplex types, the obvious immediate solution is to update with the more efficient SSBSC system.

Other alternatives include sectionalizing the system by using baseband blocking or multiplex interconnects; evaluating the legal and technical possibilities of increasing the number of channels; evaluating the noise performance levels to see if modest relaxing might not permit an increase in capacity; and finally, considering whether it might not be more expedient to simply update the entire system.

In a simple microwave system consisting of only one hop or a few hops in tandem, with most of the required channels going end-to-end over the complete system, the problem is to increase the capacity of the individual hops.

In complex systems, on the other hand, the key to a more efficient use of capacity may lie in sectionalizing the system in such a way as to allow portions of the baseband to be blocked off at intervals and reused in different sections. This principle can be demonstrated by the following hypothetical example.

Example A:

An in-line microwave system (no spurs) connects the imaginary towns of (A), (B), (C), (D); channels are required only between these points, so intermediate repeater stations, if required, will not affect the situation. All microwave hops are designed for 300 channel capacity, and the full baseband is available at all four points. The system is operating at full capacity, with 60 channels in supergroup 1 between (A) and (B), 60 channels in SG 2 between (B) and (C), 60 channels in SG 3 between (C) and (D), and 120 channels in SG 4-5 end-to-end between (A) and (D).

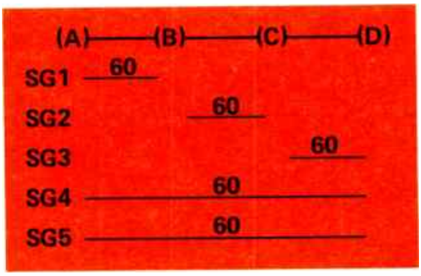


*Figure 1.*

In this system, a channel or group of channels once used anywhere in the system appear in the baseband throughout the whole system and cannot be used elsewhere. Consequently, this system is at full design capacity.

## Sectionalizing With Filters

The system outlined in Figure 1 can be changed as follows: At (B) and at (C) the baseband can be sectionalized by putting in appropriate sets of high-pass/low-pass filters which divide the baseband so that supergroup 1-2 pass through the low-pass side and SG 3-4-5 through the high-pass side. At each of these stations there will be two sets of filters, one looking east and one looking west. The high-pass sides will be cross-connected through the station so that SG 3-4-5 pass through end-to-end. But insofar as SG 1-2 are concerned, the system is now broken into three independent sections, and the full 120 channels of SG 1-2 can be used in each of them creating the following situation:

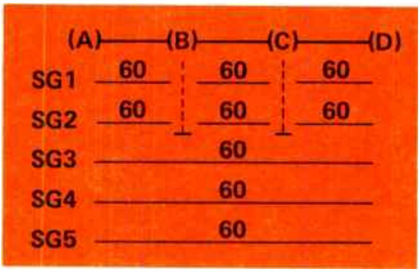


*Figure 2.*

This relatively simple change produces a microwave system capable of providing 120 channels from (A) to (B), 120 from (B) to (C), 120 from (C) to (D), and 180 from (A) to (D) for a total of 540 channels, yet no portion of the microwave system is carrying more than 300 channels. This has required additional multiplex equipment and some slight rearranging of original equipment. Figure 3 shows the filter arrangement used at the two intermediate stations. The cross-over point for the filters used in this particular application lies in the slot between SG 2 and SG 3, so that SG 1 and 2 pass through the LP side but are blocked from the HP side, while the reverse is true with SG 3 and higher supergroups.

Filters can be arranged either to pass the high groups through the station and drop the low groups, as shown in Figure 3, or the reverse. (The filters shown handle only one direction of transmission. Another identical set is needed for the opposite direction.)

There are many other possible filter arrangements. For example, filters are also available to split the baseband between SG 1 and SG 2, and others to split between SG 3 and 4, SG 3 and 5. Combinations of filters can be used to separate and drop an intermediate supergroup, while passing through the supergroups above and below it. Figure 4 is an example of such a complex filter arrangement. It could be used, for example, to pass SG 3, 4, 5 (and higher if necessary) straight through the station via the HP side of the upper pair of filters; SG 1 passes through via the LP (Low Pass) side of the upper pair and the LP side of the lower pair, while SG 2 is dropped and inserted via the HP (High Pass) side of the lower pair.

Figure 4 also shows another feature which may be needed — a pilot bypass arrangement. This might be required where a pilot must pass through the station which happens to be in the blocked section. The bypass equipment then is used to pick off this pilot and reinsert it on the other side.

Filter arrangements as shown in Figure 4 are relatively inexpensive and simple to apply, but they have some limitations. One is they are somewhat inflexible and difficult to modify or

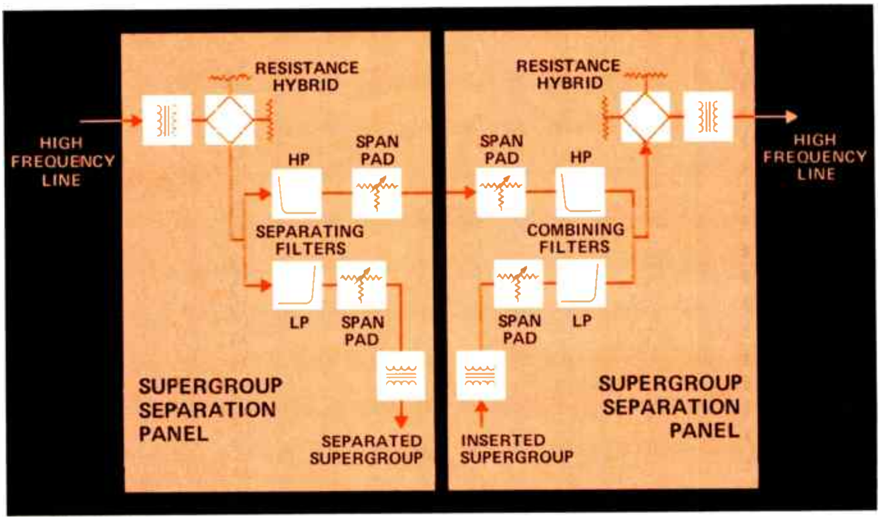


*Figure 3. An example of two supergroup separation panels arranged for dropping and inserting a supergroup.*

change without taking the system out of service. Another is the fact that separations between the higher supergroups (SG 4 and above) generally involve the loss of a few of the carrier channels in the vicinity of the crossover point. Further, if a number of such filters are used in tandem in a long system, there may be enough degradation in the response of the through paths to affect the end-to-end channels.

## Sectionalizing With Carrier Interconnects

The filter type of sectionalizing is done in the microwave baseband. An alternative method of sectionalizing is available which provides maximum flexibility and does not have the limitations of the filter method, though it is somewhat more expensive.

When this alternative method is used, there are no through baseband connections at the sectionalizing station. Instead, each incoming microwave leg is completely terminated in a carrier terminal. Blocks of through channels are passed through the station by means of supergroup interconnects (60 channels) or group interconnects (12 channels) without demodulation. Those groups or supergroups destined for local drop are of course provided with channel modem equipment.

This carrier type of sectionalizing is almost universally used today in the telephone industry. In industrial systems of relatively high density there are often situations in which it is desirable to use carrier interconnect sectionalizing at some of the intermediate points. It is particularly advantageous, for example, at a junction station where several routes converge, with substantial numbers of channels terminating locally, but some blocks of channels needing to pass through the station in various ways. Setting up such a station on a carrier interconnect basis allows efficient use of the capacities of all the microwave branches, and perhaps even more important, allows great flexibility in any rearrangements which may develop as a result of changed requirements. Such rearrangements can be done without affecting service on anything except the particular blocks of channels being rerouted.

Figure 5 shows a simplified example of a three-way junction station arranged with carrier interconnects. Circuits passing through the station as shown are: SG 1 West to SG 2 North; SG 2 West to SG 2 East; SG 1 North to SG 3 East.

Thus this junction station could have 180 circuits to the west, 180 to the north, and 180 to the east, plus three supergroups passing through the station, giving a total of 720 channels.

The great flexibility available for rearrangements or for future additions is quite apparent. Although only supergroup interconnections are shown in Figure 5, it is also possible to make group interconnects in blocks of 12 channels, providing an added degree of flexibility.

Both types of sectionalizing have their advantages and disadvantages. In

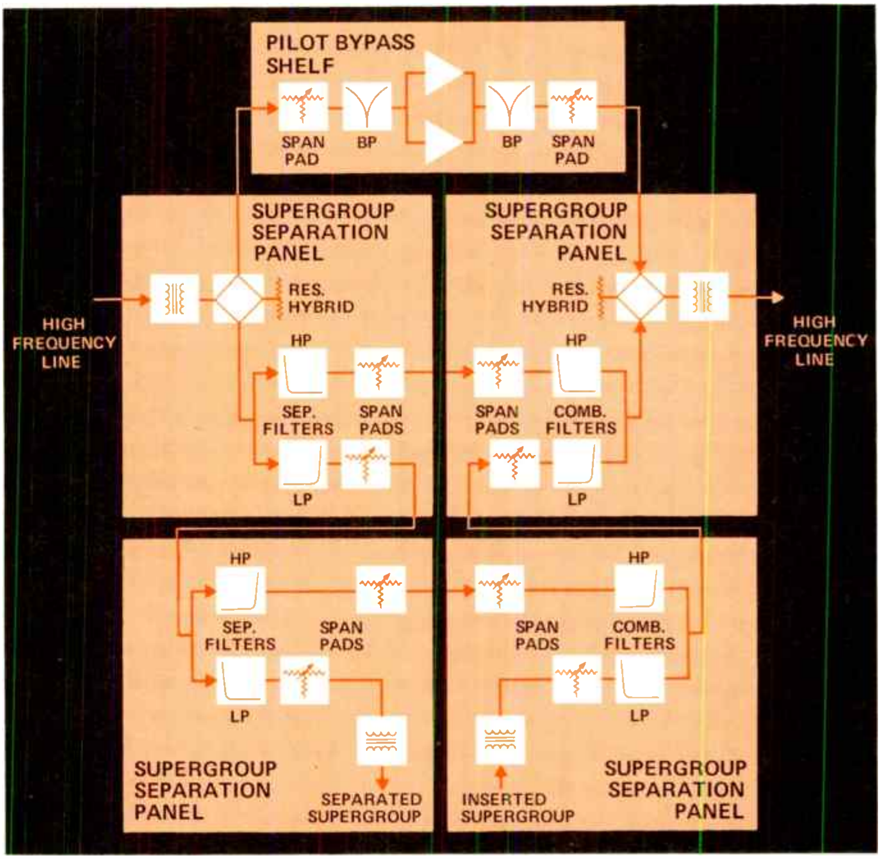
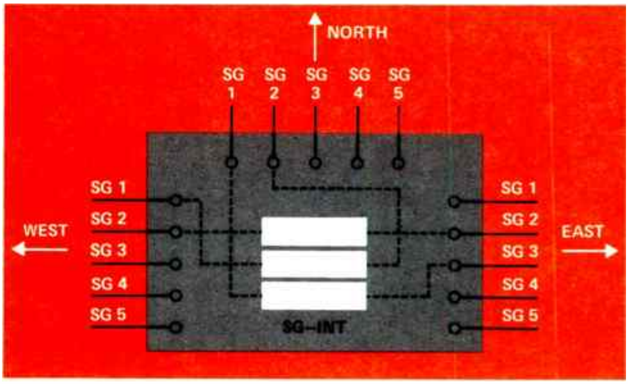


*Figure 4. Four supergroup separation panels are shown with pilot bypass shelf arranged for dropping and inserting an intermediate supergroup.*

*Figure 5. An example of a junction station with supergroup interconnects.*



long microwave systems it is often desirable to use carrier interconnections to sectionalize at points of high channel density, and filter interconnects to sectionalize at points of lower channel density. Almost every situation has its own special characteristics, and only by studying the actual situation in light of the overall requirements can a decision be made as to the best method to use in a given station.

## Noise Performance Criteria

A relaxation of a few dB in the requirements for channel noise performance can, under certain circumstances, permit a substantial increase in a microwave system's total channel capacity. This same circumstance can often make possible a more efficient use of the existing communications system.

The key lies in properly evaluating the true requirements for noise performance in relation to channel arrangements. Industrial microwave systems tend to perform essentially the same function as the public telephone networks. As a result they are designed to about the same standards of noise performance as long-haul telephone systems. For example, a common objective is 32 dBa0 or better in the worst channel for a system of 1,000 miles. There are very sound reasons for establishing such an objective for the initial system design. But in *using* the system, the user may very well recognize that a noise performance of 35 dBa0 would still provide an extremely good circuit which would be adequate to his needs. It should be remembered that the switching hierarchy in the public telephone network is such that up to eight or more trunks in tandem may occur on a given call, and the intertoll objectives thus must be very stringent indeed. Private microwave systems, even when they are very long, are much less complex and are more easily controlled by the user.

When it is not desirable to relax the end-to-end noise performance requirements in a system, there is still another useful possibility. This is to reserve the lower noise portions of the microwave baseband for the long-haul circuits, and use the higher-noise portions for short-haul circuits. This is in line with practices on the public networks, where considerably lower objectives are applied (on a per mile basis) for short-haul, toll-connecting and direct trunks than are applied to the intertoll trunks.

In an imaginary example, expansion of a 300 channel system to 420 channels could be accomplished by

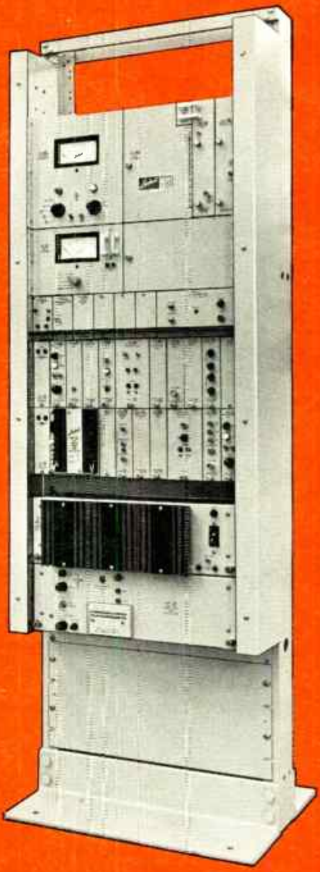


*Figure 6. Lenkurt's 78 Microwave Radio System has been specifically designed with the wide flexibility needed to meet the rapid growth rates of modern message and data communications.*

adding SG 6 and 7. If deviation were left unchanged the noise in the original 300 channels could be expected to increase by about 1.5 to 2 dB, but the noise in the top channel of SG 7 would be perhaps 5 dB poorer than the worst original channel. If the original system were a 1,000 mile system with end-to-end performance of 32 dBa0, and if the new SG 6 and 7 channels were used on relatively short sections of the system (up to 250 miles), the new channels would be around 31 dBa0 (6 dB improvement because they would traverse only 1/4 of the total system length, 5 dB degradation as indicated above) while the end-to-end channels would be no worse than about 34 dBa0. These values might well be thoroughly acceptable to the user.

Obviously this approach would require careful evaluation and good judgment. It must be recognized that it would not be satisfactory if the noise performance on the original system were marginal. But when properly used in combination with the other methods of system expansion, it can provide very worthwhile results.

## Update the System

If other measures prove inadequate the possibility of upgrading the microwave system itself should be considered at least in the most heavily loaded portions by such means as increasing antenna sizes or changing out i-f filters to provide wider bandwidth. In many situations these changes may be relatively simple and inexpensive when compared to the increased capacity obtained.

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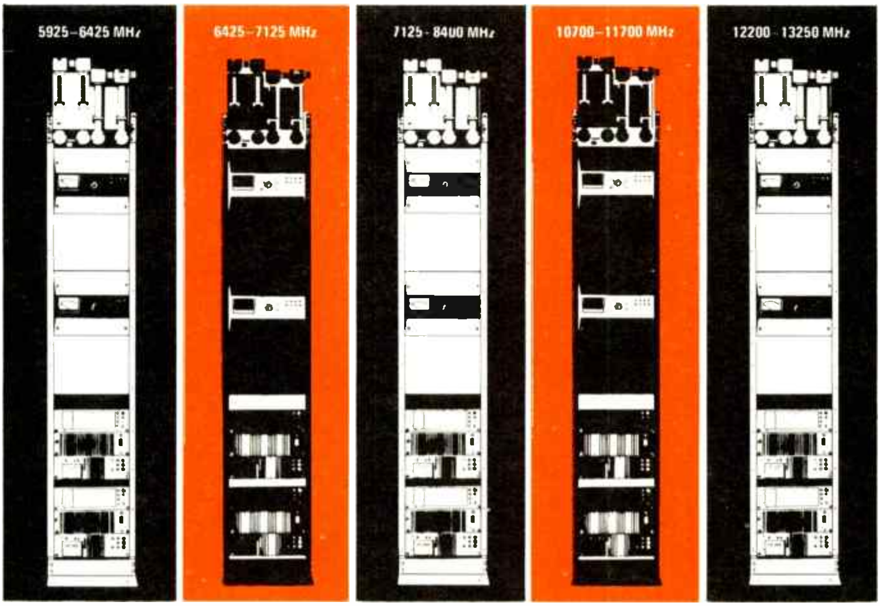

# BUILT FOR HEAVY LOADS

All five of Lenkurt's 75 type Microwave Systems are capable of 1200 channel loading. These solid-state microwave systems use traveling wave tube output and heterodyne repeaters and meet critical CCIR noise objectives. Used primarily for heavy-density, long-haul routes carrying voice, data, or black and white or color television signals, these systems offer frequency, space, and crossband diversity as well as two-for-six path protection arrangements. For additional information, write Lenkurt, Dept. C720.

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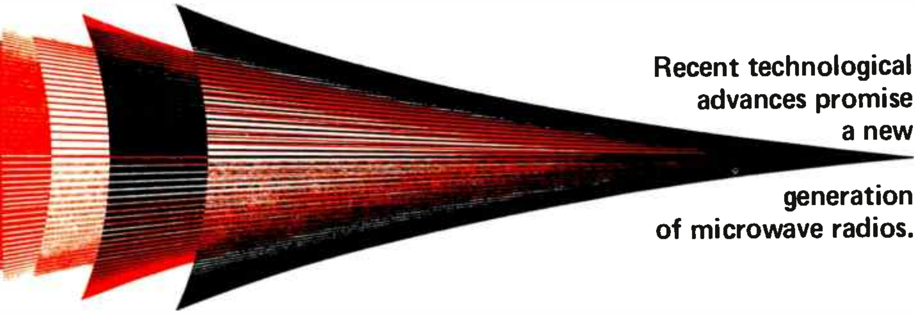
The Lenkurt

# DEMODULATOR

JULY 1969

## Microwave Sources



# Recent technological advances promise a new generation of microwave radios.

In many respects, supercession and obsolescense might be called the "name of the game" in communications technology. When a new product or process is announced, it is seldom very long before refinements or even a replacement comes on the market.

The transistor replaced the vacuum tube and is itself being refined and improved upon daily. Data transmission rates climb ever higher as modems are improved and new modulation techniques are developed. Circuitry is being made constantly smaller and more reliable.

These are but a few examples of the rapid and dramatic changes in the industry. This rule of change is rendered even more noteworthy by some of its exceptions – the holdouts. Most notably, the klystron source for microwave transmission has become so entrenched as to appear almost impervious to change. It has been around for a long time and has performed well – it does the job.

Now, even this old standby is being challenged. Solid-state technologists have long searched for a replacement for the klystron signal generator. Ideally this replacement will be a single, discrete, solid-state device – probably it will be of the Gallium Arsenide variety.

But until that breakthrough occurs, there are many interim, compromise replacements for the klystron in the market today – and others should be forthcoming.

## The Venerable Klystron

Invented more than thirty years ago, the klystron source revolutionized communications. In the intervening years, it has been continually improved and now is the ultimate in reliability and efficient performance. Obviously, one of the advantages offered by a device that is so familiar is that its problems have very likely all been long since solved. (One example of this in the klystron is how problems of heat dissipation have been overcome.) Even though many improvements have been made, the basic operating principles are the same.

In essence, the klystron is based on the rule of the conservation of energy. When a moving electron is accelerated it must draw its added energy from *somewhere*; conversely, when slowed, it loses energy *which must go somewhere.* In an electronic circuit, this energy is either taken from or supplied to the field. Interestingly enough, the "new" solid-state devices are based on the same set of principles.

This being so, it should be worthwhile to review the operation of klystrons as an aid to understanding solid-state devices.

Figure 1 shows a simplified circuit of a klystron amplifier. It works like this: A positive accelerator grid acts as a cathode gun drawing electrons and shooting them in a high velocity stream toward a pair of grids in the cavity resonator. The cavity acts much like a tuned LC circuit. The signal is fed into the cavity by means of a waveguide or a probe or by a coupling loop as shown.

Applied signal voltage creates an electrical field between the grids, called *buncher* grids. During the positive half cycle of the input voltage, this field accelerates the approaching electrons and on the negative half cycle, the effect is just the opposite. At zero, of course, the field has no effect at all. As a result the electrons moving from the buncher grids have varying velocities – some have accelerated, some decelerated and some show no change.

Referring to Figure 1, the space between $G_3$ and $G_4$ is free of any fields and is hence called the *drift space.*

Because of the varying velocities of the electrons, faster ones will overtake slower ones and form into groups or *bunches* in this drift space. These bunches form in another resonant cavity equipped with a set of catcher grids ($G_4$ and $G_5$) and induce an r-f voltage. Given the proper phase relationship between this voltage and the incoming electron bunches, the field will cause the electrons to slow down as they pass through the catcher gap. In slowing, the electrons surrender some of their energy which goes into the resonator field and is extracted by a coupling loop. From here, the electrons continue on and strike a collector plate which returns them to the cathode for regeneration and repeat of the cycle.

The resultant amplification is due to the fact that, in passing through the gap, more electrons are slowed than are accelerated, thus surrendering more energy to the field than is taken out. Hence, the klystron has amplified the signal.

In addition to amplifiers, klystrons are also used as oscillators and frequency multipliers. The reflex klystron is typical of the ones being used as oscillators for microwave radio, such as Lenkurt's Type 76 and Type 78 radio families.

## Reflex Klystron

The basic reflex klystron uses only one resonant cavity and one set of grids which acts as both buncher and catcher. In place of the amplifier's collector, the reflex klystron has a negative-voltage electrode for returning the electrons.

It works like this: The potential of the first grid draws electrons from the cathode through the resonator gap and

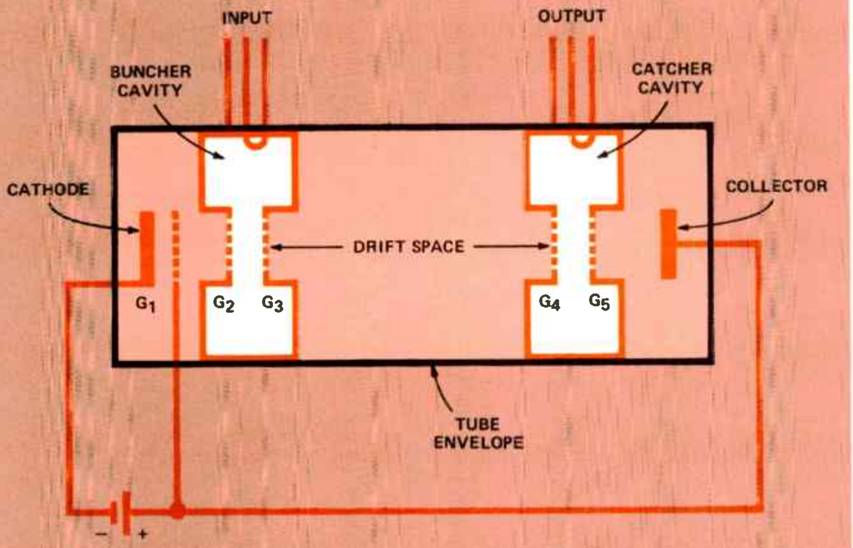


*Figure 1. Simplified diagram of a klystron amplifier. An actual klystron usually has a set of electrodes at the cathode which focuses into a narrow beam.*

toward the repeller. Since the electrons' positions are random, they induce small noise voltages in the gap – some of which will fall into the resonant cavity's frequency range. Just as the signal source does in the klystron amplifier, these voltages will velocity-modulate the electron beam, causing some electrons to have different speeds from others on their way from the gap to the repeller. And since they are traveling at different velocities, the same bunching effect occurs as it did in the klystron amplifier.

In the reflex klystron, these electron bunches pass back through the gap toward the cathode and induce reinforcing voltages in the gap. This reinforced voltage modulates the velocity of the other electrons coming from the cathode and the cycle repeats itself. A state of equilibrium is created when returned energy and circuit losses balance and the klystron oscillates at the frequency of a resonant mode of the cavity.

Since both frequency and power output are directly dependent on elec-

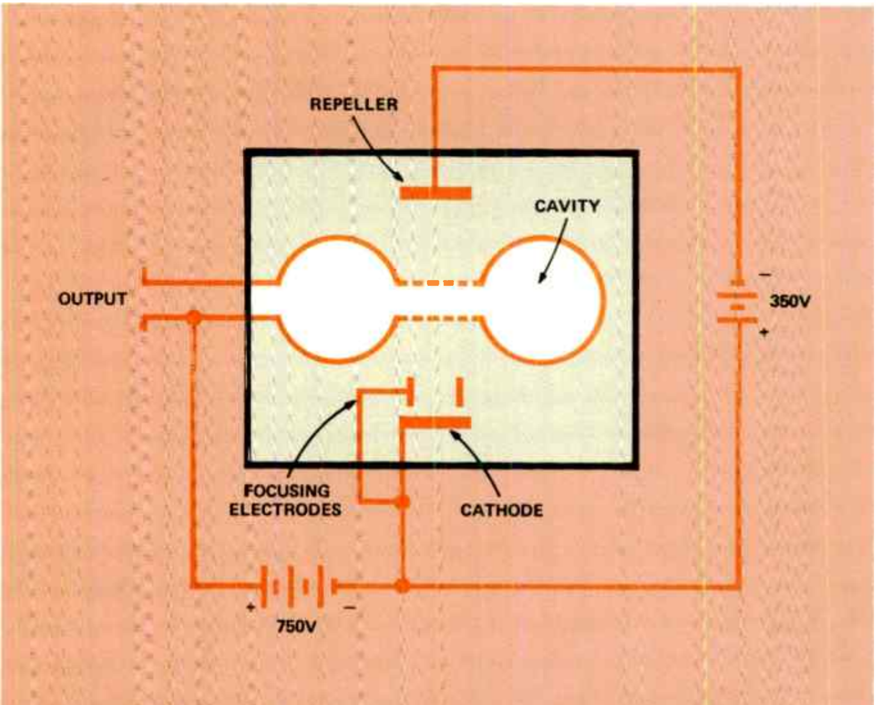


*Figure 2. Diagram of a reflex klystron. The output may be through a waveguide, coaxial cable or probe.*

tron transit time, they can be controlled and the klystron tuned simply by varying the distance between gap and repeller controlling the grid voltage. Making the voltage more negative reverses electron flow at a point further from the repeller, thus decreasing transit time and increasing frequency. Frequency can be reduced by applying a less negative voltage.

## Microwave Transmitter

In microwave radio transmitters, the reflex klystron is used as an oscillator tuned to produce a CW signal at a power of one to two watts. Baseband signals are applied through a modulating amplifier to the repeller of the klystron. The resultant FM signals are conveyed to the antenna through a ferrite isolator, a directional coupler and a waveguide filter. The isolator prevents reflections from disturbing the operation of the klystron.

A small amount of RF energy is taken through the directional coupler into a highly stable AFC discriminator. Here the output frequency of the klystron is compared with the reference, and any difference provides an error voltage to correct the operating frequency by changing klystron repeller voltage.

One primary advantage of reflex klystrons is that they produce a usable microwave frequency directly – without the need for frequency multiplication of any kind.

Even so, the klystron's long tenure as the industry standard is currently being challenged by solid-state sources which, however, do rely on frequency multiplication to achieve microwave output.

Certainly one of the most successful efforts in the area of solid-state source radios is the Lenkurt 71 type microwave system. Operating in the 2 GHz range, this all solid-state radio was developed at Lenkurt over four years ago. With the 71 as a foundation, Lenkurt engineers continue vital work in the development of the solid-state art.

## "Solid-State Oscillators"

Research engineers throughout the industry have long been involved in

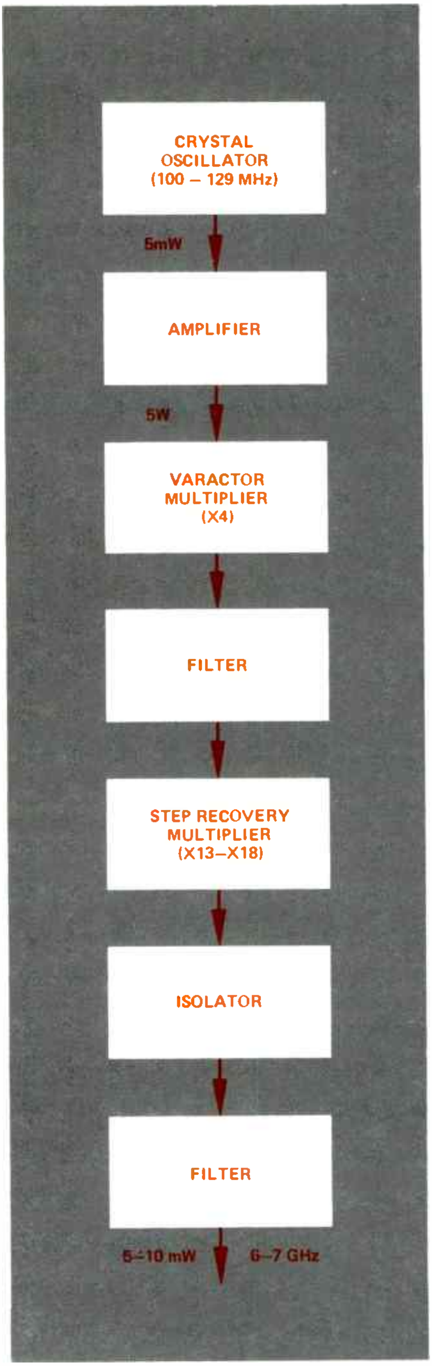


*Figure 3. Typical solid-state local oscillator design uses crystal oscillator frequency reference source, varactor diode multiplier for times four multiplication and step recovery diode for times thirteen to times eighteen multiplication. Microwave frequency in the 6 to 7 GHz range, determined by the step recovery multiplication, has from 5 to 10 milliwatts output.*

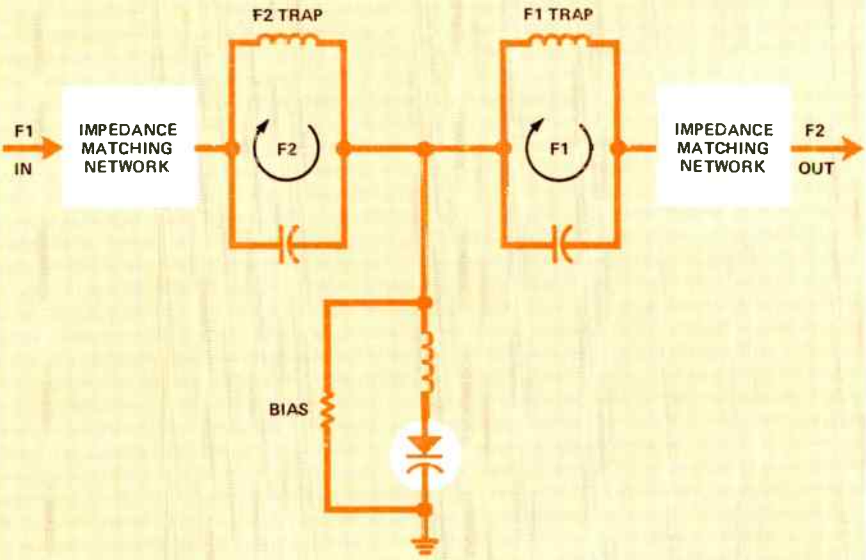


*Figure 4. This greatly simplified schematic represents multiplier's typically found in solid-state microwave radios. A six-stage multiplier would use three such circuits, a twelve-stage, six and so on.*

the development of a solid-state frequency source for microwave radio. Transistors, diodes and other devices of the same general description have been tried with varying degrees of success. The problems with such devices are many, with efficiency as the knottiest. Up to now, engineers have been unable to develop a solid-state oscillator that is immune to prohibitive power trade-offs. In order to achieve sufficient power output at the microwave frequencies, supplied power was necessarily so high that it was either too expensive or, more often, beyond the power handling capabilities of the device itself.

Although still awaiting the breakthrough that will provide a single-component microwave transmitter source, designers have a kind of interim solid-state device to work with. It is called the frequency multiplier, or semi-conductor varactor chain. More commonly, it is called a "black box".

Using a very stable crystal reference source, it is possible to harmonically multiply the output through amplification. Currently this technique is being employed in both transmitter sources and local oscillators (LO's) in microwave radio receivers.

Basically, solid-state oscillators – receive and transmit – depend on the same physical principles for their operation as do klystrons. The rule of the conservation of energy is the operating principle for both devices.

However, the electron movement in solid-state devices is much more confined and, as the name implies, takes place in solids rather than in gases. For a detailed description of solid-state physics, see the December 1968 Lenkurt DEMODULATOR.

Semi-conductor manufacturers are providing packaged multiplier chains for use as solid-state local oscillators at 2, 4, 6 and 8 GHz. All are used in various microwave systems manufactured by Lenkurt. As a matter of fact, the Lenkurt Type 78 family of radios is completely solid-state except for the reliable transmit klystron.

## Varactor Chains

By providing sufficient power amplification to a 100 MHz crystal reference source, it is possible to achieve microwave frequencies on the order of 6 GHz. This is done through the use of frequency-multiplier step-recovery diodes, commonly called varactor chains. Obviously, one result of this kind of multiplication is loss of power – as frequency goes up, power goes down. However, this is not too critical in LO's. Typically, five to ten

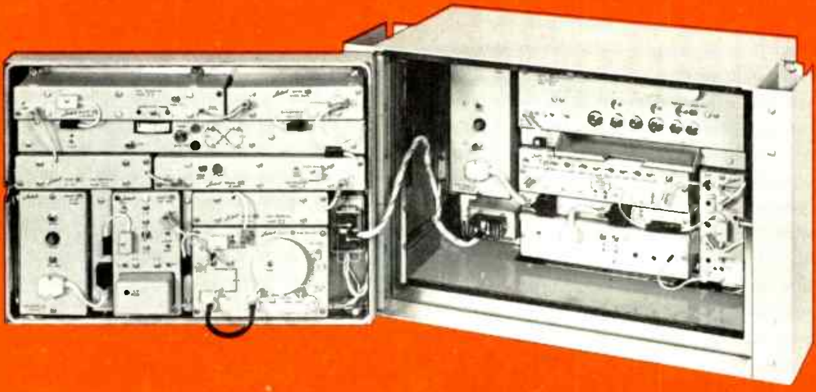


*Figure 5. Construction of the Lenkurt 71F 2-GHz Microwave Radio typifies the advanced modular design and high density packaging afforded by total solid-state construction.*

watts of power at 100 MHz will decline to about 10 *milli*watts at 6 GHz, which is sufficient for a local oscillator signal. (See Figure 3).

The varactor is a simple p-n junction whose prime characteristic is the ability to generate harmonics of the signals or waveforms applied to it. Basically a capacitor, the varactor has the added characteristic of being able to continuously vary its capacitance as the applied signal wave or voltage is varied. The effect of this on the signal is quite complex.

The changing signal value causes the circuit reactance to vary continuously while at the same time changing the amount of signal energy absorbed and returned to the circuit by capacitance. The result is a highly distorted output wave which is extremely rich in harmonics.

A simple varactor frequency doubler consists basically of two resonant circuits coupled through a common impedance — the diode itself. The input circuit is series resonant to the frequency to be doubled. The output circuit is tuned to the 2nd harmonic of the input frequency. Return of either the basic frequency or its harmonic is blocked by frequency "traps" in the circuit. A simplified frequency doubler varactor is illustrated in Figure 4. It is possible to tune such circuits to obtain the third, fourth, sixth or even higher harmonic to achieve higher orders of multiplication. However, such circuits tend to become less efficient as they become more complex. Nonetheless, it is this higher order of multiplication that is of interest to designers of microwave transmitter sources.

Recently, several manufacturers have introduced new microwave radios. They are new inasmuch as they are all solid-state — in both receiver and transmitter. But they do not yet employ the single semiconductor component that will be the true all solid-state source. Instead, they use the varactor frequency multiplication devices discussed above. Variations in the number of multiplication steps involved are considerable. They range all the way from eighteen down to six.

Problems seem to be directly proportional to the number of stages involved. Although the efficiency of each stage may be high, depending on the degree of multiplication, the total efficiency of the chain will be lower. For example, if six frequency doublers are used to convert a 100 MHz signal to 6 GHz for microwave transmission, and each link in the chain is 50% efficient, only about 6% of the input power would be converted to the microwave signal. Consequently, it is necessary to apply about 16 watts at the input to achieve an output signal power of one watt.

Another obvious problem is one of maintainability. Each varactor in the chain consists of many discrete components. The number of components in an entire system then, will increase geometrically with the number of multiplication steps involved. And here, as in any other system, difficulty in trouble-shooting and the likelihood of component failure will increase in direct proportion to the increase in complexity of the system.

There are also some interesting statistical comparisons between micro-

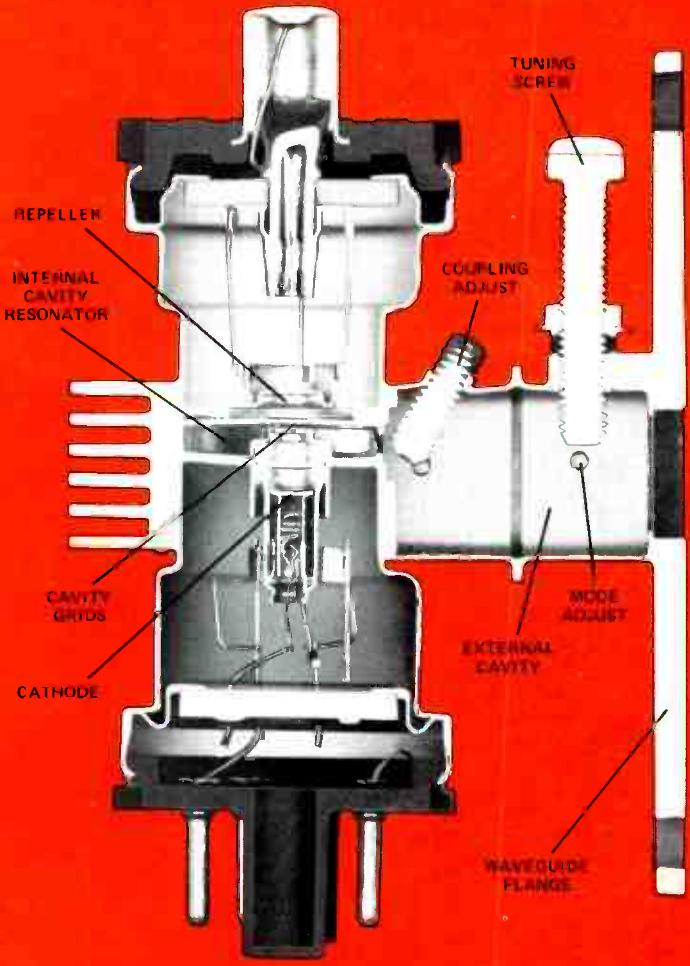


*Figure 6. Cross-section view of external-cavity reflex klystron. Internal resonator cavity is shaped at time of manufacture, has no moving parts within vacuum. Over-coupling between internal and external cavities permits tuning output frequency by simple mechanical screws in outer cavity. Waveguide output is under-coupled to load, preventing frequency "pulling" by changing load impedance.*

wave systems with klystron transmitters and those using "black boxes" of varactor chains.

From an engineering point of view it is interesting that klystron source radios such as the Lenkurt 76/78 family are engineered for and rated at 1200 channels. A comparable solid-state system is fully loaded at 600 channels.

Now, whether or not 1200 channels are *required* is not nearly so important as the fact that the system is *designed to meet* requirements imposed by 1200 channel loading.

It follows then that such a system loaded with anything less than 1200 channels would actually be loafing – hence its reliability and longevity increase accordingly.

This situation is further complicated by the addition of inherent noise problems and lack of linearity in solid-state devices. This is because varactors are, by their very nature, *non-linear* devices. And, as in any electronic circuit, noise increases correspondingly with the number of circuit elements involved. Consequently, sources employing higher orders of multiplication will contribute more noise to the system than those operating closer to the theoretically ideal single source.

The mathematics of this developing technology are interesting indeed. Designed to overcome some of the problems encountered in the klystron – such as power requirements and heat resulting from the high power – a tradeoff stage is reached where newer problems, inherent in the device itself, all but cancel the advantage derived. At the current state of the solid-state art it seems about an even trade-off – familiar problems traded for new ones.

This is not to say that the solid-state varactor chain doesn't work – it does. But the art is in its infancy, and some of the problems that will surely develop – as they must with all new technologies – haven't even been anticipated, to say nothing of being solved.

But problems exist to be solved, and work goes on. One direction that the solid-state art seems to be taking is that the nearer designers come to eliminating multiplication altogether – that is, developing a single discrete source – the better the devices become.

Frequency multipliers now employ from eighteen to six multiplication stages. Development engineers are approaching the theoretical ideal geometrically and it is a safe bet that a microwave transmitter source employing only four or even two stages will be forthcoming soon.

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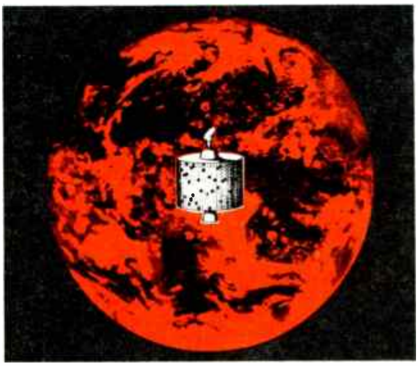
# The Lenkurt DEMODULATOR

AUGUST 1969

## DEVELOPMENTS IN SATELLITE COMMUNICATIONS



In the four short years since the launching of Early Bird there have been dramatic advancements in both satellite and earth station technology.

The Communications Satellite Act of 1962, a unique piece of legislation recommended by the late President Kennedy, called for the establishment of a new and unprecedented private corporation to act as an instrument of the United States in establishing a world-wide communications satellite system as quickly and expeditiously as practicable.

This Act by Congress did not attempt to prescribe the nature or form of the international arrangements, but left this responsibility to the President, the Department of State, and a new corporation which was formed a few months later, the Communications Satellite Corporation (COMSAT).

After holding discussions with a number of countries around the globe, COMSAT drafted the Interim Agreements and opened them for signature in August of 1964. The original body of signatories representing 11 countries, now represents over 68 countries and is known as the International Telecommunications Satellite Consortium (INTELSAT).

In the brief time since its founding, INTELSAT has become the largest international joint venture ever undertaken.

Under the Interim Agreements, COMSAT represents the United States in INTELSAT, has 53 percent ownership in the system, and acts as manager for the consortium. The Agreements provide joint ownership of the space segment of the global system, with voting power being proportionate to ownership of participants as representatives of the Interim Communication Satellite Committee (ICSC). Membership of the interim committee is composed of space segment owners or combinations of owners having quotas of 1.5% or more. The committee is the executive organ of INTELSAT while COMSAT is the manager.

## Geo-Stationary Satellites

The successful launching and orbiting of Telstar and Relay in 1962, with their low, non-synchronous orbits and brief 30 minute transmission periods assured the future of active satellite repeaters.

Under a contract from the National Aeronautics and Space Administration (NASA) the synchronous*, geo-

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*A satellite in synchronous, geo-stationary orbit travels around the earth at 6,870 miles per hour in a circular, easterly path 22,300 statute miles above the equator. Because it travels at the same angular velocity around the earth's center, it appears to stand still – hence the reference to such satellites as being "fixed" or "stationary".

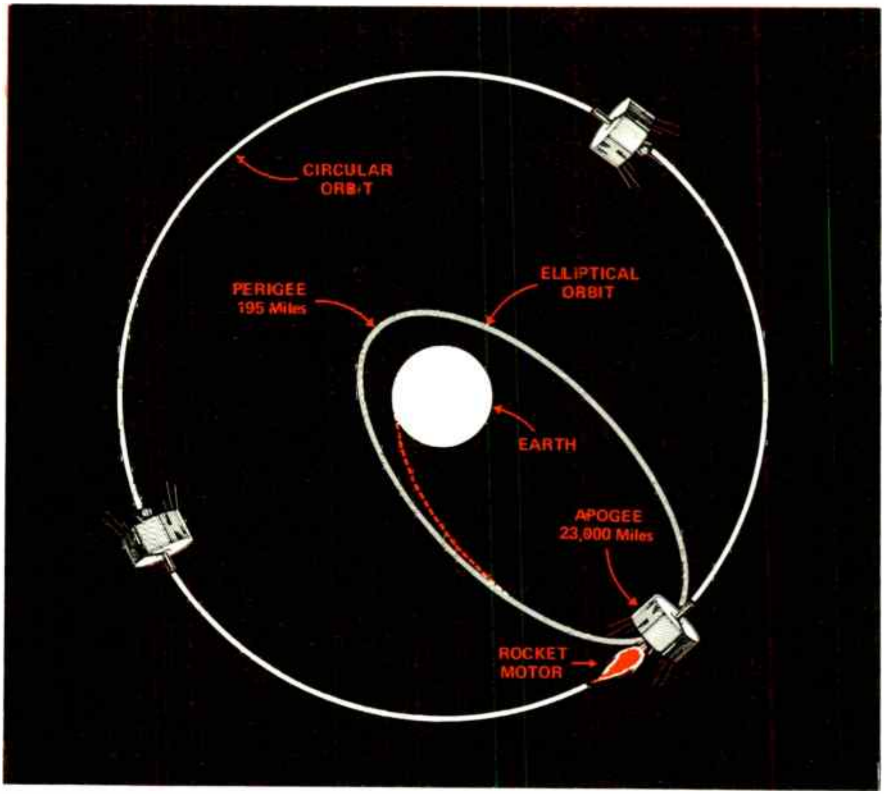


*Figure 1. Accomplishing a synchronous, geo-stationary orbit requires the satellite be launched in an elliptical orbit, whose apogee aproximates 22,300 statute miles. When the satellite approaches this point an apogee rocket motor, on command from the ground, is fired emplacing the satellite in "fixed" orbit. Additional thrusters are employed from time to time to maintain proper attitude and earth alignment.*

stationary satellite series termed SYNCOM was developed. SYNCOM I, intended for a synchronous equatorial orbit 22,300 miles above the earth early in 1963, failed to operate. SYNCOM II was launched later that year. SYNCOM III was placed in a stationary, equatorial orbit over the Pacific Ocean in mid-1964. The SYNCOM series dispelled any final doubts about the feasibility of a geo-stationary satellite communications network.

It is an interesting historical note that the concept of a geo-stationary satellite was first published in October, 1945 in an article entitled "Extra Terrestrial Relays" by British scientist, A.C. Clarke. Although Mr. Clarke's article seemed pure fiction to many at the time, it now stands as a prophecy to the events which have come to pass.

Clarke's idea of a satellite 22,300 miles above the earth in a stationary 24-hour orbit anticipated the actual event by some eighteen years.

The world's first commercial communication satellite was orbited April 6, 1965. This synchronous satellite, named Early Bird, was placed in a geo-stationary equatorial orbit over the Atlantic Ocean. From its vantage point 22,300 miles above the Atlantic, Early Bird linked North America and Europe with 240 high-quality voice circuits and made live television commercially available across the Atlantic for the first time. Early Bird, although the oldest communication satellite, has far exceeded its expected lifetime of 18 months and is still operating.

## Since Early Bird

In the four short years since Early Bird was launched, six larger and more powerful satellites have successfully been placed in operation over the equatorial regions of the Atlantic, Pacific and Indian Oceans.

Early Bird, designated INTELSAT I, was the first of the INTELSAT series. By September 1967 four INTELSAT II satellites had been launched; the first of these failed to achieve orbit due to a malfunction of the apogee motor. The second was successfully parked in orbit over the Pacific Ocean, while the third was positioned, as planned, 6° W longitude over the Atlantic Ocean. The fourth of the INTELSAT II satellites was emplaced above the Pacific Ocean at 176° E longitude, only 2° W of the previous Pacific Ocean satellite.

INTELSAT I and II satellites were designed with 240 channel capacities, about one fifth the channel capacity of the INTELSAT III satellites which followed.

By May of 1969, three INTELSAT III satellites had been placed in orbit, one each over the Atlantic, Pacific and Indian Oceans. These three solar powered, 130 watt, giant satellites are capable of handling 1200 separate two-way telephone conversations, or four TV channels, or any combination of the two. In actual practice, part of their bandwidth has been assigned for TV use and the remainder for telephone, telegraph, data and facsimile communications.

There were seven commercial INTELSAT satellites over the equator in fixed, operational orbits by June of 1969 (See Figure 3). The objective, according to COMSAT's schedule, is to have an additional INTELSAT III satellite in orbit (over the Atlantic Ocean) by fall of 1969.

In contrast to the communications system of the INTELSAT III series, which includes two earth coverage transponders, the INTELSAT IV satellites will have a communications system that includes twelve transponders. Each of these receiver-transmitters is an independent frequency translator and amplifier. One of the unique features of the INTELSAT IV satellites will be the ability to switch the transponders in orbit to cover the precise earth area desired. This flexibility will make it posssible to adjust the satellite's capability to changing communications requirements. (Figure 2).

Using solar cells, the INTELSAT IV will generate more than 500 watts of power, about four times that of the INTELSAT III. This new model is expected to provide about 3600 circuits if all transponders are used for earth coverage, but as many as 9000 circuits if maximum use of spot coverage is made. It is expected that the mix of transponders will be such that each of these satellites will have a functioning capacity of at least 5000 circuits.

## Earth Stations

The possibilities confirmed by the success of the synchronous satellite were revolutionary. With a minimum of three satellites, global coverage could be achieved. This would provide telephone, radio and television services, a vast communication and navigation service for aircraft and shipping, and many more applications.

The immediate implication of geostationary satellites greatly concerned earth station technology and mechanics. The huge tracking station antennas would require only very limited movement to follow a "fixed" satellite. This

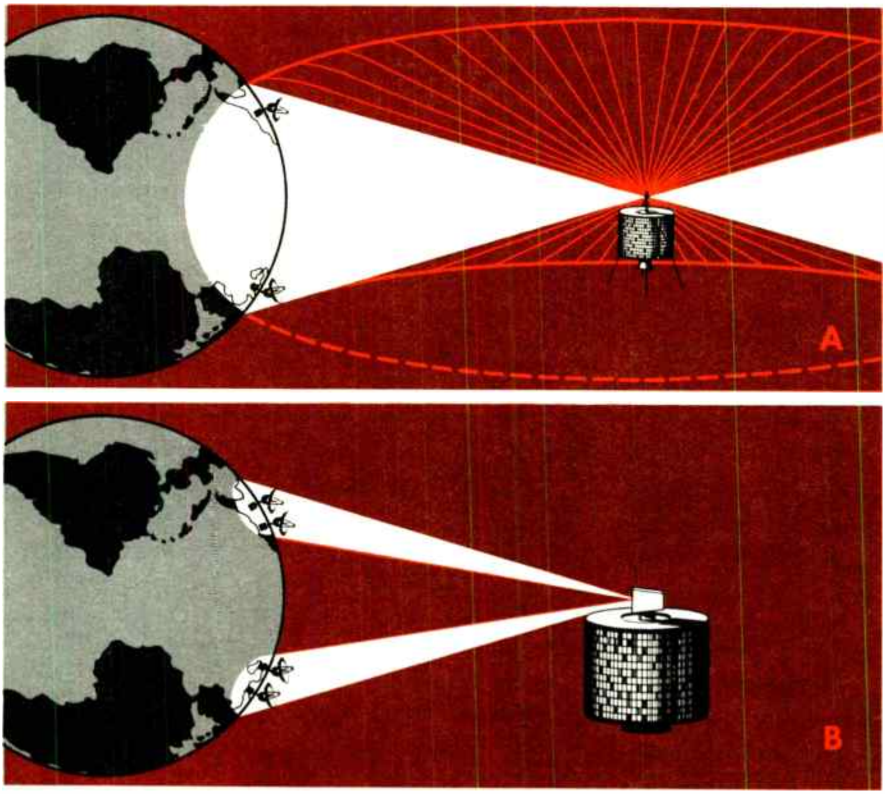


*Figure 2. Early Bird employs a toroidal transmission pattern (A) which loses much rf energy to space. The proposed INTELSAT IV satellites will employ a more sophisicated and efficient transmission pattern (B).*

would permit tremendous savings in the cost of material and maintenance. Further, because the tracking station would be operating with a synchronous satellite, the variable path-delay compensation required for operating a system of moving satellites as well as the complex hand-over problems created as a satellite passes from one earth station area to another, would become unnecessary.

Simplifying earth station technology, particularly the complex tracking requirements, not only allowed more attention to be focused on the development of new and better radio equipment, it realistically meant that many more earth stations could be erected in less time at less expense.

When Early Bird went into service in 1965, there were only a few experimental earth stations in the United, States, Japan, and Europe. By mid-1969, 25 earth stations were operating in 15 different countries. And 21 additional earth stations in 14 countries were either under construction or contract. This made a total of 46 stations in 29 countries (See Figure 3), around the world, with many more in the planning stage.

In spite of the fact that the INTELSAT group is not part of the space segment, it is understandable that they necessarily dictate the critical characteristics for each earth station interrelating with its satellites. A "standard" station specification has been

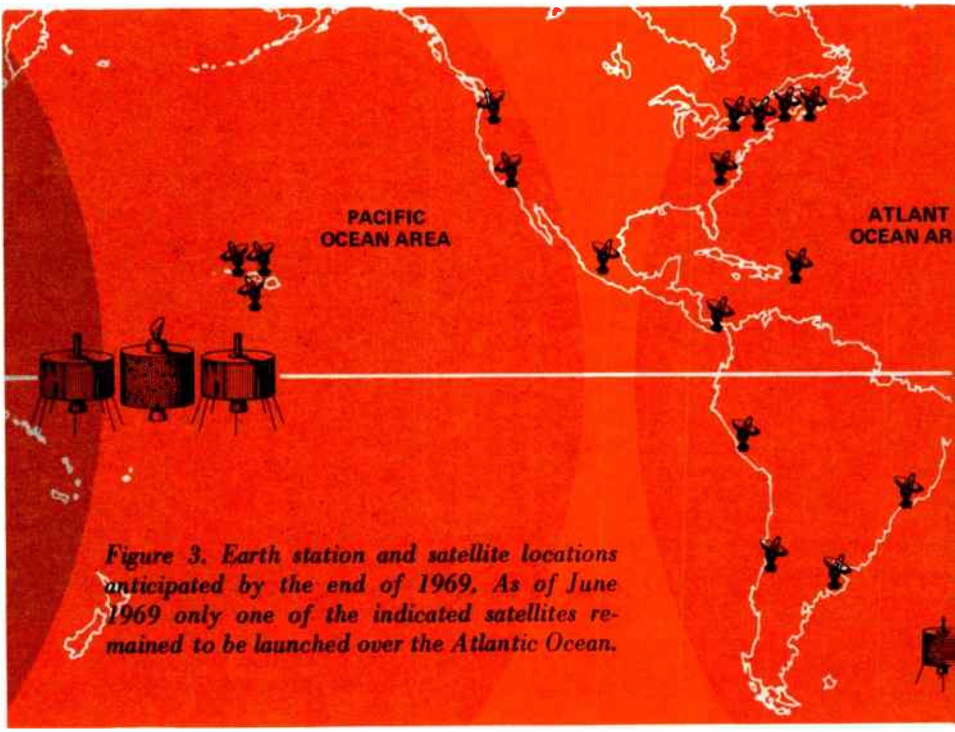


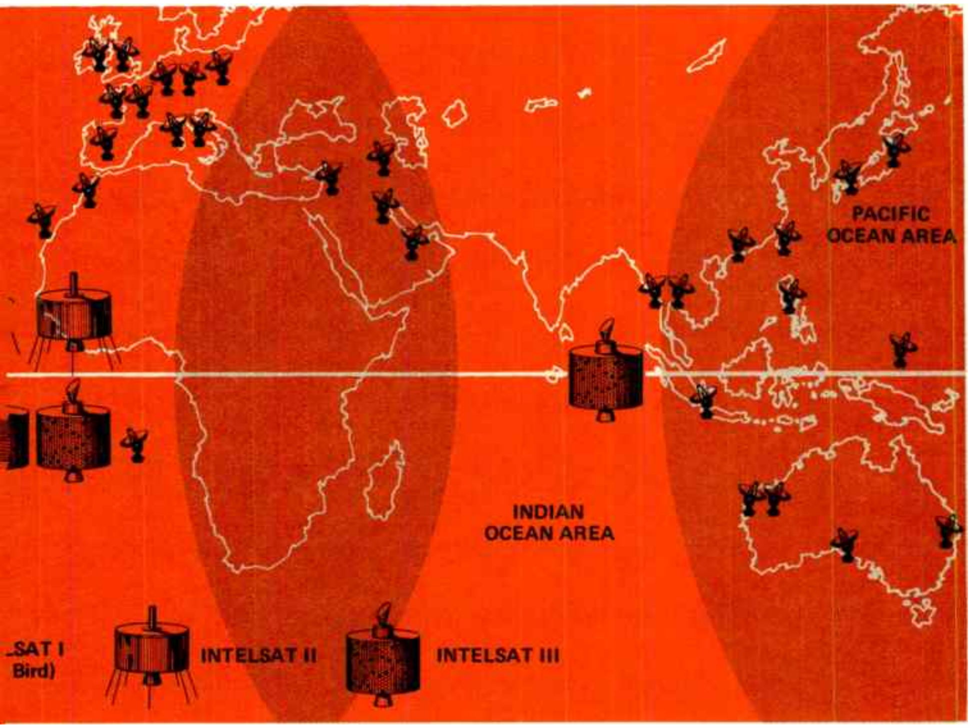
*Figure 3. Earth station and satellite locations anticipated by the end of 1969. As of June 1969 only one of the indicated satellites remained to be launched over the Atlantic Ocean.*

written to cover technical characteristics which may in any way affect the operation of the space segment or the use of it by any other earth station. Many features are specifically defined, such as the ratio of antenna gain to noise temperature, side lobe levels, maintenance of the transmit e.i.r.p. (effective isotropic radiated power) in the direction of the satellite to within ±0.5 dB of the nominal value, polarization, tracking modes, steering capabilities, RF out-of-band emission and amplitude frequency characteristics – to mention a few.

Improvements in earth station technology have not always received the same publicity as the launching and orbiting of the various satellites because of the more spectacular nature of the latter. There have been, however, some rather exciting developments in earth station systems. Some of these have been in specific response to unique problems accentuated by the satellite system. Lenkurt's 931C Echo Suppressor was especially designed for this type of service. The solid-state 931C suppresses the echos which are a problem partly due to the tremendous distances radio signals travel through space, to and from the extra-terrestrial satellites.

## Molniya and Others

The Soviet Union, on October 4, 1957, launched Sputnik I. This event heralded man's first step into the field



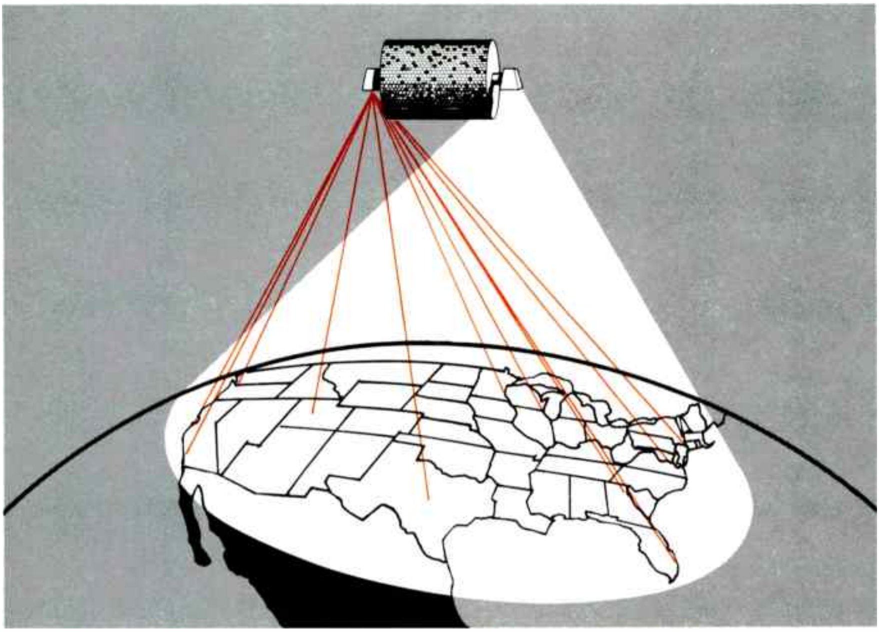


*Figure 4. Advanced domestic satellites will use more efficient "direct beam" transmission.*

of earth satellites with special attention going to the Soviet Union.

Only seventeen days after the launching of Early Bird, the Soviet Union successfully orbited their Molniya I on April 23, 1965. Molniya I was Russia's first experimental communications satellite. This active repeater satellite followed a highly elliptical orbit ranging from about 300 miles above the earth to more than 24,000 miles transmitting all forms of communication between Moscow and Vladivostok.

To date, Russia has launched several Molniya-class satellites in 12 hour elliptical orbits. Successful transmissions of many types of signals, including color television, have been carried out in joint experiments with the French. While the Russian satellites have an apparent lack of channel capacity, they do boast, among other things, high-powered transmitters. The Molniya has a command receiver, 40-watt transmitter, two reserve transmitters, and two steerable parabolic antennas.

Of the various nations which are non-members to the INTELSATgroup, the Soviet Union is the most noteworthy. Even though they do not have a synchronous, geo-stationary satellite, the Soviet Union has constructed a network of earth stations and, by using several Molniya-class satellites, have established a domestic satellite communication system.

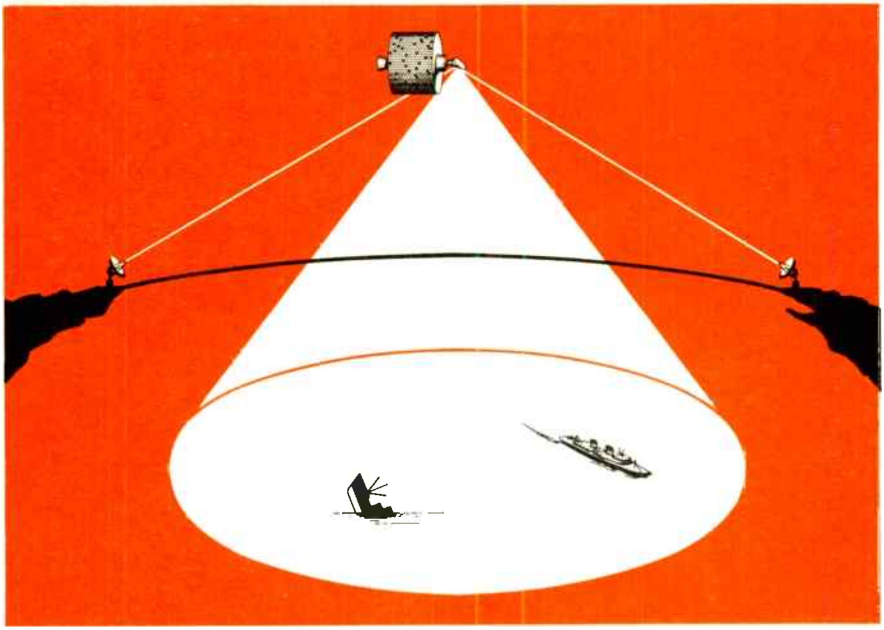


*Figure 5. Unlike trans-oceanic cables, satellites can provide immediate communications at sea.*

## Frequency Utilization

All INTELSAT satellites presently employ radio frequencies within 500-MHz bands allocated for that purpose by the International Telecommunications Union (ITU) Radio Regulations. Earth station-to-satellite transmissions have been assigned frequencies in the 5925 to 6425 MHz band. Satellite-to-earth station transmissions use frequencies in the 3700 to 4200 MHz band. These frequency bands are shared on an equal right-of-use basis with terrestrial microwave systems.

The desirable range of frequencies for international communications lies within the range of 1 to 10 GHz. It is expected that the present band allocations will have been exploited within the next ten years.

A more efficient use of bandwidth has resulted from the increased power of the INTELSAT III and IV satellites. Even though this makes it possible to decrease the per channel bandwidth, it will still be necessary to look for new bands to allocate for exclusive satellite communications use.

## Expansive Ideas

Modern satellites are capable of transmitting all forms of communications simultaneously — telephone, telegraph, television, data and facsimile. Satellites can operate competitively with cable networks and have the advantage of multipoint, multiple access. This means that synchronous satellites, in geo-stationary orbits can make possible direct communications between all countries having earth stations within a satellite's line of sight, eliminating much of the circuitous routing which has been so characteristic of international communications. A large number of innovations and expansions can be expected during the next decade.

A pilot domestic satellite program has been proposed to make available the benefits of satellite technology to the people of the United States. The development and use of "direct beam" transmission (See Figure 4) is now being planned.

In addition to people, computers in one country are now talking with increasing frequency to computers in other countries, and at speeds 20 times greater than anything possible by more conventional means.

High-quality telephone service is now becoming available from the United States to a growing number of countries that were previously difficult to reach by cable or short wave transmission.

Entire news pages can be transmitted via facsimile across the ocean and reproduced a matter of hours after the original publication.

Weather maps are already being quickly transmitted via facsimilie from one country to another to assist intercontinental airline pilots in charting plans for flights.

Passenger and cargo data has also been transmitted across the Atlantic to customs officials in the United States while a plane was in flight. With all the necessary information on hand inspectors were able to speed passengers and cargo through customs.

Satellites will soon make available maritime communications systems at sea which will compare, in quality and reliability with services now commonplace on land. This can mean the potential saving of hundreds of ships that are lost at sea each year, many without any communication.

The most dramatic role of the communications satellites is the part they play in the space program. Atlantic and Pacific satellites of the INTELSAT II series are a key part of the communications system developed for NASA's Project Apollo – the moonlanding program.

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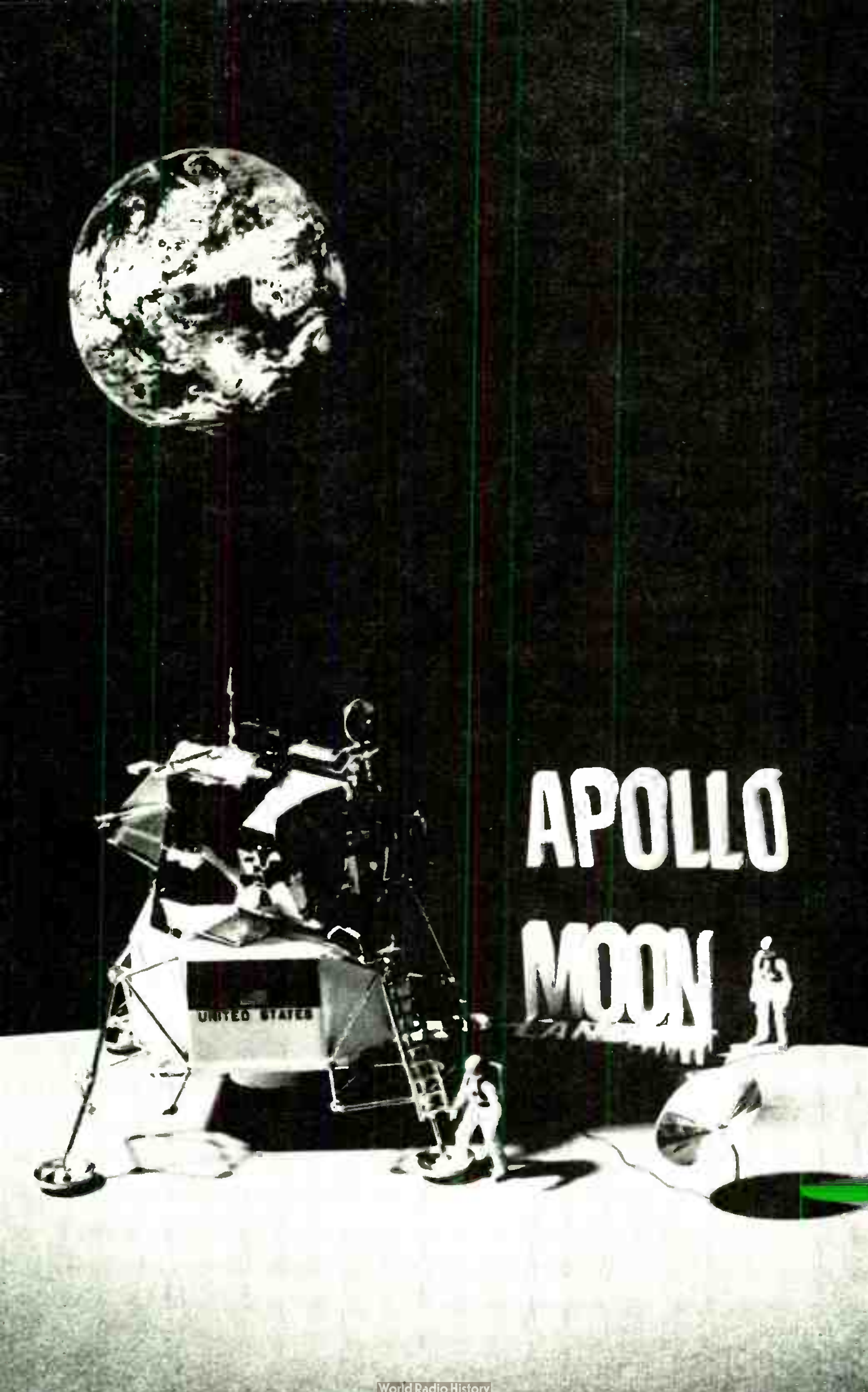
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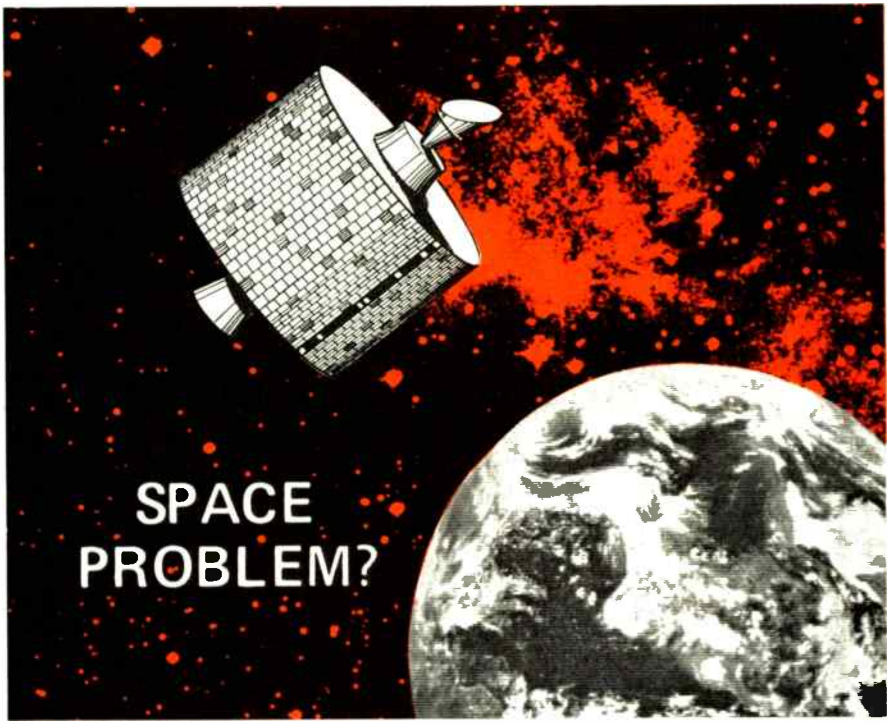

Lenkurt's solid-state 931C Echo Suppressor eliminates the echo encountered in satellite, transoceanic and transcontinental circuits. Featuring micro-electronic design with reliable printed circuit construction, this equipment will operate end-to-end with Western Electric's 3A and other suppressors meeting CCITT recommendations. For further information, write Lenkurt, Dept. C134.

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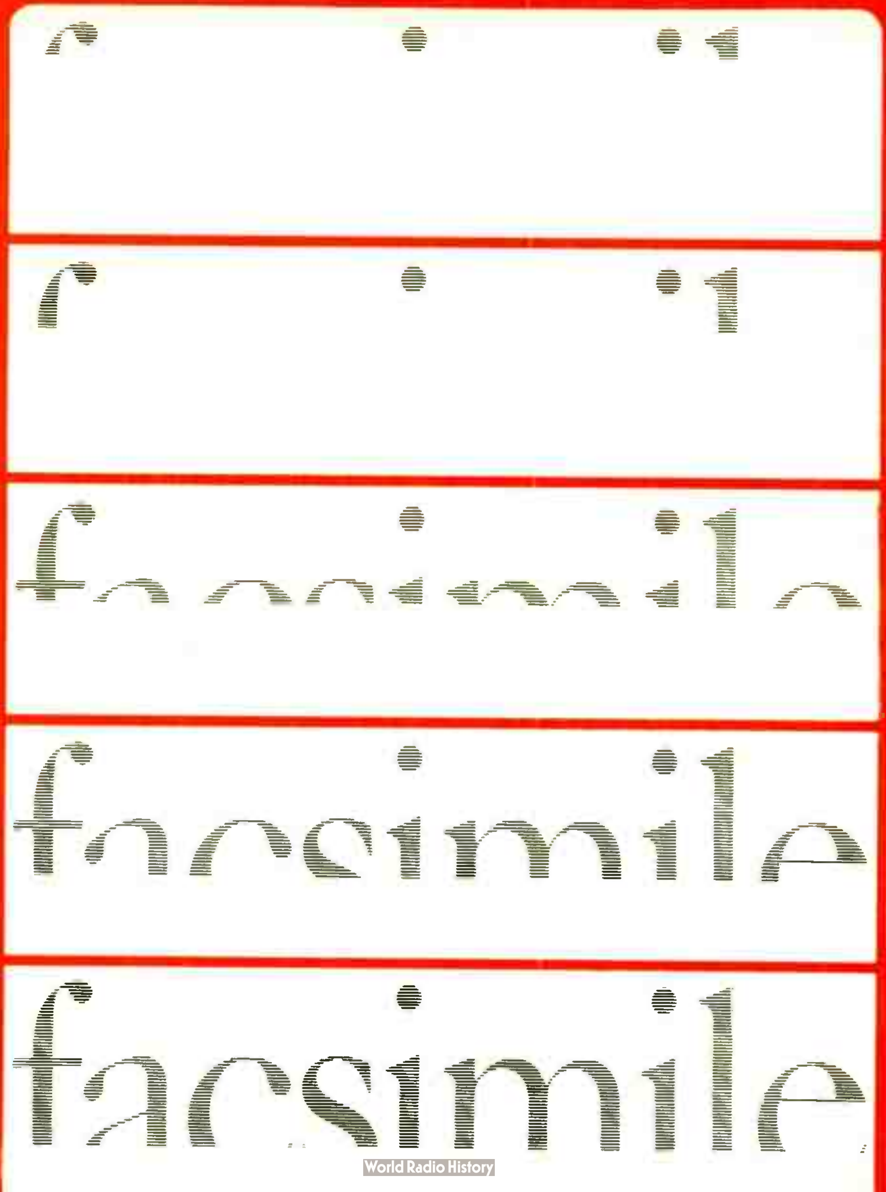
# The Lenkurt. DEMODULATOR

SEPTEMBER 1969



# facsimile

**That old Chinese proverb about a picture being worth a thousand words is no less true in this day of highspeed electronic communications than it was in the early days of paper. As technology improves, the relative value of picture transmission may well exceed that of a thousand words.**

The art of sending pictures, maps or whole messages over radio, telephone, telegraph and cable facilities is known as facsimile transmission, or "fax". The basic principles of fax have been understood for almost 100 years. Only in recent years, however, have transmission techniques improved to the point that this unique form of telecommunications can begin to be commercially exploited.

Technological advances in the field of data transmission have, incidentally, made it possible to develop fax systems which significantly reduce transmission time and thereby lower line cost. The expense associated with older transmission techniques has been the most limiting factor in the history of fax. A reduction of common carrier rates, in 1962, considerably improved the commercial outlook of fax, but future advances in data transmission technology will probably have a greater effect.

## Background

The early applications of facsimile were essentially limited to the transmission of photographs, telegrams and weather maps. One of the oldest commercial users of fax is Western Union Telegraph Co., presently operating more than 30,000 units for the delivery of telegrams. Thousands of fax equipments are used by the military, weather bureaus and commercial airlines for the recording of weather maps. The advent of weather satellites has made this function more reliable and timely.

The transmission of photographs and weather maps requires high resolution and good quality reproduction. Even early fax systems were capable of this kind of performance – quality was not the problem. The problem, until recently, has been providing economical methods for the transmission of large volumes of lesser quality material, such as letters and line drawings. Many similar applications do not require high resolution.

The early uses of fax persisted because of the need to transmit certain kinds of high resolution graphic material from one place to another regardless of cost. Photographs for newspapers, emergency telegrams for people unreachable by phone, and weather maps to chart airline flights are examples of such indispensable services. The use of facsimile as a necessary tool in keeping the public informed was assured by the Federal Communications Commission when

● VOL. 18, NO. 9

they reserved a portion of the radio spectrum specifically for the transmission of fax by newspapers.

In the light of its present development, it is appropriate to reassess facsimile's role in the field of electronic communications. In a fundamental way, fax provides some unique advantages over other methods of communication. Visual material is often less ambiguous than audio material; most people are better visually-oriented than audio-oriented. Because of this, visual material is not as often misperceived as material which is only "heard". There is also the added benefit of having a readily available permanent record for verification when accuracy is in doubt. Fax material can be more quickly copied for distribution or filing. It can also handle a broad scope of information without the problem of language barriers. Noisy rooms do not impair reception. Fax is as easy to use as a telephone. Another interesting facet is its capacity to transmit legally acceptable documents and signatures.

Low resolution, black and white machines are now being widely manufactured. The availability of these new devices and prognostications of a substantial market, has ushered in a new nationwide business – the facsimile franchising service field which promises to become a booming enterprise. Offices already exist in more than 200 cities across the U.S., making this new service available to any commercial activity wishing to participate. New offices are being opened with each passing week.

There are two types of franchising currently in use. One method has a central office to maintain a pick-up and delivery service to subscribing customers for a monthly rate. The second method invites the franchise holder to establish a secretarial service-type office where anyone desiring to transmit written information presents the information, by person or phone, and is charged on a cost-per-copy basis.

## Basic Fax

The principle types of fax are gray-scale and black-and-white. Recently announced color fax is essentially an extension of gray-scale fax technology. All types require a revolving drum, upon which can be attached the copy to be transmitted, and a scanning device which "sees" the copy as it revolves. Line by line the scanner picks up the image, in the form of light impulses, as it sweeps across the page. The received light pattern passes through a precision optical system to a photocell which, in turn, converts the light impulses into an analog signal pattern. Both gray-scale and black-and-white fax can be transmitted over common communications channels by analog means.

## Shades of Gray

The signal pattern, or waveform, from a wide-range gray-scale fax system differs from that of a black and white system. A wide-range gray-scale waveform may have an infinite number of tone values between black and white. The waveform produced is a precise electronic representation of the original image on the drum. This kind of waveform is both asynchronous and analog in nature. It is asynchronous because the waveform has not been "sampled" or "clocked" at measured time intervals (see figure 1) and is considered analog because its amplitude varies in direct proportion to the illumination spectrum of the original material. Asynchronous, analog fax systems are well suited for the transmission of pictures and other graphic material where good definition of a wide range of gray tones is necessary.

Good quality gray-scale transmis-

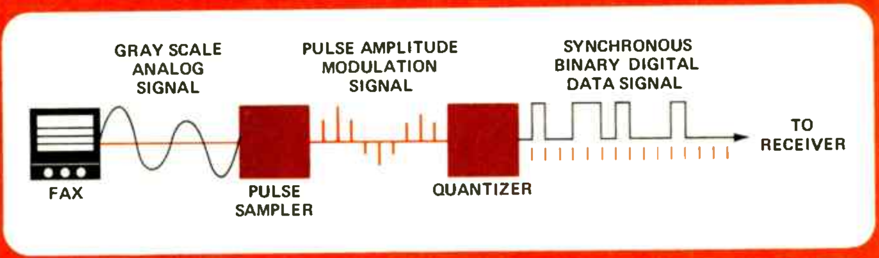


*Figure 1. By using a "sampling" device, a continuous, analog signal can be converted into a synchronized, pulse amplitude signal. This signal can further be quantized and encoded into binary digital form.*

sion is costly. Since it requires broadband facilities capable of high signal-to-noise ratios.

## Fax in Black and White

A simpler system operates only in black and white – no shades of gray. This system employs a scanning device which only registers a black or white impulse and therefore generates a waveform with only two values corresponding to black and white. The digital binary waveform produced by this system is asynchronous and analog in nature because the time interval between two successive transitions corresponds directly to the original image. The application of the word analog is, thus, somewhat less meaningful when it concerns black-and-white systems; its common use is generally reserved for reference to gray-scale systems.

The binary nature of a black and white waveform makes it convenient for this form of fax to take advantage of present and future advances in data transmission techniques.

## Fax Transmission

In telecommunications transmission there is an inverse relationship between transmission bandwidth and transmission time. This is particularly significant with fax. As bandwidth is increased, the time is decreased, and vice-versa. In general, the bandwidth necessary for fax transmission depends on the required resolution and the speed of transmission.

The relationship between resolution and bandwidth is such that doubling resolution requires four times the bandwidth – if transmission time remains constant. In the future, any significant innovations in effectively reducing transmission costs must reduce both transmission bandwidth and transmission time.

## PCM and FAX

A significant new development in the telecommunications industry took place in 1937 with the invention of pulse code modulation (PCM). However, not until the advent of transistors and integrated circuits was this new idea given serious attention. In the 1950's, Bell Telephone Laboratories began to explore the PCM system.

The basic concept of PCM was entirely different from frequency division multiplex (FDM) which has served the industry for so many years. Unlike FDM, which provides frequency separation for all channels, PCM involves switching rapidly from one channel to another – producing a time division multiplex (TDM) system where each channel is allotted a separate time interval.

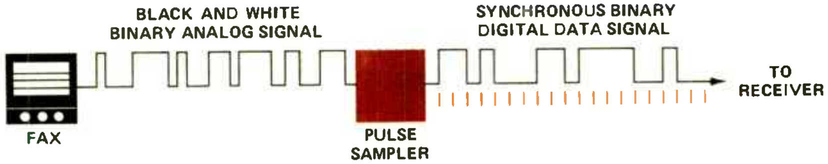


*Figure 2. A "sampling" device applied to a black-and-white, binary signal, produces a synchronous, digital binary signal in one step. The binary nature of this mode effectively lowers transmission noise but introduces "jitter".*

The Bell System designated their 24-channel time division multiplexing PCM system as T1 carrier. Although primarily designed for voice transmission, the T1 has proven to be ideally suited to the transmission of data or fax.

The use of PCM systems in the telephone network is increasing very rapidly. An example of this growth is the increasing number of Lenkurt's 91A (comparable to Bell's T1) time division multiplex PCM systems now in operation.

Lenkurt's 9003 and 9005 high-speed data terminals are designed for use over 91A (or T1) repeatered lines. Providing data rates of 50 Kb/s (and higher), these data terminals are well suited to the transmission of fax.

The PCM mode of transmission is not greatly troubled by signal distortion caused from noise. It has, however, another kind of distortion problem for black and white fax. When a black and white fax binary wave is synchronized by a sampling pulse it produces an error in the signal pattern which is called "time jitter" (see figure 3). This "jitter" occurs because the sampling pulse rarely takes place at the actual point of transition between black and white. As a result, the synchronized waveform rounds-off the original pattern, causing the intervals to be stretched or compressed, accordingly. The received image may therefore present a slightly fuzzy appearance due to this "time jitter", although legibility is not greatly impaired.

One advantage of binary data transmission is the fact that since there are only two possible waveform pulse values – one or zero, transmission distortion is relatively low and does not increase with distance. The efficiency of this system results from the fact that each positive pulse is regenerated at full amplitude, regardless of signal degradation up to that point. Likewise, every zero pulse is regenerated at zero amplitude.

## Data Compression

Another promising field of investigation for bandwidth and time reduction, is the elimination of image redundancy. Nearly all graphic material has a dominant tone-value. For example, a page of typewritten material is essentially white – even when filled with words. This repetition of the same tone, over and over, is redundancy. The conclusion has been logically drawn that if only the non-redundant data could be transmitted (the black letters on a typed page, for example) a reduction in required bandwidth and time might be accomplished. Several

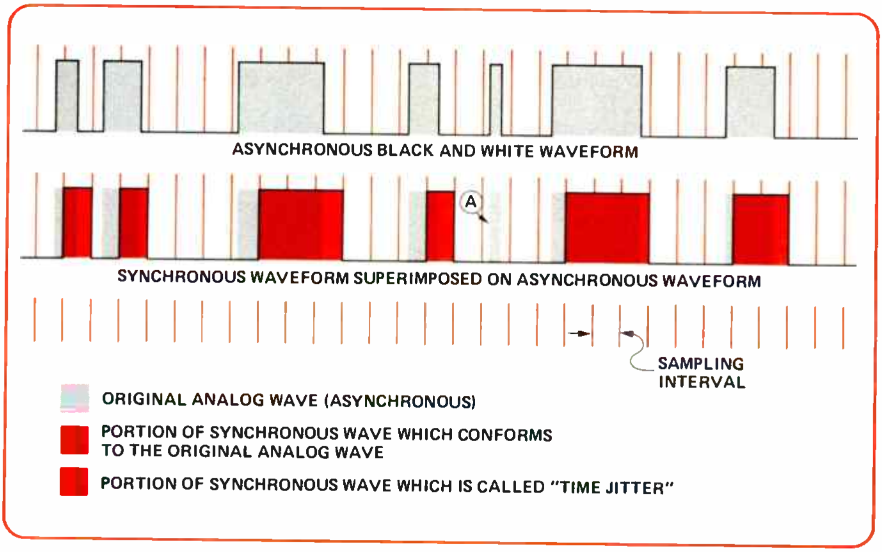


*Figure 3. When a black and white analog waveform is synchronized by sampling pulses (vertical red lines), a certain amount of distortion occurs which is called "time jitter". This jitter results from the fact that the sampling eliminates changes in the original waveform which take place between pulses. The entire interval between pulses will read either "up" or "down" depending on the location of the original waveform at the time of the last pulse. Obviously, some complete white-to-black-to-white (and vice versa) changes can take place between pulses and therefore be completely eliminated from the synchronized wave (A).*

techniques are being explored to eliminate redundancy and some methods are presently in use. One system of this type encodes the location of black-white and white-black transitions and transmits this information through digital transmission systems such as Lenkurt's type 26C or 26D data modems. Using Lenkurt's 26D, speed improvements as high as four to one have been achieved.

## Present Applications and Future Possibilities

Early uses of facsimile have been enhanced and new uses are constantly being explored. Effective techniques for removing redundancy promise to place facsimile within the reach of many new applications.

Significant improvements in facsimile technology have reawakened the interest of police authorities around the globe.

Police departments which have installed facsimile systems are finding their use indispensable in communication of fingerprints and "mug" shots. There has long been a need for rapid identification of suspected criminals. Court imposed restrictions on police detention practices served to highlight this need. Rapid and positive identification not only makes it easier to identify wanted criminals, it has the added benefit of facilitating the release of innocent persons.

The Chicago and Los Angeles police departments have had, for some time, operational facsimile systems using high resolution data transmission equipment. This application requires good quality gray-scale reproductions and 200 line per inch resolution – twice the resolution of a typical copying machine.

The newspaper industry represents one of the largest single markets for facsimile transmission systems. Many newspapers are now making use of various available devices for this purpose. It has been found desirable to provide high resolution of this large format material with wide-range grayscale. It is necessary that newspaper pages be transmitted at very high resolution rates, on the order of 1000 lines per inch, to maintain sufficient standards of quality of half-tone picture material. Perhaps a system could be devised to transmit newspaper printed material at about 200 lines per inch, then slow down for half-tone picture material at 1000 lines per inch.

Facsimile systems have been used to transmit full size newspaper proof sheets from the main plant to remote satellite printing plants where the transmitted page is converted into a photographic negative which is then used for direct reproduction. At the present state of technological development, this application is still relatively expensive.

The future of facsimile transmission in the newspaper industry is very promising. Elaborate systems have been proposed which would require complete microwave networks capable of transmitting a standard newspaper page at 1000 lines per inch resolution within time limits of about four minutes per page between plants.

The Wall Street Journal already achieves fast service to parts of California and other Western states by using facsimile to transmit page proofs. Many banks are now using facsimile to speed stop-payment notices on checks by transmitting the notice from the bookkeeping office to the main banking office. Manufacturing companies are using facsimile equipment as an adjunct to their teleconferences in order to provide charts and diagrams so that each participant has precise references for the topics of discussion.

Courtesy of Dacom, Inc.

*Figure 4. This black and white fax system transmitter produced by Dacom, Sunnyvale, California, makes use of Lenkurt's 26D data modem.*

It has been reported that there are over 18,000 current users of facsimile systems. This list includes railroads, hospitals, schools, airlines and general business. It can be safely predicted that as new advances are made in compression techniques, bandwidth requirements will be reduced, costs will drop and new applications will become virtually endless.

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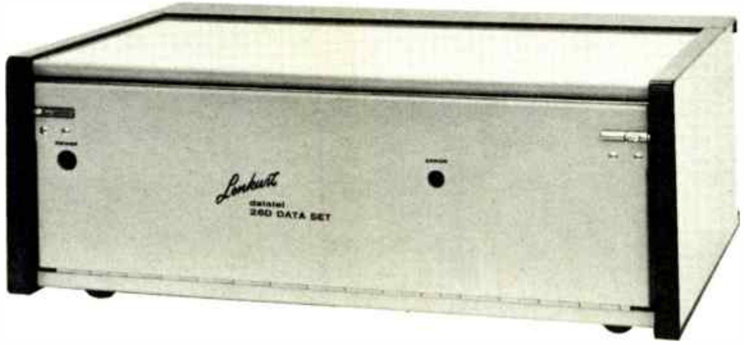

## INTRODUCING LENKURT'S NEW 26D DATA SET.

Lenkurt's 26D, using the Modified Duobinary technique, transmits 4800 bits per second on a single conditioned voice channel without the need for automatic equalization. Eliminating the DC component from the transmitted signal, the Duobinary technique compresses required bandwidth, therefore concentrating more transmitter power in the useful part of the spectrum. As a result data errors are significantly reduced, allowing more throughput and effectively lowering transmission costs. For additional information, write Lenkurt Department C134.

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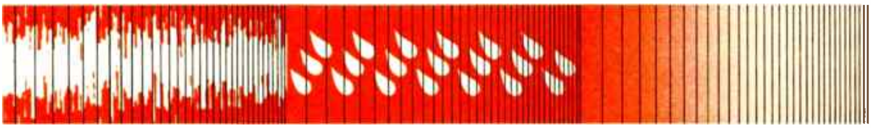
# The Lenkurt DEMODULATOR

OCTOBER 1969

## the reach for higher frequencies

### PART 1



## The trend toward higher radio frequencies creates new problems in system design.

Congestion of the radio-frequency spectrum has been foreseen almost from the beginning of commercial radio transmission. As radio technology has advanced, increasing demands for radio services have outpaced improvements in the efficiency of spectrum usage.

The result has been a continuing trend toward the use of higher and higher frequencies. There is no end in sight, with the upsurge in data transmission and other services that require the bandwidth of hundreds of voice channels.

Not too many years ago, "higher frequencies" referred to the VHF and UHF bands, with the then-new concept of line-of-sight propagation. Then came the microwave frequencies – 2, 4, and 6 GHz – where the signal behaved even more like a light beam. Each frequency "plateau" required new approaches to systems as well as hardware design.

Today, the 4 and 6 GHz bands form the heart of many communications systems. But new allocations in these bands are often difficult to get (impossible for some kinds of service). And in some major metropolitan areas, where the demand for service is the heaviest, no allocations are available at all. There is literally no place to go but up. For most types of service, the next available frequency bands are above 10.7 GHz.

The problems involved in building equipment for these higher frequencies were solved several years ago (Lenkurt introduced the highly reliable 76D Microwave Radio System in 1964). But the most reliable equipment is worth little if the system "goes down" because of propagation failure.

### Path Considerations

In many ways, the higher microwave frequencies behave just like the lower ones. The path-attenuation calculations, for example, are identical. For a given path, they show that a 12 GHz signal has 6 dB more path attenuation than a 6 GHz signal. On the other hand, the gain of a parabolic antenna of given size is 6 dB higher at

12 GHz. Since both the transmitting and receiving antennas are involved, the 12 GHz signal would appear to have a 6 dB advantage. In practice, however, this advantage is essentially cancelled by higher receiver noise figures and higher waveguide losses at 12 GHz.

Selective fading at the higher frequencies can be effectively combatted by methods used at lower frequencies. Space diversity, for example, with its redundant transmission paths, substantially increases path reliability. The chance of both paths fading simultaneously is remote. In the types of service for which the allocations are available, in-band frequency diversity is an excellent defense against selective fading. Its chief disadvantage is the total amount of frequency spectrum it uses.

The effect of selective fading varies only slightly with frequency. For any given path reliability, the required fade margin in the 11 GHz band is at most a few dB greater than that needed at the lower frequencies.

Slightly less path clearance is required at the higher frequencies because the Fresnel-zone radii are smaller. Except in critical cases or on short hops, however, the difference is not likely to be very significant. For instance, on a 20 mile, 6.175 GHz hop, the first Fresnel-zone radius at 10 miles is 64.9 feet. If the frequency on the same hop is increased to 11.2 GHz, the radius decreases by only 16.8 feet.

## Effects of Precipitation

In the design of most microwave systems, the path attenuation is assumed to be the same as that encountered in free space. This is a good approximation for frequencies up through the 6 GHz band. But as frequency increases, the signal becomes progressively more sensitive to precipitation.

Rain attenuates a microwave signal in two ways: the water absorbs energy, and the droplets scatter it. The severity of the attenuation is a function of the drop size, the temperature, the volume of water involved, and the signal frequency. The most significant part of this complex relationship can be summed up this way: the harder it rains, the bigger the drops, and the higher the frequency, the more severe the attenuation will be.

Of course, other forms of atmospheric moisture also affect signal attenuation, but rain is usually the dominant factor. Fog and mist are essentially light rain. Attenuation due to hail is only a small fraction of that caused by rain. The effect of snow varies widely, depending on the moisture content, the flake size, and the temperature; but snow generally carries a much lower volume of water than rain does.

At the higher frequencies, heavy rain can be a real problem. The theoretical curves of Figures 1 and 2 show how frequency would increase excess path loss if the rainfall rate were constant along the path. While actual rainfall rates are never uniform along the entire path, a hypothetical example based on Figure 1 gives some feel for the effect of extremely heavy rain (4 inches per hour) on signals of different frequencies.

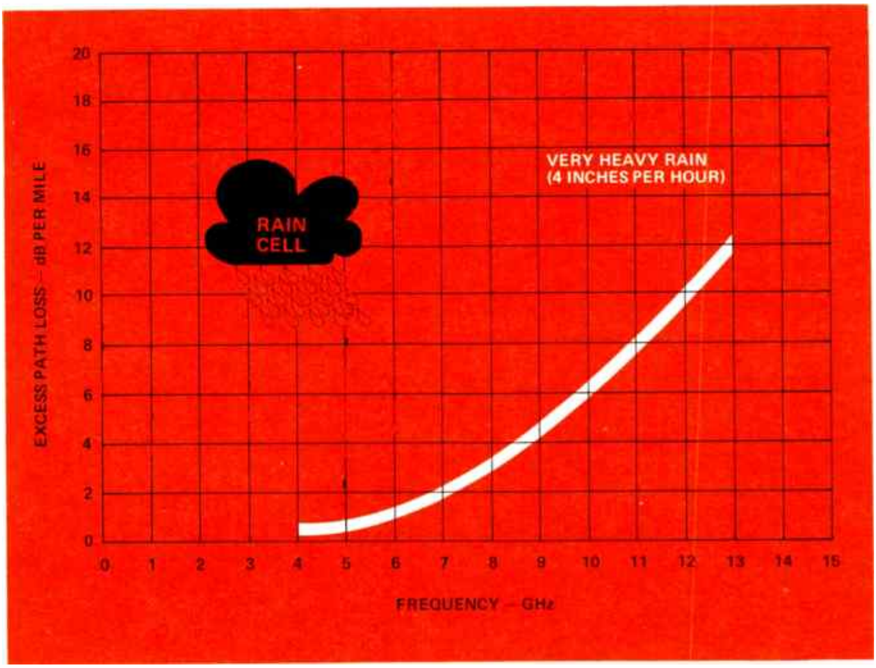


*Figure 1. Excess path loss caused by heavy rain increases rapidly with increasing frequency.*

A 6 GHz signal, with an excess path loss due to rain of only about 1.2 dB per mile, would be attenuated by about 24 dB over a 20 mile hop. That is centainly significant, but it is within the operating capability of a system engineered with, say, a 40 dB fade margin.

A 13 GHz signal, on the other hand, would suffer rainfall attenuation of about 240 dB.

As shown in Figure 2, a "heavy" rainfall of 0.6 inch per hour would cause excess path loss of only about 1.1 dB per mile at 13 GHz – roughly the same as the 6 GHz signal would suffer at the much higher rainfall rate.

The trouble with curves such as these is that they fail to take into account the changing nature of heavy rain.

## Local Rainfall Distribution

It is relatively easy to measure the effect of rain on a microwave path. The difficulty arises in trying to measure the rainfall rates along the path for accurate correlation with the attenuation measurements. The harder it rains, the more likely it is that the rainfall rate will show wide and almost instantaneous variations. Furthermore, there may be very heavy rain at one point, and almost none a short dis-

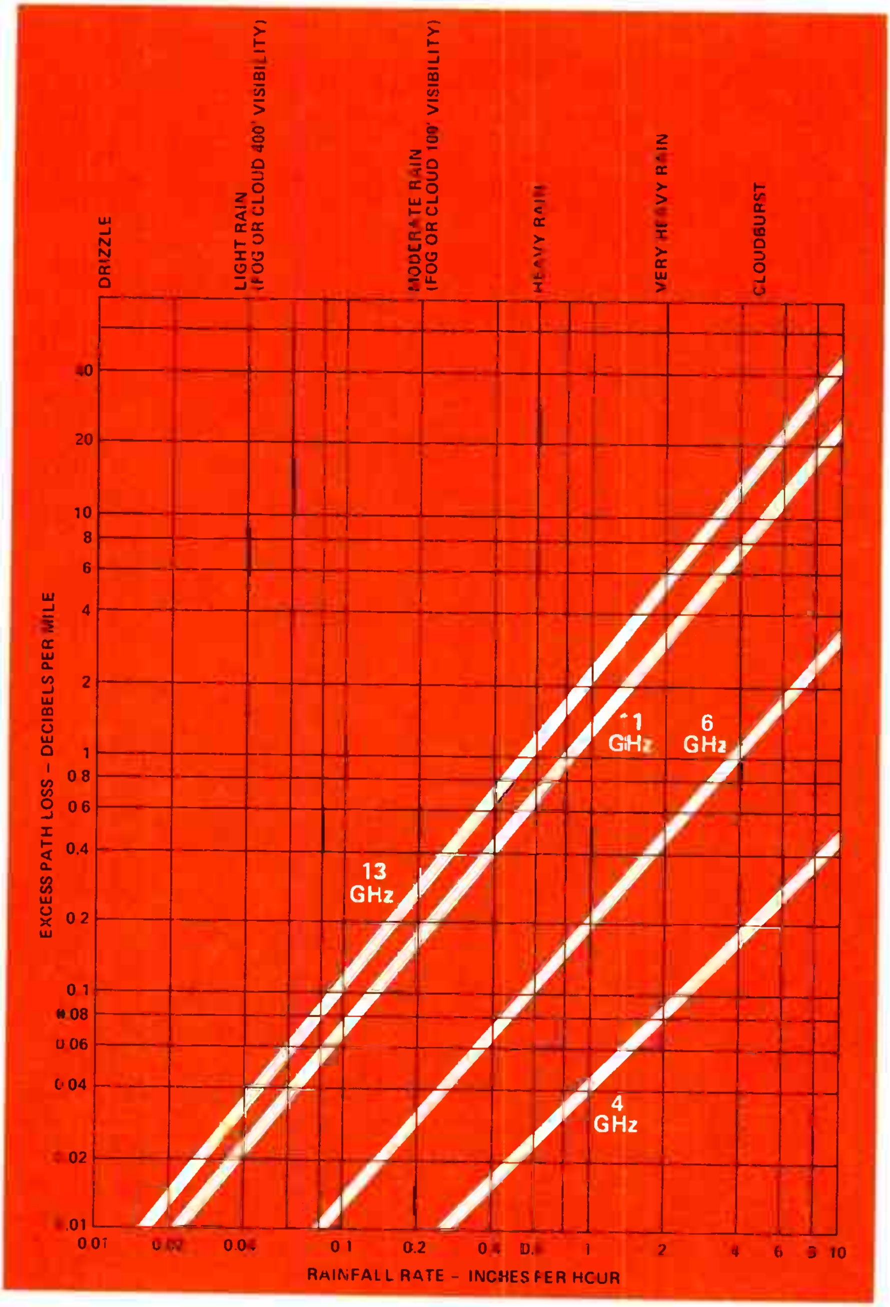


*Figure 2. Theoretical curves show how attenuation increases with rainfall rate (based on calculations by Ryde and Ryde).*

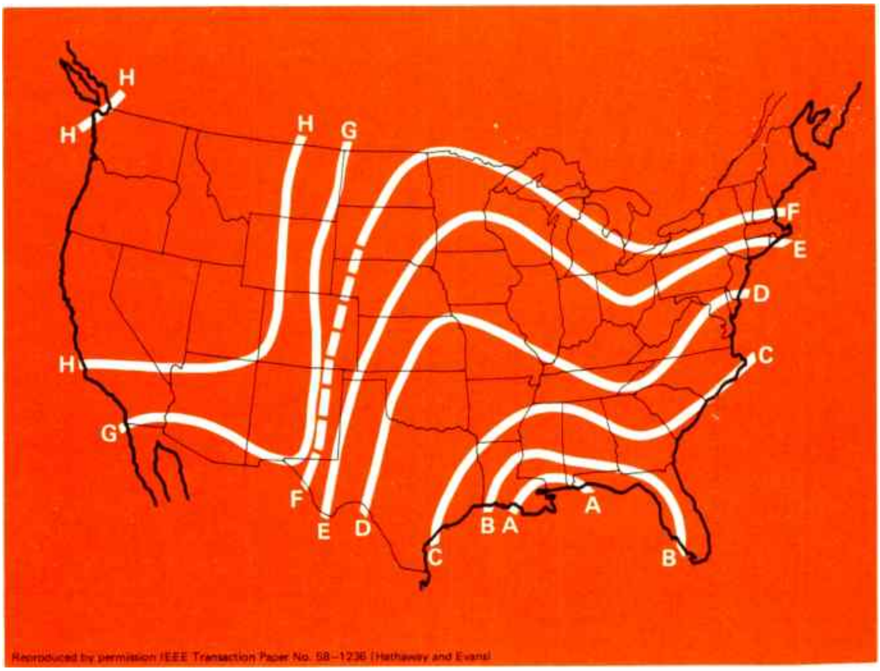


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*Figure 3. The contours of this map are for fixed transmission outage time and can generally be used in conjuction with the curves of Figure 4, to predict the effect of rainfall on outage time.*

tance away. The cumulative figures for the total length of a microwave path are often irrelevant.

Much work has been done in recent years on the nature of rainfall patterns. The results are not conclusive, but they indicate that the most intense rain, the rain that significantly affects microwave propagation, occurs in relatively small cells. Available evidence indicates that these cells rarely exceed a few miles in diameter, and the rainfall rate varies even within the cell.

This variation means that even an intense cell may not block a microwave path for the entire time it takes to cross the path. A five mile wide cell, moving at 20 miles per hour, takes 15 minutes to cross a particular path at right angles. But regardless of its intensity, it may only cause some short outages. It is unlikely to block the path completely for 15 minutes.

## Rainfall Distribution

Paradoxically, some geographical regions known for their large annual rainfall (such as the rain forests of Oregon and Washington) do not present as difficult a transmission problem as do other "drier" areas. The reason is, of course, that the total annual

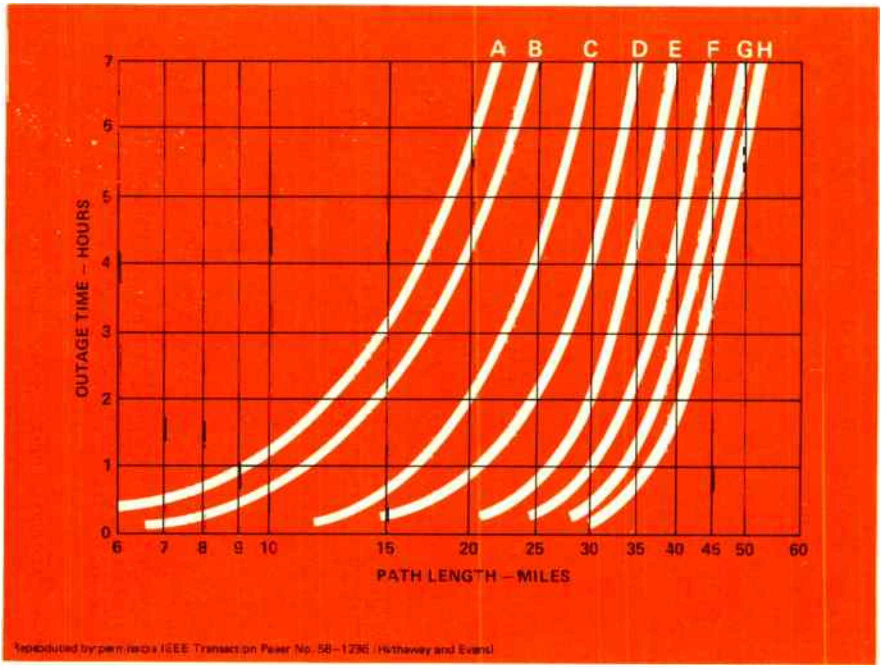

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*Figure 4. Expected outage time varies greatly with changing geographical rainfall distribution. These curves, for use with the contour map of Figure 3, are based on 11 GHz paths with 40 dB fade margins.*

rainfall is of little consequence. *Concentrated* rain causes the trouble. The significant questions are: How heavy are the rainfall rates that can be expected? How often can such rates be expected?

The problem in any area is complicated by the fact that although much information is available on *annual* rainfall, very little is known about *instantaneous* rates. Gradually, however, the body of knowledge has built up so that it is now possible to generalize about many geographical areas.

The key factor, of course, is the amount of outage time a particular system is likely to suffer. Some types of service can tolerate substantial outages, while others cannot. Figures 3 and 4, the results of empirical studies, indicate generally how expected outage time varies with geography in the United States. For example, an 11 GHz path, 30 miles long and engineered for a 40 dB fade margin, would have an expected outage time of about 0.2 hour per year on Washington's Olympic Peninsula (contour H). This translates to a reliability of 99.998 percent.

If the same path were located on the coast of the Carolinas (contour C),

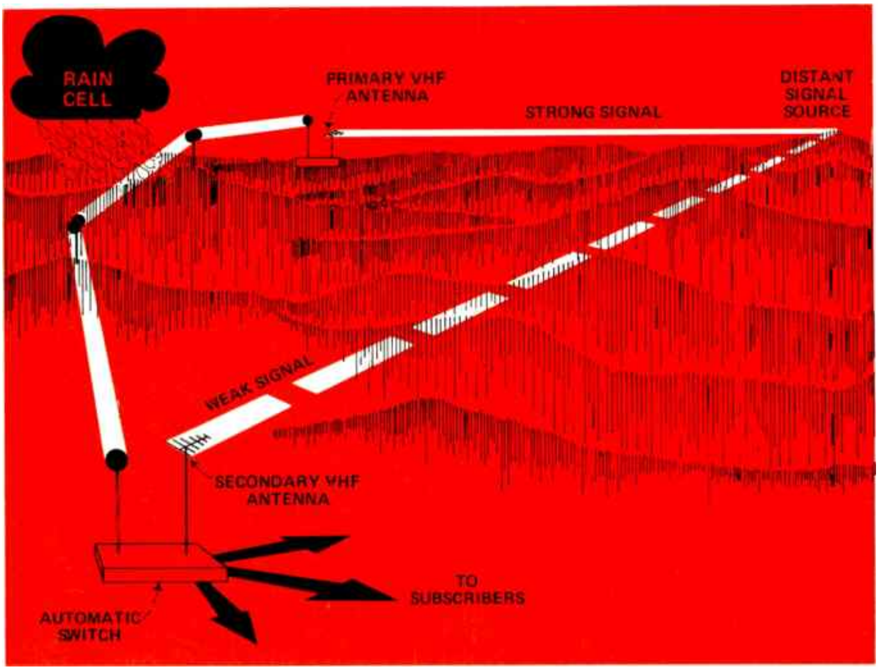

*Figure 5. Many CATV systems can use a secondary off-the-air antenna as a back-up for a microwave link.*

the predicted reliability would drop to 99.92 percent because the expected outage time would increase to 7 hours per year.

Now consider the same path on the Gulf Coast of Mississippi (contour A) and assume that the expected annual outage time must be held to the same 7 hours. The path would have to be shortened from 30 miles to 22 miles, or the fade margin would have to be increased substantially.

It must be remembered that these calculations are for a single hop. The outage time for the entire system can be expected to equal the sum of the single-hop outages. In terms of reliability, 10 hops with 99.99 percent reliability form a system that is only 99.9 percent reliable.

## Living With the Problem

It may appear from what has been said that the frequencies about 10.7 GHz are a poor second choice, to be considered only when allocations at lower frequencies are not available. But this is only partly true. When the limitations of the higher bands are recognized, they give very good service. This really means learning to live with the rainfall problem.

First, of course, rainfall attenuation may not even be a problem. If the system is located in an area where rain rarely falls in cloudburst proportions, it can probably be engineered like any other system, with little worry about excess outage time.

Second, the type of service may be able to tolerate occasional outages of a few seconds to a few minutes. Some services, such as telephone common carrier, demand very high reliability. Others may be able to live with a few short outages.

A case in point is a CATV relay. Typically, the system operates only 18 hours a day. Thus, 25 percent of the heavy rains would be expected to occur during off-the-air hours. In some areas, heavy rainfall is consistently concentrated in these early morning hours.

Furthermore, many CATV systems can use a kind of "microwave/VHF diversity". If there is an outage in the microwave link, the signal is simply taken from the secondary antenna as shown in Figure 5. This provides an inferior signal, but it is usually watchable for the short periods of rain-induced outages.

The third factor in living with the rainfall problem is the length of the proposed system. Outages are cumulative. So a very long microwave system may have comparatively low reliability, even though the reliability of every hop is high. The longer the system, the greater the chance of a severe rain cell moving across the path somewhere. An obvious solution is to use the higher frequencies for short systems, and to reserve the lower frequencies for long, cross-country systems.

## Diversity Arrangements

Heavy rain is not the only thing that will put a microwave system temporarily out of business. The mechanisms of selective fading are completely separate from those of rainfall attenuation. When the effects of rainfall attenuation cannot be completely controlled, one way to keep annual outage time down is to pay special attention to selective fading. This implies some sort of diversity arrangement. All diversity arrangements combat selective fading, and some provide protection against rainfall attenuation, as well.

Space diversity is no defense against rainfall attenuation because the two transmission paths are quite close, and subject to essentially the same rainfall pattern. In the typical case, where one path is directly above the other, the same rain will block both paths simultaneously.

While in-band frequency diversity also offers good protection against selective fading, it still provides no defense against rainfall attenuation. The two frequencies are so close together (typically separated by only two percent of the frequency) that the effect of rain is essentially the same on both.

On the other hand, if frequency diversity is extended to include both the 6 GHz and the 11 GHz bands (cross-band diversity), it can provide excellent protection against both selective fading and rain. It is true that when the 11 GHz path fails because of rain the entire load falls on the 6 GHz path. Fortunately, however, severe selective fading rarely occurs during per-

*Figure 6. Raising the fade margin by 5 dB, (as in B above) can permit transmission through a rain cell of substantially greater intensity.*

iods of heavy rain. This makes the 6 GHz path exceptionally reliable during such periods. Thus, cross-band diversity is probably the best solution — provided, of course, that frequency allocations and regulatory approval are available.

Perhaps the ideal solution would be route diversity — an extreme form of space diversity. The same signal would be sent over two paths separated by several miles. This would all but eliminate the possibility that rain would block both paths simultaneously. In practice, however, route diversity is not often used in present-day systems. The main reason is simple economics. Equipment and installation costs are quite high. Furthermore, the process of dropping and inserting channels is complicated — not to mention the difficulty encountered at the receiving end in trying to combine the signals from two paths of substantially different length.

## Conservative Engineering

It is apparent that there is no easy, clear-cut way to avoid problems with rain. The most effective defense is a combination of techniques. And conservative engineering is the first one. A marginally engineered system is an invitation to excess outage time.

One thing that can be done, for example, is to increase the fade margin. This does not guarantee transmission through the heaviest rain, but it does effectively lower the expected outage time.

Because of variations in the instantaneous rainfall rate, it is not always possible to specify exactly how much effect a higher fade margin will have on rainfall attenuation. But some idea can be gained from a hypothetical example like this: Suppose a particular 11 GHz microwave hop can withstand an average rainfall along the path of 1 inch per hour – an excess path loss of about 1.3 dB per mile. If the fade margin is then raised by 5 dB, the hop can still withstand the 1 inch per hour rain along the path, except for a two mile segment where it passes through a rain cell. In that segment, it can withstand excess path loss of 3.8 dB per mile – equivalent to a rainfall rate of over 2 inches per hour (see Figure 6). In many areas, that much improvement will not eliminate rainfall outages. But it will reduce them.

Of course, increasing the fade margin may not always be desirable. If it means an increase in the number of hops, for instance, any gains in path reliability may be more than offset by the decrease in equipment reliability as more transmitters and receivers are added.

Equipment reliability is equally as important as path reliability. So is the reliability of the power source. And good maintenance is important, too. Improving the reliability of any one of these naturally improves the end product – total system reliability. Thus, economics is the common denominator in improving system reliability.

## Where to Next?

The move to the 11 GHz microwave band is not the final rung on the ladder of ascending frequencies. This band will eventually become congested like all the others below it. What then? Still higher frequencies, with even more severe attenuation problems? Coaxial cable? Millimeter waveguides? Laser transmission?

◆

**The second part of this two-part article, to appear in next month's *Demodulator*, will discuss the future of transmission technology.**

**LENKURT ELECTRIC CO., INC.**
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**Lenkurt's 75D and 75E microwave radio systems,** operating at 10.7-11.7 GHz and 12.2-13.25 GHz, transmit as many as 1200 SSBSC multiplex channels or a video signal with accompanying FM program subcarrier channels. Level stability and low noise performance of these members of the 75 family far exceed CCIR requirements. Both systems are long-haul broadband radio transmission systems; 75D is designed to operate in the common carrier band and 75E for the industrial and studio-transmitter-link bands. For additional information, write Lenkurt, Department C134.

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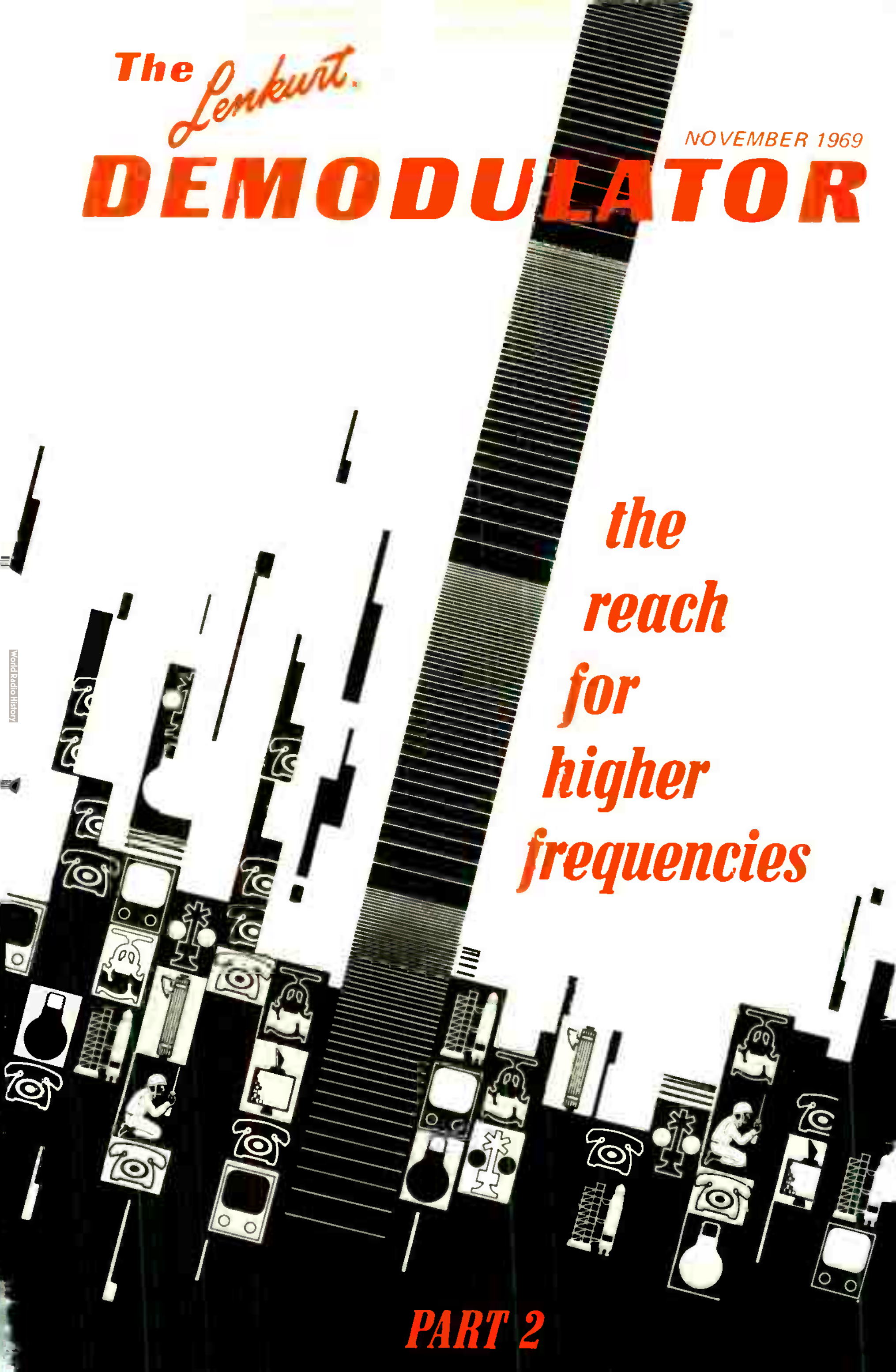
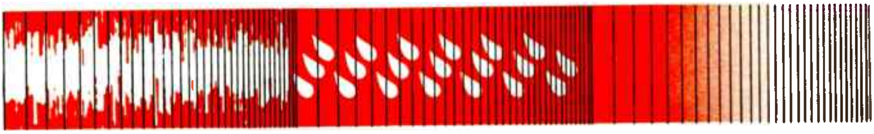
# The Lenkurt DEMODULATOR

NOVEMBER 1969



## the reach for higher frequencies

PART 2



**The electromagnetic spectrum still has much untapped potential. Some frequencies are suitable for radio transmission through the atmosphere, while others require different transmission methods.**

Part one of this two-part article discussed the transmission problems encountered as frequency congestion forces the shift to higher microwave frequencies. That discussion was limited to what is commonly called the 11 GHz band, because that is the highest band in general use today.

It is apparent to long-range planners, however, that this band will also become congested as the demand for more communications services accelerates. This trend shows no sign of tapering off and rapidly increasing services such as video and wideband data transmission continue to require enormous bandwidths.

The higher frequencies which can provide this bandwidth are unused, waiting to be tapped. They range in a continuous spectrum from the microwave frequencies through millimeter waves and infrared to the visible light region. Eventually, they may even include the ultraviolet range. The problem is finding a way to use them in practical communications systems.

The allocation of specific higher frequency bands is still under discussion. (It will be considered at the World Administrative Radio Conference, to be held in 1971 by the International Telecommunications Union.) Considerable work has already been done on microwave transmission in the 18 GHz region and above.

## Atmospheric Considerations

Since rainfall attenuation is one of the most significant problems in the 11 GHz band, and the effect increases with frequency, the problem can be expected to be even more severe at higher frequencies. Figure 2 shows theoretical rainfall attenuation as a function of rainfall rate for selected frequencies up to 40 GHz. (Some empirical studies have indicated even higher attenuation than predicted.)

While rainfall attenuation is still the most significant atmospheric problem, fog and mist become increasingly important at the higher frequencies. The deciding factor is the volume of water in the air, which is perhaps easiest to understand in terms of visibility. At 30 GHz, for example, fog that cuts visibility to 150 feet attenuates the signal by about 0.5 dB per mile. It takes more than twice the moisture concentration to reduce the visibility to 100 feet at which point attenuation is about 1.6 dB per mile.

In this frequency region, another phenomenon – molecular absorption of the radio energy – also becomes a problem. Water vapor (not to be confused with water droplets) absorbs more energy as frequency increases, with the significant absorption occurring at resonant peaks. One such peak is at 22.4 GHz. At this frequency, a relative humidity of 60 percent produces absorption of about 0.4 dB per mile. At 18 GHz, the same humidity absorbs energy at the rate of only about 0.05 dB per mile.

Another minor effect is the molecular absorption of oxygen, which also increases with frequency. The loss only becomes significant, however at frequencies in the 50 GHz range.

## Modulation Techniques

The frequency allocations for present-day microwave systems are intended primarily for equipment that uses low-deviation FM, with RF bandwidths of 20 MHz or less. This technique is well suited for voice traffic, which is usually multiplexed by frequency division. But, the nature of the traffic carried by microwave radio is being changed by two major factors. One is the tremendous increase in data communications, and the other is the increasing use of pulse-code modulation (PCM) for voice communications. The two are essentially the same from the microwave engineer's point of view. Either way, he is faced with the necessity to transmit pulses at a high rate (approximately 70,000 per second for each voice channel). One method is to use digital microwave transmission. Such a system becomes one more step in the time-division multiplex scheme.

An advantage of PCM is its relative immunity to noise. Because it is only necessary to detect the presence or absence of a pulse in a particular time slot (not its height, shape, or any other characteristic), a PCM system can operate at a very low signal-to-noise ratio. Consequently, it is quite tolerant of the severe atmospheric attenuation.

A binary system can use relatively simple repeaters. They need only produce new clean pulses to replace the old distorted and attenuated ones. A simple repeater is an inexpensive one. Since economics really dictate system performance, route diversity, with paths separated to avoid simultaneous heavy rainfall, may become economically feasible (Figure 3).

However, a more efficient use of bandwidth can be achieved by using multi-level transmission, rather than simple binary techniques. This, in turn, increases repeater complexity and cost. But, it still may be possible to build relatively inexpensive repeaters that are small enough for pole mounting.

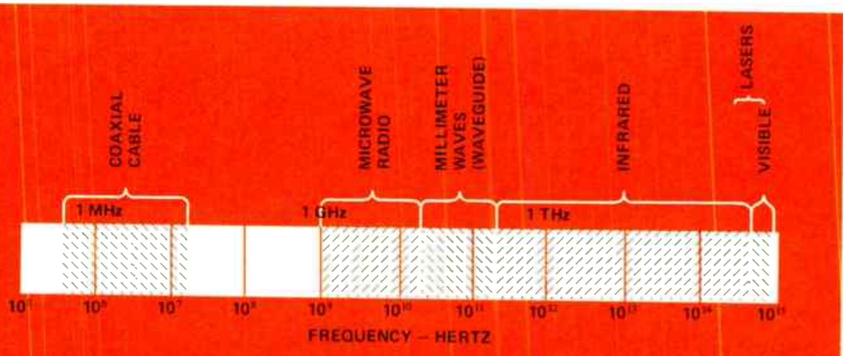


*Figure 1. Examination of the electromagnetic spectrum shows large portions unused, particularly at frequencies above 10 GHz – where the largest information-carrying potential is.*

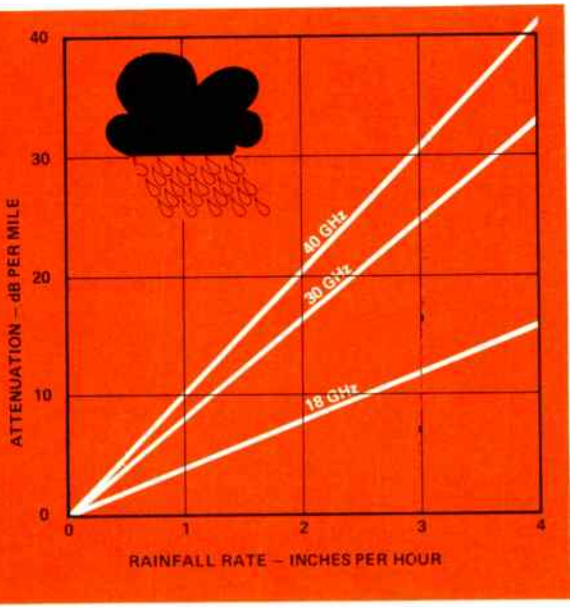


*Figure 2. Attenuation caused by rain can be a formidable problem at the higher microwave frequencies. These theoretical curves (after Ryde) should be used only as approximations. Some measurements have indicated substantially higher attenuation.*

A potential problem here is the public's increasing consciousness of aesthetic values. Current trends are toward underground installation of all utilities. And some communities might not be willing to accept pole-mounted microwave repeaters at one to two mile intervals.

## Millimeter-Waves

The millimeter-wave region, from 30 to 300 GHz, is very attractive for wideband communications systems because of the tremendous bandwidth available. At these frequencies it is not at all unreasonable to think in terms of a 1 GHz baseband that could, in theory, accommodate over 200,000 voice channels – or the equivalent in other forms of communications.

Of course, the problems of atmospheric attenuation are exceptionally severe at these frequencies. In fact, transmission through the atmosphere may not be practical except for certain applications. One such case is satellite communications. Here, route diversity, in the form of widely separated earth stations can provide the necessary reliability. Futhermore, the signal path is primarily in free space rather than the atmosphere (Figure 3).

What about earthbound millimeter-wave communications? One answer is to shut out the atmosphere. A long roof is not practical, but a waveguide is.

The idea may sound strange to those used to thinking of waveguide in terms of the connecting link between a transmitter or receiver and a tower-mounted antenna. A significant loss can occur in 100 feet of this type of waveguide, and the loss increases as the frequency goes up. Losses would be prohibitive in a long system. For example, at only 4 GHz, one type of rectangular waveguide has a loss on the order of 50 dB per mile.

However, by using a circular electric wave in a round waveguide, the loss can be reduced dramatically (Figure 4). Also, the loss decreases as frequency increases. Since the physical

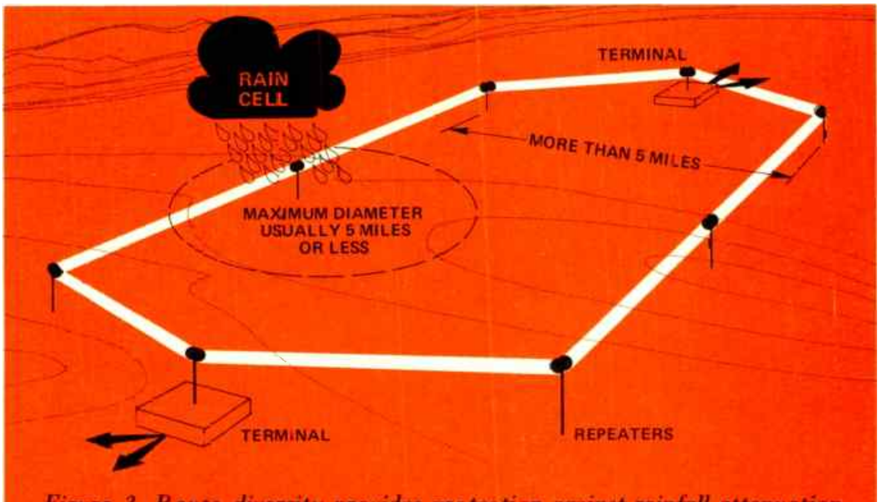


*Figure 3. Route diversity provides protection against rainfall attenuation for microwave systems operating at high frequencies. If the paths are far enough apart, heavy rain is unlikely to block both at once.*

size of the waveguide required also decreases with frequency, it is easy to visualize a small pipe carrying thousands of communications channels at millimeter wavelengths – with very low loss.

It happens that a 50 GHz signal loses only about 2 dB per mile in a waveguide with a 2 inch diameter – providing the mechanical tolerances are small enough. Theoretically, the loss would approach zero as the frequency approaches infinity. But, the mechanical requirements become so stringent that they limit the usable frequencies.

Any waveguide roughness or other imperfection causes mode conversion in the signal. Part of the energy gets "out of step" with the main signal. Not only is much of this converted energy lost, but the part that does get to the receiving end interferes with the desired signal.

Some mode conversion is inevitable, since a transmission line of any type cannot run indefinitely in a straight line – and any bend in the pipe causes mode conversion.

Consequently, the modulation method chosen must be resistant to interference. Once again, digital transmission becomes attractive. Not only is it interference resistant, but its adaptability to the increase in digital traffic is as important here as it is in atmospheric transmission.

## Coaxial Cable

Another form of signal pipe is coaxial cable. It may seem strange to consider such an "old standby" in the same light as more exotic forms of transmission, such as millimeter waveguides. But coaxial transmission still has great unrealized potential. Equipment like Lenkurt's 46C Coaxial Transmission System carries 720 channels on routes of medium density. The Western Electric L4 system handles 3600 channels on high-density routes. Such systems may be only the beginning. Bigger systems are planned, with one intended to carry over 80,000 channels with multiple coaxial tubes. (Since the potential of coaxial transmission has more immediate impact than some of the other techniques discussed here, it will be the subject of a future DEMODULATOR article.)

## Laser Transmission

Few people have been more excited over the useful possibilities of lasers than have communications engineers. The reason for their excitement is quite simple: the information-carrying potential of any communications channel is proportional to its operating frequency. Because lasers operate in a frequency range about 100,000 times higher than today's microwave radio systems, they have the potential to carry 100,000 times more information.

But, potential is sometimes far from reality. While laser beams have been used to burn through steel in industrial applications, their penetration range is limited. They are still light beams, and light beams do not penetrate very far through heavy clouds and other atmospheric obstructions. For this reason, unprotected laser transmission is practical only for short distances or in space communications. Long-range laser communications systems will have to follow an optically aligned tube. Here again, difficulties arise when the beam is bent – even enough to follow the curvature of the earth.

Therefore, any practical system will probably use a series of lenses to refocus the beam and change its direction slightly. In so doing, they will act somewhat as passive repeaters. Optical lenses can be used, but even the highest quality ones introduce substantial losses.

However, considerable promise is being shown by gas lenses. Such a lens can be formed by gas flowing through a heated tube. Because the gas is warmer near the tube wall and the cooler gas in the center is denser, it acts as a lens causing the beam to converge. The advantage of this type of lens is that it places no solid surface in the path of the light beam. Therefore the loss introduced by the lens is only that caused by the gas molecules scattering the light beam.

This principle sounds simple, but there are substantial obstacles to be overcome. A big problem is presented by the extremely critical mechanical tolerances required of a lens wave-

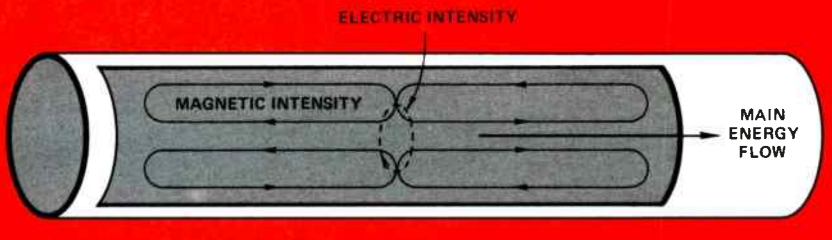


*Figure 4. Electric field lines in a circular electric wave close on themselves, preventing significant charge accumulation on the waveguide walls, thus keeping wall currents low. Since charge accumulation is even less at higher frequencies, loss decreases with increasing frequency.*

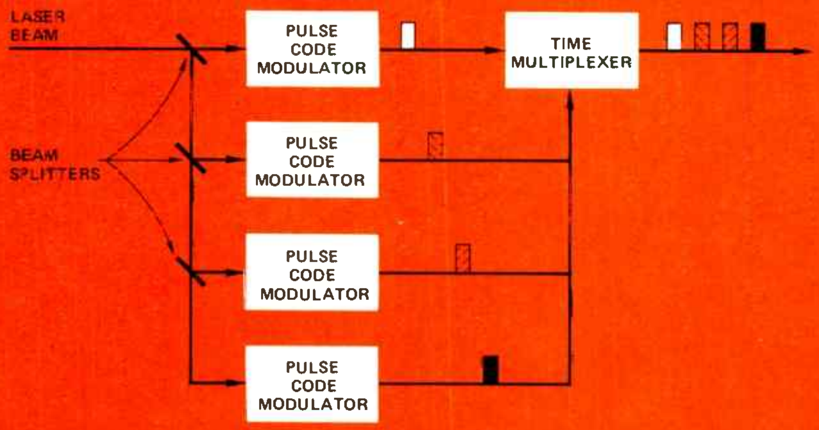


*Figure 5. PCM shows considerable promise for modulating lasers. The beam-splitting arrangement shown here forms several high-speed channels from a single laser beam.*

guide. The costs may make such an arrangement impractical.

Transmission is not the only area that presents problems for a laser communications system. Another hurdle is modulation and demodulation – and the associated area of multiplexing and demultiplexing.

One of the most promising modulation techniques is PCM – primarily because a laser can produce high pulse rates and very narrow pulses. If a laser beam is split as shown in Figure 5, parts of it can be sent to parallel modulators to form similar trains of narrow, relatively widely spaced, pulses. These pulse trains can then be interleaved for time-division multiplexing.

It is theoretically possible to add more multiplexing steps. If, say, 100 time-multiplexed signals were frequency multiplexed, the capacity would increase 100-fold. It is then conceivable that still another form of multiplexing, called spatial multiplexing, could be used. This means sending a number of beams simultaneously through a waveguide in different propagation modes.

Such a system does not exist, and may never exist. However, a system has been suggested that would time-multiplex 32 channels in each of two polarization states, then frequency multiplex 100 of these "super channels," and finally use spatial multiplexing to combine 100 such beams.

The theoretical capacity of such a system staggers the imagination. The suggested bit rate would be about $2 \times 10^{14}$ bits per second – the equivalent of 1,920,000 video signals.

The world has hardly begun to tap the potential of communications. It is not clear just what form the future uses of communication will take. But it is clear that man's capacity to devise communications systems has not been reached and the future is virtually unlimited.

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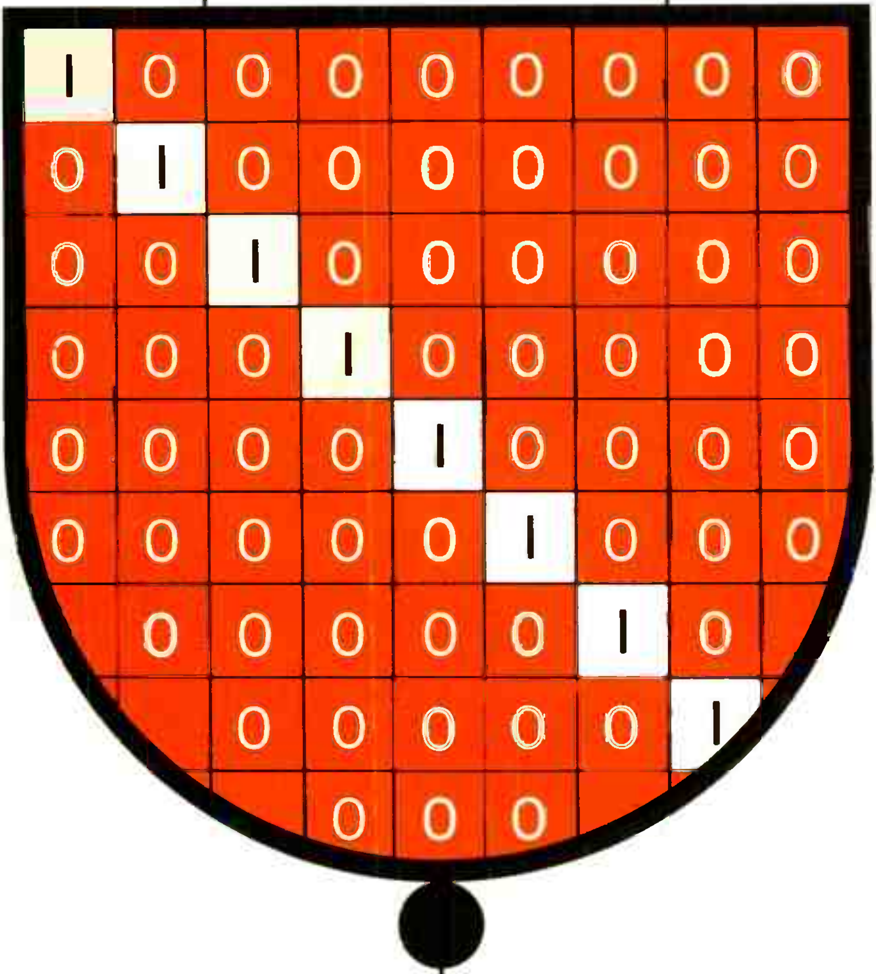
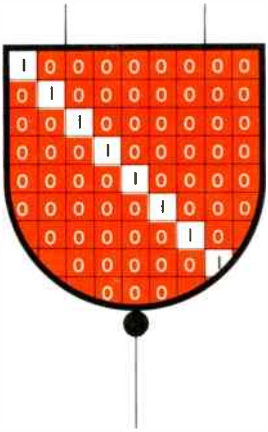
The *Lenkurt*®

DECEMBER 1969

# DEMODULATOR



## BINARY LOGIC AND PCM



**Aristotle, in 330 B.C., to explain his philosophies, developed a logic system dealing with statements that were either true or false. In 1847, George Boole reduced Aristotle's logic to a mathematical shorthand that has become a universal logic language.**

Binary logic is a way of thinking that can be applied to the design of *any* system where the "inputs" and "outputs" are just on-off actions. The invention of transistors led to the development of a series of logic modules capable of performing basic binary logic functions in electronic systems.

The complex PCM (pulse-code modulation) system can be broken down into subsystems whose inputs and outputs are simply on-off actions. This subsystem equipment is then designed using the principles of binary logic and inplemented with corresponding logic modules.

## Logic Modules

Basic logic modules are called AND gates, OR gates, and INVERTERS. These modules can be combined to obtain NAND and NOR gates. Logic building blocks called flip-flops can be made from these gates.

## AND, OR, and INVERTER

Consider the circuit with two switches (A and B) connected in series, a voltage supply (V), and a light bulb (L) shown in Figure 1.

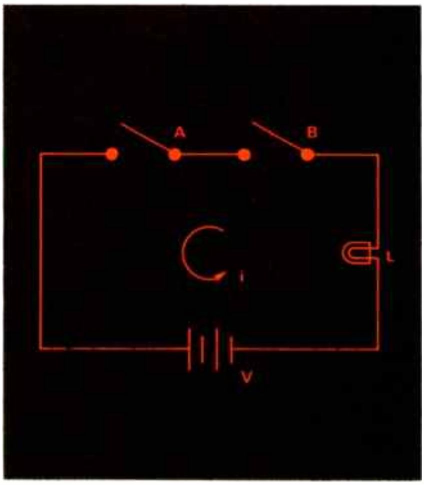


*Figure 1.*

The light will be on, if, and only if, switch A *and* switch B are closed. The logic AND gate gets its name from this simple circuit analogy.

The "switching" circuit described above can be implemented with relays or diodes as well as with switches. All these circuits are cumbersome for the logic designer, so shorthand logic symbols have been developed. The logic symbol for the AND gate is shown in Figure 2.

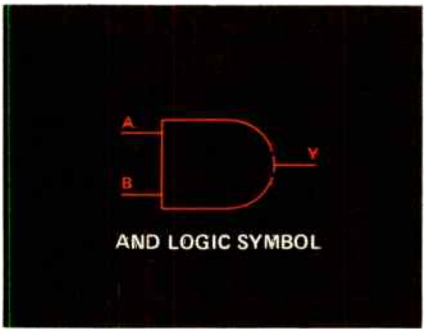
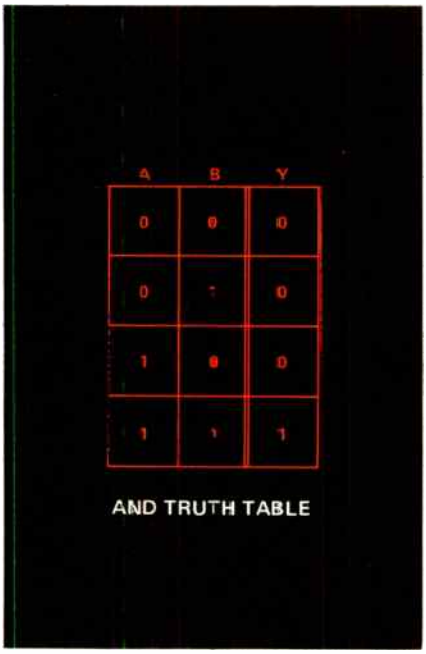


*Figure 2.*

Using a truth table and representing an "on" condition as a "1", an "off" condition as a "0", and the AND gate output as "Y", the combination of states for an AND gate is graphically displayed (Figure 3).



| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

AND TRUTH TABLE

*Figure 3.*

Using the "switching" circuit analogy again, put the two switches in parallel rather than in series (Figure 4).

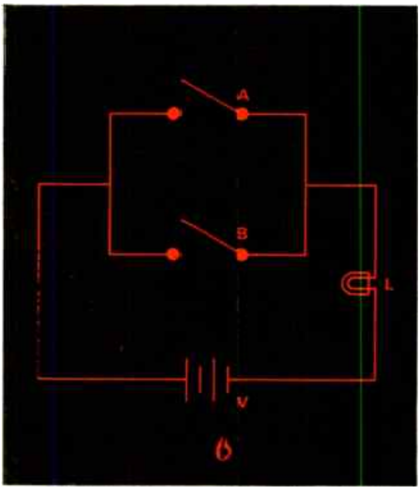
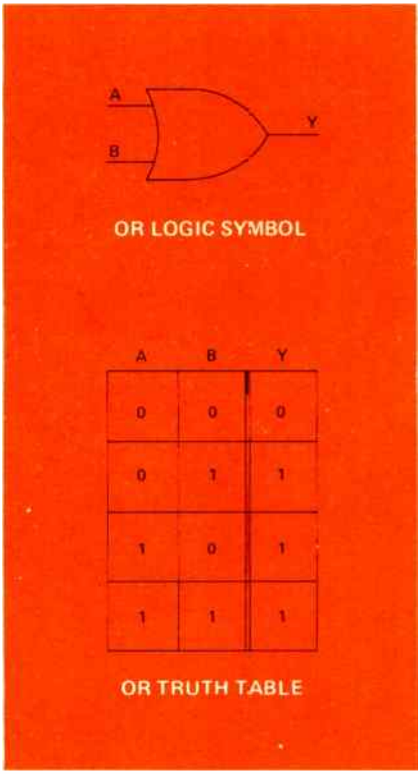


*Figure 4.*

With this arrangement, the current flows in the circuit and the bulb is on, if switch A *or* switch B *or* both are closed. The logic OR gate gets its name from this type of an arrangement. Figure 5 shows the logic symbol and truth table for an OR gate.

Logic functions can be implemented with diodes for electronic applications. But, diodes have two weaknesses. First, the output of diode AND and OR gates is attenuated. Second, diode gates are passive elements and unable to drive a network of gates.

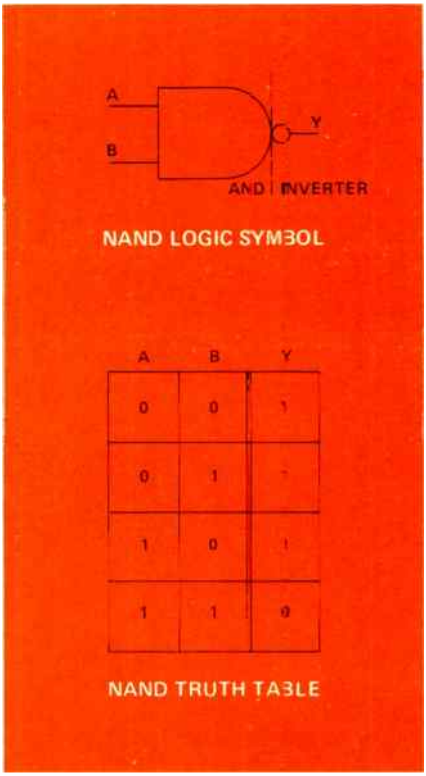
Common emitter transistors have the ability to amplify a signal. By putting a transistor at the output of the diode AND and OR gate circuitry, the attenuated signal is restored to its original level. Because transistors are



OR TRUTH TABLE

| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

*Figure 5.*



NAND TRUTH TABLE

| A | B | Y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

*Figure 6.*

active devices, they are capable of driving a network of logic functions.

As well as solving the inherent problems of diode gates, transistors perform the logic function of inversion. Regardless of the input signal state, the transistor output will be inverted (a "1" becomes a "0" and vice versa). Transistors are known therefore, as INVERTERS.

## NAND and NOR

The combination of a logic AND gate and a transistor INVERTER is called a logic NAND gate (for NOT–AND) (Figure 6).

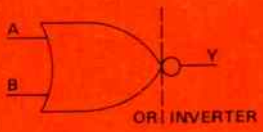
The output from a NAND gate will be negative, if, and only if, A and B are both positive.

A logic NOR gate is the combination of a logic Or and an INVERTER (for NOT–OR) (Figure 7).

If, and only if, both the NOR inputs are negative, the NOR output will be positive.

Integrated circuit technology has made NAND and NOR gates less expensive than the use of discrete components to construct NOT–AND and NOT–OR circuits.

For simplicity, the inputs to the logic gates have been limited to two,



NOR LOGIC SYMBOL

| A | B | Y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

NOR TRUTH TABLE

*Figure 7.*

| A | B | C | Y |
|---|---|---|---|
| 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 |

NAND TRUTH TABLE
FOR THREE INPUTS

*Figure 8.*

but in practice, the gates can have more than two. The same logic rules prevail. For a NAND gate, the output will be negative, if, and only if, all the inputs are positive. Similarly, for a NOR gate, the output will be positive, if, and only if, all the inputs are negative. The truth table for a NAND gate with three inputs is shown in Figure 8.

## Flip-Flops

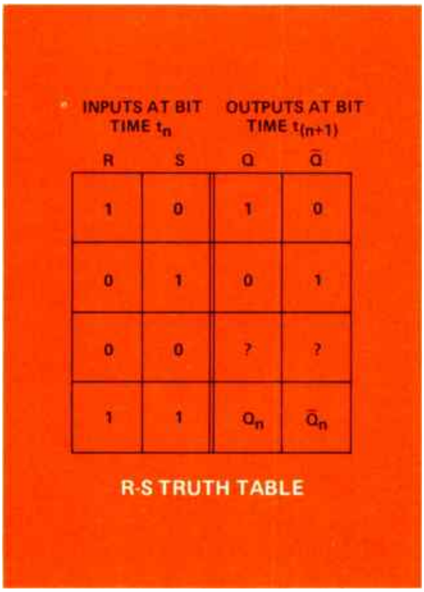
One of the most common circuit building blocks formed from groups of logic gates is a flip-flop — widely used for storing a single bit of information. The popularity of flip-flops is due to the following factors:

1. They are available in integrated circuits or can be built from readily available discrete components.
2. They are fast acting — can be made to change states in as little as a few nanoseconds (depending upon the propagation delay of the logic family).
3. They are active devices.

Truth tables rather than circuitry will be used to explain flip-flops. The designer is interested more in what happens to his signal, than how it happens. Having selected his logic modules from the same family (compatible power requirements, etc.), the designer works with a "black box" and its corresponding truth table. The flip-flops discussed are from the 930 DTL (Diode Transistor Logic) family used in the Lenkurt 91A PCM system.

The basic flip-flop is made of two NAND gates. It has two inputs (R and S) which determine what state ("0" or "1") the flip-flop will assume next, and two outputs (Q and $\overline{Q}$) which determine the flip-flop's present state. The Q and $\overline{Q}$ outputs from any flip-flop are always opposite states; if Q is "1", $\overline{Q}$ is "0" and vice versa.

The inputs and resulting outputs for an R–S flip-flop are shown in the truth table for a particular bit time (Figure 9). The output is a function of the flip-flop's outputs and its inputs at the previous bit time.



| INPUTS AT BIT TIME $t_n$ | | OUTPUTS AT BIT TIME $t_{(n+1)}$ | |
|---|---|---|---|
| R | S | Q | $\overline{Q}$ |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 0 | 0 | ? | ? |
| 1 | 1 | $Q_n$ | $\overline{Q}_n$ |

R-S TRUTH TABLE

*Figure 9.*

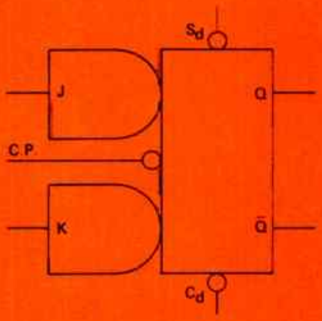
If the R input is "1" and the S input is "0", the Q output will be "1". If the input states are reversed, the output states will also be reversed. If the input states are both "1", the output will be unchanged from what it was at the previous bit time. The "?" in the truth table indicates the output is undesirable, and therefore to be avoided, when the input states are simultaneously "0".

Although it is possible to design a circuit such that the input states are never simultaneously "0", it is also possible to use a J–K flip-flop which tolerates all possible input combinations (Figure 10).

Regardless of what the output was, it will change to the opposite state, when both inputs are "1". The output will be unchanged, if both J and K are "0".

The J–K flip-flop is essentially two R–S flip-flops in series. The J–K inputs affect the flip-flop only when synchronized with a clock pulse – a steady stream of signals used to allow the input voltages to reach their final value. The direct set and clear inputs ($S_d$ and $C_d$), on the other hand, operate directly on the output without being synchronized with the clock pulse. The first R–S flip-flop reacts at time "1" as shown in Figure 11; the second R–S flip-flop at time "2"; while the direct set or clear can react at anytime.

If a "0" is applied at $C_d$, the J–K flip-flop is placed in the clear state (Q=0). If a "0" is applied at $S_d$, the J–K flip-flop is placed in the set state (Q=1). The $S_d$ and $C_d$ inputs dominate the output even if synchronized with the J–K inputs.

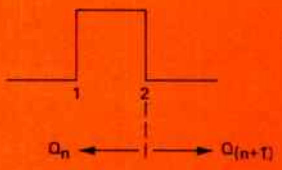


J-K LOGIC SYMBOL

| INPUTS AT BIT TIME $t_n$ | | OUTPUTS AT BIT TIME $t_{(n+1)}$ | |
|---|---|---|---|
| J | K | Q | $\bar{Q}$ |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 0 | 0 | $Q_n$ | $\bar{Q}_n$ |
| 1 | 1 | $\bar{Q}_n$ | $Q_n$ |

J-K TRUTH TABLE

*Figure 10.*



CLOCK PULSE FOR J-K FLIP-FLOP

*Figure 11.*

## Logic Modules for PCM Sampling

The sampler at both transmitting and receiving terminals in Lenkurt's 91A PCM system is basically a shift counter. This counter is the heart of the electronic mechanism that sequentially opens and closes the sampling gates for each channel – thereby multiplexing or demultiplexing the signals.

The number of stages in the shift counter is half the number of channels to be sampled; therefore, a 12 stage shift counter is needed to sample 24 channels.

Such a counter can assume $2^{12} = 4096$ binary states. Only 24 states are required for sampling – the other 4072 states are undesirable and must be suppressed. The counter is operating properly when these undesirable states have been eliminated and the desired mode 1 operation (Figure 13) is sequentially sending out 24 separate pulses to the gates of 24 separate channels.

Mode 1 operation is accomplished by connecting 12 J–K flip-flops in series – one for each stage (Figure 14).

These flip-flops are driven by a clock pulse. With each clock pulse, the flip-flop state is shifted one stage to the right – the state of stage I at time $t_1$ will be the state of stage II at time $t_2$; etc. At stage XII, the Q output is fed back to the K input of stage I and $\bar{Q}$ is fed back to J of stage I. This "crossover" of output to input causes the state to reverse.

In a shift counter, the same state is shifted from one stage to the next with each clock pulse, reversing state when shifting from stage XII to stage I. Mode 1 fits this definition; there-

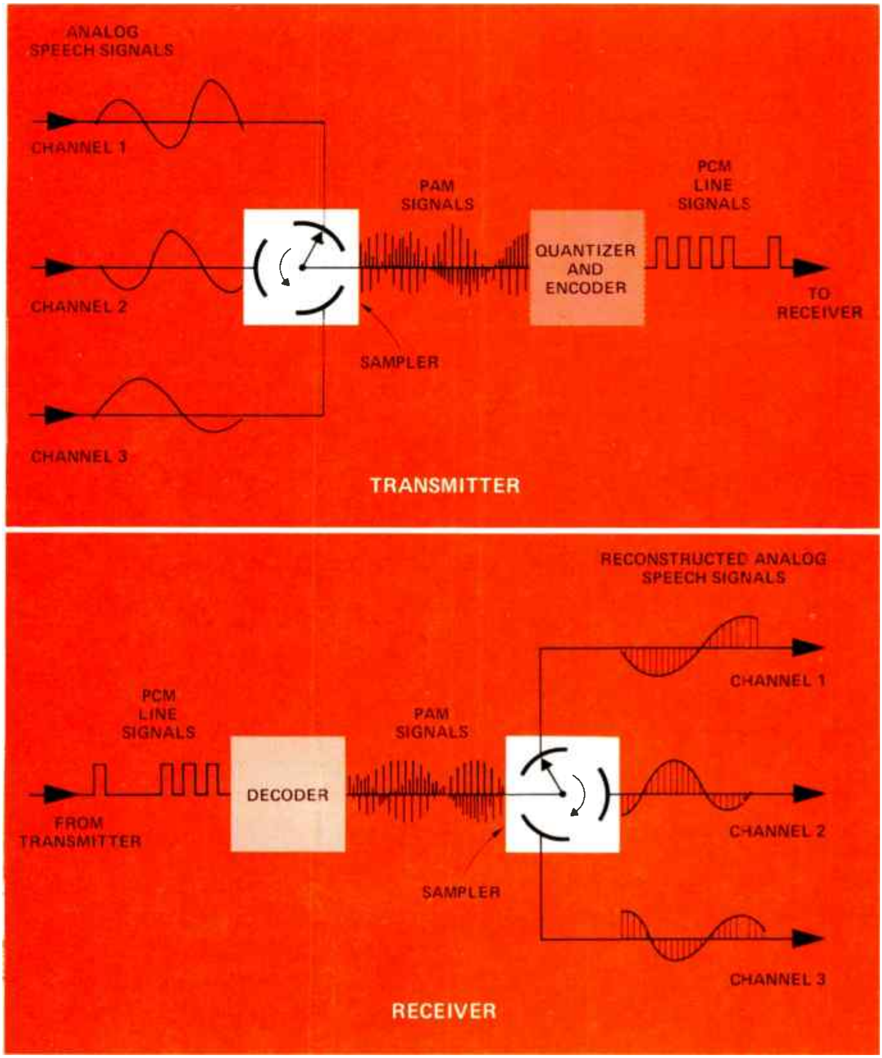
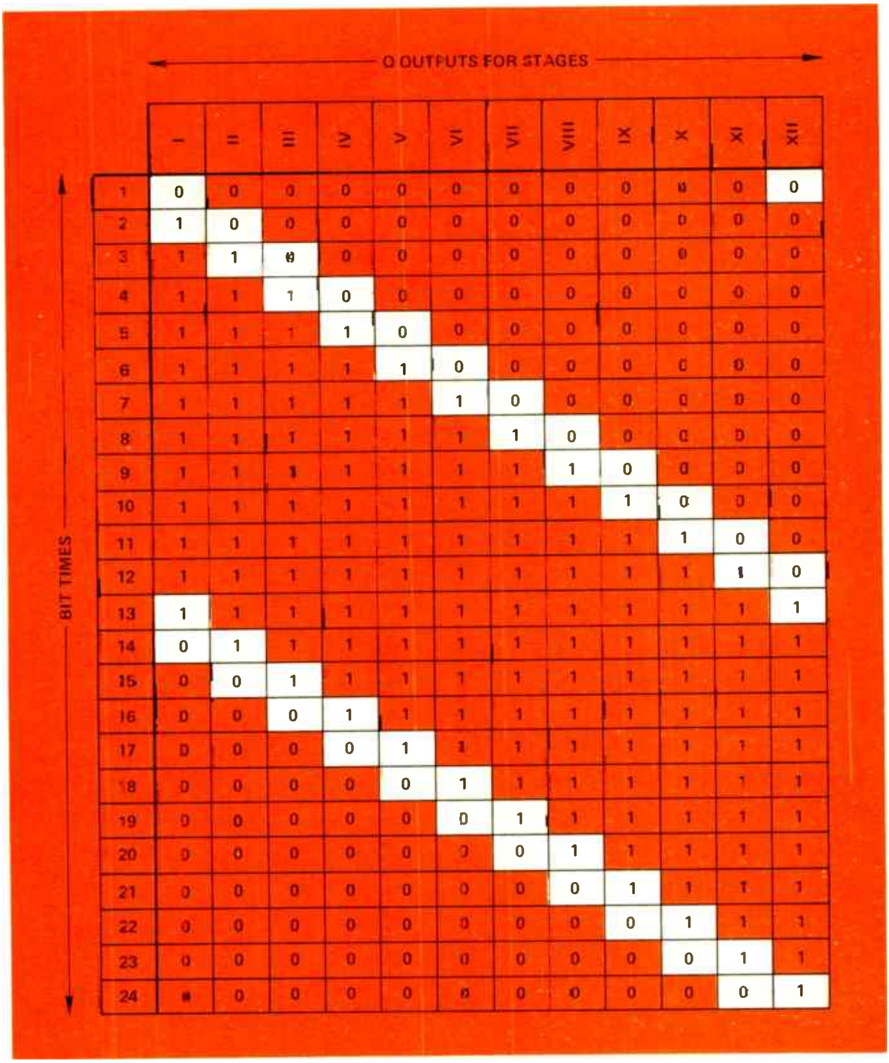


*Figure 12. Simplified PCM system (only 3 of the 91A's 24 channels are shown).*

fore, once the register assumes a mode 1 pattern, the counter will begin to cycle within this mode.

Applying power to the counter, the register may contain any one of the 4096 possible binary states (110001110000, for example). It is necessary to add either gate "X" *or* gate "Y", to suppress the undesirable states in the shift counter (Figure 14).

Gate "X" is actuated when both stage I and stage XII are in state "1", setting all the internal stages (II – XI) to "1". On the following clock pulse,



Q OUTPUTS FOR STAGES

| BIT TIMES | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 16 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 17 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 18 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

*Figure 13. The 24 possible register patterns for mode 1.*

stage I goes to "0" and all other stages are "1" as required for mode 1 operation. Figure 15 shows a sequence of patterns which starts with an arbitrary display when the power is applied and continues until the display matches mode 1.

If gate "Y" is used instead of gate "X", all the internal stages (II – XI) are set to "0" when stages I and XII are both "0".

For each of the 24 desirable states of the shift counter there is a readout gate made up of a two-input NAND

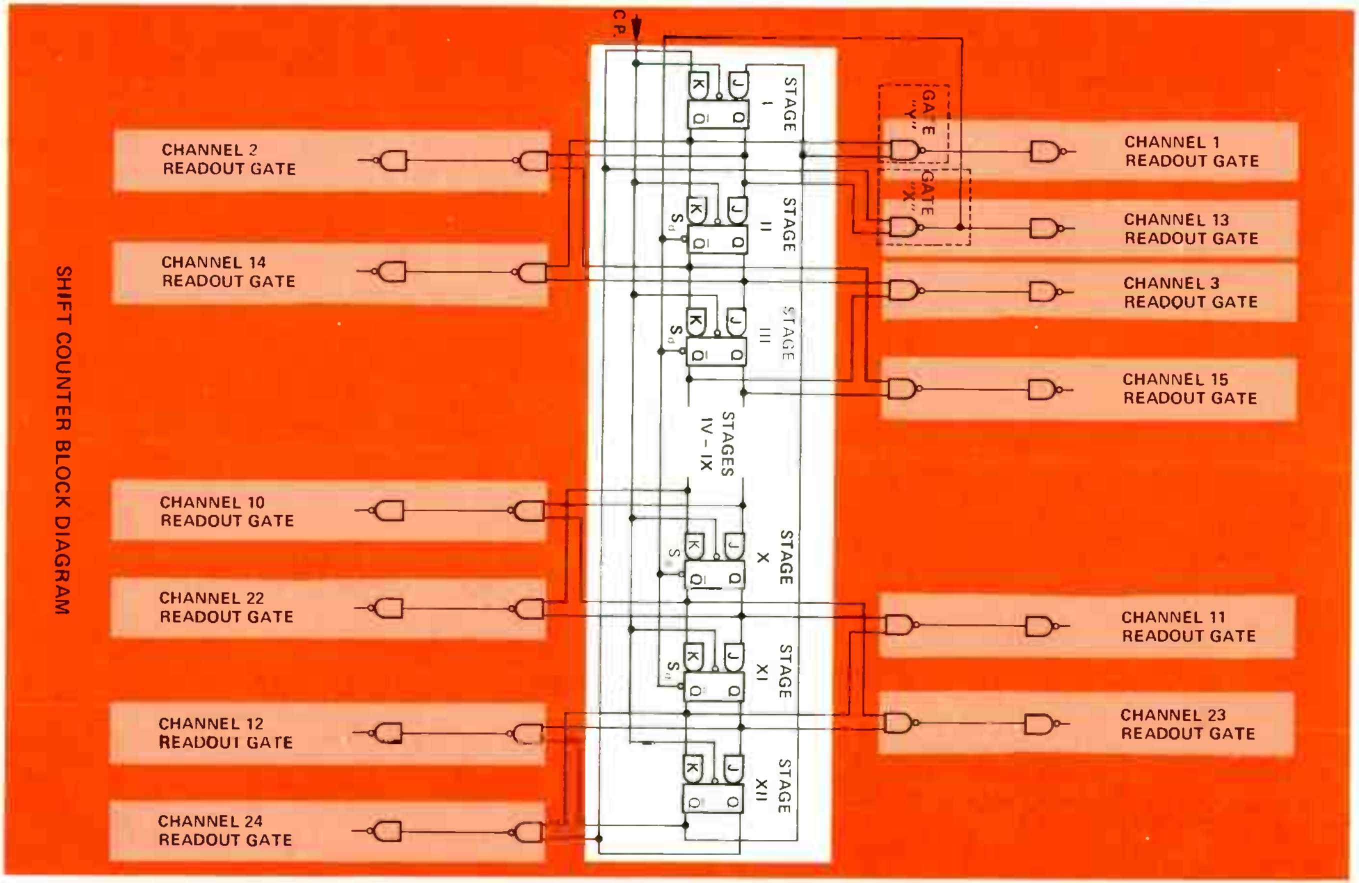
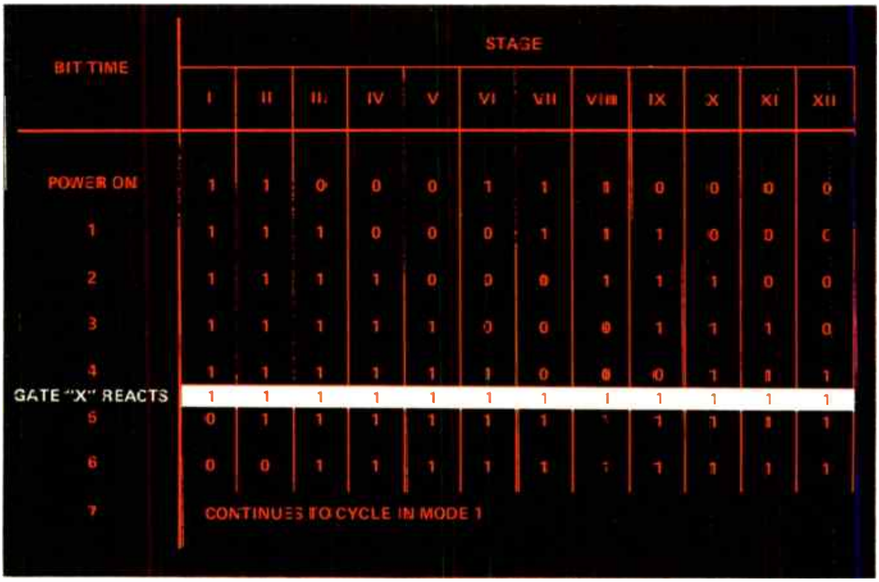

SHIFT COUNTER BLOCK DIAGRAM

*Figure 14.*



| BIT TIME | STAGE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
| POWER ON | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| GATE "X" REACTS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | CONTINUES TO CYCLE IN MODE 1 | | | | | | | | | | | |

*Figure 15.*

gate followed by a single input NAND gate. (Figure 14)

The register state can be determined by knowing where there is a transition from "0" to "1" or vice versa, or by knowing that there is no transition (all "0's" or all "1's"). By comparing the outputs of adjacent stages (white areas in Figure 13), the register transition points can be determined. This comparison is done with the readout gate. For each bit time only one readout gate will be in state "1" – indicating the position of the transition point or the lack of any transition.

When a readout gate is in state "1", it opens the corresponding channel sampling gate. The cycling of the 24 readout gates for the shift counter successively opens and closes the sampling gates of each of the 24 multiplexed channels in the 91A PCM system.

Figure 14 shows that the "X" and "Y" gates used for mode suppression of the counter are required for readout – allowing the mode suppression without additional logic modules.

Binary logic and the 930 DTL modules are also utilized in the quantizing and coding equipment for Lenkurt's 91A PCM system.

## Framework for Expansion

PCM has achieved its present state in the communications industry because of efficient application of binary logic and the timely development of reliable, low cost logic modules.

Binary logic provides the framework for PCM's future expansion.

* * *

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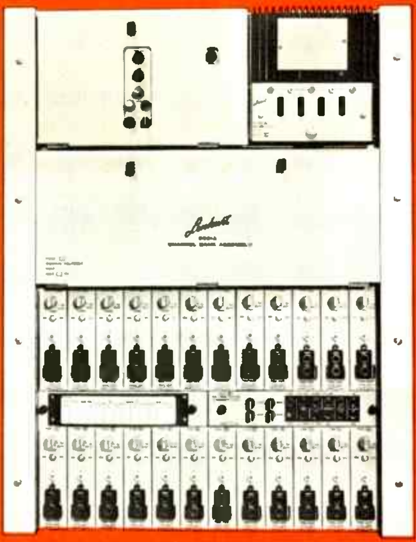

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