The Lenkurt® Demodulator

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How to increase microwave reliability

Microwave systems are being used more than ever before to satisfy a seemingly insatiable demand for more and better communications of all types. Larger numbers of channels are transmitted over individual microwave paths than was common even quite recently. The use of data transmission is growing so fast that within a decade or so it may provide the greatest volume of all communications traffic. Both of these trends place a very high premium on the reliability of microwave communications. This article discusses some of the more important factors which influence the reliability of a microwave communications system.

Reliability has two meanings in the microwave communications business. First there is the conventional meaning concerning the ability of the equipment to stay in service for extended periods with minimum attention. The other aspect of reliability is transmission reliability. It is a measure of system engineering, propagation characteristics, and the ability of the equipment to yield high quality performance through adverse transmission conditions. It is also influenced by the equipment's freedom from distortion or tendency to degrade a signal, especially when numerous repeaters are employed in the transmission path.

Transmission reliability is particularly important where numerical data are transmitted. Pipelines use data for monitoring and controlling remote unattended pumping stations and even refineries. Railroads are increasing their use of microwave for transmitting routing, scheduling, and other information. Great quantities of accounting and other management data are transmitted by many companies, and this is increasing as more companies use business machines that handle and transfer data directly, rather than going through human channels. For such use, transmission must be as nearly perfect as possible. Unlike speech, which is little affected by "static" or other momentary degradation of transmission, data usually has little redundancy. Where a word might be easily recognized despite interference, a noise pulse could alter a data character to a different value. Such errors could remove the wrong car from a train, raise a man's pay to a ridiculous figure, or increase an order beyond the wildest dreams of the sales manager!

Path Engineering

One of the big factors affecting microwave transmission reliability is fading caused by changing propagation characteristics over the transmission path. Some types of fading may reduce signal strength only a few db. Others may drop the signal level 40 db or more. Fade characteristics vary from place to place and from time to time.

Since propagation variations cannot be controlled except, perhaps, by choice of operating frequency and by care in selecting the path, the best way of overcoming such fades is to design the system with enough operating margin to assure a strong signal during all but the deepest fades. It is necessary to choose receiver sensitivity, transmitter power, path length, and antennas so that the desired signal-to-noise ratio is achieved even under severe fading conditions.

Microwave Antennas

At microwave frequencies, transmission is achieved with very low powers by concentrating most of the radio energy into a narrow beam. The larger the antenna (and reflector), the narrower the beam and the stronger the received signal. Large antennas increase system cost, but provide increased reliability. Large reflectors require much heavier towers, not so much because of their weight as because of increased wind loading. Since large, high-gain antennas reduce beam width, they also increase the requirement for accurate beam positioning. This may cause fades due to deflection of the radio beam by wind action on antennas or reflectors. This is usually resolved by using heavier towers and more extensive guying, often a very expensive procedure.

Transmitter Power

The development of klystron oscillators capable of more power than previously available affords the system designer a rather painless way of increasing transmission reliability. Other aspects of transmission being equal, doubling the transmitter power adds 3 db to the fade margin. Raising output power from 100 milliwatts to 500 milliwatts provides a 7 db signal-to-noise advantage. This means that the 500-mw transmission will tolerate a 7 db deeper fade than the 100-mw signal, for equal performance. This extra operating margin may be used to lengthen the transmission path or reduce the size of antennas and reflectors if the margin is not required to maintain the desired reliability.

Noise Threshold

Another way of keeping a tight rein on interference is to restrict receiver bandwidth. All FM receivers strongly suppress noise as signal strength increases. During a deep fade, noise usually increases in direct proportion to the reduction in signal strength, db for db, until the receiver detection

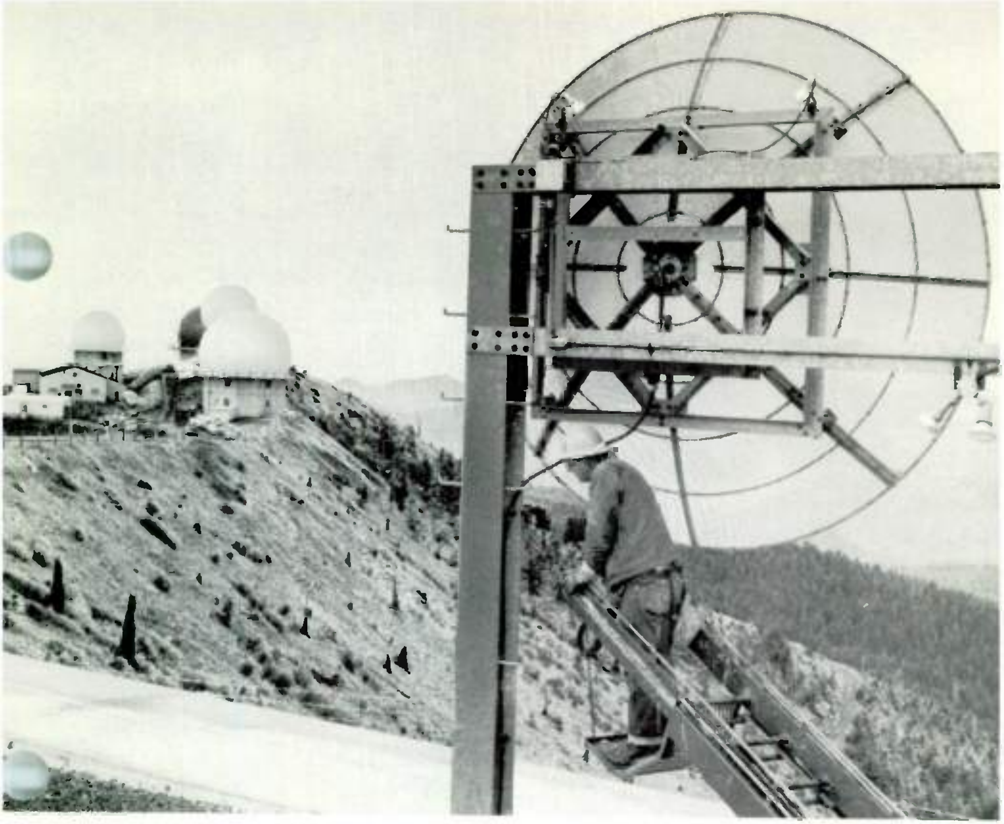

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Figure 1. Vital SAGE data is transmitted from defense warning radar to computer center by microwave relay. Microwave equipment must be reliable and relatively immune to interference from the radar itself.

threshold is reached. At this point, noise jumps dramatically, drowning out whatever residual signal may be present.

One of the controlling factors of receiver noise threshold is the bandwidth of the receiver, largely controlled by the i-f amplifier. Although receiver quieting on stronger signals soon equalizes the difference between a broadband and a narrower band receiver, the narrow band receiver is less susceptible to noise—that is, its noise threshold is lowered in direct proportion to the reduction in bandwidth. Assuming equal i-f amplifier performance, a receiver with half the bandwidth of another will enjoy a 3 db noise threshold advantage over the wider bandwidth receiver. These are the most important 3 decibels in the performance of the receiver, for these "bottom" dbs—not the high level ones—determine the limits of good receiver sensitivity and reception reliability.

Diversity Combiners

Fades usually vary with the operating frequency and the physical path characteristics. Even fairly closely spaced frequencies or physically spaced paths will not fade simultaneously. While one fades, the other usually maintains a good signal, as shown in Figure 2. Although space or frequency diversity normally can yield about the same protection from fades, space diversity costs more because of the additional antennas, reflectors, and tower expense. Diversity advantage is diagrammed in Figure 3.

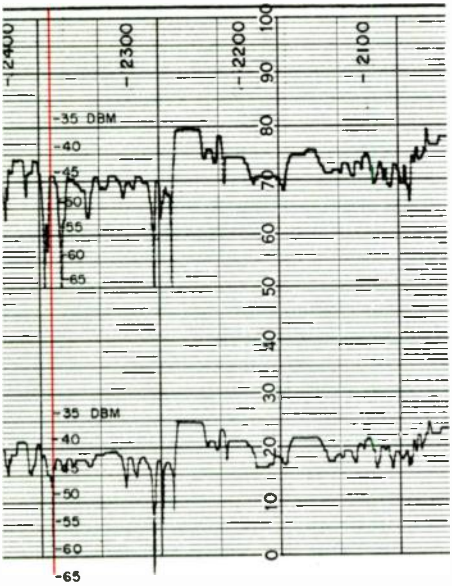

Figure 2. Actual recording of frequency diversity reception at 6,000 megacycles. The two signals are spaced approximately 118 megacycles apart. Note that most fades do not occur simultaneously on the two frequencies.

In a diversity system, some sort of combiner is required to select the stronger of the two signals and reject the noise from the faded receiver. Several forms of combiner are in common use.

The *linear combiner* is usually a passive device that adds the two receiver output signals together. This form of combiner has the disadvantage of being unable to reject the tremendous increase in noise from a receiver during a very deep fade, and the signal-to-noise ratio will not be more than 6 db better than the worst channel, except when the two signals are equal. When this occurs, the linear combiner provides a 3 db improvement in signal-to-noise ratio over either individual signal. On the good side, intermodulation or distortion products from the two paths can be arranged to nearly cancel out, thus improving noise performance.

The *switching combiner* senses noise, pilot tone, or both, and selects the better signal of the two. A relay in the signal path usually performs the actual switching. This method suffers the disadvantage of introducing transients and transmission errors at the moment of actual switching, even when fast-acting relays are used.

The *ratio-squared combiner* adds the two signals in proportion to their freedom from noise. Thus, the output from a noisy receiver is largely suppressed, while the other, with less noise, supplies a larger portion of the final signal. Theoretically, this method can yield optimum performance as a combiner. The disadvantage of this approach is complexity, cost, and the necessary use of electron tubes or similar active elements in the signal path. Electron tubes are always a source of potential failure, for they are the least reliable of all electronic circuit elements. Practical combiners based on this principle do not always achieve their potential advantage because of design compromises made to reduce complexity and cost.

A very practical and reliable arrangement is a combination of the linear combiner and the switching combiner. In such an arrangement, the linear combiner's reduction of intermodulation is usually available, and under fair transmission conditions, the combination of both signals provides a 3 db increase in the signal-to-noise figure. When either receiver fades below normal good performance, it is muted and the unfaded receiver provides the signal, thus eliminating the major defect of the linear combiner — the lack of noise suppression. Relay failure does not interrupt reception, and relay operation may be arranged to avoid the errors that are characteristic of the switching combiner. And the passive linear combiner portion is inherently more reliable than any combiner that uses electron tubes in the signal path.

Internal Noise

In systems where many repeaters are used, noise from within the equipment becomes an important factor in transmission reliability. Such noise adds up to reduce the signal-to-noise ratio and reduce the margin against fades.

An important source of noise in microwave systems is the imperfect matching of characteristic impedances of coupled transmission elements. In an ideal system, there is perfect transfer of energy from the antenna to the waveguide, from the waveguide to the receiver mixer, and from the mixer to the intermediate frequency amplifier. This would be possible only with perfect matching of characteristic impedances at each junction. Unfortunately there are several conflicting conditions in a microwave receiver that make this difficult.

The first stage of an intermediate frequency amplifier is usually designed for the highest gain possible, consistent with bandwidth and noise considerations of the circuit used. Since the gain of the stage is partially a function of the input impedance, impedance is usually high. The antenna and waveguide, however, exhibit a much lower impedance. Normally, a coupling be-

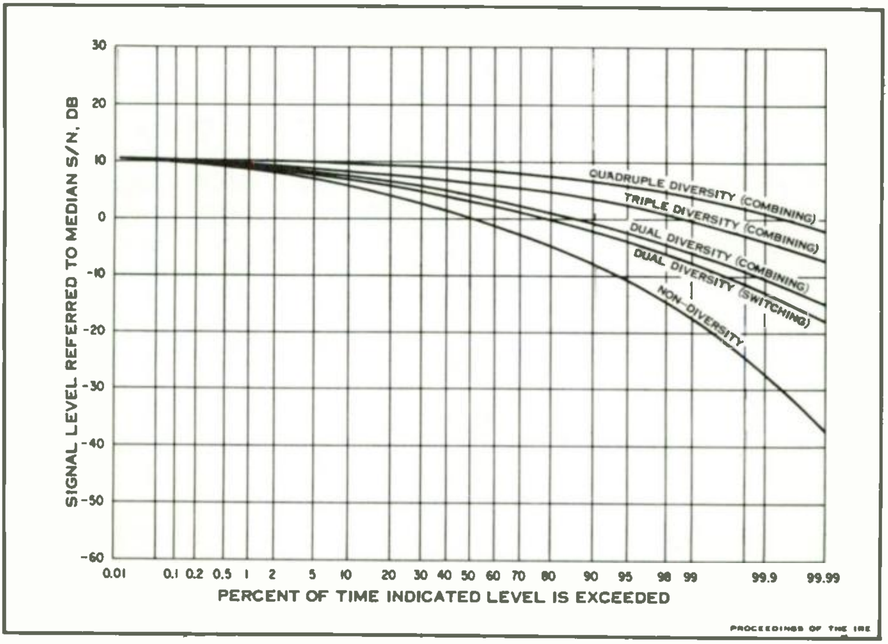

Figure 3. Theoretical advantage of various diversity systems over non-diversity system.

tween the low impedance source and the high impedance load would result in part of the energy being reflected back up the waveguide to the antenna. This reflection may be expected because perfect power transfer is never realized. In the antenna and waveguide portions of the circuit, a perfect impedance match can be achieved at only one discrete frequency. Since microwave and carrier transmissions are essentially broadband, some impedance mismatch may occur. This gives rise to a particular form of distortion peculiar to microwave frequencies.

Radio energy picked up by the antenna is coupled to the waveguide. Because of a slight impedance mismatch between the antenna and the waveguide, a very small part of the energy received is reflected and lost from the antenna. Most of the energy, however, is transmitted down the waveguide to the receiver. At the receiver, most of the energy is coupled to the mixer, where it is absorbed. However, once again, impedance mismatch causes part of the energy to be reflected, this time back up the waveguide to the antenna. Again, a small portion is reflected because of the impedance mismatch between the antenna and the waveguide. As a result, incoming signal and twice-reflected signal travel down the waveguide together.

The phase relationship between the original signal and the reflected signal will vary continuously with the component frequencies, causing phase distortion, which increases the background noise. Since the phase distortion is a function both of the signal frequencies and the travel time in the waveguide, this phase distortion is much greater for long sections of waveguide. The chances of impedance mismatch are far greater in the mixer than in the waveguide and antenna, because of the conflicting impedance requirements of the various circuits that join in the mixer.

An excellent way of overcoming the problem of energy transfer in the mixer, and at the same time greatly reducing strong adjacent channel interference and locally-originated noise, is the balanced mixer.

A balanced mixer for microwave use is diagrammed in Figure 4. Incoming signals are received in the waveguide chamber on the right. Local oscillator energy, differing in frequency from the incoming signal by the desired i-f frequency, enters the left chamber. An aperture between the two chambers is so arranged as to split input power from either branch equally between the two chambers. Energy from both chambers is picked up and mixed by two balanced diode probes connected together so that there is cancellation of input signal and local oscillator signal. The i-f frequency produced by the mixing of the two frequencies does not cancel out, and is applied to the i-f amplifier. Input energy not coupled to the i-f amplifier is reflected only down the local oscillator branch, where it is absorbed in an attenuator used to adjust local oscillator injection voltage. Local oscillator energy in the input branch of the mixer is rejected by a preselector filter which prevents it from being radiated.

This type of mixer has the advantage of balancing out all energy except that derived from both branches. This reduces noise sidebands from the local oscillator and strong adjacent channel interference that might get through the RF preselector filter. It is particularly beneficial at locations where there are strong sources of pulsed energy such as near airports or other locations where radar is used.

Somewhat similar performance may be obtained by using an unbalanced

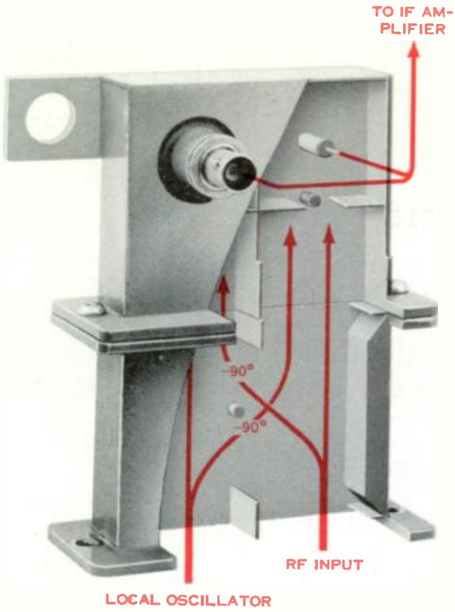

Figure 4. A balanced mixer for microwave signals. Such a mixer suppresses noise or interference appearing in one branch only, but provides low-noise mixing of desired input signal and local oscillator frequency.

mixer, but including an isolator and a filter in the local oscillator branch. The filter reduces noise from the local oscillator, and the isolator tends to absorb reflected energy from the mixer chamber. Such an arrangement is still vulnerable to adjacent channel interference, even with additional filtering in the input branch, for any two signals spaced by the amount of the i-f frequency, will mix and enter the i-f amplifier as interference. Pulses, such as those from radar, provide a rich source of frequencies suitable for such mixing, and often appear at sufficiently high peak powers to cause interference, despite heavy input filtering.

Equipment Reliability

All major suppliers of microwave equipment take special pains to select components and materials that will provide the utmost in reliable operation under a variety of operating conditions. However, the most carefully built and tested component is not entirely free of the possibility of failure, as missile designers are learning the hard way. The most reliable system will be one that provides the fewest opportunities for failure. The more active a component, the more likely it is to fail. Electron tubes are most likely to fail. Transistors don't operate reliably at temperature extremes. Although we can't eliminate electron tubes or transistors yet, we can concentrate on other unreliable items such as blowers, heaters, and thermostats. Parts of this type may not be part of the actual electronic circuitry, but their failure is no less damaging than the most critical electronic component.

Under the pressure of business and competition, it may be tempting to reduce initial cost of a system by cutting corners. The cost of achieving reliability may seem high, but with increased use of data and high-density multiplex or carrier systems, this apparent high cost may be a real bargain, particularly when compared to the cost of unreliable transmission. Such "extravagances" as diversity transmission and redundant common equipment (such as power supplies) may pay for themselves many times in systems where communications reliability is important.

The "Communications Measurements" table in the August issue was based on a paper by Mr. Newton B. Fowler of Cincinnati, Ohio. Our apologies to Mr. Fowler for changing his name.

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