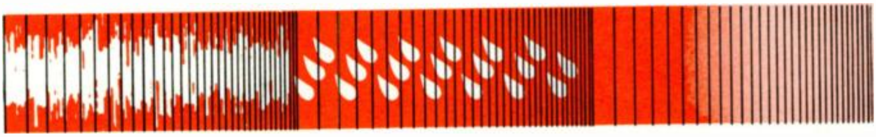
The *Lenkurt.*

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.

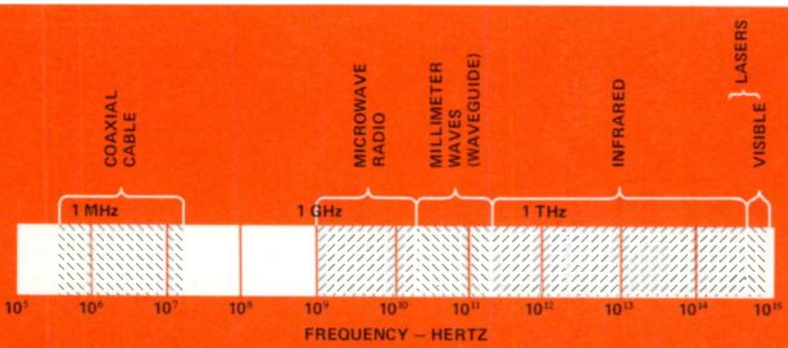


Figure 1. Examination of the electromagnetic spectrum shows large portions unused, particularly at frequencies above 10 GHz – where the largest information-carrying potential is.

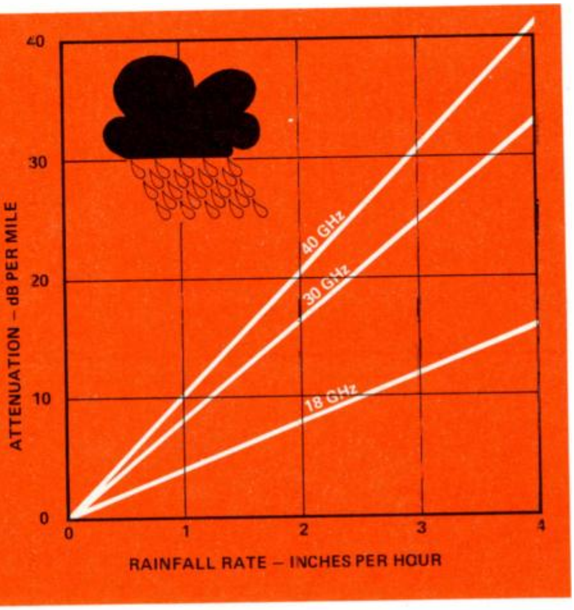


Figure 2. Attenuation caused by rain can be a formidable problem at the higher microwave frequencies. These theoretical curves (after Ryde) should be used only as approximations. Some measurements have indicated substantially higher attenuation.

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

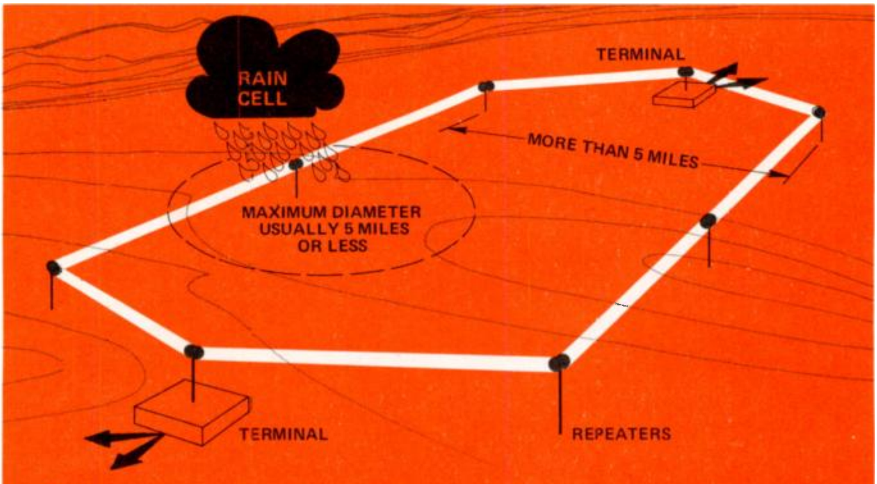


Figure 3. Route diversity provides protection against rainfall attenuation for microwave systems operating at high frequencies. If the paths are far enough apart, heavy rain is unlikely to block both at once.

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-

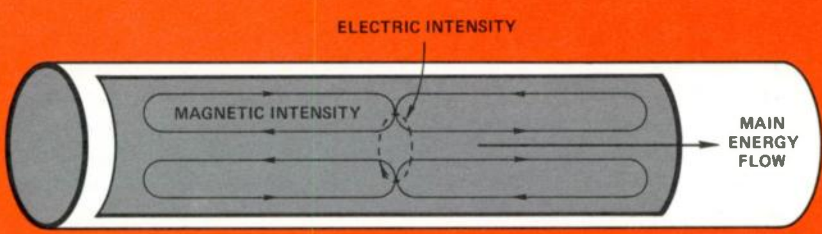


Figure 4. Electric field lines in a circular electric wave close on themselves, preventing significant charge accumulation on the waveguide walls, thus keeping wall currents low. Since charge accumulation is even less at higher frequencies, loss decreases with increasing frequency.

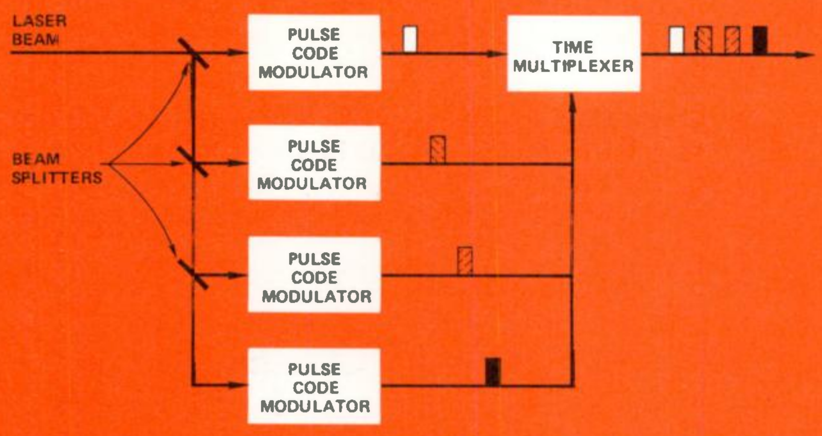


Figure 5. PCM shows considerable promise for modulating lasers. The beam-splitting arrangement shown here forms several high-speed channels from a single laser beam.

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 2×10^{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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