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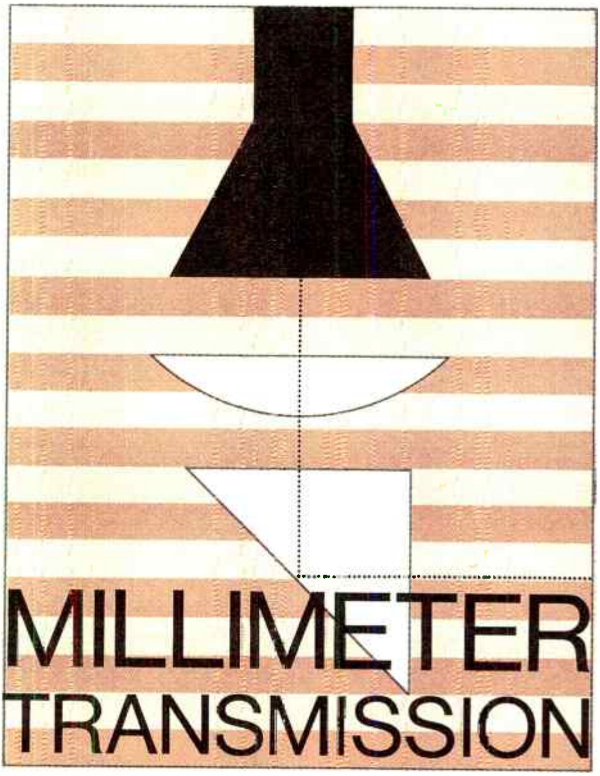
The Lenkurt DEMODULATOR



more room for communicators in the frequency spectrum

World Radio History

The millimeter band in the electromagnetic spectrum lies in a gap between classical electric waves and optics. Traditionally this band, between the top microwave frequencies at 30 GHz and the bottom infrared at 300 GHz, has belonged to no one.

The physical properties of millimeter waves are such that until recently neither microwave nor optical techniques had been able to use them effectively. In theory the waves can serve several purposes. Their shorter wavelengths are well suited to radiometry, spectrometry, radar, and navigation.

To communicators the millimeter band is more than another source of transmission frequencies. By conventional standards it has about nine times the capacity of all the lower radio frequencies combined.

Broad bandwidth, highly directional antenna beam radiation, and small components are all available in millimeter communications systems. As might be expected these apparent advantages have some inherent difficulties. Physical size and atmospheric attenuation, aside from being valuable in certain applications, are two basic snags in the development of an operational system. Narrow beamwidth which requires precise pointing and, for a mobile system, accurate tracking are also drawbacks.

So far none of these problems has been insurmountable. Millimeter systems have been built and tested satisfactorily. All that remains is that the need for a millimeter system be great enough to support its cost.

From Optics

Because millimeter waves fall in the no man's land between electronics and optics, attempts to develop a satisfactory communications system have drawn on both fields. To date optical techniques have met with the least success.

Most optical approaches use atomic excitation, usually in a gas, to generate high frequencies. Known as the multiple quantum effect, this phenomenon is used to produce the maser or microwave version of the laser.

The phenomenon takes place in a resonant cavity where an external power source "pumps" atoms up to an excited state. When the atoms relax, they emit electromagnetic waves. In one experiment hydrogen cyanide produced a frequency of 105 GHz.

Unfortunately, the high frequency waves emitted have extremely low energy. The result is that effective generation by direct quantum mechanisms is not promising for communications applications.

Other efforts at generation include mixing coherent signals from two powerful lasers. Two lasers mixed in an element such as quartz or a potassium dihydrogen phosphate (KDP) crystal could theoretically produce millimeter waves.

Electronics

In spite of the ingenious approaches taken so far, adequate energy has yet to be developed using optical techniques. Electronic devices, in spite of obstacles, have brought more success.

Size is the major obstacle to electronic generation of millimeter waves. The usual method for generating power at radio wavelengths has been with tube type, free electron devices. But the free electron principle is directly linked to wavelength.

As the wavelength of a signal becomes smaller, a phenomenon known as the *transit time effect* seriously hampers the performance of a free electron tube. (Transit time refers to the time it takes an electron to travel from the tube's cathode to its plate.)

At short wavelengths the ac component of the voltage applied to the control grid reverses before an electron can

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transit the gap between plates. As a result, electrons cannot follow signal variations precisely. This causes losses in the oscillator which become excessive as the frequency increases and the wavelength shortens.

Fortunately the klystron tube was developed which overcame transit time limitations at microwave frequencies. The klystron produced continuous wave (cw) oscillations, but required small, resonant cavities at dimensions near the wavelength.

In the even smaller cavities required to produce millimeter waves a large amount of input power is lost as heat rather than converted to wave energy. This inefficiency could be accepted if the input power and the resulting output power were increased. But the small cavity does not dissipate heat fast enough to accommodate a larger input.

The klystron tubes which do operate in the low millimeter range are expensive. They have lifetimes limited to a few thousand hours and require high voltages.

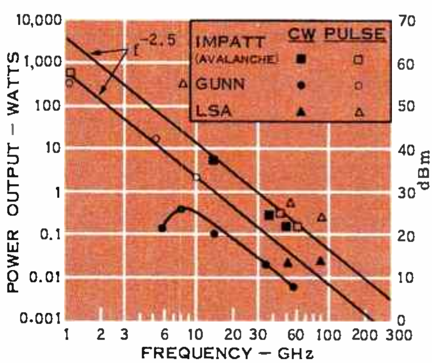

Figure 1. Maximum power produced by three solid-state devices. Note that the maximum pulsed power of the IMPATT avalanche type diode and Gunn diode decreases as frequency increases in the proportion $f^{-2.5}$.

Some electronic devices such as periodic beam devices have been able to produce relatively high outputs in the millimeter range. One such device has delivered 1 mW at 300 GHz. Similar devices have had outputs of one watt at frequencies ranging from 80 to 140 GHz but at efficiencies of 2 per cent.

Another Way

As an alternative, semiconductor devices have also been tried. They have the advantage of requiring less input power. But they still do not produce sufficient output power at high frequencies.

The frequency of most solid-state devices depends on the time it takes a space-charge (an electrical charge in space between the electrodes of a transistor or the plates of a tube) to travel through the device—the transit time. The smaller the transit time, the higher the frequency.

At General Telephone and Electronics Laboratories tests have been run using the thermoelectric effect of heated carriers in bulk semiconductors. Using this method General Telephone and Electronics Laboratories has been able to produce a pulsed output of 5 mW at 210 GHz. Generation took place in a frequency tripler. As might be expected the efficiency was quite low and, of course, the pulsed power output was not suitable to communications.

Until recently the two most promising solid-state devices were the avalanche-transit time diode and the Gunn effect diode. Both diodes have produced relatively high power and frequency outputs.

The avalanche diode uses an inductive cavity tuned to the diode capacity to build up oscillations. In the Gunn effect diode an electric field is applied across a crystal of gallium arsenide. The period of oscillation in the Gunn diode is roughly equal to the time it

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takes an electron to travel from one end of the crystal to the other at the voltages applied. Both diodes are transit time devices.

To attain higher frequencies in solid-state devices, therefore, it was necessary to shorten the transit time between electrodes. This meant shrinking the so called active region. The smaller active region, unfortunately, made transistors inefficient thereby limiting the output power.

The LSA

A new mode of oscillation, the "limited space-charge accumulation" (LSA), has been discovered which does not depend on transit times. The new mode makes possible high frequency, solid-state oscillators with useful power outputs. It is not susceptible to decreased powers at millimeter wave frequencies—the problem that had dogged every other attempt at generating short wavelengths.

LSA diodes, developed at the Bell Telephone Laboratories, have attained a continuous wave power output of 20 milliwatts at 88 GHz. This is reported to be the highest frequency recorded for a continuous wave, solid-state oscillator. LSA diodes operating at lower frequencies have produced correspondingly higher outputs.

In the LSA diode oscillator no space-charge is allowed to accumulate. As a result transit time does not play an important part in the oscillator's functioning, and physical size is not as critical as it is in other devices. The LSA diode, therefore, can be made thick enough to withstand relatively high applied voltages.

For LSA oscillation the diode functions as part of a resonant circuit which is tuned to the desired operating frequency. Both the diode and the resonant circuit must be properly designed and matched. Since the frequency is determined primarily by this circuit, the power is for all practical purposes independent of frequency.

LSA diodes have operated continuously for over four months in the solid-state repeater of an experimental millimeter communications system. The diodes are being tested as replacements for klystron tube oscillators which require high voltages from large regulated power supplies.

The operating life of LSA diodes is expected to be comparable to that of transistors and much greater than that of tubes which operate in the same frequency range.

Limited Successes

Most earlier millimeter transmission systems did not generate their waves directly. An experiment at TRW Systems used a 70 GHz klystron source and har-

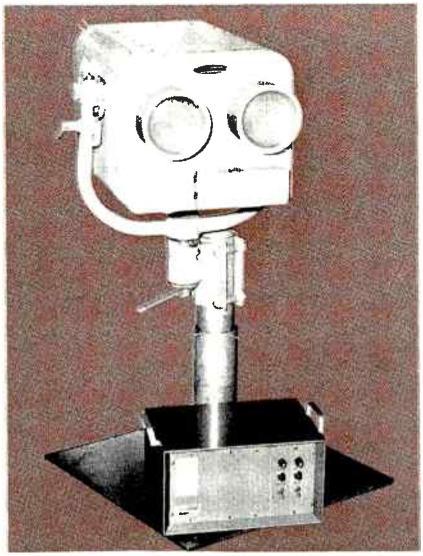

Figure 2. Sylvania Electronics System's solid-state millimeter transceiver mounts on pedestal or tripod. At the bottom of the pedestal is the power supply.

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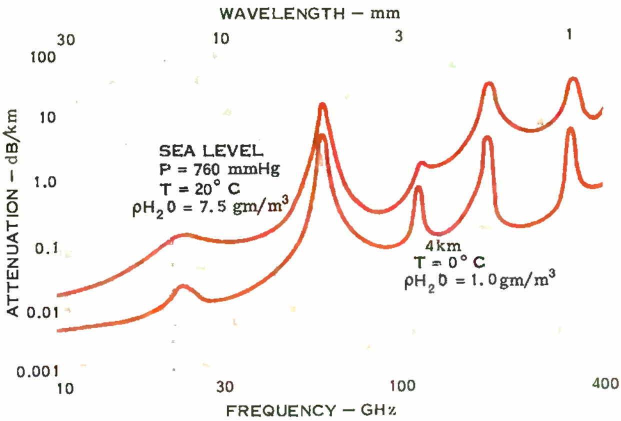

Figure 3. Attenuation of high frequencies at different altitudes is affected by oxygen and water vapor. P indicates barometric pressure, T atmospheric temperature and ρH_2O is water vapor density.

monic generation to reach 140 GHz. Another experiment at General Telephone and Electronics Laboratories operated a 90 GHz system across a distance of 1.2 miles with a high degree of reliability.

Sylvania Electronics Systems has developed a solid-state millimeter system which uses harmonic generation to reach 36-38 GHz. The transmitter uses a semiconductor amplifier and multiplier circuits to increase a low-frequency, crystal generated signal to a high frequency output. It is a frequency modulation system capable of 100 milliwatt output power.

The transmitter and superheterodyne receiver employ an identical horn and lens combination antenna. The surprising feature of the system is that it has a communications range of several miles through the atmosphere. Prior to the development of the Sylvania system, atmospheric propagation under anything less than ideal conditions was considered extremely tenuous.

In the Air

Changes in atmospheric temperature and pressure can have a critical effect on propagation. These two meteorological properties along with the oxygen and water vapor content of the atmosphere determine its dielectric constant and therefore its radio refractive index.

The refractive index indicates the speed at which a radio wave travels through a medium. In the atmosphere a change in the index of refraction can cause significant fluctuations in the angle of arrival of a signal at the receiver. In fact, a variation across the signal path can bend a signal enough to cause it to miss the receiver antenna. A change can also partially destroy a signal's coherence, making it unusable at the receiver. For a millimeter wave with its narrow beamwidth a variation in the index of refraction can be especially critical.

In general, atmospheric attenuation due to the molecular absorption of oxygen and water vapor easily disrupts millimeter waves. Fortunately, atmospheric attenuation is not constant for all wavelengths.

"Windows", as they are called, are spread across the millimeter band between oxygen and water vapor absorption lines. These windows are actually areas in the frequency spectrum which have relatively low attenuation. Fig. 3 shows where they occur in the millimeter band.

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To complicate matters further the effects of scattering from water droplets are superimposed on atmospheric absorption. Here the ratio of particle size to wavelength is critical in determining the amount of energy scattered. If the scattering particles approach the size of the wavelength, near total extinction can result. Thus, it is important to consider the size of atmospheric particles in relation to the size of a wavelength.

Judged by typical particle sizes microwaves are relatively immune to rain, millimeter waves to fog, and infrared waves to haze. Obviously, atmospheric propagation in the millimeter band will be best in a hot, dry climate. Poor propagation would seem certain in wet weather, although Sylvania found that a moderate rainfall (2.5 mm/hr) had little effect on its millimeter system.

At rainfalls of 5 mm/hr and 12.5 mm/hr the range of the system did drop as low as 8.9 and 4.7 nautical miles respectively. Of course, dust and dirt could have the same effect as rain particles on these delicate waves.

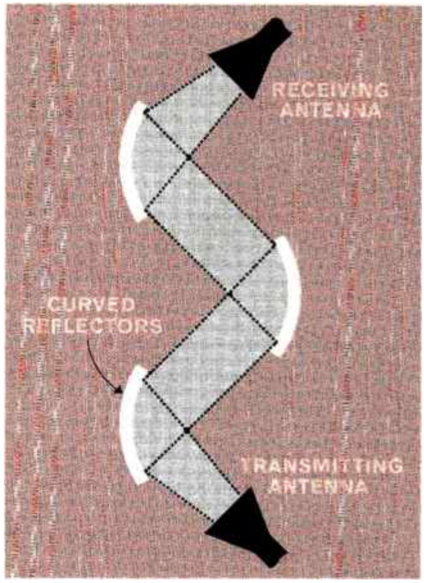

Figure 4. Reflecting beam waveguides use optical techniques to reflect millimeter wave energy along a path. Reflectors are usually curved to focus energy and reduce spreading losses.

Protection

Waveguides, on the other hand, are immune to the buffeting of the open atmosphere. They can provide a closed, controlled system which is well suited to millimeter transmission.

Waveguides do have drawbacks. They become less efficient as they are made smaller—a problem not unlike that encountered in generation.

Transmission losses increase at smaller wavelengths because currents crowd toward the surface of the guide. This phenomenon, known as the skin effect, increases resistance as the frequency becomes higher. The skin effect can be reduced by using circular waveguides with low transmission losses. Theoretically circular waveguides have an energy propagation mode with an electric field of zero along the inner wall of the waveguide. This zero electric field means low wall currents and low losses.

The circular waveguide transmits ever-increasing frequencies in the circular electric mode with ever-decreasing attenuation. Unfortunately, an extensive waveguide system is expensive. Its eventual use depends on the demand for broader communications channels.

More Optics

Other forms of guided transmission use such optical techniques as lenses, mirrors, and beam splitters. Curved mirrors form a reflective beam waveguide. In it a beam of millimeter wave energy travels from one mirror to another along a zig-zag path.

The mirrors are curved in order to focus the energy of the beam or other-

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wise collimate it to reduce spreading losses. Mirror size and materials must be carefully chosen to keep diffraction and surface losses low.

Beam waveguides using glass lenses to keep the beam tightly collimated suffer from losses on the order of 1-3 dB per lens. Gas lenses have much lower losses. They depend on a temperature gradient through the gas caused by heating the waveguide pipe.

The temperature difference across the gas causes a variation in the index of refraction. The gas, because of its index of refraction, forces the millimeter beam to remain in the tube's center (or just below the center where the coolest area of the gas settles because of convection). It actually focuses the beam.

Using heated gas in a long waveguide is unwieldy. In order to maintain the desired index of refraction, it is necessary to maintain the same temperature and pressure along the entire waveguide. This is not easily done over a long distance.

Detection

Detection does not run into as many problems as do transmission and propagation. Superheterodyne detection will work. The superheterodyne method mixes the incoming signal with one generated by a local oscillator to produce a usable signal. This new signal, the difference between the original two, is low enough in frequency to be applied and detected by available devices.

Any method of detection must take into consideration the angular tolerances of the narrow, millimeter wave beams. These tolerances are extremely small, imposing strict demands on the angle of arrival of a signal.

If a millimeter system is used on a moving vehicle such as a satellite or aircraft, precise position information is required. For heterodyne detection the vehicle's velocity must be known in order to compensate for Doppler frequency shifts. Moving vehicles must be tracked in angle and velocity—a function not normally associated with communications.

Useful

The broad bandwidth found in the millimeter region could accommodate high data rates easily. It appears to be ideally suited for machine-to-machine communications, especially for high speed computers. Photo transmission from space probes could be increased considerably if millimeter wave transmission were available.

In terms of equipment the millimeter band affords new possibilities for compactness. Because the size of component parts normally varies inversely with frequency, those in a millimeter system should be smaller and lighter than those used in a lower frequency system.

The beam emitted is highly directional. This, plus a high attenuation rate in the atmosphere, gives millimeter waves built-in security—of particular value to the military. On the other hand the negligible amount of attenuation in space and the expected size of equipment makes millimeter waves promising in this area.

Commercially millimeter transmission systems will help keep pace with the expanding need for wideband communications.

At present the millimeter band is waiting to be used. Technology exists which can put at least part of the band to work. But economic considerations measured against need are the most influential factors slowing its extensive use. No doubt as demands on the frequency spectrum become greater, the millimeter band will come into its own.

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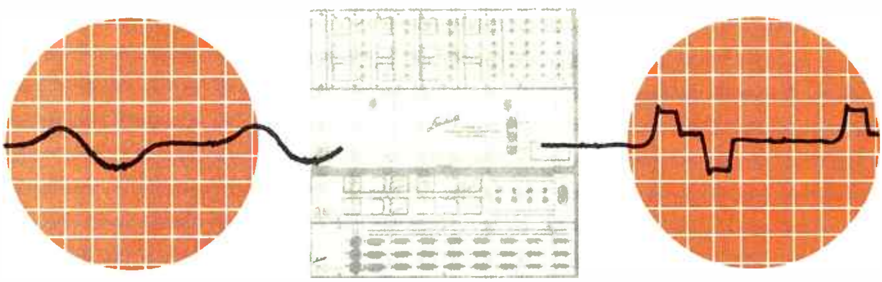

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