The Lenkurt.

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DEMODULATOR

progress in solid-state radio

"Progress begins by getting a clear view of the obstacles."

Whenever there is a technological breakthrough, there is an automatic demand for "things" incorporating this new concept. Before design changes are made, however, it is mandatory to examine the present system closely to see what weaknesses exist and to determine what new problems might be created by incorporating this new development.

Unless careful thought and planning precede design changes, these changes can lead to a technological standstill —or even a regression— rather than a step forward.

More than a decade ago, semiconductors made their debut in the electronics world. Ever since that time, the demand for "solid-state everything" has become a way of life.

Microwave radio systems have not escaped the challenge to change to solid-state. Although, examining the obstacles involved, progress has not been as rapid as some expected.

Progress, as it concerns an all solid-state microwave radio system, must improve at least one of these areas —reliability, efficiency, noise performance, channel capacity, maintenance, or cost. If none of these areas are improved, the change is simply *that* —a change— and not progress.

To understand the progress of solid-state radio, it is necessary to get a clear view of the obstacles involved with microwave transmission —principally, generating a high power signal.

Microwave Repeaters

The baseband or remodulating type repeater shown in Figure 1 illustrates how the modulated carrier is received and demodulated and then remodulated into a transmittable electromagnetic wave. For comparison, a heterodyne repeater is shown in Figure 2. The heterodyne repeater amplifies the signal, without demodulating.

The received modulated carrier must be amplified, because it has a low power level. It is easier, however, to amplify a low frequency signal. So before amplification, it is desirable to lower the frequency of the received signal. This is done by mixing the received modulated carrier with a signal from a local oscillator (L.O.). The L.O. produces a fixed frequency signal equal to the carrier frequency plus or minus an intermediate frequency (IF).

The mixer takes the sum or difference of the received modulated carrier and the L.O. signal. Since a lower frequency signal is desired, the mixer output is the difference of the two signals –resulting in a modulated IF signal. A mixer used in this configuration is a down converter.

This IF signal is then amplified. At this point in the heterodyne repeater, the signal is converted back to a higher frequency, in an up converter. The signal is amplified once again and is ready for transmission.

Once amplified in the baseband repeater, the signal is fed to a discriminator which changes the frequency variations into a varying voltage. The discriminator is the demodulator; therefore, this varying voltage represents the baseband signal (the original signal before it modulated the carrier frequency to form the transmitted radio signal).

This baseband signal is used as the input to the transmitter where the varying voltage is modulated again to form a frequency varying carrier. This modulated carrier has the proper frequency and power for subsequent radiation.

A desired output power of at least one watt has been established as a nominal level for baseband repeater systems. This output power has been a major obstacle in designing an all solid-state microwave radio system.

First Attempts

Microwave radios began to change from vacuum tubes to solid-state designs, in the early 1960's. Total solid-state construction involves more than simply adapting semiconductor components and microwave design principles to meet existing industry standards for stability, noise performance,

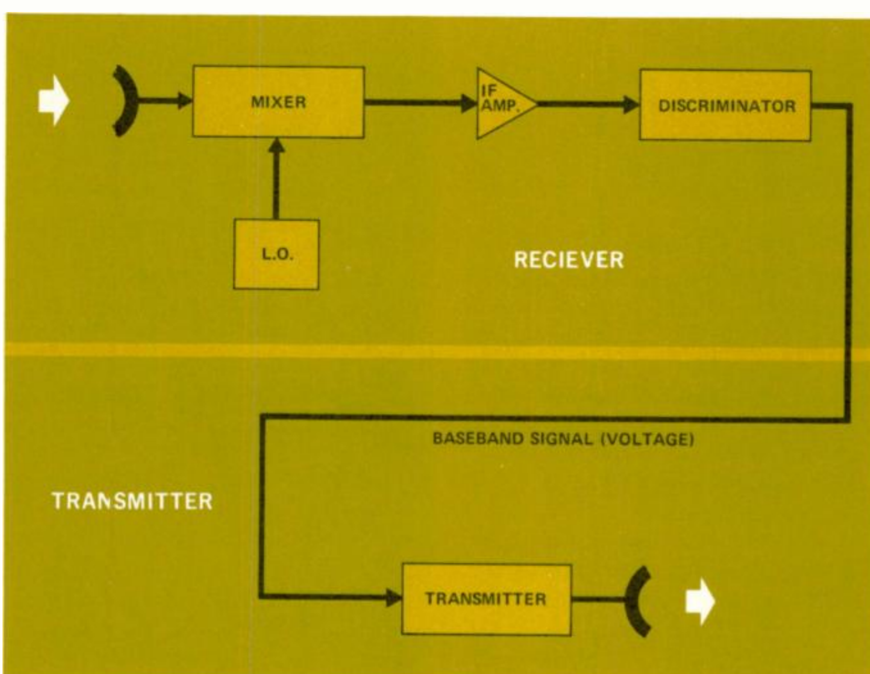

Figure 1. A microwave radio baseband or remodulating repeater is a receiver and transmitter in series.

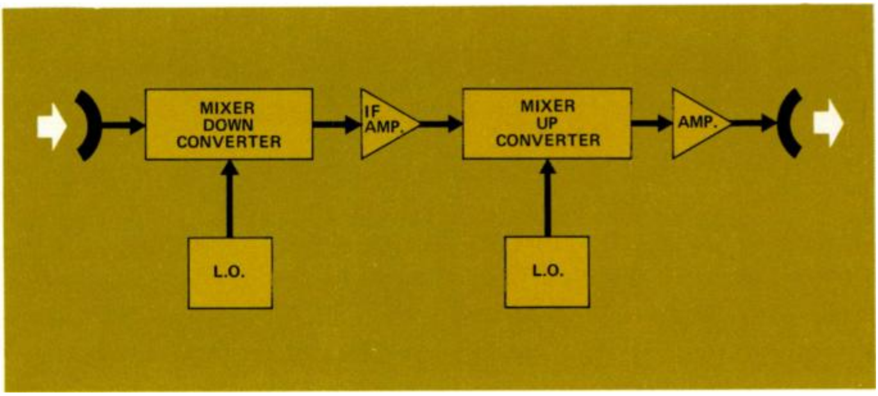

Figure 2. In a heterodyne repeater, the signal is amplified without being demodulated and remodulated.

bandwidth, and power. Cost, space, and reliability considerations are just as important.

The baseband receiver and transmitter both had a vacuum tube holdout—the klystron tube. In the receiver, the klystron tube was used as the local oscillator, and the transmitter was a klystron tube preceded by a modulation amplifier. A klystron tube simply takes a voltage input and produces a frequency output.

A solid-state replacement for the klystron would eliminate the need for a stable, high voltage power supply required for klystron operation. Solid-state devices do not need high voltages. It was expected that solid-state oscillators would also increase reliability making frequent field replacement of tubes unnecessary.

The local oscillator has one design requirement—low noise at low power. The transmitter design, on the other hand, has three such requirements—high power, low noise, and stable frequency output. The tighter specifications for the transmitter design makes it necessary to permit a higher noise level in the transmitter oscillator.

A solid-state oscillator was more readily designed to replace the L.O. klystron because of its lower power requirement. Consequently, a solid-state replacement for the transmitter klystron tube was an obstacle in the progress of all solid-state radio.

All Solid-State

Since solid-state devices generate high power signals more readily at lower frequencies, an all solid-state microwave radio in the 2 GHz frequency band, rather than 6 GHz or even higher, was easier to achieve.

Lenkurt's 2 GHz all solid-state radio system, which provides up to 300 voice frequency channels, is shown in Figure 3. In this system a nominal power output of 2 watts is obtained by using high power varactor diodes in the multiplication stage.

As well as improved reliability with a 2 watt output, the all solid-state design offers many advantages. Replacing vacuum tubes with solid-state devices has the added benefits of longer life, reduced power consumption, and smaller systems in modular designs for simplified maintenance.

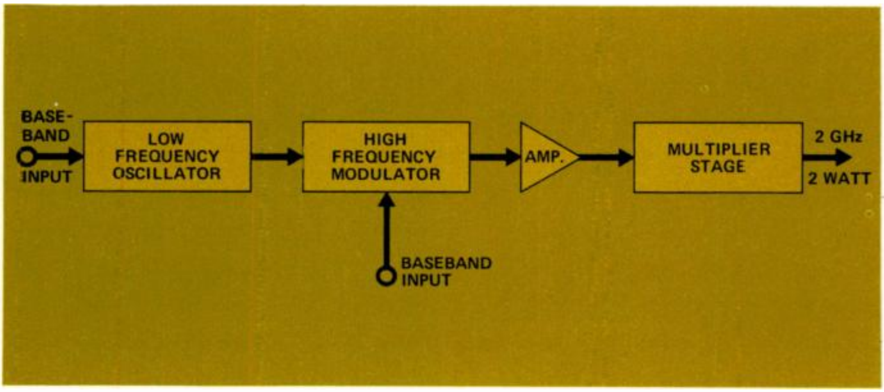

Figure 3. Lenkurt's 2 GHz radio transmitter was among the first on the market in that frequency band.

An operative all solid-state transmitter was a great challenge. Designers, working with state of the art components, persisted in their efforts to meet this challenge.

A marketable, all solid-state, 6 GHz microwave radio system was first produced, in 1962, by R.C.A. This system uses a crystal oscillator and has a capacity of 300 voice channels with an output power of about 1/2 watt.

The system shown in Figure 4 uses a crystal oscillator for generating a carrier frequency which is then amplified. Subsequent multiplication is accomplished by a varactor-diode multiplier chain, producing the desired carrier frequency at a reduced power level.

The transmission signal (the baseband signal) is used as the input to an FM oscillator (FMO). The FMO, in turn, converts the signal voltage to a varying frequency. The multiplied carrier frequency and the output of the FMO are up converted through a mixer, the output of which is the sum of the two frequencies. This output is also the desired modulated carrier frequency. One disadvantage of this system is that power is lost in the up conversion.

The first obvious improvement desired in the crystal oscillator transmitter was an increase in the system's output power since it is directly related to the channel capacity. Another needed improvement was the lowering of the necessary multiplication factor, since noise is closely related to the frequency multiplication.

As transistors are improved for microwave application, it becomes possible to replace the crystal oscillators with transistor oscillators which could offer higher frequency outputs; therefore, a lower multiplication factor, to reach 6 GHz. It might also be possible to improve solid-state transmitters to provide a power output of one watt.

Transistors pose severe challenges to circuit designers; their problems are not worse than electron tubes but they are quite different. The problems associated with klystron circuits are all very familiar, and can be approached, therefore, with known alternatives. This is not the case when working with transistors in the microwave range.

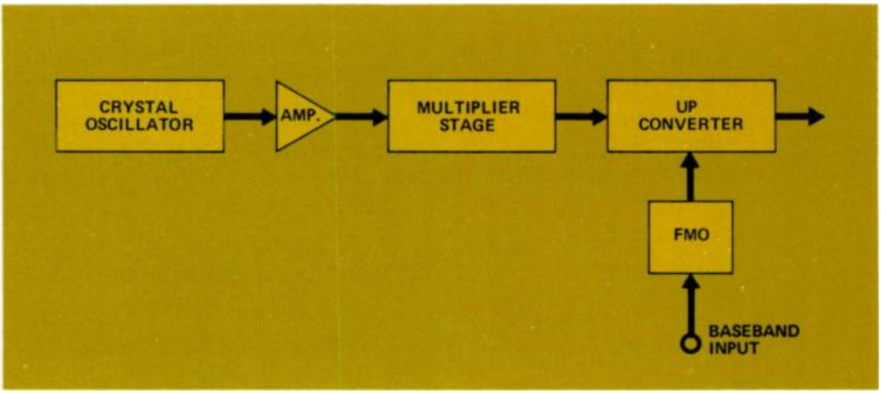

Figure 4. Crystal oscillators were the first solid-state replacements for the transmitter klystron.

These transistors are so new that the problems associated with them are not necessarily all understood. The preferred solutions to even the known problems have not yet all been found. Because of the newness of these transistors, it is necessary to follow design principles conservatively in order to guarantee a sufficient degree of system reliability. It is possible that present transistor designs will prove capable of meeting higher specifications than are now guaranteed.

Transistor Oscillator

Transistor oscillators used in the present 6 GHz, all solid-state transmitters have a higher frequency output than the crystal oscillators first used. This higher frequency requires a lower multiplication factor to obtain the desired carrier frequency.

Transmitters using transistor oscillators have an automatic frequency control (AFC) device to insure that the output frequency is 6 GHz. In these solid-state transmitters, the baseband signal is used as the input to the transistor oscillator rather than being mixed with the carrier frequency

Lenkurt's new 6 GHz microwave radio offers improved, low noise performance. This all solid-state radio has a one watt output and a channel capacity of 1200 channels —large enough for transmission of two video signals, as well as voice and data. The low per channel deviation of this system makes it possible to provide 600 channels in the industrial band.

The "heart" of the transmitter is the FMO as shown in Figure 5. This unit provides a modulated microwave signal output at one-fourth the desired operating frequency. A crystal referenced AFC device provides precise frequency stability.

After modulation, the signal is fed through an amplifier. With a new power level of 6 to 8 watts, the modulated carrier goes through two frequency doublers. The output is a frequency modulated signal at one watt and a carrier frequency of 6 GHz —ready for transmision.

The one watt output insures a high enough signal-to-noise ratio for Lenkurt's large channel capacity. The thermal noise amplification introduced by the frequency multiplication is dir-

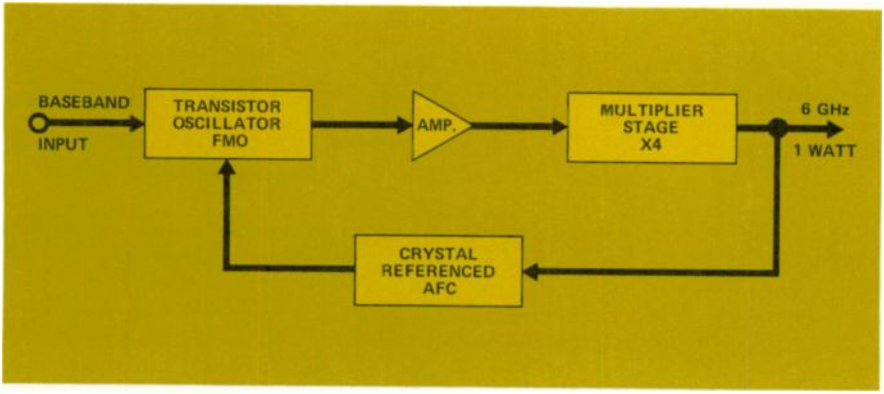

Figure 5. Lenkurt's 6 GHz solid-state microwave radio system uses two frequency doublers in the transmitter.

ectly related to the multiplication factor. Since the oscillator is by far the major source of transmitter thermal noise, this low multiplication factor minimizes output noise.

Ideal Transmitter

The ideal solid-state transmitter would have a baseband input to a single "black box" whose output is a one watt, or greater, 6 GHz signal —without any need for power amplifiers or frequency multipliers.

At this point, high power output transistors have uncertain life expectancies. But, it is possible that such a transistor or even a new type semiconductor device may become available in the future. When these devices are developed, it could be several years before a new system could be in production.

There are two devices presently available that may, eventually contribute to the design of an ideal solid-state transmitter. The avalanche diode might be used in place of the transistor oscillator to produce a 6 GHz signal at almost one watt.

The unsolved problems with the avalanche oscillator are that it is noisy and difficult to simultaneously stablize and frequency modulate.

The Gunn diode has also been considered as an oscillator. It is much quieter than the avalanche diode at 6 GHz, but its present maximum power output at this frequency is only about 100 milliwatts. The same stabilization problems exist as for the avalanche diode.

Still another possibility is to use the Gunn diode as the oscillator, since it is quiet, and the avalanche diode in a power amplifier configuration. However, at present, neither the power nor frequency of the avalanche amplifier are sufficient for a solid-state transmitter. Despite these obstacles, the avalanche/Gunn combination appears to be the most promising next step in solid-state transmitter design.

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