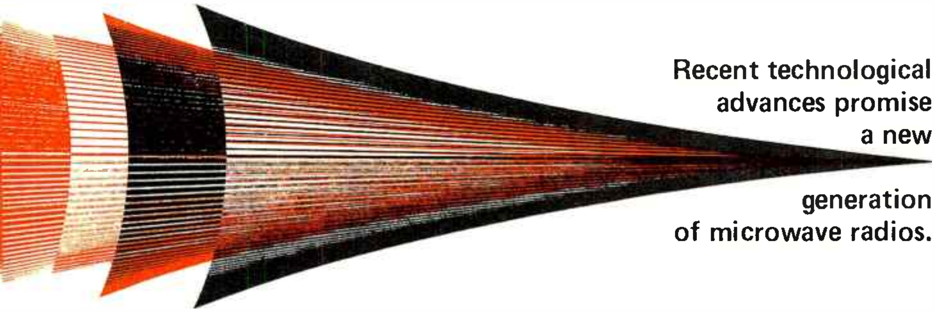
The Lenkurt DEMODULATOR

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

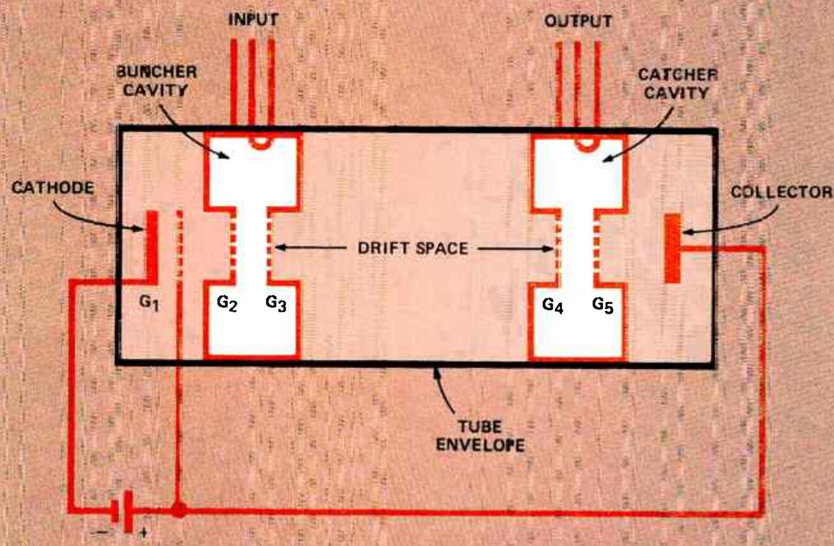


Figure 1. Simplified diagram of a klystron amplifier. An actual klystron usually has a set of electrodes at the cathode which focuses into a narrow beam.

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-

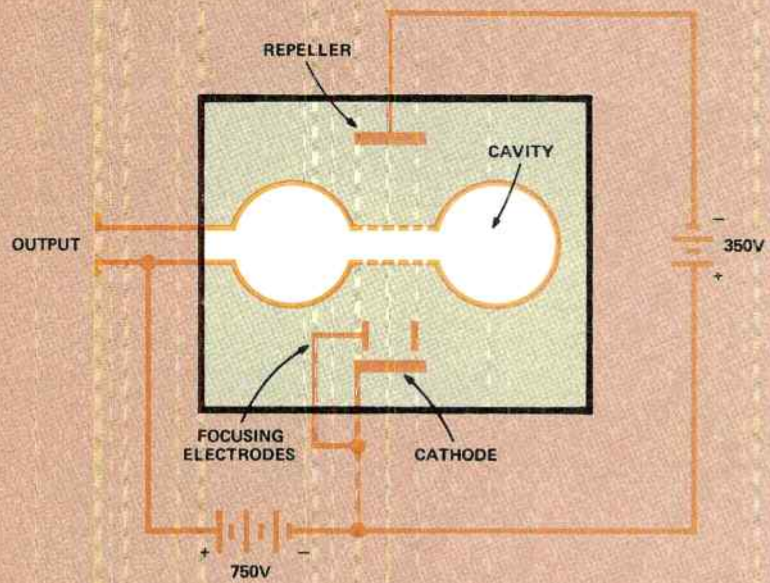


Figure 2. Diagram of a reflex klystron. The output may be through a waveguide, coaxial cable or probe.

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

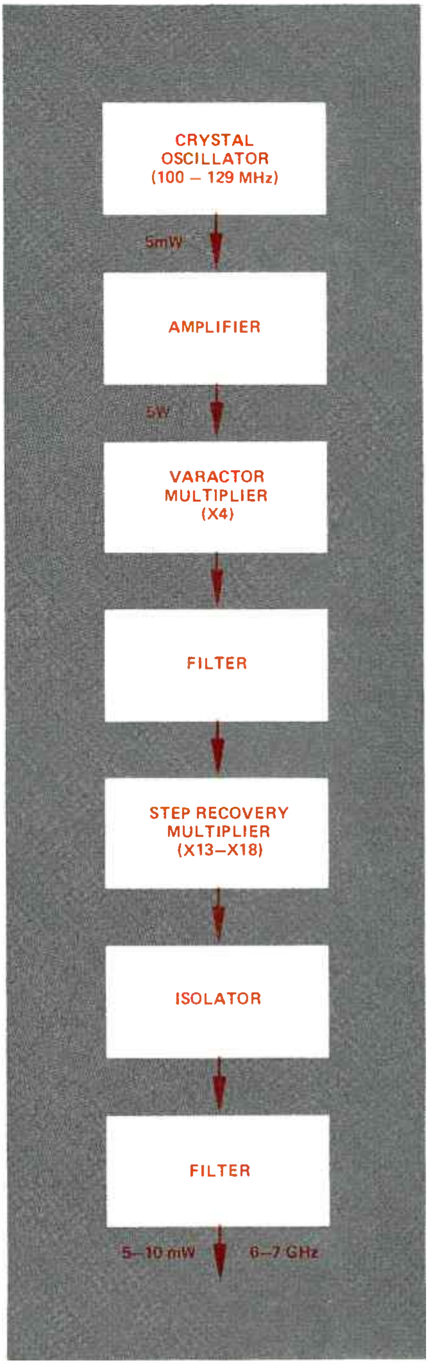


Figure 3. Typical solid-state local oscillator design uses crystal oscillator frequency reference source, varactor diode multiplier for times four multiplication and step recovery diode for times thirteen to times eighteen multiplication. Microwave frequency in the 6 to 7 GHz range, determined by the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

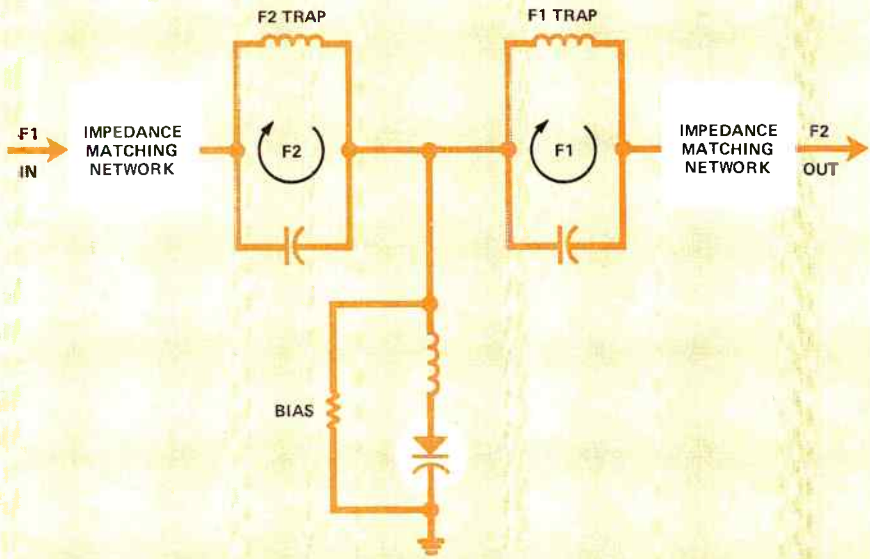


Figure 4. This greatly simplified schematic represents multiplier's typically found in solid-state microwave radios. A six-stage multiplier would use three such circuits, a twelve-stage, six and so on.

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

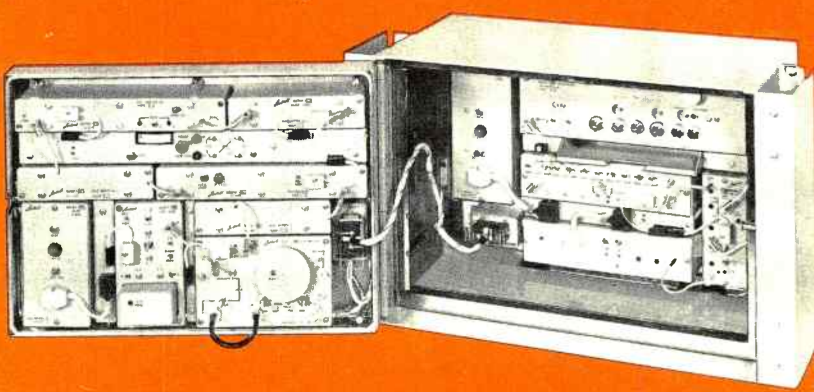


Figure 5. Construction of the Lenkurt 71F 2-GHz Microwave Radio typifies the advanced modular design and high density packaging afforded by total solid-state construction.

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-

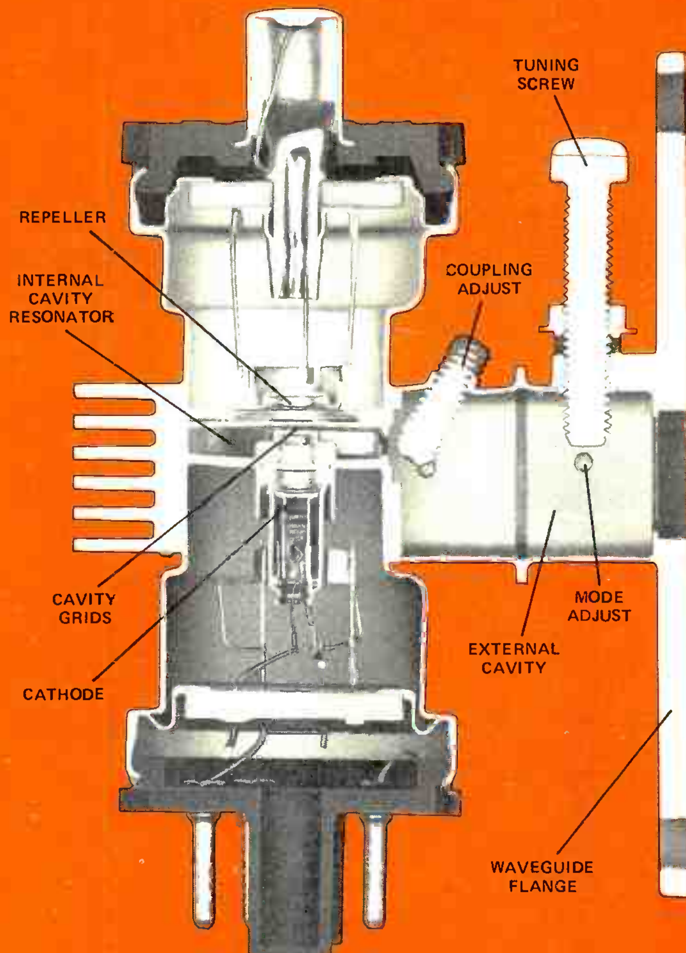


Figure 6. Cross-section view of external-cavity reflex klystron. Internal resonator cavity is shaped at time of manufacture, has no moving parts within vacuum. Over-coupling between internal and external cavities permits tuning output frequency by simple mechanical screws in outer cavity. Waveguide output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