Applications of Microwave Solid State Power Sources—An Overview

A highly diversified market is building for IMPATTs, Gunns, and GaAs FETs as power sources. A summary of important parameters for several applications is presented in tabular form.

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The broad application of low-power microwave sources, as exemplified by the Gunn diode, has been made possible by the low cost and reliability of various microwave semiconductors. Large-scale application of solid state power sources, at X-band and above, is also now becoming a reality. A substantial business in radar, communications, and even commercial electronics is now in the offing. In fact there is an intense rivalry among devices for supremacy: Gunn diodes, silicon IMPATTs, GaAs IMPATTs and GaAs FETs are all competing for similar sockets.

Applications From 8 to 40 GHz. The wide range of applications also encompasses a wide variety of performance requirements for sources. While a complete and quantitative description of each requirement is beyond the scope of this overview, a summary of important parameters for specific applications can be given. Table I attempts to identify three levels of importance (A, B, C) of specific parameters as required for specific applications. The value of the table lies in comparing the various source approaches discussed in the companion articles of this issue. Hopefully, the system designer can use the matrix as a check list in making the decision as to what type of source to employ. The most important parameters, denoted by A, will now be discussed more fully.

For Doppler radars, the most important parameters are power, efficiency, frequency stability, wide temperature range, FM noise both quiescent and under vibration, and ruggedness. Doppler radars are mainly used as velocity sensors for airborne navigation or spaceborne landing systems. As such, they are subjected to a relatively severe environment. Temperature ranges of −55° C to +95° C are common because they usually mount on an exterior surface of the host craft. Vibration levels of 5 Gs up to 2 kHz are also specified with vibration Q multipliers of 10 expected in the vibration band.

Power output (usually 50 mW to 2 W) at 13.3 GHz for Doppler radar is important to maintain required signal-to-noise ratio.[1,2] Efficiency is valuable because airborne applications are sensitive to power drain and weight. Present efficiencies of 2 to 8 percent are realized using the older Gunn or silicon IMPATT technology. Frequency stability is particularly critical in an oscillator configuration because of the effect of frequency on antenna beam angle. Usually a ±15 MHz stability within the temperature range is acceptable, though a source-to-source conformity is desired. FM noise close to the carrier is a particularly undesirable parameter for Doppler radar since the Doppler receiver processes energy removed from the carrier by only 100 Hz to 10 kHz, due to Doppler shifts. Under vibration, this parameter is particularly troublesome; it is only with the most careful design that an acceptable 200 Hz/G of vibration FM noise level can be achieved. Finally, being airborne for military or space use, Doppler radar sources must be rugged and have a high MTBF.

Pulsed radar sources are only seeing limited applications now outside of a few developmental phased arrays. The required power levels for most radars are beyond the state of the art for solid state. There are many future possibilities, however. Pulsed power of 10–100 W could be used now (many kilowatts is the dream).

Two factors associated with pulsed systems are important: droop and chirp. Most solid state pulsed devices experience a rapid junction temperature rise during the pulse with a resultant power drop. This would cause a sensitivity loss. Chirp, or frequency change during the pulse, poses a severe problem for many systems because a specific frequency change during the pulse is often used in pulsed compression or for clutter rejection. In addition, for the airborne application, the same environmental and life factors as described with Dopplers apply except that vibration effects are no longer as important.

The missile seeker is closely related to pulsed radar, being a relatively long-pulsed system striving for 10 W or more output.[3] Frequencies utilized have been at X- and K_u-bands, although interest is developing at 35 and 94 GHz. Operating from missile batteries, efficiency is obviously an important factor. The source must operate after only a short warm-up from a possible -55°C environment and be able to withstand the severe shock of a missile launch.

Also related to the pulsed radar are satellite beacons, which usually are also pulsed systems. These could be used for a variety of applications, for instance, propagation studies in the K-band region for communication. For satellite service high power, good efficiency and high MTBF are paramount.[4] For beacon application usually frequency and power stability and droop must be good.

Jamming systems are using an increasing number of solid state diode sources both as VCOs and power amplifiers in the X- and K_u-band regions. Both VCOs and amplifiers have to operate over full military environments in airborne applications.[5] For VCOs there must be good frequency stability, low noise, low spurious so the system can lock on the desired signal, and linear and wideband tuning; furthermore, they must not exhibit a tuning drift after the tuning command is gone. Jammer amplifiers, on the other hand, must have high output power and efficiency, high amplifier gain and good gain linearity, the latter because specific amplitude information is often applied to the jamming signal. The GaAs FET amplifier is particularly attractive as a driver for jammer TWTs because of its wide bandwidth capability.[6]

Radar VCOs have identical requirements as jammer VCOs except the frequency range is usually more restricted. A popular band is 8.5 to 9.6 GHz.

Communications Transmitters. In the communications field, FM radio relay was probably the earliest use of diode sources. A variety of frequency bands are utilized around 8, 11 and 20 GHz. At 11 GHz, there is extensive use of solid state amplifiers (IMPATTs and GaAs FETs).[7,8,9] In some cases phase-locked Gunn sources are used to power IMPATT amplifiers.[10]

Power output is obviously important in extending the range of a system. Since most systems use amplifiers, FM noise is usually not a problem; however, AM noise should be low. Further AM-to-PM conversion should also be very low; 2–3 deg/dB is usually considered acceptable and competitive with TWTs. Good gain and gain linearity are important. The latter along with low spurious is important to keep interference down. The amplifiers usually have to simultaneously handle signal channels, and nonlinearities can produce intermodulation products.

With the increasing need to send high-speed digital data, digital communication is becoming more important. Many methods of modulation are possible, but one that seems popular is PSK (phase shift keying). Frequencies used are 8 GHz for government, 11 GHz for commercial, 11/14 GHz for space and 20 to 30 GHz and 32 GHz, the latter two for more recent systems. The relatively wide spectrum needed for high-speed data and the crowding of the lower frequency bands are pushing the use of the millimeter wave frequencies.[11,12] In general, the important parameters for FM radio are also important for digital radio both for terrestrial and satellite applications.

Portable communications is rapidly increasing in both commercial and military applications. In the commercial realm, for example, 13 GHz is used for electronic news gathering. For this application besides power output, important parameters are efficiency, low-voltage operation, wide temperature range and fast warm-up. These keep weight down and the equipment operational in all kinds of environment. Many of these desirable features are also needed for military battlefield communications. Here the need is for secure links; therefore the higher frequencies like 38 GHz are picked. Small, directive antennas are possible at these frequencies. In almost all of these portable radios Gunn oscillators are used.

The millimeter frequencies of around 40 GHz are also employed for parametric amplifier pumps.[13] The power source is usually a Gunn diode, but IMPATTs are also used. Low noise,

TABLE I

Matrix of Important Performance Parameters of Sources for Various Applications

Note frequencies

	Frequency range GHz	Cost	Power output	Efficiency	Wide temperature range	Power stability	Frequency stability	AM noise	AM to PM conversion	FM noise	Vibration noise	Spurious and Harmonics	Gain	Gain linearity	Wideband tuning	Linear tuning	Post drift tuning	Pulse power droop	Chirp	Low voltage supply	Warm-Up time	MTBF	Ruggedness
1. Doppler radar	13.3	B	A	A	A	A	A	B		A	A	B								B	B	A	A
2. Pulse radar	X, 35, 94	C	A	B	A	B	A											A	A	C	B	A	A
3. Missile seeker	17	B	A	A	A	B												B		B	A	B	A
4. Radar VCO	8.5-9.6	C	C	C	A	B	A	A		A	A	A			A	A	A			C	B	A	A
5. Jammer VCO	X, K_u	C	C	C	A	B	A	A		A	A	A			A	A	A			C	B	B	A
6. Jammer ampl.	X, K_u	C	A	A	A	B		C		C			A	A						C	B	B	A
7. Satellite beacon	19, 28	C	A	A	B	A	A	B		A	C	B						A		B	C	A	B
8. FM radio	8, 20	B	A	C	B	B		A	A			A	A	A						C	C	A	C
9. Digital communications	8, 11, 20	B	A	C	B	B		A	A			A	A	A						C	C	A	C
10. Satellite communications	11, 14	C	A	B	B	B		A	A			A	A	A						B	C	A	B
11. Portable communications	13, 38	A	B	A	A	B	A	B	B	C	C	B								A	A	B	B
12. Parametric amplifier pump	40	C	C	A	A	A	A	A		A	A	C								C	C	B	C
13. Police radar intrusion alarms	10, 24	A	B	A	A	B	B	B												A	B	B	C
14. Test equipment	X, K_u	B	C	C	C	B	A	A		A		A			A	A	B			A	A	A	C

Note: The ratings A, B and C represent decreasing levels of importance. Where no rating is given, the parameter is either unimportant or does not apply to the application.

with frequency and power stability, is the important parameter.

A low-cost commercial application of diode power sources is in police radars and intrusion alarms.[14] Obviously, here price is an important parameter along with efficiency, low voltage and wide temperature range. Operating frequencies are 10.525 GHz mostly, with increasing use of 24.150 GHz. Again because of cost and the desire for a low-voltage supply, the Gunn diode is popular. GaAs FETs could change this in time because of their inherent efficiency. In Germany, a Gunn diode oscillator at 25 GHz is being used for a railroad speedometer based on the Doppler principle.[15]

A range of applications that seem somewhat unusual in requirement is diode sources for test equipment as spectrum analyzers and sweepers.[16] Gunn diodes are mainly used in the X- and K_u-bands because of their inherent wide and linear tuning range. Again, however, GaAs FETs should soon make inroads in this market. For spectrum analyzers noise is especially important as these instruments are used to measure noise themselves. A low-voltage supply is attractive to keep weight down, and fast warm-up is also a desirable feature. The MTBF is also expected to be quite high to support the concept of solid state reliability.

This brief overview of applications for microwave power sources covering approximately 8 GHz to 40 GHz is not all-inclusive. The other articles in this issue delve further into the design and the use of these specific devices. ■

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