Oscillator and Amplifier Product Capability

Millitech offers a complete line of power generating and amplifier components for use in the 18 to 220 GHz range. These products cover virtually any performance requirement and technical specification. The wide diversity of products allows the user to select the source or amplifier that ideally meets the needs of the application. Please click on the Product Descriptions and Datasheets button in the Products tab for more information.

Sources of Millimeter-Wave Power

Solid-state sources have contributed significantly to the feasibility of current millimeter-wave systems and their applications. These sources are reasonably compact, affordable and practical for most millimeter-wave applications. In addition, amplifier products are provided to enhance the power generation capability of the basic oscillators or other sources such as upconverters and frequency multipliers.

Several different devices are employed to produce these products. The most commonly used devices are:

- Gunn diodes: Gallium Arsenide (GaAs) and Indium Phosphide (InP).
- IMPATT diodes (Silicon and Gallium Arsenide).
- GaAs FET, HEMT and other three-terminal devices.

The frequency of operation, power output, tunability and other performance characteristics determine which device will provide optimal results and a cost-effective solution. **Figure 1** summaries the capability of devices currently available and the components which utilize them. Higher performance is generally achieved by configuring more complex products, which either combine many devices or use multiple stages to enhance the capability of the component. Some of the commonly employed source and amplifier products are described below.

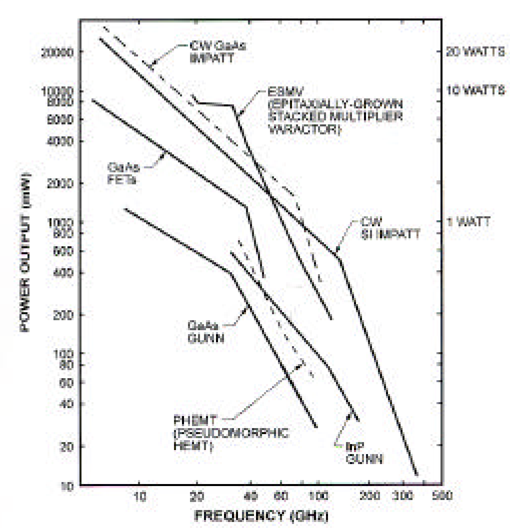

Figure 1. Solid-State Source Devices.

CW Oscillators

For the majority of applications at millimeter wavelengths, a CW operation at either a fixed or a tunable range of frequencies is desired. Gunn and IMPATT diodes are the most commonly used active devices for tunable oscillators. By employing a suitably designed cavity or resonant structure optimal operating characteristics are obtained.

Gunn diode oscillators using GaAs or InP diodes operate over the 18 to 170 GHz range with power levels ranging from a few milliwatts at the high frequency end to about 400 mW at the lower frequencies. These oscillators are mechanically tunable over a fairly wide range, offering up to 40% (total) of their center frequency. A limited amount of electrical tuning is achieved either by varying the bias voltage or through the use of a tuning varactor within the oscillator. Gunn oscillators generally produce very low noise content and are free of spurious signals. They make excellent sources for local oscillator, transmitters and signal generators. These oscillators can be phase-locked to a low phase noise, high stability reference signal at RF or microwave frequencies.

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Pulsed Oscillators

Both Gunn and IMPATT diodes can be designed to produce much higher peak power over short pulse intervals than on a continuous basis. For some devices, peak powers on an order of magnitude greater than their CW capability can be extracted if the pulse width (and duty cycle) is short in comparison to their thermal time constant (typically 100 ns). The design of these IMPATT devices is quite different to allow the extremely high current densities to occur without device failure. The net DC power, and hence the heat dissipated by these sources, is comparable or even lower than the CW version. The current impulse results in rapid heating of the diode junction which can produce a frequency chirp. By shaping the applied current pulse suitably to compensate for the thermal frequency drift, this chirp can be minimized.

Gunn diodes can readily provide pulsed power by the application of suitable voltage pulses. Peak power levels several times higher than the CW levels can be obtained. The voltage must be kept below the device breakdown voltage, and the duty cycle low enough to keep junction below the maximum allowable temperature. Duty cycles up to 10% are generally achieved.

In all cases, a chirp-free, stable pulsed operation can be obtained if the pulsed source is “injection-locked” to a high-stability, low-noise source. This is further explained below.

Amplifiers

Two- and three-terminal devices can be utilized to produce power amplifiers at millimeter wave frequencies. Three-terminal devices are generally employed for low-noise amplifiers and low-signal power amplifiers (up to a few milliwatts of output power). For higher output power (a few hundred milliwatts) Gunn and IMPATT devices are more suitable. Millimeter-wave amplifiers can be classified in the following categories:

- Low-noise amplifiers
- Low-signal power amplifiers
- Injection-locked amplifiers
- Stable amplifiers
- Linear amplifiers

Low-noise amplifiers (LNAs) are normally employed at the front-end of millimeter-wave sensitive receivers before the mixer/downconverter. Currently, HEMT-based LNAs are available up to 110 GHz.

low-signal power amplifiers generally follow either an LNA or an upconverter or frequency multiplier to boost the low signal power to moderate power levels (a few milliwatts). These amplifiers use three-terminal based devices and are available through 100 GHz. Gunn diodes can also be used to produce low-signal amplifiers, but with poorer noise figure than three-terminal versions.

injection-locked amplifiers (ILAs) are an interesting class of millimeter-wave amplifiers, which are essentially oscillators with circulators at their input. In the absence of an input signal of suitable strength and frequency, these may free-run as oscillators at some frequency. However, upon the application of proper input signal, they “lock” themselves to the input signal. The “gain” of such amplifiers is the ratio of the locked output power to the input signal power, If the input power drops below a certain level or deviates in frequency beyond certain limits, the “lock” is broken and the amplifier “free-runs” or oscillates at or near the oscillator’s basic frequency. The output power level is relatively independent of the input power level.

The frequency interval over which a reliable lock is maintained for a given input signal level is called “injection-lock bandwidth.” This bandwidth is determined by a number of factors which pertain to the oscillator’s design and operating characteristics. The bandwidth is inversely proportional to the square root of the gain of the amplifier, as expressed by the relationship given below:

$$BW = k\sqrt{(P_{IN} / P_{OUT})}$$

where **BW** = lock bandwidth, **G** = gain = $\mathbf{P_{OUT}/P_{IN}}$, and **k** is a constant determined by the amplifier properties such as external Q-factor. Since the output power of injection-locked amplifiers is nearly constant with the input power, the power gain drops as the input level is raised and the lock bandwidth increases. **Figure 2** below shows this behavior for a typical Gunn injection-locked oscillator.

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IMPATT ILAs are generally not as well-behaved. This class of injection-locked oscillators is useful for relatively narrowband transmitters or other similar sources that operate at a constant power output. Since the amplifier is capable of “free-running” as a unlocked oscillator, due precautions must be taken to prevent the input signal from dropping below the critical level or out of frequency range of the injection lock. However, in several applications a free-running oscillator is acceptable when the input signal is either absent or out of proper range of power and frequency.

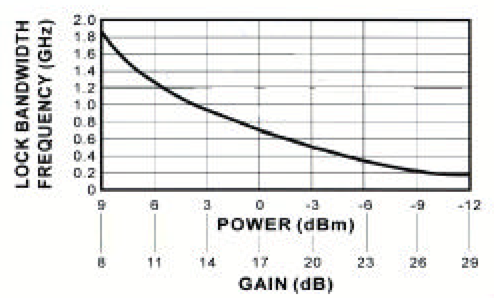

Figure 2. Gunn Injection-Locked Oscillator Performance

Power Combining

In order to produce greater millimeter wave power output than is available from a single device (Gunn or IMPATT), it becomes necessary to synergistically combine the power of two or more devices. Significantly high power levels can be economically achieved in this manner. Power combining can be accomplished by using one or more of the following techniques:

- **Device Level Power Combining:** More than one diode can be mounted in a single package to produce a device which is capable of a much higher power level, often up to several times the single diode.

- **Circuit Level Power Combining:** More than one packaged device is used in an oscillator or amplifier using a circuit configuration which produces the combined power.

- **Component or Module Level Power Combining:** Individual components (oscillators or amplifiers) are connected using external power combining network made up of couplers or similar passive, hybrid components. Modules consisting of several components can be further combined to produce even higher power.

Power combining is a powerful, reliable and economical method of obtaining fairly significant output power levels. Millitech produces high power Gunn oscillators and IMPATT injection-locked amplifiers by employing both circuit level and component/module level power combining. Typical combining levels range from the most common two-diode combiner to fourteen-device combining using individual models. Power from stable amplifiers can also be combined using similar techniques.

Oscillator Stability and Phase Noise

In addition to output power level and tunability, the most important performance parameters for most applications are the thermal stability and noise content of the oscillator, since ultimately these often determine the performance capability of the entire system. In fact, source phase noise is generally the limiting factor in the operation and ultimate capability of many systems such as radars, radiometers and communication links. Similarly, thermal drift of frequency and power level may have a serious impact on the operation of certain millimeter wave systems.

High stability of operating frequency can be achieved using one of several possible schemes:

- **Drift Compensation schemes,** which employ compensating material or mechanical structures to reduce frequency drift due to resonator thermal expansion and/or device characteristics.

- **Cavity Stabilization,** by employing a resonator made of very low thermal coefficient of expansion. This produces very low frequency drift and reduces phase noise.

- **Phase or Frequency-Locked Oscillators,** which use a low-frequency, ultra-high stability reference. The oscillator’s operating frequency is locked to a harmonic of the reference source using a lock loop. The stability of the millimeter wave source is largely determined by this reference.

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Noise associated with an oscillator has two basic components: AM and FM noise (phase noise). These are generally characterized by the amount of noise power per hertz of bandwidth (dBc/Hz) at a certain offset frequency with respect to the peak. Phase noise of an oscillator is determined by a number of factors such as active device and cavity characteristics, operating parameters and bias supplies. Generally, the characteristics of the active device have the maximum impact on the noise contents of the oscillator or amplifier. Typical noise characteristics of several types of sources are shown in **Figure 3** for comparison.

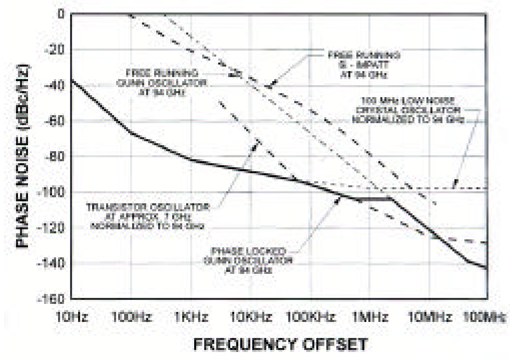

Figure 3. Typical Source Noise Characteristics