Cavity Choice is Critical For Stable Wireless Communication

All wireless communication relies on one basic physical phenomenon: An electric current generates mutually re-enforcing electrical and magnetic fields perpendicular to the wire through which the current flows. Everything else boils down to controlling and detecting the electromagnetic (EM) field as it propagates.

On the transmit side, this control includes switching the EM emissions on and off at various frequencies, controlling their power levels and shaping the waves to encode useful information. On the receive side, the waves need to be to selectively detected (tuned into) and the encoded information extracted.

Building from those basic principles are techniques to efficiently oscillate the electrically charged particles (electrons) required to generate the EM field and various means of controlling an EM wave's propagation to maximize information transfer in the face of both naturally occurring obstacles and wave absorption, as well as other powerful man-made interferers.

All this needs to be done while staying within government-regulated envelopes of operation. Those envelopes define the power levels, frequencies of operation, interference and other characteristics, and vary widely according to region.

Of course, there are natural sources of EM besides man-made radio and millimeter waves -- light sources being the most obvious -- and they are bucketed according to frequency or wavelength.

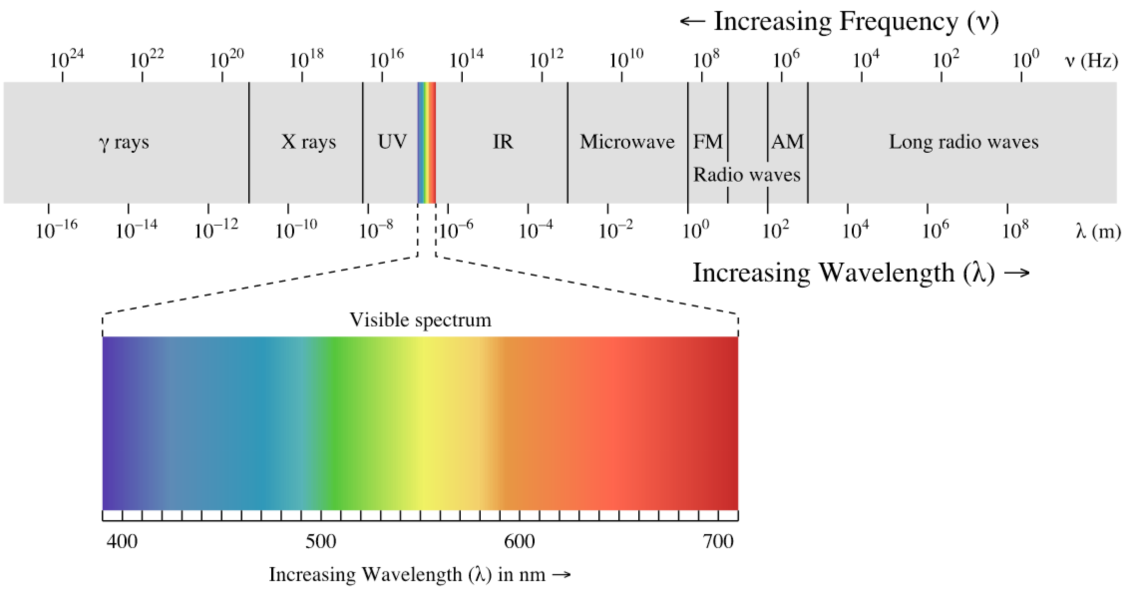


Figure 1: Human eyes are "tuned" to that portion of the electromagnetic spectrum we call light. However for high-speed, high-frequency wireless communications, the microwave portion of the spectrum – between 300 MHz and 300 GHz -- is much more interesting. (Image source: Wikipedia.com)

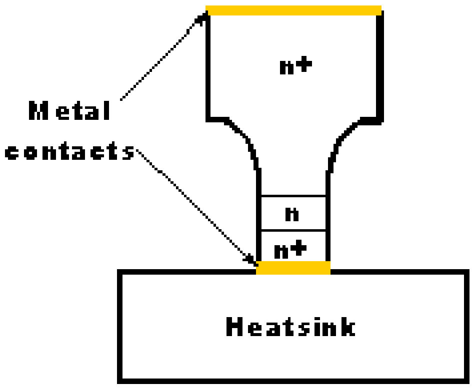
Since all EM waves – including light – propagate at 299,792,458 meters/second when in a vacuum, and that speed (c) is the result of wavelength (λ, measured in meters) multiplied by frequency (f, measured in Hertz), then the inverse relationship between frequency and wavelenth is clear ($c = \lambda f$, so $\lambda = c/f$).

As most mainstream wireless communications occur in the microwave region of the EM spectrum, between 300 MHz and 300 GHz, that's where we'll focus our discussion of devices.

EM Wave Generation

The key to any microwave system is the generation of a clean signal, and this starts at the source, which for many real-world microwave designs begins with the Gunn diode, a transferred electron device (TED) that is placed within a cavity to guide its emissions.

Gunn diodes are typically made from a single piece of gallium arsenide (GaAs) or indium phosphide (InP) n-type silicon[1] and depend upon on the negative-resistance characteristics of these materials to generate the oscillation required for the microwave signal.



(a)

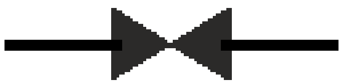

(b)

Figure 2: A Gunn diode (a) is typically made from a single piece of GaAs or InP n-type semiconductor and is deceptively simple in its construction. It comprises a heavily n+ doped top and bottom region for the contacts. These sandwich a very narrow active region with negative resistance characteristics that are fundamental to its ability to oscillate. Its symbol is also shown (b). (Source: Radio-Electronics.com.)

The frequency of oscillation is determined by the size of the active region, while the power is determined by the size of the region as well as the DC bias power.

The role of cavities
While the Gunn diode generates the oscillation, it's up to the cavity to stabilize, control, direct and tune the resultant EM waveform for the application. The cavity must also have sufficient heatsinking capability, as the microwave power output is so dependent upon the diode bias voltage. The higher the voltage, the more heat is generated within the diode as it oscillates between the two extremes of negative-resistance zone.

The construction of cavities is a fine art and takes two distinct forms: waveguide and coaxial.

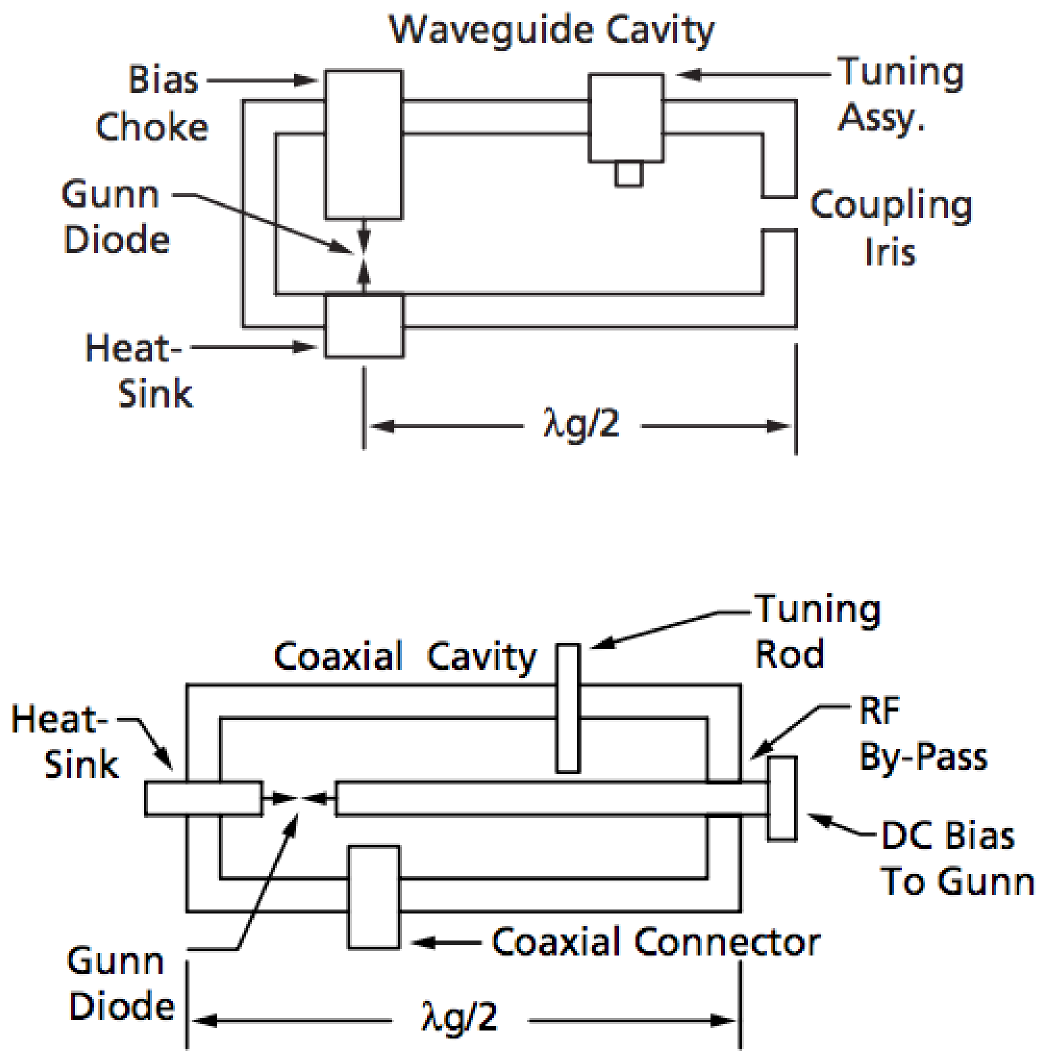


Figure 3: Either a waveguide or coaxial cavity can be used to stabilize, control and tune the diode oscillations and couple the EM waves to the application.

The series equivalent circuit of a Gunn diode is a capacitance in series with a negative resistance, so the device can be tuned mechanically using the cavity to create a matching inductance to form a resonant circuit. In the waveguide cavity this would be the tuning assembly, while in the coaxial cavity it's simply a tuning rod that is adjusted as needed. The rod should be made of a low-loss dielectric material.

Alternatively, electronic tuning can achieved using a YIG sphere or a varactor in the oscillator. In this case, the tuning bandwidth and the efficiency of the oscillator depend on the junction capacitance of the chip, the package capacitance (if any) and the Q of the diode[2].

As mentioned, the cavity keeps the oscillator stable, but this stability depends upon the cavity material, as well as the reactance stability of both the varactor and the diode itself. They're all tightly coupled so each must be selected with care. As frequency varies with temperature, temperature compensation may also be required.

All told, the cavity is a critical part of the microwave system design, affecting frequency of operation, stability, output power, temperature, and allowable bias voltage.

Model	Freq. (GHz)	Typical Power Output (mW)	Mech. Tuning Range (MHz)	Varactor Tuning Range (MHz)	Typical Bias Voltage (V)	Typical Bias Current (mA)	Typical Operating Temp. (° C)	Freq. Stability (kHz/ ° C)	Output Method	Features
C2070 Series	10.5	10 to 200	±250	-	8 to 10	125 to 750	-30 to +70	500	Waveguide	Commercial sources
C2093A	9.0 to 9.5	3 to 10	500	-	10.5	350	-55 to +70	48	SMA	Military local oscillator
C2093N	10.5	300	±25	100	8 to 12	2,000	-40 to +70	52	SMA	Muzzle velocity radar transmitter

Figure 4: A portion of a CW diode cavity selection guide shows the key parameters and applications to be considered.

The criticality of cavity selection translates to various options to best suit the design and application. Continuous-wave (CW) diode cavities are available that can also be specified with varactor tuning. Power outputs as high as 500 mW are available, with outputs that can be either waveguide flange or coaxial. Ask for a custom design if needed: they should be available upon request.

When operated in continuous mode, a Gunn diode has a certain set operating limit before diode breakdown occurs. This limits its output power. To get around this, the diode can be pulsed get much higher instantaneous output power, typically three times that of CW devices. Pulsed diode cavities are used primarily in military applications and proprietary techniques come in the areas of heat transfer, power combining and testing to ensure unmatched performance and producibility.

For even higher power, more optimal life, lower cost and ruggedness, look for avionics cavities. These make use of a planar triode instead of a solid-state element as the active device. They're also radiation and EM pulse (EMP) immune, making them suited to aircraft and missile transponder applications, as well as radar, altimeter transmitters and oscillators, and as local oscillators.

As customer requirements change, innovation ensues. A proprietary technique used in avionics broadband pulsed cavities broadens the passband characteristic of triode cavity amplifiers without hampering output power. This greatly increases power density (output power versus physical volume) and lowers the cost of triode amplifiers for spread spectrum, frequency hopping, and electronically tuned transmitter applications.

Such applications include missile datalink transmitters, frequency-tunable proximity fuses, spread spectrum transmitters and expendable decoys.

To avoid the expense of a GaAs FET amplifier, look at the S1006 DRO dielectric resonator-stabilized oscillator. The device provides high output power in a package measuring only 2.9 x 3.2 x 1.0 inches and comes with exceptionally low AM noise. Designed for military or commercial use, it also features TTL control; excellent frequency stability and minimal pushing and pulling. A typical application would be doppler navigation radar.

References:

1: Radio-Electronics.com
http://www.radio-electronics.com/info/data/semicond/gunndiode/transferred-electron-device-operation-theory.php

2: Gunn Diodes: Application Note
http://www.just.edu.jo/~nihad/files/mat/529/Gunn-Diodes.pdf