# Millimeter Wave Gunn Oscillators

## GENERAL NOTES

## GUNN OSCILLATOR APPLICATIONS

Gunn diodes have been commercially successful as microwave oscillators since the late 1960's. They are employed wherever a stable low cost microwave source is needed. Gunn oscillators have found many slots throughout the industry including communications: as mixer local oscillators, pumps for parametric amplifiers, TX and RX oscillators for radio communications, radar sources - including police radar, commercial, and military, wireless LANs and also as detectors: commercial sensors for detecting: velocity, direction, proximity, or level sensing alarms. They have now found new markets in vehicular collision avoidance and intelligent cruise control.

### "GUNN EFFECT" OPERATION

The "Gunn Effect" has been widely known since the discovery of microwave current instabilities in bulk N - type GaAs by J. Gunn in 1963. This transferred electron device or TED produces oscillations using the negative resistance property of bulk Ga As. This "negative resistance" phenomenon results when the electrons in N type Ga As traverse from a high mobility to a lower mobility valley thus producing a lower net electron velocity.

A Gunn diode has a unique characteristic current vs. voltage response. The current tracks the voltage from the application of 0 volts until a point called the voltage threshold or $V_{TH}$ is reached. At this point the current reaches a maximum value which is known as the threshold current or $\mathbf{I}_{TH}$. This point is also noted by an electric field of 3.2 kV/cm. Any further increase in bias voltage results in the current decreasing as a result of the "Gunn effect" This "negative resistance" phenomena will continue until the breakdown voltage or $\mathbf{V_{BR}}$ is reached and operation beyond this point will cause diode failure. Typical operating voltage ($\mathbf{V_{OP}}$) ranges 2.5 - 3.5 times the $\mathbf{V_{TH}}$ values for cw operation.

There are other considerations in the operation of a Gunn oscillator. The oscillator will not operate in the proper mode until the $\mathbf{V_{OP}}$ point is reached. No output is seen when bias is first applied and noise and unwanted lower frequencies of a magnitude which can harm the diode are produced. Bias suppression elements are used especially shunt capacitance to suppress these unwanted signals and prevent turn on damage to the diode. The bias is increased until $\mathbf{V_{OP}}$ is reached which is 0.5 - 1.0 V above turn-on or $\mathbf{V_{TO}}$. The "power peak" or $\mathbf{V_{PP}}$ is the voltage where maximum RF power is generated. An oscillator is usually operated at a $\mathbf{V_{OP}}$ which is 15% below $\mathbf{V_{PP}}$ at $25^0$C.

The bias properties discussed so far all change with temperature: the $\mathbf{V_{TH}}$ and the $\mathbf{V_{PP}}$ decrease with increasing temperature while the $V_{BR}$ increases with increasing temperature. At lower temperatures, the turn on and the power peak voltages are higher than at room temperature. The selection of the operating voltage at an optimum point to cover a temperature range is critical if a wide operating temperature range is required. The voltage must be high enough to turn on the diode at low temperatures but not exceed $V_{PP}$ at the higher temperature. Figure 3 shows the temperature characteristics of $\mathbf{V_{TO}}$, $\mathbf{V_{PP}}$, and $\mathbf{V_{BR}}$ of a Gunn oscillator.

## OSCILLATOR DESIGNS

The oscillator design selected depends on performance requirements such as: RF power, frequency, frequency and power stability, mechanical tuning, voltage tuning, and cost requirements including cavity material, size, weight and cost. The design considerations for these oscillator types are discussed below. There are many oscillator designs used to achieve various performance goals which include:

- waveguide cavity
- iris coupled waveguide cavity
- coax cavity
- waveguide harmonic cut off cavity
- resonate hat harmonic cavity
- planar - micro strip, finline, DRO, etc.

The output interface may be either coaxial or waveguide. Oscillators of all these types are manufactured at HARMONIX covering the frequency range 5 to 110 GHz for cw and voltage tuned applications.

One of the primary design considerations is the Q of the oscillator which is a measure of cavity resonance. A low Q allows the cavity to operate over a great frequency range with a trade off in frequency stability vs. temperature. A high Q cavity is more frequency stable than a lower Q cavity but is narrower in frequency bandwidth. Coaxial and planar circuits have a lower Q than waveguide cavities so the active device dominates their performance. It is difficult to compensate for this low Q and high frequency drift. Waveguide cavities have a higher Q and better frequency stability. They can achieve even higher stability by using materials like Invar for the cavity which has a low temperature expansion coefficient as compared to brass and aluminum.

Coaxial designs are often preferred in the frequency range 5 - 65 GHz because of the ease of obtaining mechanical tuning over a 10 - 20 % frequency range. Varactor diodes can be easily coupled to the coax cavity to fabricate a varactor tuned oscillator (VCO).

### Waveguide Cavity:

The simplest cavities to fabricate are waveguide cavities and these are the most common types found at microwave thru low millimeter wave frequencies. Waveguide iris coupled cavities have the highest Q which provides better frequency stability. Typical frequency stability @ 38 GHz would be 1.0 MHz / $^0$C in an uncompensated iris coupled cavity.

Frequency compensation techniques can be applied to waveguide cavities by the use of differential material expansion or by using a family of titan ate ceramics. With ceramic rod temperature compensation, stability of 250 KHz / $^0$C @ 38 GHz are easily realizable. In an iris coupled cavity the operating frequency is determined by the ½ λg spacing between the iris and the Gunn diode with the backshort close to the Gunn position. Fine tuning is accomplished by dielectric tuning with a sapphire rod or a similar dielectric.

Waveguide iris coupled cavities are used typically to 50 GHz with Ga As Gunn diodes, higher with InP Gunn diodes. From 50 - 100 GHz, coax or 2nd harmonic cavities are commonly used. An example of an iris coupled cavity is shown in Figure 1.

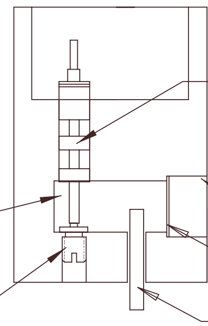



**Figure 1**

**<u>2nd Harmonic Resonate Hat Waveguide Cavity:</u>**

The first type of 2nd harmonic cavity design used is the resonate top hat structure. The frequency is determined by the diameter of the disk on the Gunn choke that contacts the Gunn diode. A back short is commonly used to tune for maximum power. The resonate top hat structure is used for 60 - 110 GHz osc CW, pulsed, and VCO oscillators. Frequency stability @ 77 GHz would be 5.0 MHz / $^0$C. An example of this circuit is shown in Figure 2.

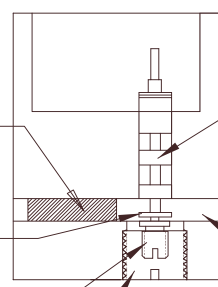



**Figure 2**

## 2ND Harmonic Cut-Off Waveguide Cavity:

The second type of 2nd harmonic cavity is used when greater frequency stability or increased varactor tuning is needed in a VCO. This is a 2nd harmonic cutoff cavity where ½ the desired fo is generated in the waveguide cavity and this signal is filtered out or cut off to enhance the generation of the 2nd harmonic output. This cavity has a higher Q than a resonate hat or coax cavity. Typical stability or $F_S$ @ 77 GHz would be 3.0 MHz/ $^0$C. This circuit is less efficient than the resonate hat structure do to critical coupling considerations necessary for low temperature turn on. An example of this cavity is shown in Figure 3.

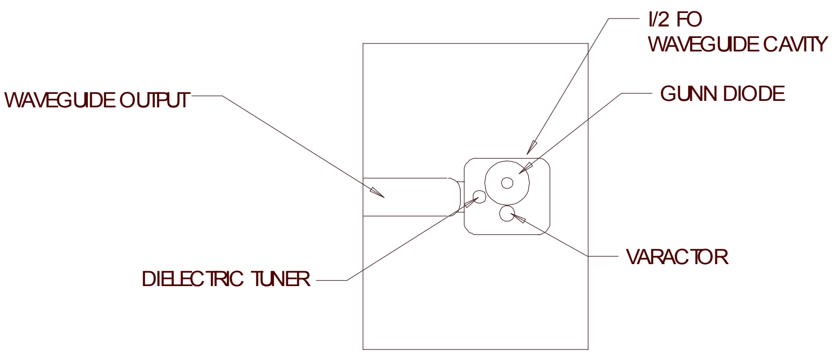



**Figure 3**

## Coaxial Cavity:

The coax cavity is used up to frequencies of 65 GHz. It is the design choice for wide mechanical tuning requirements since the lower Q makes them easier to tune. They can be mechanically tuned 10 - 20 % of center frequency and electrically tuned 1 - 2 % with varactor tuning. The Gunn diode dominates the cavity due to the lower Q resulting in more frequency drift than that found in a waveguide cavity at the same frequency. Typical frequency stability with temperature @ 35 GHz would be 2.0 MHz/ 0C with an aluminum housing. Coaxial cavities are the easiest design to use for varactor tuning. The varactor is typically probe coupled making tuning bandwidth selection easier to accomplish. This design provides the most power of any other design since critical coupling is less of an issue for low temperature turn on. Figure 4 shows an example of this design.

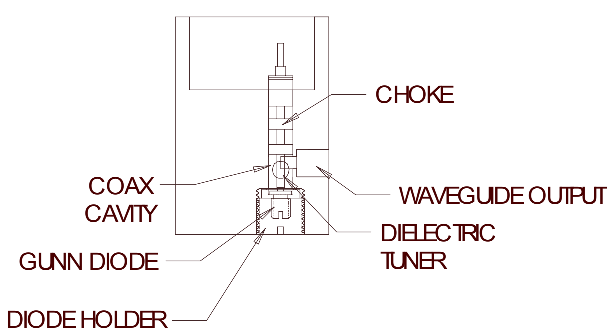



**Figure 4**

**Planar Micro strip Oscillators:**

Planar micro strip oscillators can be fabricated to operate at millimeter wave frequencies. Designs include a DRO (or dielectric resonator oscillator) and a planar micro strip Gunn oscillator using micro strip, finline, or coplanar transmission lines. Such circuits offer lower cost and size over conventional cavities. DRO's offer excellent stability due to the dielectric resonator as a compensator. Other planar circuits without a dielectric resonator are lower Q. A DRO  example is shown in Figure 5.

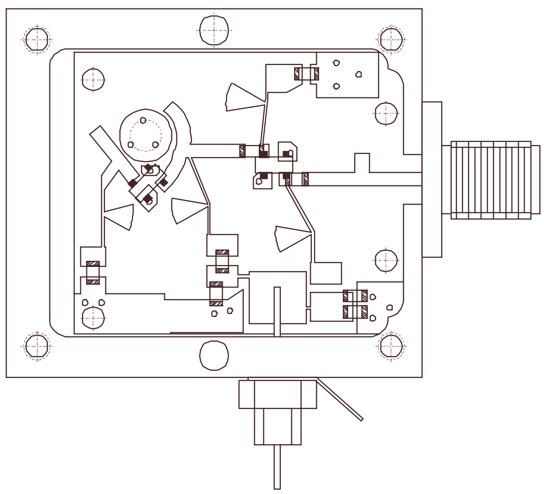


**Figure 5**

**Frequency Compensation:**

All designs can be made more stable with the use of a hybrid heater which can hold the operating temperature to a 10 $^{0}$C. window. These heaters are available to operate from 9 to 32 VDC and 115 VAC. Frequency stability can be improved in most designs depending on the Q of the cavity. Frequency compensation techniques can be applied to waveguide cavities by using differential material expansion or by utilizing a family of titanate ceramics. Typical frequency stability @ 35 GHZ would be 1.0 MHZ/ $^{0}$C for an unstabilized cavity. This can be improved to 0.1 MHZ / $^{0}$C with the combination of chimney or differential material expansion methods and ceramic compensation.

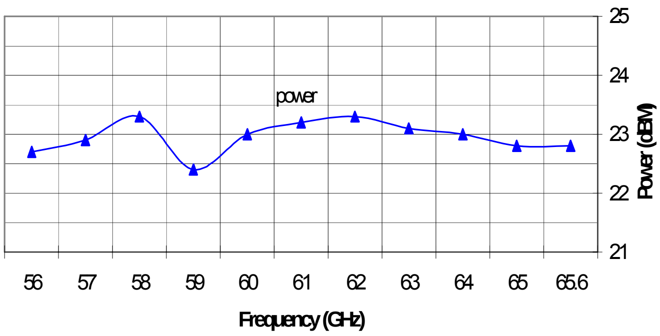
# OSCILLATOR TYPICAL DATA

| $F_0$ GHz | P0 mW | F STAB MHz / $^0$C | M TUNE MHz | V TUNE MHz | V TUNE VDC |
|---|---|---|---|---|---|
| 9 | 100 | □0.4 | 1000 | 100 | 0 TO 20 V |
| 10 | 150 | □0.1 | 300 | 100 | 0 TO 20 V |
| 10 | 100 | □0.4 | 500 | 300 | 0 TO 50 V |
| 13 | 100 | □0.2 | 500 | 100 | 0 TO 10 V |
| 15 | 100 | □0.2 | 500 | 100 | 0 TO 10 V |
| 18 | 250 | □0.3 | 500 | 250 | 0 TO 20 V |
| 23 | 250 | □1.5 | 500 | 250 | 0 TO 20 V |
| 24.1 | 80 | □2.0 | 100 | 1000 | 0 TO 25 V |
| 24.5 | 100 | □2.5 | 4000 | CW | N/A |
| 30 | 50 | □2.5 | 4000 | CW | N/A |
| 38 | 200 | □2.5 | 1000 | 500 | 0 TO 20 V |
| 42 | 100 | □2.5 | 4000 | CW | N/A |
| 47 | 200 | □2.8 | 1000 | CW | N/A |
| 60 | 100 | □3.5 | 500 | 500 | 0 TO 20 V |
| 77 | 40 | □3 | N/A | 1000 | 0 TO 20 V |
| 94 | 100 | □6 | 250 | CW | N/A |
| 105 | 20 | □8 | 750 | CW | N/A |

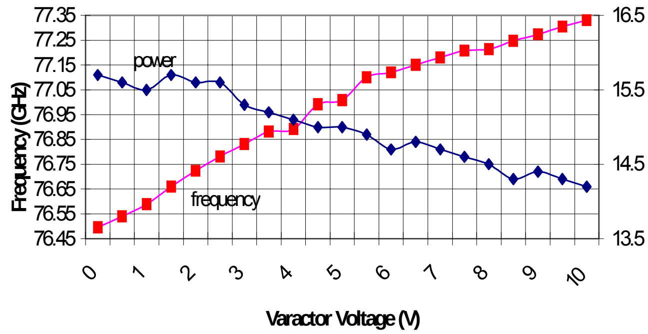
**12 Lancaster County Road, Harvard, Massachusetts 01451 Tel: (978) 772-7774 FAX: (978) 772-7775**
**MMWcomponents@hxi.com**
**Visit us on the web at www.hxi.com**

# Application & Design Notes
# Gunn Oscillators

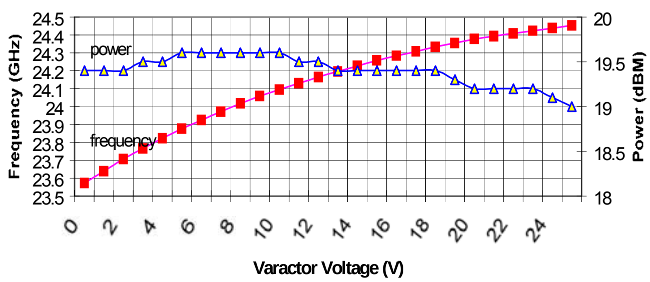
Power & Frequency vs Mechanical Tuning
HGM63.7202015 InP CW Gunn Oscillator
60 GHz @ 200 mW Power With 7 GHz Bandwidth



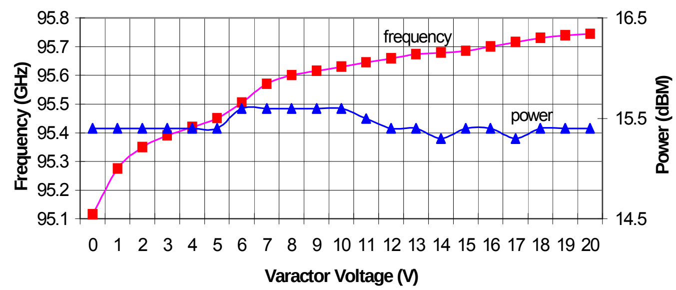

Power & Frequency vs Tuning Voltage
HGV77.0141510 GaAs VCO
77.0 GHz



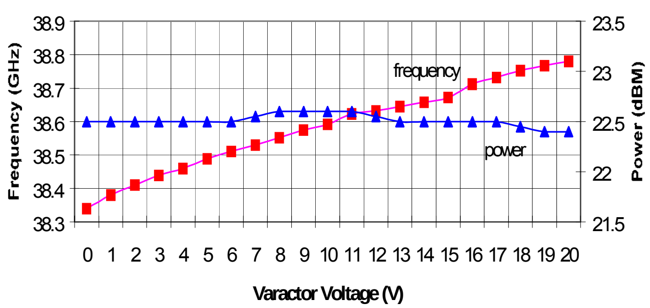

Power & Frequency vs Tuning Voltage
HGV24.1041742 GaAs VCO
24.125 GHz 50 mW 800 MHZ Etune



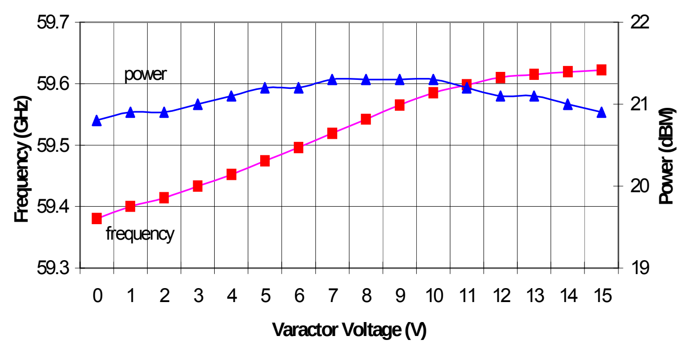

Power & Frequency vs Tuning Voltage
HGV95.4231510 GaAs VCO
95.4 GHz




Power & Frequency vs Tuning Voltage
HGV38.5242228 GaAs VCO
38.5 GHz 160 mW




Power & Frequency vs Tuning Voltage
HGV59.5022015 InP VCO





**12 Lancaster County Road, Harvard, Massachusetts 01451 Tel: (978) 772-7774 FAX: (978) 772-7775**
**MMWcomponents@hxi.com**
**Visit us on the web at www.hxi.com**