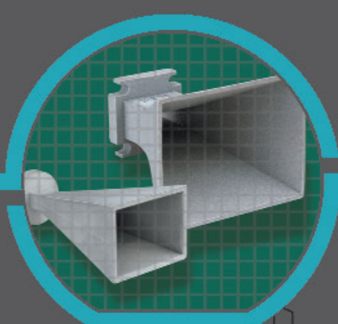
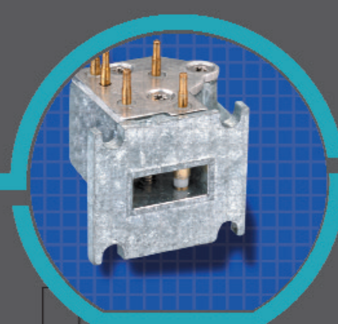
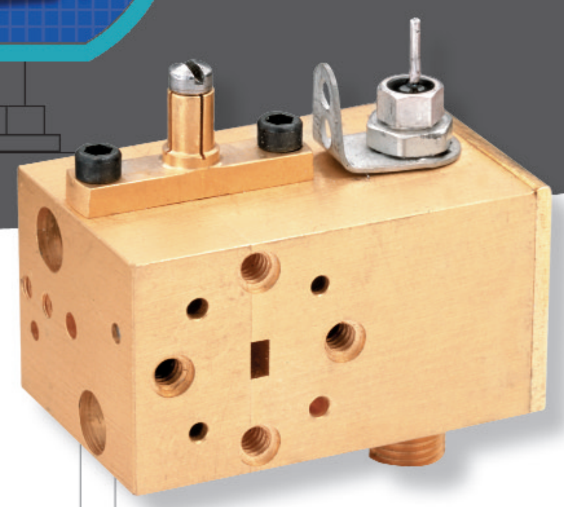
MDT

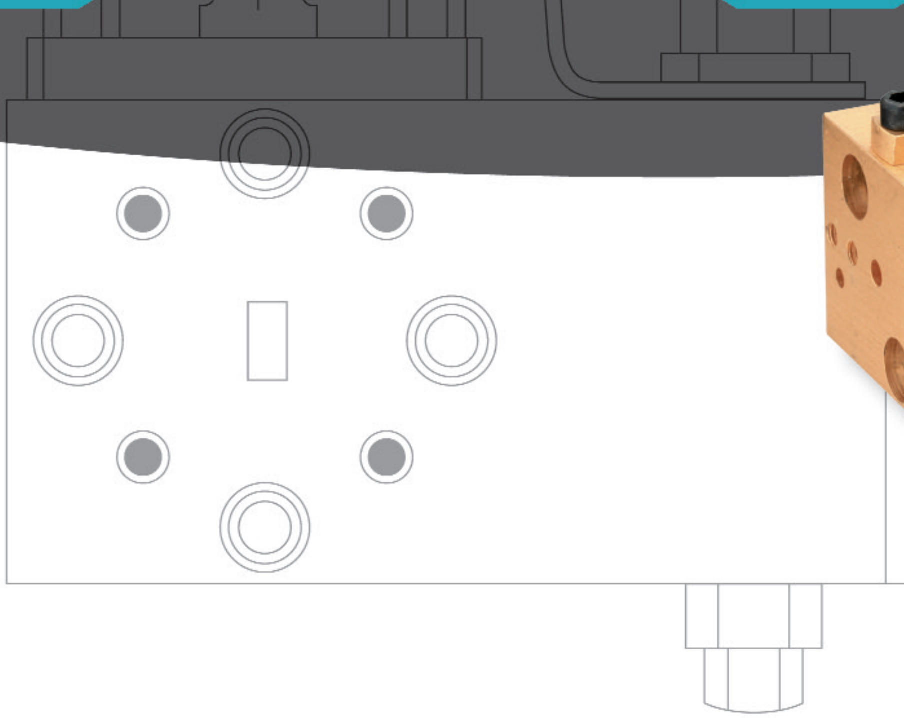
Better by Design.™

Microwave Device Technology









Semiconductors

Components

Subsystems

To Our Valued Customers

MDT is pleased to offer our latest product brochure which highlights our current capabilities. MDT manufactures high-performance gallium arsenide diodes, sensors, sources and mmW components in support of commercial as well as military markets. MDT is a leading custom designer and manufacturer of advanced devices, components and subsystems for: telecommunications, wireless, automotive, security, safety, industrial processing, and traffic management applications.

MDT has grown significantly since our founding in 1988. This has been augmented by our acquisition in July 2000 of M/A-COM's Gunn diodes, Gunn diode oscillators, voltage controlled oscillators, motion detector modules and telecommunication transmitters and receivers.

It is our Mission to provide timely, high-quality solutions that are "Better by Design" to our customers utilizing innovative, high-reliability technical solutions. To this end, we pledge our commitment to work with you in a proactive partnering relationship to our mutual success.

We believe that Quality is by design and that strict adherence to design and process controls, coupled with concurrent engineering and continuous improvement plans on all products, is what makes MDT stand apart from our competitors. We currently meet all ISO requirements, and plan to be registered to ISO 9000:2000 by December 2002.

We welcome you as either an existing or a new customer, and we are sure that we will have a very successful business relationship for years to come.

Dr. T. B. Ramachandran
CEO

Better by Design.

Table of Contents

Gunn Diodes

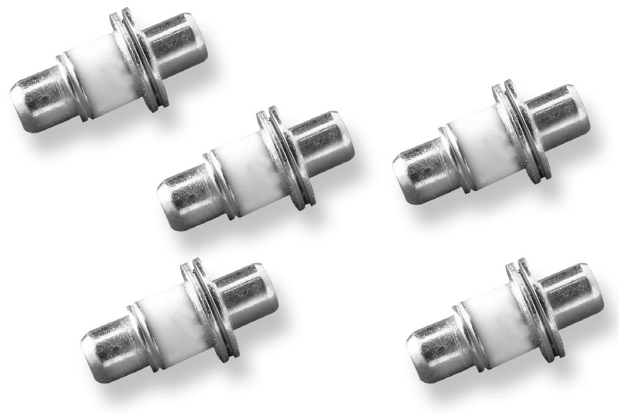
Discrete Frequency: Anode Ground

Features

- High Reliability and Performance
- Low-Phase Noise
- High-Power Output at mmW Frequencies
- Pulsed or CW
- Unconditionally Guaranteed

Applications

- Motion Detectors
- Transmitters and Receivers
- Beacons
- Automotive Collision Avoidance Radars
- Radars
- Radiometers
- Instrumentation



Description

The Gallium Arsenide Gunn diodes, epi-up (anode ground), are fabricated from epitaxial layers grown at MDT by the Vapor Phase Epitaxy technique. The layers are processed at MDT using proprietary techniques resulting in ultra-low phase and 1/f noise. The diodes are available in a variety of microwave ceramic packages for operations from 8–35 GHz.

CW Epi-Up Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Max.	Package Outline
MG1052-11	9.5–11.5	10	8	140	M11
MG1056-11	9.5–11.5	20	8	200	M11
MG1054-11	23.0–25.0	5	5	200	M11
MG1058-11	23.0–25.0	10	5	300	M11
MG1059-11	33.5–35.5	5	5	300	M11

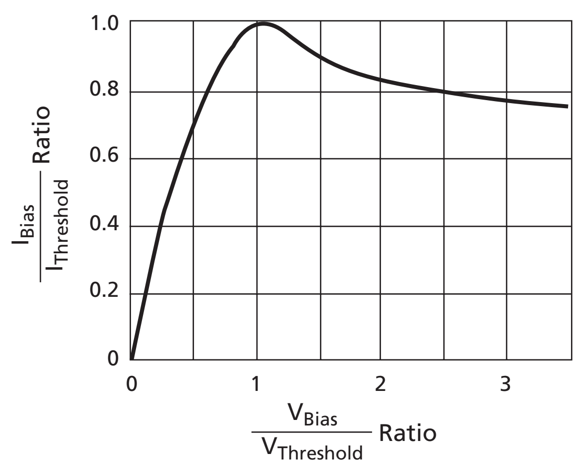
Pulsed Epi-Up Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Max.	Package Outline
MG1041-11	9.5–11.5	10	9	110	M11
MG1042-11	9.5–11.5	20	9	140	M11
MG1043-11	9.5–11.5	30	10	180	M11
MG1044-11	23.0–25.0	5	8	120	M11
MG1045-11	23.0–25.0	10	8	150	M11
MG1046-11	23.0–25.0	20	8	200	M11

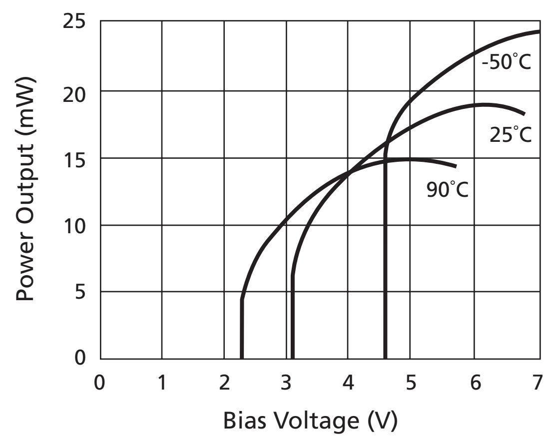
[1] Operation over a narrow band around a specific center frequency. Other frequencies available upon request. Call factory.
[2] Power is measured into a critically coupled cavity. For pulsed diodes, pulse width = 1 microsecond, duty = 1% typ.

Note:
Polarity: cathode is the cap and anode is the heat-sink.

Performance Characteristics



$\frac{I_{Bias}}{I_{Threshold}}$ Ratio vs. $\frac{V_{Bias}}{V_{Threshold}}$ Ratio; MG1000 Series



Power Output vs. Bias Voltage (MG1058)

Gunn Diodes

Discrete Frequency: Cathode Ground

Features

- High Reliability and Performance
- Low-Phase Noise
- High-Power Output at mmW Frequencies
- Pulsed or CW
- Unconditionally Guaranteed

Applications

- Motion Detectors
- Transmitters and Receivers
- Beacons
- Automotive Collision Avoidance Radars
- Radars
- Radiometers
- Instrumentation

Description

The Gallium Arsenide Gunn diodes, epi-down (cathode ground), are fabricated from epitaxial layers grown at MDT by the Vapor Phase Epitaxy technique. The layers are processed at MDT using proprietary techniques resulting in ultra-low phase and 1/f noise. The diodes are available in a variety of microwave ceramic packages for operations from 5–110 GHz.

C Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1001-11	5.4–6.9	50	12	200	400	M11
MG1002-11	5.4–6.9	100	12	300	600	M11
MG1003-15	5.4–6.9	250	12	600	1100	M15
MG1004-15	5.4–6.9	500	12	900	1300	M15

X Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1005-11	9.0–11.0	50	10	200	400	M11
MG1006-11	9.0–11.0	100	10	400	700	M11
MG1007-15	9.0–11.0	250	10	700	1200	M15
MG1008-15	9.0–11.0	500	10	1000	1600	M15

Ku Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1009-11	13.0–16.0	50	8	300	500	M11
MG1010-11	13.0–16.0	100	8	400	800	M11
MG1011-15	13.0–16.0	250	8	800	1200	M15
MG1012-15	13.0–16.0	500	8	1100	1700	M15

K Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1013-16	18.0–26.5	50	6	400	600	M16
MG1014-16	18.0–26.5	100	6	500	1000	M16
MG1015-16	18.0–26.5	200	6	800	1400	M16
MG1016-17	18.0–23.0	400	6	900	1700	M17

[1] Operation over a narrow band around a specific center frequency. Other frequencies available upon request. Call factory.
[2] Power is measured in a critically coupled cavity.
[3] Polarity: anode is the cap and cathode is the heat-sink.

Ka Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1017-16	26.5–40.0	50	4.5	300	700	M16
MG1018-16	26.5–40.0	100	4.5	600	1100	M16
MG1019-16	26.5–40.0	200	5.0	800	1400	M16
MG1020-16	26.5–40.0	250	5.5	800	1600	M16
MG1039-16	26.5–35.0	300	5.5	1000	1700	M16
MG1040-16	26.5–35.0	350	5.5	1000	1800	M16

U Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1021-16	40.0–60.0	50	4	400	800	M16
MG1022-16	40.0–60.0	100	4	700	1200	M16
MG1023-16	40.0–50.0	150	4	800	1600	M16

V and W Band Gunn Diodes (Specifications @ 25°C)

Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (mA) Min.	Operating Current (mA) Max.	Package Outline[3]
MG1036-16	60.5–85.0	10	4.5	400	900	M16
MG1037-16	60.5–85.0	50	5	500	1100	M16
MG1024-16	85–95	10	4.5	450	1100	M16
MG1025-16	85–95	20	4.5	500	1000	M16
MG1038-16	85–95	50	5	450	1200	M16

[1] Operation over a narrow band around a specific center frequency. Other frequencies available upon request. Call factory.
[2] Power is measured in a critically coupled cavity.
[3] Polarity: anode is the cap and cathode is the heat-sink.

High Power Pulsed Gunn Diodes (Specifications @ 25°C)

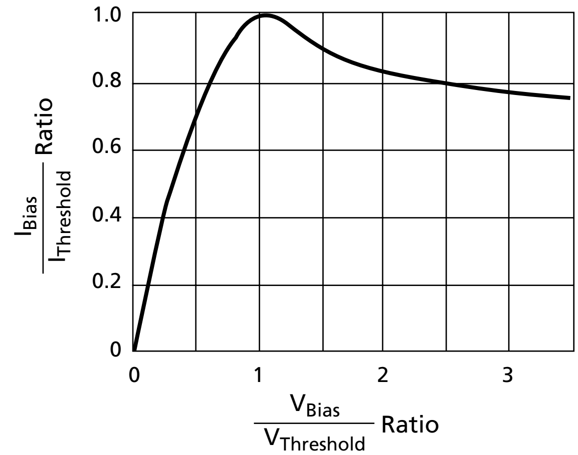
Part Number	Frequency[1] (GHz)	Min. Power[2] (mW)	Operating Voltage Typ.	Operating Current (Amps.) Typ.	Package Outline[3]
MG1034-15	9.3	5	35	8	M15

Stacked Pulsed Gunn Diodes (Specifications @ 25°C)

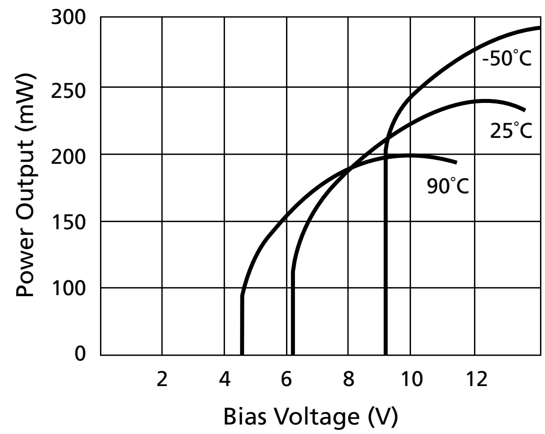
Part Number	Frequency[1] (GHz)	Min. Power[2] (W)	Operating Voltage Typ.	Current A Typ.	Number of Stacks	Package Outline[3]
MG1060-15	9.3	10	70	6	2	M15

[1] Operation over a narrow band around a specified center frequency. Other frequencies available upon request. Call factory.
[2] Power is measured into a critically coupled cavity with a nominal pulse width of 350 ns and a nominal duty cycle of 0.2%. Consult Factory for other pulse conditions.
[3] Polarity: anode is the cap and cathode is the heat-sink.

Performance Characteristics

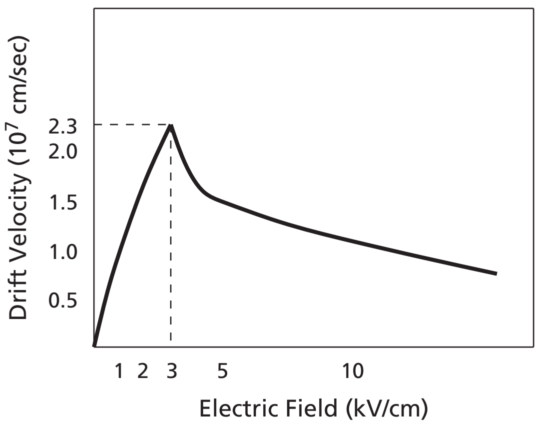


$\frac{I_{Bias}}{I_{Threshold}}$ Ratio vs. $\frac{V_{Bias}}{V_{Threshold}}$ Ratio;
MG1000 Series



Power Output vs. Bias Voltage (MG1007)

Gunn diodes are used as transferred electron oscillators (TEO) by using the negative resistance property of bulk Gallium Arsenide. The figure below shows the electron velocity in GaAs as a function of the applied electric field. Greater than about an electric field of 3.2 KV/cm, the electrons in N type GaAs move from a high-mobility, low-energy valley to another valley where the mobility is lower. Consequently, the net electron velocity is lower. This negative resistance is used for generation of microwave power.



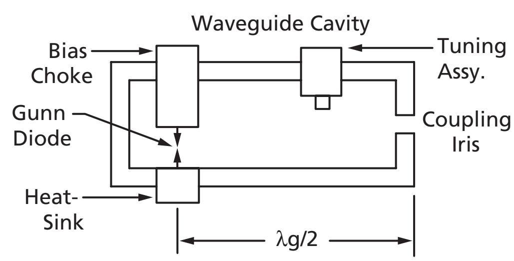
Dependence of Carrier Velocity on Electric Field In GaAs

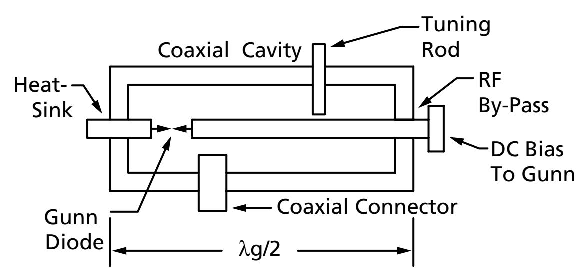
Oscillator Design Considerations

Stable TEO oscillators are most easily designed by mounting a Gunn diode in a coaxial cavity or in a waveguide cavity as shown in the accompanying schematics. Microstrip oscillators also may be used. However, particular attention must be paid to heat-sink the diode adequately.

Normally, TE modes are used for excitation in the waveguide cavities. The series equivalent circuit of a Gunn diode is a capacitance in series with a negative resistance. This capacitance may be resonated with the inductance of a shorted waveguide section of suitable length located behind the diode. The coupling to the external load may be controlled by an iris of appropriate dimensions. The distance between the diode and the iris is roughly $\lambda g/2$ at the desired frequency.

The Gunn diode may be mounted on a post to provide adequate heat-sinking. The coupling to the waveguide is through the post. The DC bias is conveniently applied through a dumbbell filter choke combination. For the coaxial cavity design, the diode is conveniently mounted at the end of the line to provide adequate heat-sinking. The diode may be coupled to the load by an inductive loop located near the diode. Such a coupling also isolates the bias supply from the load. A sliding short on the inner conductor may be used to adjust the frequency.





Bias Circuit Oscillations

Inherently, the Gunn diode has a negative resistance from DC and up. This negative resistance, together with the lead inductance and any stray capacitance, may lead to relaxation type of oscillations. In many cases, the oscillation amplitude is large enough to cause the diode to burn out. This type of failure may be minimized or even avoided by connecting a large capacitor(s) across the diode as close to the diode as possible. This capacitor combination must have a frequency response of at least a few tens of MHz.

Tuning

Mechanical-frequency tuning is accomplished by inserting a tuning rod (preferably made from a low-loss dielectric such as sapphire with a dielectric constant K of 9) into the cavity. The tuning rate is proportional to the rod diameter; however, too large a diameter may cause waveguide modes. The cut-off wavelength for a rod of diameter (D), is given by:

$$\lambda_{CO} = 1.7 * D * \sqrt{K}$$

Electronic tuning is accomplished either by using a YIG sphere or by using a varactor in the oscillator. In the case of electronic tuning by varactors, 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 (see MV 2000 and MV 3000 varactor series for selection).

Frequency Stability With Temperature

In general, the frequency stability of the oscillator depends on the material of the cavity, the reactance stability of the Gunn diode and the varactor (if any is used). Frequency stability may be improved by:

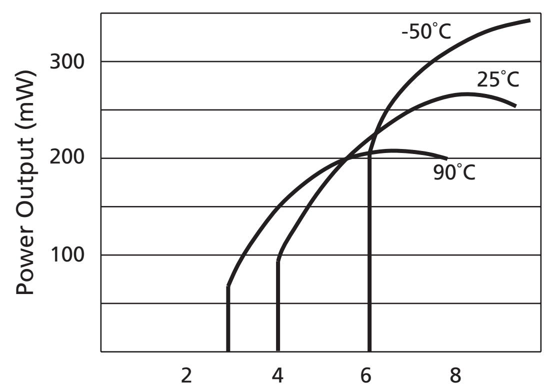
- Proper selection of the material of the cavity
- Mechanical temperature compensation or
- Proper selection of Gunn diodes

Power Stability With Temperature

The power stability depends on the operating bias voltage in relation to the turn-on voltage and the power peak voltage, the oscillator coupling to the load, the Gunn diode and proper heat-sinking.

The accompanying figures show the variation of the turn-on voltage and the power peak voltage with temperature. The operating bias voltage must be chosen so that the turn-on voltage is below the operating bias over the operating temperature range. Similarly, the power peak voltage must be higher than the operating bias voltage over the operating temperature range.

Proper heat-sinking is essential to obtain low turn-on voltage and high-power peak voltage.



Power Output vs. Bias Voltage and Temperature of a Typical MG1015 Gunn Diode

The tighter the coupling of the oscillator to the load, the greater the power variation.

Again, proper selection of Gunn diodes for a given application would minimize the power variation.

Noise Performance of Gunn Diodes

In common with all oscillators, the Gunn diode oscillators have both AM and FM noise which vary with frequency from the carrier. The noise arises from random nucleation of domains. Far from the carrier — say greater than 30 MHz — the noise is essentially independent of frequency and depends on the device temperature and the loaded Q of the cavity. Closer to the carrier, both the AM and the FM noise vary inversely with frequency off the carrier. This 1/f behavior is characteristic of semiconductor surfaces.

Semiconductor surfaces also exhibit a random noise which is commonly known as "popcorn" noise in the 1/f flicker noise region. The "popcorn" noise appears as a burst of noise randomly. Some diodes exhibit this aperiodic noise quite often. In others, the frequency of appearance is rather low. The 1/f noise and the "popcorn" noise strongly depend on the surface preparation. MDT has developed a unique surface treatment technique which minimizes both the "popcorn" noise and the flicker noise.

External circuitry, including the cavity and the power supplies, influence the noise behavior. The power output and the frequency of the oscillator depend on the bias supply. Thus, the AM and the FM noise of the oscillator may be written as:

Noise Power/Carrier Power (AM Noise) =
$(\Delta P) + (dP/dV) * (\Delta V)$

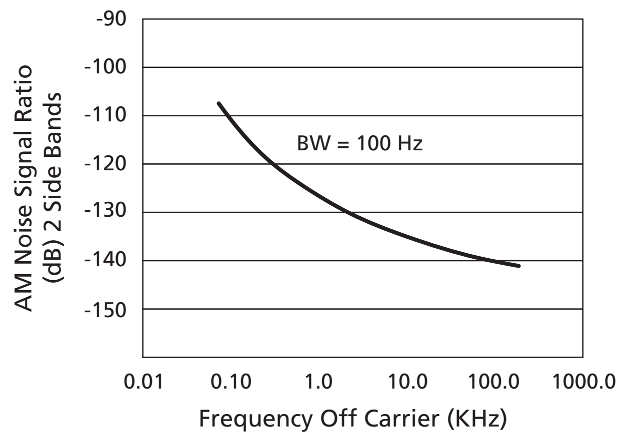
Frequency Deviation (FM Noise),
$f_{RMS} = (\Delta f) + (df/dV) * (\Delta V)$

The first term is the noise power contribution due to the diode in the oscillator cavity. The second term is the contribution due to the power supply ripple (ΔV volts). The dependence of power output and frequency on bias voltage are dP/dV and df/dV, respectively. Since, in general, dP/dV and df/dV vary rapidly with bias past the power peak voltage, it is advisable to operate the device below the power peak voltage at all temperatures to minimize the noise.

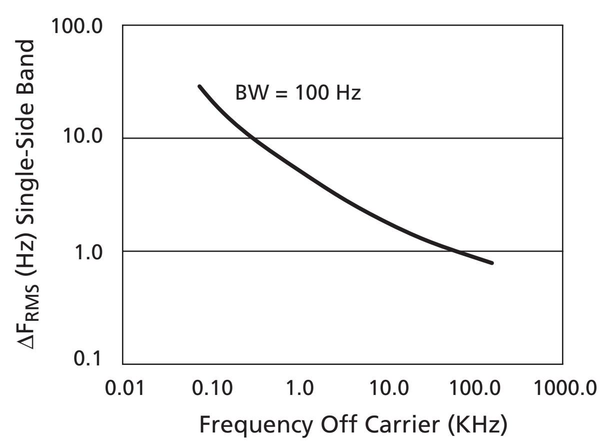
In summary, both AM and FM noise of Gunn diode oscillators depend on:

- Proper selection of Gunn diodes
- Loaded Q of the oscillator
- Power supply ripple
- Operating bias voltage

The figures below show typical AM and FM noise spectra of X band Gunn diodes.



AM Noise Spectrum of a 10 GHz Gunn Oscillator, Loaded Q = 4,000



FM Noise Spectrum of a 10 GHz Gunn Oscillator, Loaded Q = 4,000

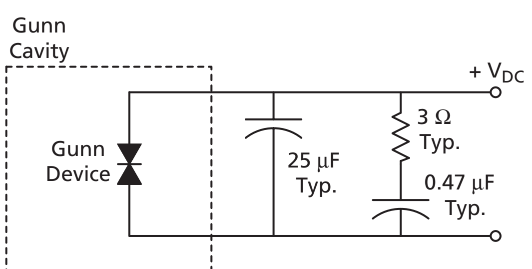
Application Notes

1. Frequency of operation for the Gunn diode must be specified with the order.
2. Minimum specified power is measured in a critically coupled high Q cavity.
3. Threaded stud or the prong opposite the weld flange is the cathode.
4. All Gunn diodes are burnt-in for a minimum period of 16 hours at a case temperature of 85 ± 5°C and at a minimum bias voltage of 1.1 * V_{OP}.
5. Jan TX and Jan TXV equivalent screened diodes are available on request.
6. Adequate heat-sinking must be provided for the diode to operate properly. A reasonable test is to measure the threshold current and compare it with the data supplied with the diode. Agreement within 5% would be an indication that heat-sinking is adequate. (See the section on "Bias Circuit Oscillations and Mounting Precautions" below.)

Bias Circuit Oscillations

The Gunn diode has a negative resistance from DC through microwave frequencies. Consequently, it is prone to oscillate at low frequencies with the lead inductance from bias circuit connections.

The voltage due to bias circuit oscillations may be large enough to burn the device out if adequate precautions are not observed. It is prudent practice to suppress the bias circuit oscillations with a circuit similar to the one shown below.



Gunn Diode Mounting Precautions

The Gunn diode is a power-generating device with a relatively low efficiency — about 2–5%. Consequently, considerable power is dissipated. Although MDT Gunn diodes are designed with long-term reliability in mind (with an MTTF in excess of 10^6 hours at an active region temperature of 260°C) with rugged construction by design, an adequate heat-sinking is still essential to keep the active region temperature within the prescribed limit.

The heat-sink material must have a high thermal conductivity. Materials like OFHC copper (k = 3.9 W/°C/cm) are suitable. If the package is threaded, then a sharply tapped heat-sink may be used with the diode screwed into the heat-sink with a torque of not more than 6 in-oz (4.5 cm-newtons) to prevent damage to the threads.

A vise-like holder should prove adequate for a diode with a prong. Or, the diode may be soldered in the heat-sink. If the diode is soldered into the heat-sink, then the case temperature must not be allowed to exceed 225°C in a non-operating condition.

Ordering Information

Orders for products may be placed directly with the factory or with our authorized representatives. Please indicate part number and package outline. For example, if you wish to place an order for a 250 mW Gunn diode to operate at 10 GHz, the part designation should be:

MG1007-15, f_{OP} = 10 GHz

Varactor Diodes

Abrupt

Features

- High Q Values for Enhanced Systems Performance
- Large Tuning Ratios
- Low Leakage
- Available in Chip Form
  (Passivated to Enhance Reliability)
- Available in Ceramic Packages
- Custom Designs Available

Applications

- VCOs
- Phase-Locked Oscillators
- High Q Tunable Filters
- Phase Shifters
- Pre-Selectors

Maximum Ratings

Reverse Voltage: (V_R)	Breakdown Voltage (V_{BR})
Forward Current: (I_F)	50 mA Max. @ 25°C
Incident Power	+20 dBm Max. @ 25°C
Operating Temperature: (T_{OP})	-55°C to +175°C
Storage Temperature: (T_{ST})	-55°C to +200°C

Description

The Gallium Arsenide abrupt varactor diodes are fabricated from epitaxial layers grown at MDT by the Chemical Vapor Deposition technique. The layers are processed at MDT using proprietary techniques resulting in a High Q factor and very repeatable tuning curves. The diodes are available in a variety of microwave ceramic packages or chips for operation from UHF to mmW frequencies.

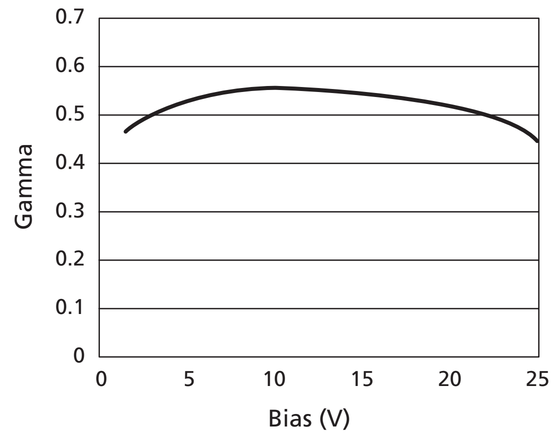
High Q Abrupt Tuning Varactors (Specifications @ 25°C)

Gamma = 0.5

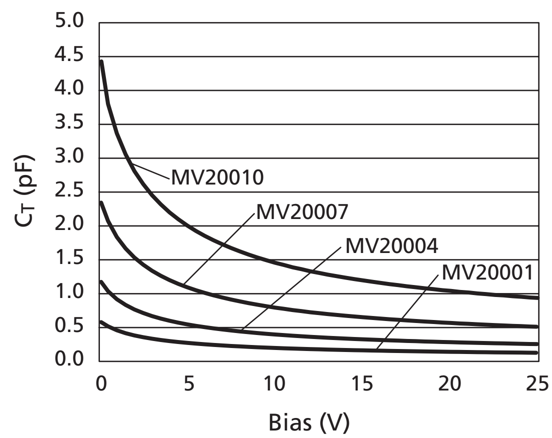
Part Number	C_T4 ± 10% (pF)[1, 3, 4]	$\frac{C_T0}{C_TV_{BR}}$ Typ.[5]	V_{BR} @ 10 µA	Typical Q @ -4 V[2]
MV20001	0.3	2.4	15	8000
MV20002	0.4	2.6	15	7500
MV20003	0.5	2.8	15	7000
MV20004	0.6	2.9	15	6500
MV20005	0.8	3.0	15	6000
MV20006	1.0	3.1	15	5700
MV20007	1.2	3.2	15	5000
MV20008	1.5	3.3	15	5000
MV20009	1.8	3.4	15	5000
MV20010	2.2	3.4	15	4000
MV21001	0.3	2.8	30	8000
MV21002	0.4	3.1	30	7500
MV21003	0.5	3.4	30	7000
MV21004	0.6	3.6	30	6500
MV21005	0.8	3.8	30	6000
MV21006	1.0	4.0	30	5700
MV21007	1.2	4.2	30	5000
MV21008	1.5	4.3	30	5000
MV21009	1.8	4.5	30	5000
MV21010	2.2	4.6	30	4000

1 Capacitance is measured at 1 MHz using a shielded fixture.
2 Measured by DeLoach Technique and referenced to 50 MHz.
3 Tightened tolerances available upon request.
4 Package parasitics are included in above specifications. The contributions of package capacitance add to the overall total capacitance and will vary depending upon package style selected. The values for package capacitance, C_P, can be made available upon request.
5 The capacitance ratio is calculated using C_P = 0.15 pF. Ratios will vary depending upon case style selection.

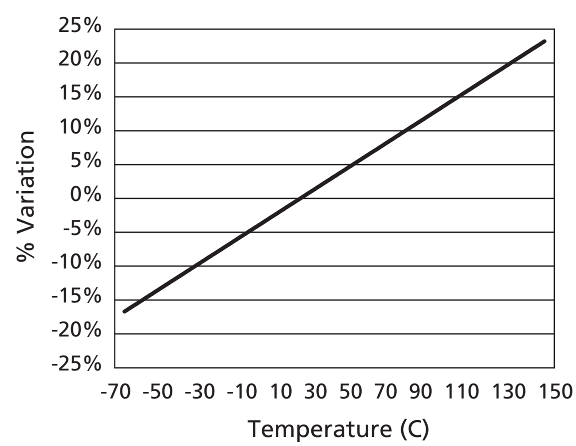
Performance Characteristics



Typical Gamma vs. Bias
Gamma = 0.50 ± 10%



Typical Total Capacitance vs. Bias



Typical % Variation of Reverse Voltage vs. Temperature (Normalized to 25°C V_{BR} @ 10 µA)

Varactor Diodes

Hyperabrupt

Features

- High Q Values for Enhanced Systems Performance
- Large Tuning Ratios
- Low Leakage
- Gamma Values Up to 1.5
- Available in Chip Form
  (Passivated to Enhance Reliability)
- Available in Ceramic Packages
- Custom Designs Available

Applications

- VCOs
- Phase-Locked Oscillators
- High Q Tunable Filters
- Phase Shifters
- Pre-Selectors

Maximum Ratings

Reverse Voltage: (V_R)	Breakdown Voltage (V_{BR})
Forward Current: (I_F)	50 mA Max. @ 25°C
Incident Power	+20 dBm Max. @ 25°C
Operating Temperature: (T_{OP})	-55°C to +175°C
Storage Temperature: (T_{ST})	-55°C to +200°C

Description

The Gallium Arsenide hyperabrupt varactor diodes are fabricated from epitaxial layers grown at MDT by the Chemical Vapor Deposition technique. The layers are processed at MDT using proprietary techniques resulting in a High Q factor and very repeatable tuning curves. The diodes are available in a variety of microwave ceramic packages or chips for operation from UHF to mmW frequencies.

High Q Constant Gamma Tuning Varactors (Specifications @ 25°C)

Gamma = 0.75

Part Number	C_T4 ± 10% (pF)[1, 3, 4]	C_T2 / C_T20 Typ.[5]	V_{BR} @ 10 µA Min.	Typical Q @ -4 V[2]
MV32001	0.6	2.8	22	4000
MV32002	1.0	3.1	22	3000
MV32003	1.2	3.2	22	3000
MV32004	1.5	3.3	22	3000
MV32005	1.8	3.4	22	3000
MV32006	2.2	3.5	22	3000
MV32007	2.5	3.6	22	2500
MV32008	3.0	3.6	22	2500
MV32009	3.6	3.7	22	2000
MV32010	4.5	3.8	22	1500

Gamma = 1.00

Part Number	C_T4 ± 10% (pF)[1, 3, 4]	C_T2 / C_T12 Typ.[5]	V_{BR} @ 10 µA Min.	Typical Q @ -4 V[2]
MV30001	0.6	3.2	15	4000
MV30002	1.0	3.7	15	3000
MV30003	1.2	3.8	15	3000
MV30004	1.5	4.0	15	3000
MV30005	1.8	4.1	15	3000
MV30006	2.2	4.2	15	3000
MV30007	2.5	4.3	15	2500
MV30008	3.0	4.4	15	2500
MV30009	3.6	4.5	15	2000
MV30010	4.5	4.5	15	1500

Part Number	C_T4 ± 10% (pF)[1, 3, 4]	C_T2 / C_T20 Typ.[5]	V_{BR} @ 10 µA Min.	Typical Q @ -4 V[2]
MV30011	0.6	3.9	22	4000
MV30012	1.0	4.6	22	3000
MV30013	1.2	4.9	22	3000
MV30014	1.5	5.2	22	3000
MV30015	1.8	5.4	22	3000
MV30016	2.2	5.6	22	3000
MV30017	2.5	5.8	22	2500
MV30018	3.0	6.0	22	2500
MV30019	3.6	6.1	22	2000
MV30020	4.5	6.3	22	1500

Gamma = 1.25

Part Number	C_T4 ± 10% (pF)[1, 3, 4]	C_T2 / C_T12 Typ.[5]	V_{BR} @ 10 µA Min.	Typical Q @ -4 V[2]
MV31001	0.6	4.2	15	4000
MV31002	1.0	5.1	15	3000
MV31003	1.2	5.4	15	3000
MV31004	1.5	5.7	15	3000
MV31005	1.8	5.9	15	3000
MV31006	2.2	6.2	15	3000
MV31007	2.5	6.3	15	2000
MV31008	3.0	6.5	15	2000
MV31009	3.6	6.7	15	2000
MV31010	4.5	6.8	15	1500

Part Number	C_T4 ± 10% (pF)[1, 3, 4]	C_T2 / C_T20 Typ.[5]	V_{BR} @ 10 µA Min.	Typical Q @ -4 V[2]
MV31011	0.5	5.5	22	4000
MV31012	0.7	6.5	22	4000
MV31013	1.0	7.7	22	3000
MV31014	1.2	8.3	22	3000
MV31015	1.5	9.1	22	3000
MV31016	1.8	9.6	22	3000
MV31017	2.0	9.9	22	3000
MV31018	2.2	10.2	22	3000
MV31019	2.7	10.8	22	2000
MV31020	3.3	11.3	22	2000
MV31021	3.7	11.5	22	2000
MV31022	4.7	12.0	22	1500
MV31023	5.6	12.3	22	1500
MV31024	6.8	12.6	22	1500
MV31025	8.2	12.9	22	1500
MV31026	10.0	13.1	22	1500

[1] Capacitance is measured at 1 MHz using a shielded fixture.
[2] Measured by DeLoach Technique and referenced to 50 MHz.
[3] Tightened tolerances available upon request.
[4] Package parasitics are included in above specifications. The contributions of package capacitance add to the overall total capacitance and will vary depending upon package style selected. The values for package capacitance, C_P, can be made available upon request.
[5] The capacitance ratio is calculated using C_P = 0.15 pF. Ratios will vary depending upon case style selection.

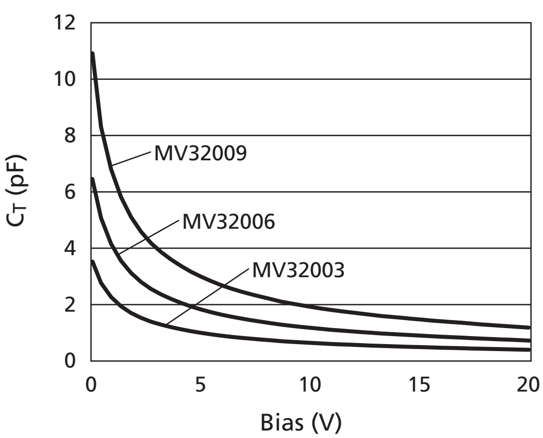
High Q Constant Gamma Tuning Varactors (Specifications @ 25°C)

Gamma = 1.50

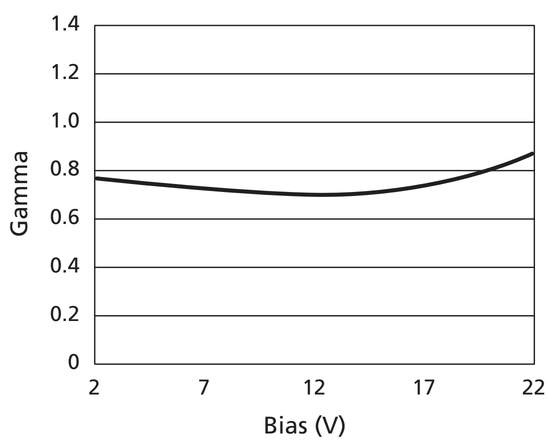
Part Number	C_T4 ± 10% (pF)[1, 3, 4]	$\frac{C_T2}{C_T12}$ Typ.[5]	V_{BR} @ 10 µA Min.	Typical Q @ -4 V[2]
MV34001	0.5	4.5	15	3000
MV34002	1.0	5.9	15	2500
MV34003	1.8	7.1	15	2500
MV34004	2.8	7.3	15	2500
MV34005	2.2	7.4	15	1800
MV34006	2.5	7.6	15	1800
MV34007	3.0	7.9	15	1800
MV34008	3.8	8.1	15	1800
MV34009	4.5	8.3	15	1200
MV34010	10.0	8.9	15	1200

[1] Capacitance is measured at 1 MHz using a shielded fixture.
[2] Measured by DeLoach Technique and referenced to 50 MHz.
[3] Tightened tolerances available upon request.
[4] Package parasitics are included in above specifications. The contributions of package capacitance add to the overall total capacitance and will vary depending upon package style selected. The values for package capacitance,C_P, can be made available upon request.
[5] The capacitance ratio is calculated using C_P = 0.15 pF. Ratios will vary depending upon case style selection.

Performance Characteristics

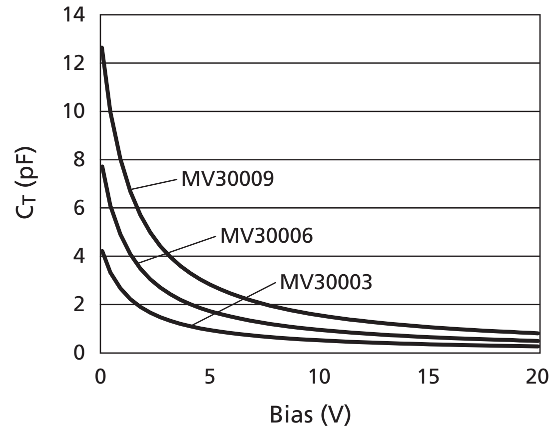


Typical Total Capacitance vs. Bias
Gamma = 0.75 ± 10%

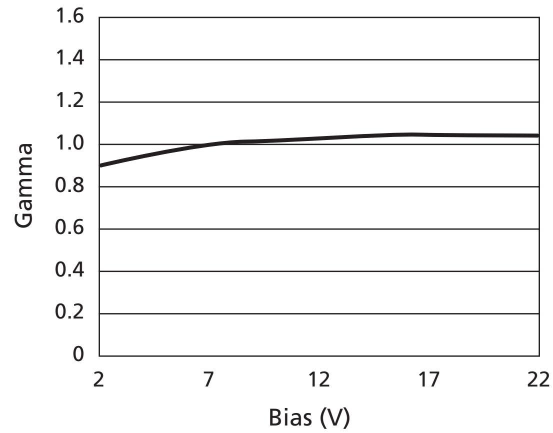


Typical Gamma vs. Bias
Gamma = 0.75 ± 10%

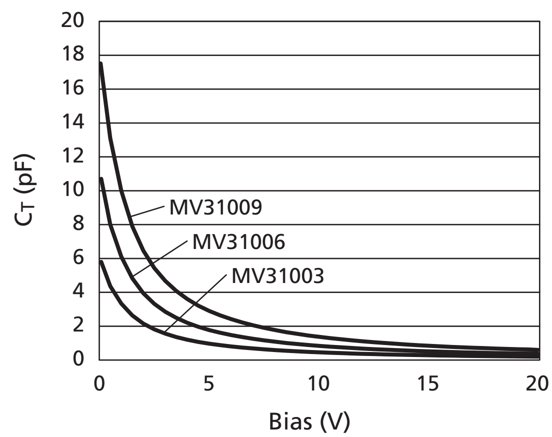
Performance Characteristics



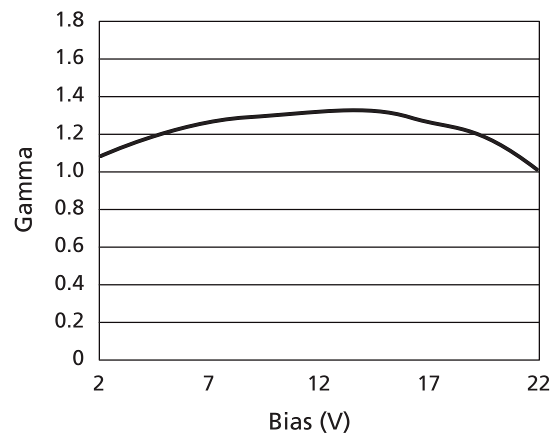
Typical Total Capacitance vs. Bias
Gamma = 1.00 ± 10%



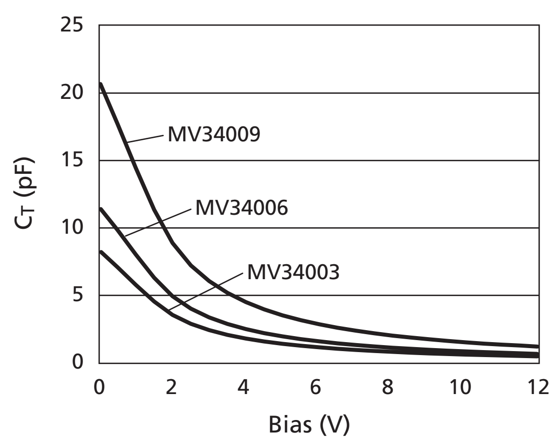
Typical Gamma vs. Bias
Gamma = 1.00 ± 10%



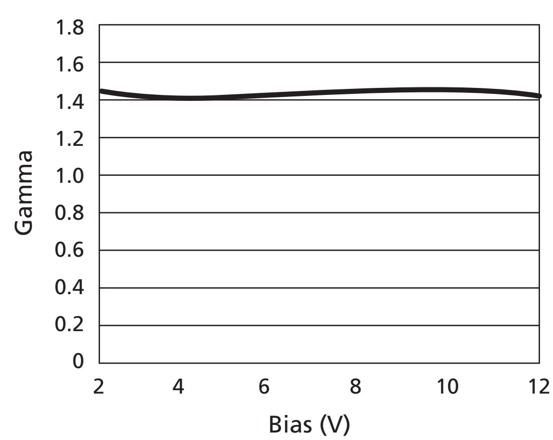
Typical Total Capacitance vs. Bias
Gamma = 1.25 ± 10%



Typical Gamma vs. Bias
Gamma = 1.25 ± 10%



Typical Total Capacitance vs. Bias
Gamma = 1.50 ± 10%



Typical Gamma vs. Bias
Gamma = 1.50 ± 10%

Varactor Diodes

Application Note

MDT offers a variety of GaAs tuning varactors for use in Microwave applications ranging from VCOs to tuning circuits. The properties of Gallium Arsenide provide high figure of merit or Q and enables circuit designers to achieve broadband tuning. MDT's line of varactor products covers a wide selection of tuning curves to fit most designs. With the incorporation of passivation, the reverse leakage current is minimized and the reliability of the device is increased. Depending upon the application or design, various package styles are offered. The available case styles cover both coplanar as well as coaxial designs. The packages are hermetically sealed and are suitable for commercial, military and space-qualified applications.

Theory

Varactor diodes are typically used in a reverse bias configuration. The varactor, when biased in this fashion, acts as a variable capacitor. The capacitance of the varactor decreases with applied reverse voltage. Depending upon the available supply voltage, the circuit designer can achieve a wide capacitance shift across the supply range. The capacitance at a given bias can be calculated from the following equation:

$$C_J(V) = \frac{C_J(0\ V)}{(1 + \frac{V}{\Phi})^{\Gamma}}$$

where
Φ = the built in potential (1.2 V for GaAs)
Γ = the tuning slope
C_{JO} = the junction capacitance at 0 V
V = the reverse bias voltage

Typically, the tuning range for MDT's line of varactors falls in the 2–20 V bias. Depending upon the steepness of capacitance variation needed, MDT offers two types of varactors, the abrupt junction and the hyperabrupt junction. The abrupt junction has a tuning slope or gamma equal to 0.5 whereas the hyperabrupt gamma value is greater than 0.5. The gamma of the device is determined by the doping density in the active region as a function of the distance from the surface. When the doping density does not change as a function of distance (i.e., constant doping) the class of varactor is defined as an abrupt junction. Conversely, when the doping density changes as a function of distance, the hyperabrupt junction is the named classification. The equation below defines the doping density within the device for both the abrupt and hyperabrupt junction varactor.

$$N_D(x) = \frac{2}{(q\varepsilon A^2 \frac{d}{dv}(\frac{1}{C^2}))}$$

where
q = the electronic charge = $1.6e^{-19}$ coulombs
ε = the permittivity of GaAs
A = the area of the junction
d/dv = bias change
C = the capacitance as a function of bias

MDT's standard hyperabrupt gamma values range from 0.75, 1.0, 1.25 and 1.50 with a ± 10% tolerance across the specified bias range. The gamma value remains constant between 2–12 and 2–20 V depending upon the device selection. For the abrupt junction devices, the tuning range is 0–30 V with a gamma of 0.5 ± 10%.

The capacitance ratio over a tuning bias range can be calculated from the following equation:

$$T_{ratio} = \frac{C_J(V_1)}{C_J(V_2)} = \left[\frac{(V_2 + \Phi)}{(V_1 + \Phi)}\right]^{\Gamma}$$

where
$C_J(V_1)$ = the capacitance at bias V_1
$C_J(V_2)$ = the capacitance at bias V_2
Φ = the built in potential (1.2 V for GaAs)
Γ = the tuning slope

The design engineer can calculate the required gamma necessary to obtain the appropriate capacitance shift for the circuit design by altering the above equations as follows:

$$\Gamma = \frac{\text{Log}\,(T_{ratio})}{\text{Log}\left[\frac{(V_2 + \Phi)}{(V_1 + \Phi)}\right]}$$

It is important to reiterate that the bias range for MDT devices is 2–20 V, although tuning below 2 V can be achieved.

The figure of merit or Q is the defining property of the varactor and determines the overall device performance. There are several components in quantifying the diode, of which the key factors are series resistance, series inductance and junction capacitance. MDT makes a direct measurement of Q using the DeLoach method. This method will be discussed further, but first the derivation of Q is explained. As mentioned earlier, the key components are series resistance, inductance and capacitance. The value of junction capacitance (C_J) is determined by the designer and is not negotiable. However, the series resistance (R_S) and inductance (L_S) are components that need to be reduced and optimized. The inductance contribution affects the high frequency response of the device and limits the overall operating range. The reduction of series inductance is always an improvement in device performance, particularly at high frequencies. The device can be improved by the selection of appropriate wirebond type and techniques to reduce series (L_S). The application and frequency of operation typically dictates the type of wirebond techniques used in manufacturing.

The calculation of Q is directly related to and derived from the cut-off frequency. As the equation below for cut-off frequency implies, low series resistance (R_S) in the calculation of Q is critical. The equation is as follows:

$$f_{cut\text{-}off} = \frac{1}{2\pi\, C_J(V)\, R_S(V)}$$

The cut-off frequency is usually specified at -4 V bias. The value of Q is then calculated from the equation below and referenced to 50 MHz as a standard.

$$Q = \frac{f_{cut\text{-}off}}{50\text{ MHz}}$$

The series resistance is critical to the improvement of Q and overall device performance. There are many contributors to series resistance. For a mesa type design, the combined series resistance is the following:

$$R_S = R_{PM} + R_{sum} + R_P + R_{UL} + R_{SK}$$

where
R_{PM} = the metal contact to the P+ region
R_{sum} = the metal contact to the substrate
R_{P+} = the P+ region resistivity
R_{UL} = the undepleted active layer resistivity
R_{SK} = the skin resistivity at high frequencies

By carefully selecting the device's physical dimensions and properties, these series resistances can be greatly reduced. The device processing, as well, will also play an important role in the reduction of these added resistances. For instance, by optimizing the alloy process, the metallization resistance can be optimized to reduce the contributions of the metal layers.

DeLoach Method for Measuring Q

MDT has incorporated the DeLoach method for measuring Q values for all of its varactor products. The measurement involves making a broadband microwave transmission loss measurement of the varactor in a shunt configuration (Figure 1). The device is reverse biased with 4 V applied and the resonant frequency is identified. The device model is shown in Figure 1. The device will resonate at the frequency when $X_{LS} = X_{CJ}$. At this frequency, the components of the model can be derived. The equations are as follows:

$$R_S = (Z_0/2)\left(\frac{1}{\sqrt{T_P} - 1}\right) \text{ where } T_P = 10^{\frac{T_P\,(dB)}{10}}$$

$$C_V = \left(\frac{1}{\pi * Z_0}\right)\left(\frac{F_2 - F_1}{F_2 * F_1}\right)\left(\sqrt{T_P} - 1\right)\left(1 - \frac{2}{T_P}\right)^{1/2}$$

$$L_S = \left(\frac{1}{4 * \pi^2}\right)\left(\frac{1}{F_2 * F_1 * C_V}\right)$$

From the calculated R_S and C_J, the cut-off frequency for the device can be determined. Once this is established, the Q can be calculated.

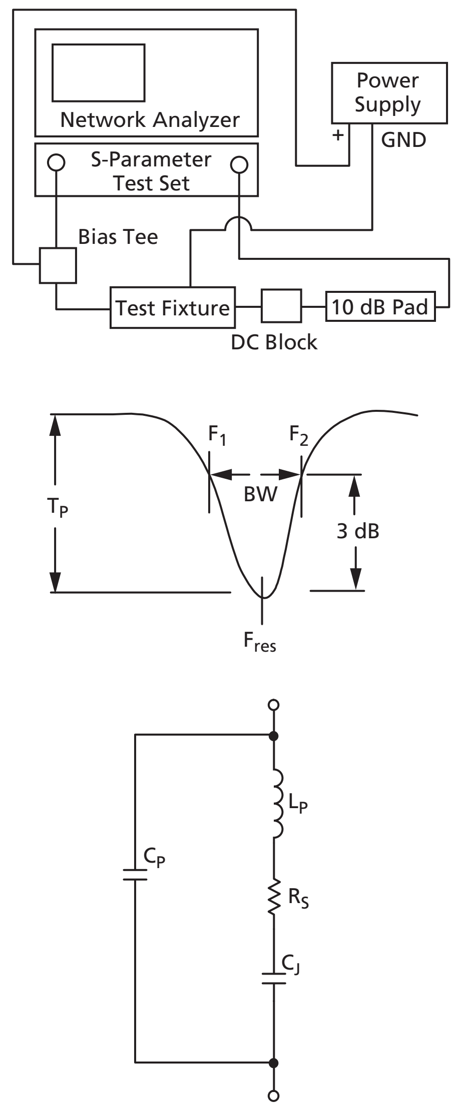


Figure 1. Test Stand Block Diagram

Multiplier Diodes

Features

- High Output Power
- Low Conversion Loss
- Low Parasitic Packages
- Low Thermal Resistance

Applications

- High-Power mmW Transceivers
- mmW Phase Arrays
- Drivers for Power Amplifiers
- Frequency Extenders to 110 GHz and Beyond
- Test Equipment
- Telecommunications
- Missile Seekers
- Electronic Warfare

High Cut-off GaAs Frequency Multiplier Diodes (Specifications @ 25°C)

Part Number	C_J0 ± 10% (pF)[1, 3, 4]	$\frac{C_T0}{C_TV_{BR}}$ Typ.[5]	V_{BR} @ 10 μA	Typical Q @ -4 V[2]
MV71001	0.2	2.1	15	8000
MV71002	0.3	2.4	15	8000
MV71003	0.4	2.6	15	7500
MV71004	0.5	2.8	15	7000
MV71005	0.3	2.8	30	8000
MV71006	0.4	3.1	30	7500
MV71007	0.5	3.4	30	7000
MV71008	0.6	3.6	30	6500
MV71009	0.7	3.7	30	6000
MV71010	0.8	3.8	30	6000
MV71011	0.9	3.9	30	5700
MV71012	1.0	4.0	30	5700
MV71013	1.2	4.2	30	5000

[1] Capacitance is measured at 1 MHz using a shielded fixture.
[2] Measured by DeLoach Technique and referenced to 50 MHz.
[3] Tightened tolerances available upon request.
[4] Package parasitics are not included in above specifications. The contributions of package capacitance add to the overall total capacitance and will vary depending upon package style selected. The values for package capacitance, C_P, can be made available upon request.
[5] The capacitance ratio is calculated using C_P = 0.15 pF. Ratios will vary depending upon case style selection.

Description

The Gallium Arsenide multiplier diodes are fabricated from epitaxial layers grown at MDT by the Chemical Vapor Deposition technique. The layers are processed at MDT using proprietary techniques resulting in a High Q factor and very repeatable tuning curves. The diodes are available in a variety of microwave ceramic packages or chips for operation from UHF to mmW frequencies.

Maximum Ratings

Reverse Voltage: (V_R)	Breakdown Voltage (V_{BR})
Forward Current: (I_F)	50 mA Max. @ 25°C
Incident Power	+23 dBm Max. @ 25°C
Operating Temperature: (T_{OP})	-55°C to +175°C
Storage Temperature: (T_{ST})	-55°C to +200°C

Multiplier Diodes

High Power ISIS

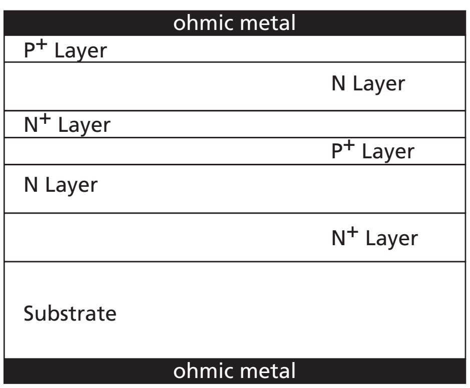
Features

- High Output Powers — Over 5 W at 35 GHz
- Low Conversion Loss
- 2 and 3 Stack Options
- Low Parasitic Packages
- Low Thermal Resistance

Applications

- High-Power mmW Transceivers
- mmW Phase Arrays
- Drivers for mm Power Amplifiers
- Frequency Extenders to D Band and Beyond
- Test Equipment

ISIS Diode Schematic



Description

ISIS multiplier varactors (see the ISIS diode schematic) are fabricated by epitaxially stacking the P-N junctions in Gallium Arsenide to obtain high powers in millimeterwave frequencies. The MIV series of ISIS multiplier diodes has been especially designed to have the highest cut-off frequency to produce very low conversion loss when used in appropriately designed circuits. MDT offers 2 and 3 stacked devices to produce high CW powers in U and W bands. Typically, CW powers of up to 3 W at 44 GHz (conversion loss >3 dB) and 1 W in W band (conversion loss >9 dB) are realizable with single devices. These diodes are offered in a very low parasitic (>10 fF) well heat-sunk M29 package and in other standard microwave packages.

Specifications @ 25°C

2 Stack ISIS Diodes — Breakdown Voltage: 55 V Min.

Part Number	Junction Capacitance @ Zero Bias (pF)	Minimum Cut-Off Frequency (GHz @ 6 V)	Package Capacitance (pF)
MIV41001-21	0.1–0.3	1000	0.15
MIV41002-21	0.3–0.5	700	0.15
MIV41003-21	0.5–1.0	600	0.15
MIV41001-29	0.1–0.3	1000	0.01
MIV41002-29	0.3–0.5	700	0.01
MIV41003-29	0.5–1.0	600	0.01

Other package styles are available on request.
Different breakdown voltages are available on request.

3 Stack ISIS Diodes — Breakdown Voltage: 75 V Min.

Part Number	Junction Capacitance @ Zero Bias (pF)	Minimum Cut-Off Frequency (GHz @ 6 V)	Package Capacitance (pF)
MIV41011-21	0.1–0.3	1000	0.15
MIV41012-21	0.3–0.5	700	0.15
MIV41013-21	0.5–1.0	600	0.15
MIV41011-29	0.1–0.3	1000	0.01
MIV41012-29	0.3–0.5	700	0.01
MIV41013-29	0.5–1.0	600	0.01

Other package styles are available on request.
Different breakdown voltages are available on request.

IMPATT Diodes

Features

- High-Power Outputs
- Both Pulsed and CW Applications
- High Efficiencies

Applications

- Oscillators
- Avionic Systems
- Electronic Warfare Systems
- Smart Antennas

Description

The Gallium Arsenide IMPATT diodes are fabricated utilizing low-dislocation epitaxial grown doping structures and with high-temperature metallization processes. The diodes have been specially designed to have high output power when measured in a critically coupled cavity at the frequency of operation. Due to the power dissipation, it is necessary to be very prudent when mounting the IMPATT diodes. The threaded stud of the package is the cathode. The diodes are available in microwave ceramic packages.

CW IMPATT Diodes (Specifications @ 25°C)

Part Number	F_{OP} (GHz)	P_O Min. (W)	V_{BR} @ 1 mA (V)	C_T (0 V) Typ. (pF)	V_{OP} Typ. (V)	I_{OP} Typ. (A)	Eff. Min. (%)	Θ Max.	Pkg. Style
MI5022	9.5–10.2	3.5	30	20	50	0.43	20	12.0	M18

Pulsed IMPATT Diodes (Specifications @ 25°C)

Part Number	F_{OP} (GHz)	P_O Min. (W)	V_{BR} @ 1 mA (V)	C_T (0 V) Typ. (pF)	V_{OP} Typ. (V)	I_{OP} Typ. (A)	Eff. Min. (%)	Θ Max.	Pkg. Style
MI5001	5.1–5.4	10[1]	70	80	95	1.2	13	8.0	M 15
MI5003	9.1–9.6	15[1]	45	75	65	1.8	15	9.5	M 18
MI5004	9.1–9.5	12[2]	35	42	58	1.2	18	9.5	M 18

[1]Pulse width 0.5–10 µS; duty cycle: 0.5–5%.
[2]Pulse width 1–2 µS; duty cycle: 20–30%.

Notes:
Power output is measured in a critically coupled cavity at the customer-specified frequency — F_{OP}.
Total capacitance is measured at 1 MHz.
Test procedure for measuring thermal resistance is available on request.
Breakdown Voltage is measured at 1 mA.

1. Frequency of operation for the IMPATT diode must be specified with the order.
2. Minimum specified power is measured in a critically coupled low Q coaxial cavity.
3. Threaded stud is the cathode.
4. All IMPATT diodes are burnt-in for a minimum period of 16 hours at a case temperature such that the junction temperature is 200°C.
5. Jan TX and Jan TXV equivalent screened diodes are available on request.
6. Adequate heat-sinking must be provided for the diode to operate properly. These IMPATT diodes have been designed to operate in the precollection mode (PCM). As the diode is tuned up from a low operating current from a constant current source, it will be noticed that at the onset of PCM, the diode voltage falls down. The power output will increase by several dBs. with a slight shift in the operating frequency. When the circuit is detuned in such a fashion that the diode falls out of the PCM, the diode voltage will increase. The power dissipation will increase as the power output falls down. If the diode is not adequately heat-sunk, the diode may burn out.

Diode Mounting Procedure and Precautions

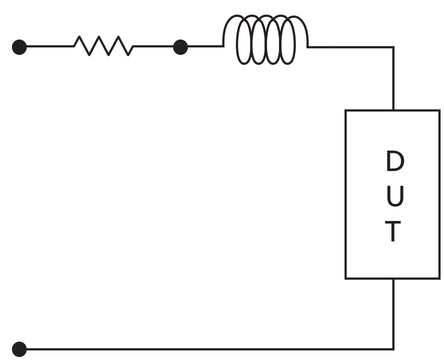
Bias Circuit Oscillations

The IMPATT diode has a negative resistance from DC through microwave frequencies. Consequently, it is prone to oscillate at low frequencies, with the lead inductance from bias circuit connections. The voltage due to bias circuit oscillations may be large enough to burn the device out if adequate precautions are not observed. It is prudent practice to suppress the bias circuit oscillations with a circuit similar to the one shown.

IMPATT Diode Mounting Precautions

The IMPATT diode is a power generating device with a moderately high efficiency — about 15–25%. Considerable power is dissipated in the diode because of the high-output powers. Although MDT's IMPATT diodes have been designed with long-term reliability in mind (with an MTTF in excess of 10^6 hours at an active region temperature of 225°C) and construction rugged by design, an adequate heat-sinking is still essential to keep the active region temperature within the prescribed limit.

The heat-sink material must have a high thermal conductivity. Materials like OFHC copper (K = 3.9 W/°C/ cm) are suitable. Since the package has a threaded stud, a sharply tapped heat-sink may be used with the diode screwed into the heat-sink with a torque of not more than 6 in-oz (4.5 cm-newtons) to prevent damage to the threads. Or, the diode may be soldered into the heat-sink. If the diode is soldered into the heat-sink, then the case temperature must not be allowed to exceed 225°C in a non-operating condition.



Schottky Barrier Diodes

Features

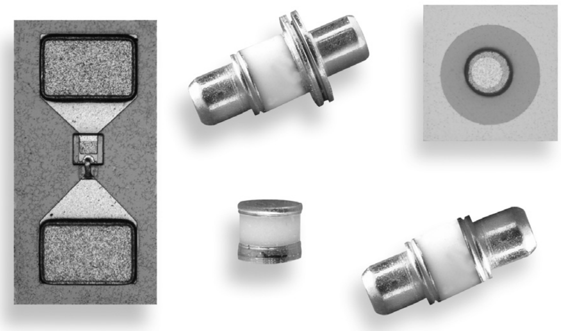
- Low-Noise Figure
- High Cut-off Frequency
- Passivated to Enhance Reliability
- Packaged Diodes, Bondable Chips and Flip Chip Configurations

Applications

- Single and Balanced Mixers and Detectors
- Transceivers X, K and Ka Bands
- 30 and 60 GHz Radios
- Automotive Radar Detectors

Maximum Ratings

Incident Power	20 dBm Max. @ 25°C Derate Linearly to 0 at 150°C
Operating Temperature: (T_{OP})	-55°C to +175°C
Storage Temperature: (T_{ST})	-55°C to +200°C



Description

The 8000 series of GaAs Schottky barrier diodes are available in packaged form, bondable chip and flip chip configurations. Packaged and bondable chip Schottky devices are designed to have low series resistance and low junction capacitance. The resulting low-noise figure makes these diodes very suitable for mixer and detector applications from X band to Ka band frequencies.

Flip chip GaAs Schottky barrier diodes are ideal for integrated circuits from 18 GHz to 100 GHz applications. These devices are fabricated using low- dislocation and low-resistivity GaAs material. High-temperature refractory metallization processes, such as Ti- Pt- Au combined with high quality Silicon Nitride passivation, are used to ensure high reliability.

SPICE Parameters for MS8000 Series (Specifications @ 25°C)

I_S (A)	R_S (Ω)	η	TT (Sec.)	C_{JO} (pF)	m	E_G (ev)	V_J (V)	B_V (V)	IB_V (A)
8×10^{-13}	6	1.05	0	0.04	0.50	1.42	0.85	4.0	1×10^{-5}

Schottky Barrier Diodes (Specifications @ 25°C)

Part Number	Typical Junction Capacitance (pF)[2]	Min./Max. Series Resistance R_S (Ω)[3]	LO Test Frequency (GHz)	Typical Noise Figure (dB)[4]	Min./Max. IF Impedance (Ω)	Minimum V_{BR} (V)[5]
MS8001[1]	0.10	3–6	9.375	5.6	250/500	5
MS8002[1]	0.10	3–6	16.000	5.6	250/500	5
MS8003[1]	0.07	3–6	24.000	6.5	250/500	5
MS8004[1]	0.06	3–6	36.000	6.5	250/500	5
MS8100[6]	0.04	6–12	24.000	7.0	300/500	3

[1] Suffix of the model number indicates the package style. Available in M22, M38 and M39 as well as in chip form P10.
[2] Capacitance C_J is measured at zero bias with a 1 MHz signal.
[3] Series resistance, R_S, is calculated by subtracting the barrier resistance R_D = kT/qI from the measured total resistance R_T at 10 mA: $R_S = R_T - R_D$:
k = Boltzmann Constant, T = diode temperature in degrees K, q = electronic charge, I = rectified current.
[4] The quoted noise figure (NF) is a single side band NF measured at LO power of 6 dBm for a single, and 10 dBm for a balanced mixer with a 30 MHz IF amplifier of minimum NF of 1.5 dB.
[5] The breakdown voltage, V_{BR}, is measured at a reverse current of 10 micro amperes.
[6] Flip chip available for MS8100 only. Consult factory for configurations other than single.

Device Reliability

The reliability of GaAs Schottky barrier diodes has been established through long-term operation and step-stress testing. A high-temperature refractory metallization structure, Ti- Pt- Au, eliminates potential problems arising from the penetration of metallization into the semiconductor during long-term use in the RF systems. Well established chip fabrication and manufacturing techniques further enhance device reliability by reducing the possibility of surface breakdown or chip damage in mounting.

Long-term operation and step stress tests have indicated that for a junction temperature of 200°C, MTTF will be greater than 1E6 hours.

Precautions for Handling Schottky Barrier Diodes

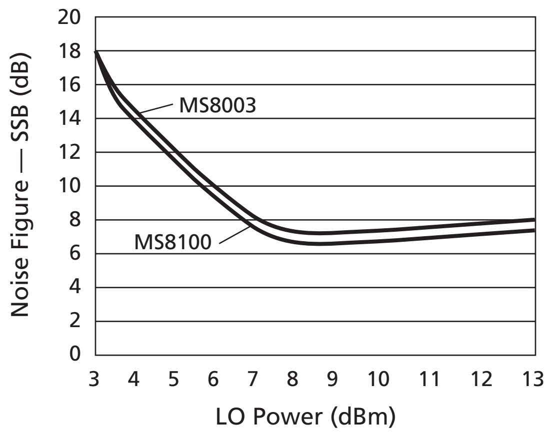
Microwave and millimeterwave Schottky barrier diodes have very small junction areas and are therefore extremely sensitive to accidental electrostatic discharge (ESD) and over voltage burnout. The first or most sensitive indication of excessive electrical stress or burnout is an increase in the reverse leakage current: I_R of the diode. A large overload will cause the reverse breakdown voltage to decrease to a lower value, and also degrade the forward voltage characteristics of the diode. ESD is responsible for both catastrophic and latent failures of high-frequency Schottky barrier diodes.

Static electricity, or ESD, is more prevalent in dry climates such as experienced during the winter months, and may be generated on one's person or by the diode packaging material. Therefore, extreme care must be taken when handling these diodes.

Grounded dual wrist straps with continuous monitor, table-top ionizers and ESD bags/enclosures should be used when handling Schottky barrier diodes.

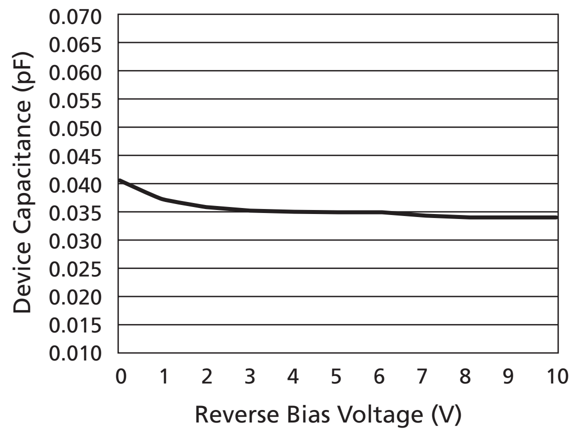
If auxiliary test equipment, such as an oscilloscope or a digital voltmeter, is to be connected and used for a monitoring diode operation, it should be connected electrically before the diode is installed if possible. If not, the ground side of the instrument must be connected first, or the diode may be damaged by the AC current flowing in the ground loop and through the diode.

Performance Characteristics

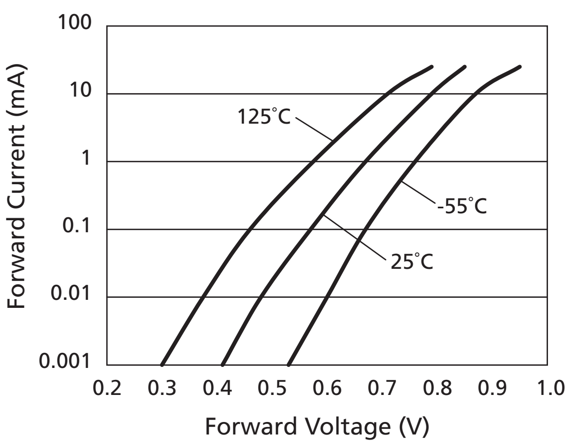


Noise Figure (dB) @ 24 GHz (Balanced Mixer)

The quoted noise figure (NF) is a single side band NF measured at LO power of 6 dBm for a single, and 10 dBm for a balanced mixer with a 30 MHz IF amplifier of minimum NF of 1.5 dB.



Typical Junction Capacitance



I-V Characteristics for GaAs Schottky Diode

Basics of Schottky Barrier Diodes

Application Note

The Schottky barrier diode is a rectifying metal-semiconductor junction formed by plating, evaporating or sputtering a variety of metals on N type or P type semiconductor materials. Generally, N type silicon and N type GaAs are used. Due to higher cut-off frequency, GaAs devices are preferred in applications above X band frequencies. This results from the higher mobility of electrons in GaAs than in silicon.

Generally, silicon and GaAs Schottky barrier diodes in the various package configurations (glass, ceramic, plastic, and beam leads) are used up to 40 GHz frequencies and above that only packageless (multijunction Schottky chip, beam lead and flip chip configurations; i.e., MDT "MS8100 series") GaAs devices are preferred.

Because of higher parasitic losses, ceramic packaged Schottkys are used up to Ka band frequencies. GaAs beam lead and GaAs flip chip Schottkys are mostly used up to 110 GHz. Multijunction GaAs Schottkys with "sharpless" whisker contact are used above 110 GHz frequencies.

GaAs beam lead Schottky devices, especially for millimeterwave frequencies, are extremely small and fragile; therefore, flip chip structure was introduced.

Current vs. Voltage Relation

The current versus voltage relationship for a Schottky barrier diode is given by the following equation known as the Richardson equation.

where:

$I = I_S\,(e^{qV/\eta\,kT} - 1)$

Saturation Current, $I_S = AA^*\,T^2 e^{-q\,\phi_B/kT}$

A^* = modified Richardson constant

A = area (cm^2)

k = Boltzmann's Constant

T = absolute temperature

ϕ_B = (Vm-x) barrier height in volts

q = electronic charge

η = ideality factor (forward slope factor, depends upon metal — semiconductor interface)

The barrier height of a Schottky diode can be determined experimentally by fitting the forward V versus I characteristic to the above equation. Notice that ϕ_B, the potential barrier for electrons in the metal moving towards the semiconductor, influences the forward current.

The barrier height (ϕ_B), is important because it determines the local oscillator power necessary to bias the diode into its non-linear region. In many radar receiver systems, available local oscillator power is less than 1 mW for mixer diodes, so low-barrier silicon Schottky diodes are desired. Schottky diodes have been fabricated with several metals and alloys using P and N type silicon with barriers ranging from 0.27–0.90 V.

However, this ideal behavior is not observed for a metal/GaAs system. The barrier height is found to be virtually independent of metal work function. This is thought to be due to "Fermi level pinning" at the metal-semiconductor interface.

Schottky Chip Equivalent Circuit

Figure 1 shows the cross section and equivalent circuit of a typical Schottky barrier chip. The rectifying metal-semiconductor junction is modeled as a nonlinear resistance (R_J) and a shunt capacitance (C_J). The nonlinear resistance is the element used for mixer and detector operations, and will be discussed in detail later.

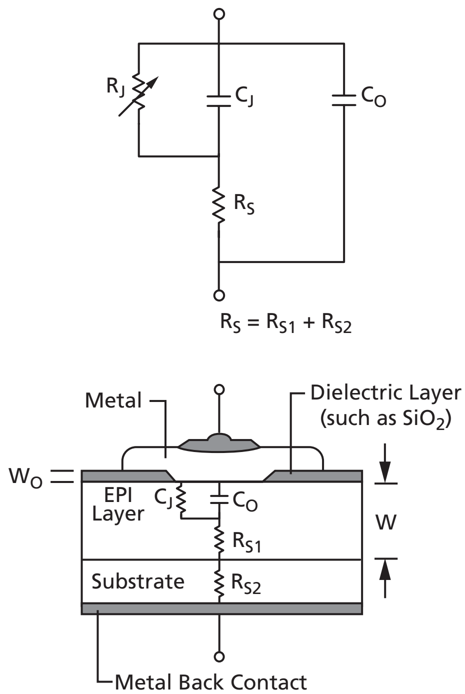


Figure 1. Schottky Diode Chip Equivalent Circuit

The nonlinear resistance can be obtained from the basic current voltage relation for the Schottky barrier. The elements R_{S1} and R_{S2} are a result of resistive losses in the undepleted epitaxial and substrate layers respectively. The resistive losses are generally represented by R_S, the total series resistance. The remaining circuit model element is C_O, the capacitance which results from the contact metal extending beyond the active region over the passivating oxide. Each of the circuit model elements will be discussed.

Total Capacitance

The total capacitance of a packaged Schottky barrier diode is given by:

$$C_T = C_J + C_O + C_P$$

where:

C_J = the metal semiconductor junction capacitance

C_O= the overlay capacitance across the oxide layer

C_P = the package capacitance

The overlay and package capacitance are either eliminated or minimized above Ka band frequencies.

Junction Capacitance

The junction capacitance of a Schottky barrier diode is given by:

$$C_J(0\ V) = \left[\frac{q \varepsilon_S N_D}{2\left(\phi_B - \frac{kT}{q}\right)} \right]^{1/2} A$$

where:

A = junction area

ε_S = electric permittivity of the semiconductor

N_D = donor density in n-layer

ϕ_B = barrier voltage seen by electrons in semiconductor for traversal into the metal

$C_J(0)$ = junction capacitance at zero volts

Overlay Capacitance

As seen in Figure 1, (C_O) the overlay capacitance is the capacitance due to the contact metallization extending beyond the active junction area over the passivating oxide. If one neglects effects of surface charges on the semiconductor or depletion of the semiconductor SiO_2 interface by the applied voltage, one can model the overlay capacitance as a plane parallel plate capacitance with the SiO_2 layer as a dielectric. Then C_O becomes:

$$C_O = \varepsilon_1 A_1 / W_O$$

where
ε_1 = electric permittivity of SiO_2
A_1 = area of overlay annular region
W_O = thickness of SiO_2

The overlay capacitance is a parasitic element which should be minimized for optimum diode performance. Containing C_O to a minimum value becomes especially important for frequencies above X band.

Series Resistance

The total series resistance as shown in Figure 1 consists of R_{S1} (due to the undepleted epitaxial layer) plus R_{S2} (due to the substrate). A low-frequency model, which neglects skin effect, will be discussed.

The epitaxial layer contribution to the resistance is given by:

$$R_{S1} = \frac{\rho \ell}{A} = \frac{\ell}{(q\mu_e N_D)A}$$

where:
ρ = resistivity of epitaxial layer
l = thickness of the undepleted epitaxial layer
A = area of Schottky junction
μ_e = electron mobility in epitaxial layer (assumes layer is N type)
N_D = donor density in epitaxial or active layer

The resistance contributed by the substrate may be modeled by using the resistance of a contact dot the size of the junction on a semi-infinite semiconductor substrate.

This model is generally valid as the active diode diameter is usually much less than the thickness of the substrate. Using this model, R_S2 becomes:

$$R_{S2} = \frac{\rho_S}{2d} = \frac{\rho_S}{4}\sqrt{\frac{\pi}{A}}$$

where
ρ_S = substrate resistivity
d = active junction diameter
A = area of Schottky junction

Using the equation $R_S = R_{S1} + R_{S2}$, the total resistance (R_S) becomes

$$R_S = \frac{\ell}{(q\mu_e N_D)A} + \frac{\rho_S}{4}\sqrt{\frac{\pi}{A}}$$

The above analysis totally neglects skin effects, which will increase the substrate contribution to R_S. For a high-frequency model, R_{S1} will be given by the same expression as above. In order to achieve model R_{S2}, one must consider that current will flow in surface layer one skin-depth thick on the substrate.

The model for R_{S2} will contain three components:

The first will be the spreading resistance of the area directly under the active region into a substrate one skin-depth thick.

The second will be the resistance of the top surface of the chip. This component may be approximated as the resistance of an annular ring of inner diameter (d), outer diameter (D), the total chip width, the thickness (δ), and the skin depth.

The third component of R_S will be the resistance of the chip sidewalls modeled with a thickness (δ). The total R_S at millimeterwave frequencies will be the sum of these three components, plus the resistance of the undepleted epitaxial layer.

Figure Of Merit

The cut-off frequency (Figure of Merit) of a Schottky barrier diode is maximized by minimizing the R_S, C_J product. Furthermore, mixer conversion loss can be shown to be directly proportional to the product of diode series resistance (R_S) and junction capacitance (C_J). By converting these parameters to semiconductor properties of the active junction, the following figure of merit for a Schottky barrier diode can be obtained:

$$\text{Conversion Loss} = L \propto R_S C_J \propto \frac{\ell}{\mu_e} \sqrt{\frac{\varepsilon}{N_D}}$$

and

$$\text{Cut-off Frequency} = f_c = \frac{1}{2\pi R_S C_J}$$

Mixer Diodes

Mixing is defined as the conversion of a low-power level signal from one frequency to another by combining it with a higher-power (local oscillator) signal in a nonlinear device. In general, mixing produces a large number of sum and difference frequencies of the signal, local oscillator and their harmonics. Usually the different frequency between signal and local oscillator — the intermediate frequency (IF) — is the desired output signal. The relationship of these signals to the mixing function is shown in Figure 2. The mixer output at the frequency

$2F_{LO} - F_{RF}$ is called the image

The local oscillator biases the diode to its nonlinear region and does not take part in the actual frequency conversion process; i.e., only RF signal power is converted to the IF and image frequencies.

Because of greater susceptibility to RF burnout, circuit complications and fabrication difficulties, tunnel and back diodes have not found wide acceptance as mixers and detectors at microwave frequencies. The Schottky barrier diode (formed by deposition of metal on a semiconductor surface) is the primary device used for mixer and detector applications at microwave and millimeterwave frequencies.

Equivalent Circuit

The Schottky mixer or detector diode may be regarded as a nonlinear conductance, g, shunted by a capacitance (C_J), in series with a resistance (R_S), as shown in the equivalent circuit of Figure 3. The conductance is the nonlinear barrier conductance at the rectifying contact and the capacitance is the barrier capacitance. At low frequencies the capacitance does not affect rectification, but at microwave frequencies its shunting action reduces the RF voltage across the barrier. Since it is impossible to tune out C at microwave frequencies with an external inductance due to the presence of R_S, C_J must be kept small so as to minimize reduction in rectification efficiency. The diode package parasitics are represented by (L_P), the series package inductance, and (C_P), the shunt package capacitance. Both L_P and C_P must be considered when packaged diodes are used.

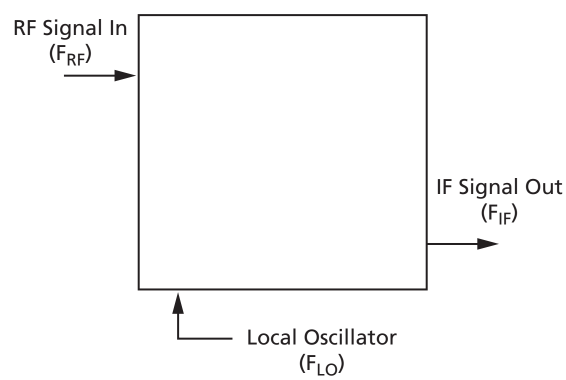


Figure 2. Mixing Function

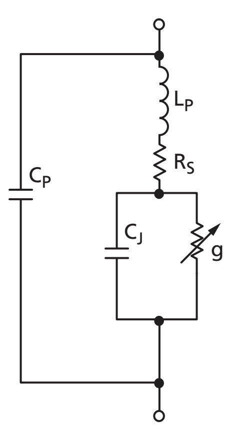


Figure 3. Equivalent Circuit of a Mixer Diode

Mixer Diode RF Parameters

A fundamental limitation on the sensitivity of a microwave receiver employing a Schottky mixer arises from the fact that, in the frequency conversion process, only a fraction of the available RF signal power is converted into power at the intermediate frequency. This "overall" loss is dependent primarily on the diode's junction properties, secondarily on the diode's package parasitics (i.e., mismatch of signal power by R_S, C_J) and on matching at the input and output ports of the mixer. An additional limitation in performance arises from the fact that the mixer itself generates noise (noise temperature ratio) when it is driven by an RF signal (local oscillator). Thus, the conversion loss and the noise temperature ratio are the essential parameters of the microwave mixer diode. The mixer diode is completely characterized by the following RF parameters: (a) conversion loss, (b) noise temperature ratio, (c) receiver noise figure, (d) RF impedance and (e) IF impedance.

A. Conversion Loss Theory
The conversion loss of a mixer diode is dependent on several factors, including both the package and the active chip. Conversion loss (L_C), can be considered to be the sum of several losses. The first component of total diode conversion loss can be called the "matching loss" as it is dependent on the degree of impedance match obtained at both the RF signal and IF ports. Less than optimum match at either of these ports will result in a reduction in the available RF signal at the diode and the inefficient transfer of the IF signal.

The second component in the loss of signal power is due to the diode's parasitic elements (R_S and C_J), and called "parasitic loss."

Since the value of R_J is strongly dependent on the local oscillator drive level, the value of L_2 is a function of LO drive. R_S is also a slight function of drive level. Further increase in the drive results in increased L_2 due to the dissipation in R_S, while decreasing drive also gives insertion loss increase due to the shunting effect of the junction capacitance.

The third component is the actual conversion loss at the diode junction. This depends mainly on the voltage versus current characteristics of the diode and the circuit conditions at the RF and IF ports. The nonlinear behavior of the diode is represented by a time-varying conductance (g), which is dependent on the DC characteristics of the diode and local oscillator voltage waveform across the diode. Conversion loss and impedance values can then be calculated for the various image terminations by means of linear network theory.

It can be shown that (L_3) min approaches, as a limit, a value of 2 or 3 dB. Thus, for an ideal mixer, the theoretical minimum conversion loss is 3 dB under broadband conditions. Thus, a maximum of half the power is delivered to the IF port and the remaining power is dissipated at the image termination.

Under narrow band conditions, the image can be reactively terminated such that RF power at the image frequency recombines with a local oscillator to improve the conversion loss of a diode. Theory predicts that a conversion loss of 0 dB for open- or short-circuited image terminations can be obtained.

The overall conversion loss (L_C), is the sum of the three described loss components.

B. Noise Temperature Ratio
In Schottky barrier diodes, there are three main sources of noise. The first is thermal noise, which is present in any conductor at thermodynamic equilibrium. The second is shot noise, which is generated under the influence of an electric field. The third component, which increases with decreasing frequency, is usually referred to as 1/f or flicker noise.

The causes of flicker noise are not yet fully understood, although it may be primarily a "surface affect" due to a large dependence of noise upon the surface and its surrounding.

C. Overall Receiver's Noise Figure
The most important criterion of mixer performance is the overall receiver's noise figure. The noise at the output of a receiver is the sum of the noise arising from the input termination (source) and noise contributed by the receiver itself (i.e., due to IF amplifier and mixer diode). The noise factor is the ratio of the actual output noise power of the device to the noise power which would be available if the device were perfect and merely amplified by the thermal noise of the input termination without contributing any noise of its own.

It is given by the relation

$$NF = \frac{\frac{S_I}{N_I}}{\frac{S_O}{N_O}}$$

where
Si = available signal power at the input of receiver
Ni = available noise power at the input of receiver
So = available signal power at the output of receiver
No = available noise power at the output of receiver

$$NF\ (dB) = 10\ Log_{10} \frac{\frac{S_I}{N_I}}{\frac{S_O}{N_O}}$$

The noise figure is the noise factor in decibels.

The overall noise figure of a receiver depends on the conversion loss (L), the noise temperature ratio of the mixer diode (t), and on the noise figure of the IF amplifier (F_{IF}). It is given by the relation:

$$NF\ (dB) = L_C\ (t + F_{IF} - 1)$$

Mixer noise is also expressed in terms of mixer input noise temperature, TM.

$$T_M = tT_O \text{ where } T_O = \text{measurement temp.}$$

Hence L and t are the important diode parameters which must be minimized to obtain the overall low-noise figure.

D. RF Impedance
The RF impedance of varistor rectifiers is a property of prime importance in the design of mixers.

Impedance mismatch at radio frequencies not only results in signal loss due to reflection but also affects the IF impedance at the IF terminals of the mixer, an effect that becomes more serious with rectifiers of low conversion loss. The RF impedance of a varistor diode can be measured by a VSWR method or directly with a network analyzer.

The RF impedance is a complicated function of package geometry, size and shape of package parts, and composition of the semiconductor and junction parameters. In order to establish a good match between a semiconductor chip and RF line, a matching transformer is generally an essential part of a microwave mixer.

E. IF Impedance
A matter of prime importance in the design of coupling circuits between the mixer and IF amplifier is the IF impedance that is seen by looking into the IF terminals of a varistor mixer. The pertinent IF impedance (Z_{IF}) is that impedance at the output terminals of the mixer when the rectifier is driven by a local oscillator. It is a function of the local oscillator power level, and depends on the RF properties of the mixer and circuit connected to the RF terminals of the mixer.

An accurate measurement of IF impedance is essential for measuring noise temperature ratio (t), and conversion loss, (L_C), of a mixer diode. The IF impedance of a mixer diode can be measured directly with an impedance analyzer.

Receiver Sensitivity

The following equation for the sensitivity of a receiver shows the parameters which affect system sensitivity:

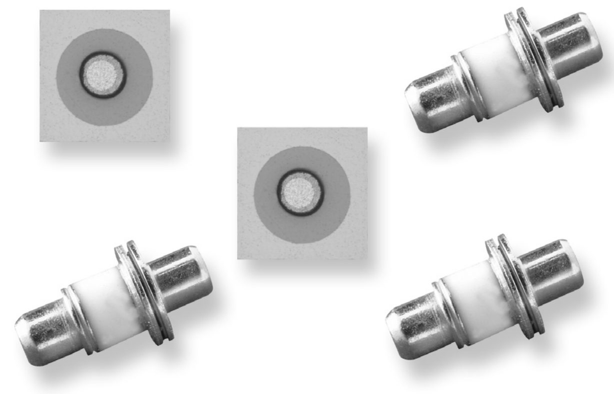
$$S = -114\ dBm + NF_O + 10\ Log_{10}\ B + 10\ Log_{10} \frac{S}{N}$$

where
S = receiver sensitivity in dBm
NF_O = receiver overall noise figure in dB
B = receiver bandwidth in MHz
S/N = minimum acceptable receiver signal to noise ratio in dB

PIN Diodes

Features

- Low Series Resistance
- Fast Switching Speed
- Low Capacitance
- No Reverse Bias Required
- Available as Passivated Chip
- Available in Ceramic Packages



Applications

- Switches
- Attenuators
- Phase Shifters
- Limiters

Maximum Ratings

Reverse Voltage: (V_R)	Breakdown Voltage (V_{BR})
Forward Current: (I_F)	50 mA Max. @ 25°C
Incident Power	+20 dBm Max. @ 25°C
Operating Temperature: (T_{OP})	-55°C to +175°C
Storage Temperature: (T_{ST})	-55°C to +200°C

Description

The Gallium Arsenide PIN diodes are fabricated utilizing a gold contact mesa and then passivated with Silicon Nitride. The diodes have been specially designed to have a short carrier lifetime for fast switching speed and low resistance. With no reverse bias needed and high impedance characteristics of the PIN, it is able to achieve nanosecond switching speeds with standard logic. The diodes are available in chip and a variety of microwave ceramic packages.

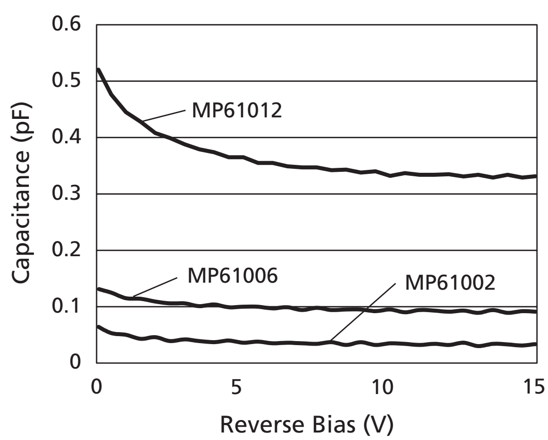
Gallium Arsenide PIN Diodes (Specifications @ 25°C)

Part Number	C_J @ -10 V Max. (pf)	Min. Reverse Breakdown Voltage (V)	Max. Forward Resistance @ 20 mA (Ω)	Typ. Switching Speed (ns)	Typ. Minority Carrier Lifetime (ns)[1]
MP61001	0.03	200	3.0	20.0	50
MP61002	0.04	200	3.0	20.0	50
MP61003	0.05	200	3.0	20.0	50
MP61004	0.06	100	2.0	9.0	15
MP61005	0.07	100	2.0	9.0	15
MP61006	0.08	100	2.0	9.0	15
MP61007	0.10	75	2.0	6.0	10
MP61008	0.12	75	2.0	6.0	10
MP61009	0.15	50	1.0	3.5	5
MP61010	0.18	50	1.0	3.5	5
MP61011	0.23	50	0.8	3.5	5
MP61012	0.35	50	0.8	3.5	5

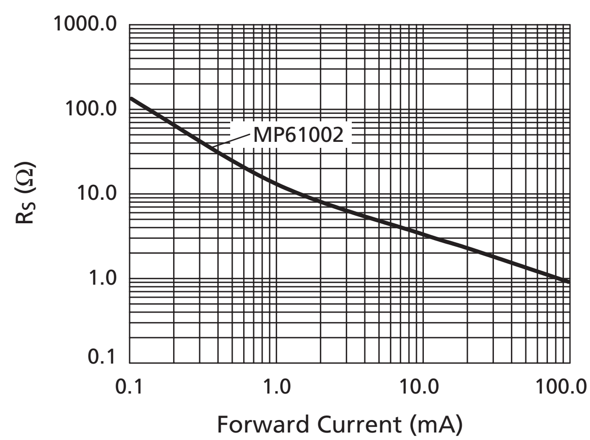
[1] Minority carrier lifetime is inferred from stored charge measurement with a forward current of 10 mA.

Note:
All GaAs PIN diodes are passivated with Silicon Nitride with a minimum bonding area diameter of 50 microns.

Performance Characteristics



Typical Capacitance vs. Reverse Bias



Typical Forward Series Resistance vs. Forward Current at 1 GHz

MDT offers a selection of GaAs PIN diodes for use in Microwave applications ranging from switches, attenuators, phase shifters to limiter circuits. The properties of Gallium Arsenide provide fast switching speeds and enable circuit designers to operate at very high operating frequencies. MDT's line of PIN products covers a variety of series resistance curves to fit most designs. With the incorporation of passivation, the reverse leakage current is minimized and the reliability of the device is increased. Depending upon the application or design, various package styles are offered. The available case styles cover both coplanar as well as coaxial designs. The packages are hermetically sealed and are suitable for commercial, military and space-qualified applications.

Theory

PIN diodes are typically used in both the forward and reverse bias configuration. The PIN diode, when biased in the forward direction, acts as a variable resistor. The resistance of the PIN diode decreases and eventually becomes constant with applied forward current. When biased with enough forward current, the device is considered to be in the full "on" state. In the reverse direction, the PIN diode, like the varactor diode, varies in capacitance with applied reverse voltage. The change in capacitance becomes constant with enough applied voltage. In the constant capacitance state, the device is considered to be fully "off". When the PIN diode is used as a switch, typically, the device is biased in both the reverse and forward directions in a full "on" and "off" condition. In Figure 1, the typical bias configurations are shown for switching applications. Depending upon the configuration or bias state, the device blocks or passes microwave power. The capacitance and series resistance inherent within the device construction determines the amount of power that is transmitted or blocked.

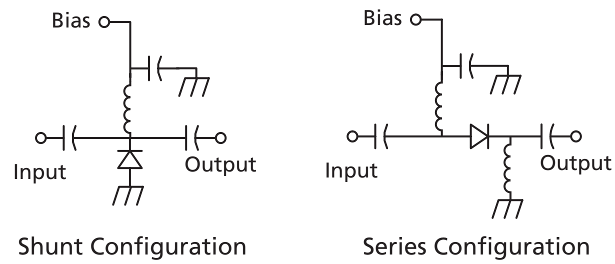


Figure 1. PIN Diodes Switch Circuits

The PIN diode, because of the series resistance change with applied forward current, can also act as an attenuator. The same configuration as the switch circuits (Figure 1) can be biased to provide attenuation within a circuit design. As an attenuator, the forward current applied to the device determines the amount of attenuation the device provides a circuit. The attenuation of these circuits can be estimated from the following equations:

For shunt configuration

$$\text{Attenuation (dB)} = 20*\text{Log}(1+Z_O/(2 * R_S))$$

For series configuration

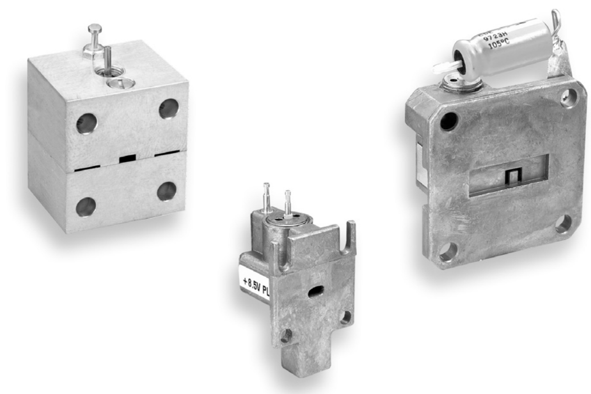
$$\text{Attenuation (dB)} = 20*\text{Log}(1+R_S/(2 * Z_O))$$

The equation also assumes that the reactance at device operating frequency is insignificant compared to device R_S. These configurations are in their simplest form and are considered reflective attenuators. Matched designs with more complex circuits can be derived. In order to obtain higher isolation, multiple diode configurations can be used to optimize performance.

Gunn Oscillators

Features

- Low Cost
- Small Size
- Low Power Consumption
- High-Volume Design
- Pulsed DC Input Voltage Available



Applications

- Speed Radar
- Intrusion Alarm Systems
- Braking Systems
- Industrial Measurement
- Level Sensing

Description

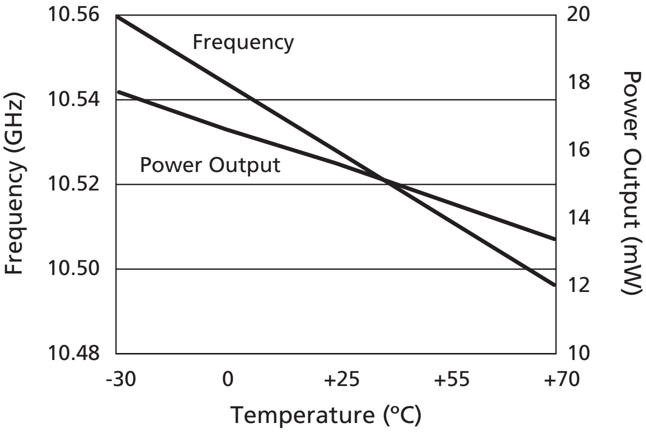
These Gunn oscillators are of waveguide type, and are an inexpensive and reliable source of microwave power. The oscillators are designed to suppress spurious and harmonic frequencies. Their low-power consumption makes them ideal for most microwave systems.

Specifications @ 25°C

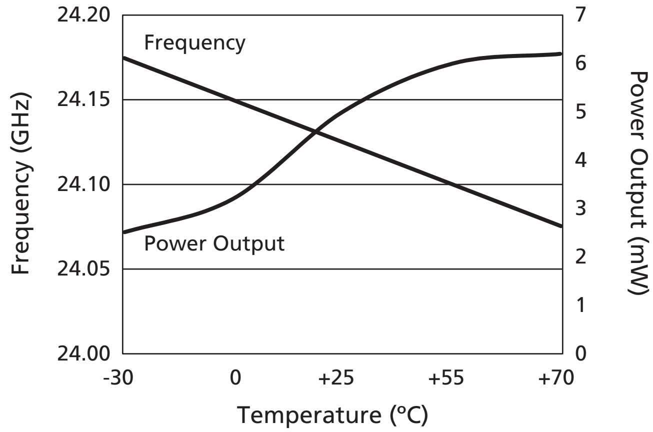
Part Number	Operating Voltage (V_{DC})	Frequency (GHz)	Output Power (mW)	Operating Current (mA)	Frequency Drift/Temperature (KHz/°C)
X Band Oscillators					
MO86751A	+8.5	10.525	10 Min.	200	350
MO86751B	+9.0 to +10.0	10.525	25 Min.	500	350
MO86751C	+9.0 to +10.0	10.525	50 Min.	600	350
MO86751D	+9.0 to +10.0	10.525	100 Min.	800	350
K Band Oscillators					
MO9060	+5.0	24.125	5	100	1000
MO86790	+3.5 to +6.5	24.150	10–20	250	555
MO86791	+5.0 to +8.0	24.150	40–100	1000	555
K Band Oscillators — Pulsed					
MO9080	+6.0 to +7.0	24.125	11–20 Peak	300 Peak	1000
Ka Band Oscillators					
MO86797	+3.0 to +6.0	35.500	15–25	450	1400
MO9205	+5.0	35.500	15–30	400	800

Other frequencies and power levels available upon request.
Maximum temperature is -30°C to +70°C.
MO9080 pulse width= 10 microseconds duty = 50%.

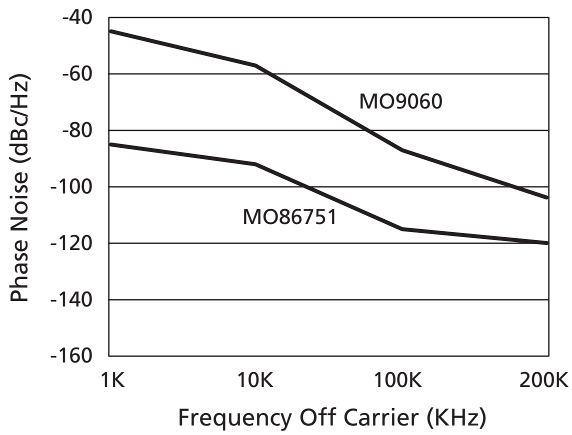
Performance Characteristics



MO86751 Series Gunn Oscillator Frequency and Power/Temperature

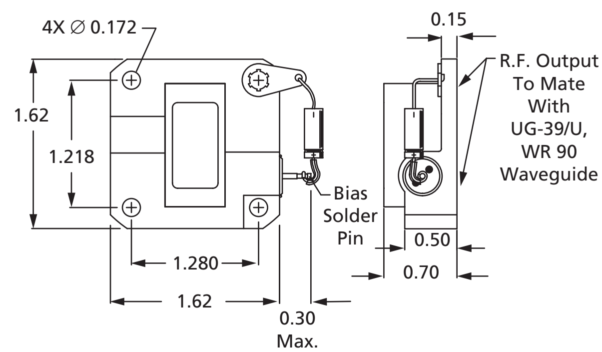


MO9060/9070 Series Oscillator Frequency and Power/Temperature



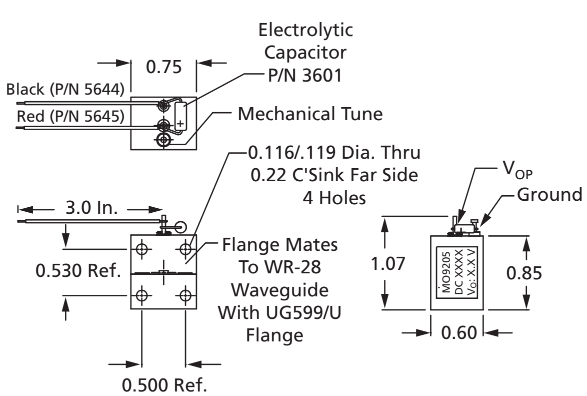
MO9060 and MO86751 Series Typical Phase Noise Performance

MO86751-A, B, C, D



Dimensions are in inches (mm).

MO9205

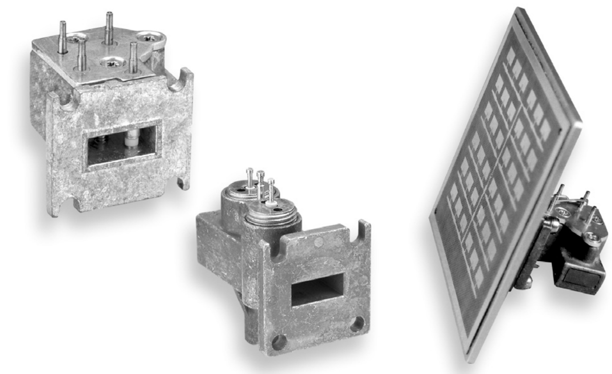


Dimensions are in inches (mm).

Gunn Transceivers

Features

- Low Cost
- Direction-of-Motion Sensing
- High-Volume Design
- Various Output Power Levels
- Dual-Channel Output
- Pulsed DC Input Voltage
- Low-Power Consumption



Applications

- Automatic Door Openers
- Intrusion Alarm Systems
- Speed Radars
- Presence Sensing
- Traffic Control Systems
- Level Sensing

Description

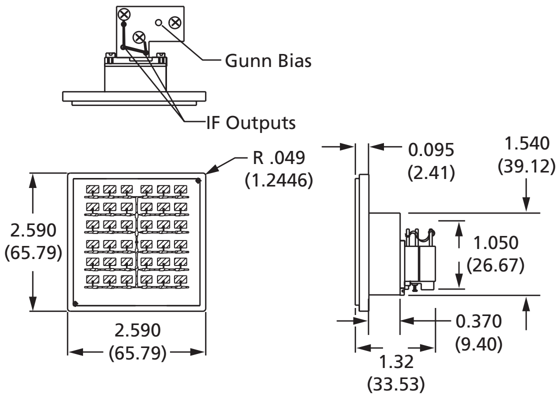
These transceivers are of waveguide type, and are a reliable source of microwave power for speed and motion detection applications. The transceivers are a fully integrated module, with a Gunn diode mounted in the cavity for the transmitter and one or two Schottky barrier diodes for the receiver. An IF output is generated whose frequency is proportional to the target's velocity. With the two-mixer design, the direction-of-motion is obtained as a phase difference between the two IF outputs.

Specifications @ 25°C

Model Number	Description	Operating Voltage (V_{DC})	Frequency (GHz)	Output Power (mW)	Operating Current (mA)	Frequency Drift/ Temperature (KHz/°C)	Nominal Sensitivity (dBc)	Mixer Phasing (Degrees)
X Band Transceivers								
MO86728		+7.5 to +8.5	10.525	5	150	450	-95	
MO86735	Dual IF Output	+8.5	10.525	5	200	450	-95	75–105
K Band Transceivers								
MO9061		+5	24.125	5	100	1000	-92	
MO9062	Dual IF Output	+5	24.125	5	100	1000	-92	50–130
MO9081	Pulsed DC	+6 to +8	24.125	10–20	100	1000	-90	
MO9082	Pulsed DC, Dual IF Output	+6 to +8	24.125	10–20	100	1000	-90	50–130
MO9300		+4 to +6	24.125	2–5	250	750	-90	
MO86861-MO8	Dual IF Output	+5	24.125	5	250	750	-90	75–105
MO9096	Dual IF Output, with Microstrip Planar Antenna	+3.5 to +6.5	24.125	8	220	1000	-90	60–120

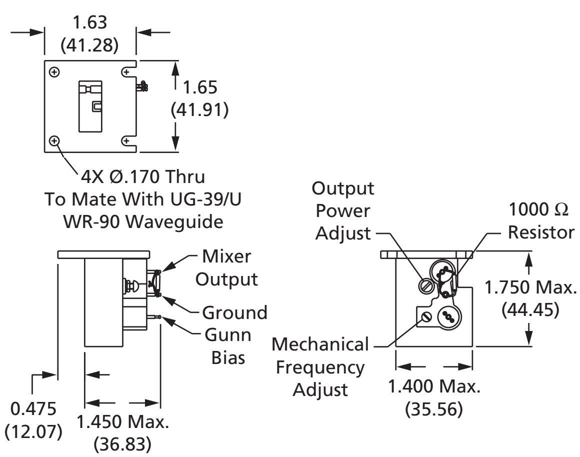
Other frequencies and power levels available upon request.
Maximum operating temperature is -30°C to +70°C.
Maximum storage temperature is -40°C to +85°C.

MO9096



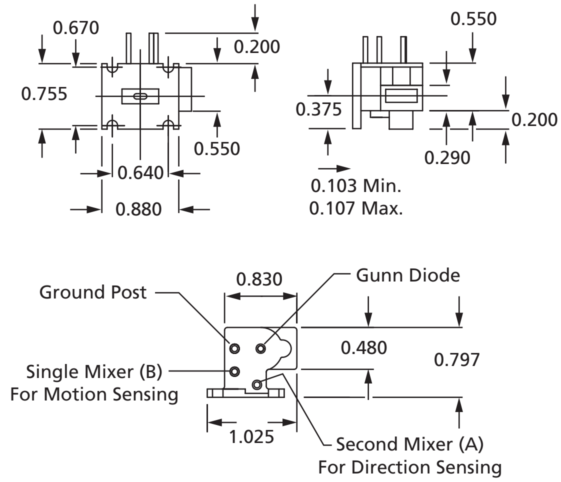
Dimensions are in inches (mm).

MO86728



Dimensions are in inches (mm).

MO9062



Dimensions are in inches (mm).

Voltage Controlled Oscillators

Features

- Low Cost
- High-Volume Design
- Various Output Power Levels
- Pulsed DC Input Voltage
- Low-Power Consumption
- FM CW Operation

Applications

- Intrusion Alarm Systems
- Speed Radar
- Presence Sensing
- Traffic Control
- Level Sensing
- Weather Radar
- Amateur Communications

Description

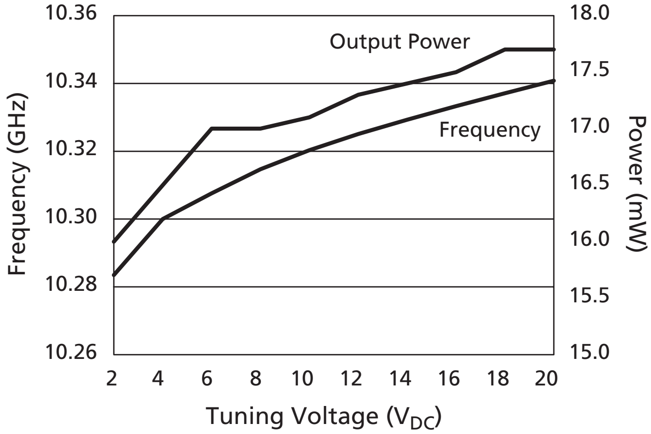
The voltage controlled oscillators are designed to provide an affordable, frequency-modulated microwave power at a discrete frequency. The varactor tuning of the oscillator permits carrier frequency modulation for ranging information.

Specifications @ 25°C

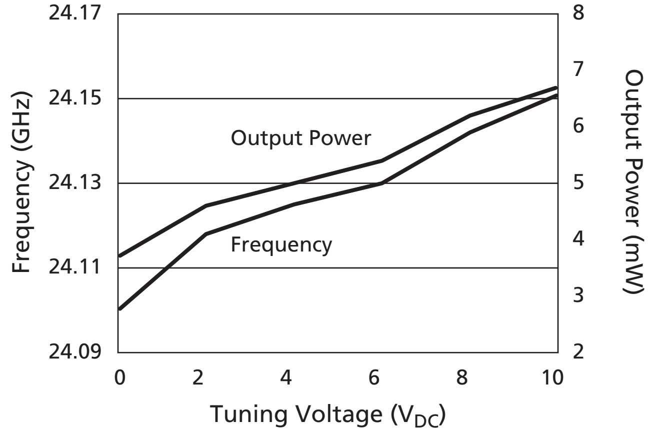
Part Number	Operating Voltage (V_{DC})	Frequency (GHz)	Output Power (mW)	Operating Current (mA)	Frequency Drift/ Temperature (KHz/°C)	Electronic Tuning Range (V_{DC})	Electronic Tuning (MHz)
X Band Voltage Controlled Oscillators							
MO87108-1	+8.0 to +10.0	10.300	15	200	400	+1 to +20	40
MO87108-2	+8.0 to +10.0	10.300	25	600	400	+1 to +20	40
MO87108-3	+8.0 to +10.0	10.300	40	600	400	+1 to +20	40
MO87603B	+10.5	9.405	7–25	200	450	0 to +13	63–100
K Band Voltage Controlled Oscillators							
MO9070	+5.0	24.125	3	100	1000	+2 to +10	25
MO87828-1	+5.0 to +8.0	21.500	10	400	300	0 to +15	40
MO87828-2	+5.0 to +8.0	22.100	10	400	300	0 to +15	40
MO87828-3	+5.0 to +8.0	22.700	10	400	300	0 to +15	40
MO87828-4	+5.0 to +8.0	23.300	10	400	300	0 to +15	40
MO87827-1	+5.0 to +8.0	21.500	60	1400	300	0 to +10	30
MO87827-2	+5.0 to +8.0	22.100	60	1400	300	0 to +10	30
MO87827-3	+5.0 to +8.0	22.700	60	1400	300	0 to +10	30
MO87827-4	+5.0 to +8.0	23.300	60	1400	300	0 to +10	30

Other frequencies and power levels available upon request.
Maximum temperature is -30°C to +70°C.

Performance Characteristics

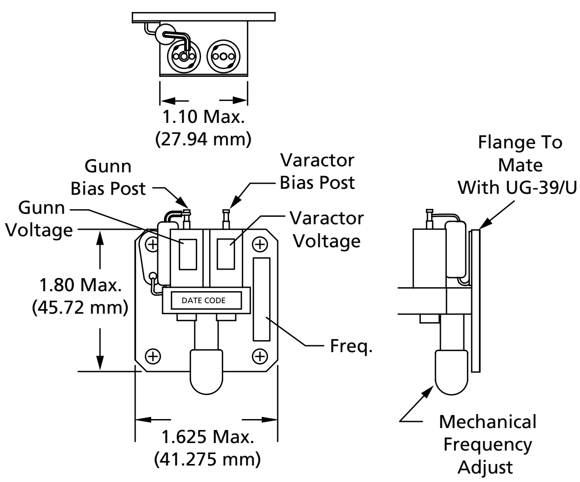


MO87108 Series VCO
Frequency and Power /Tuning Voltage



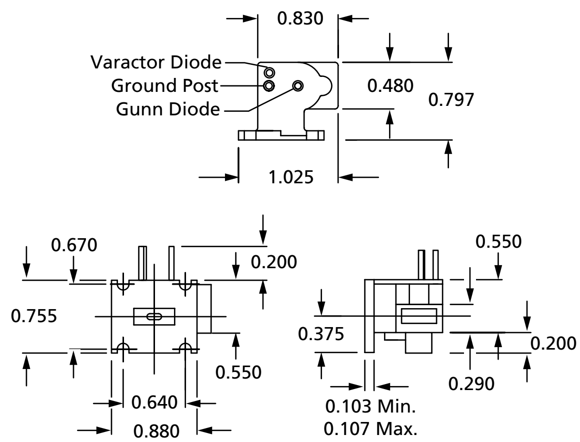
MO9070 Series VCO
Frequency and Power /Tuning Voltage

MO87108



Dimensions are in inches (mm).

MO9070

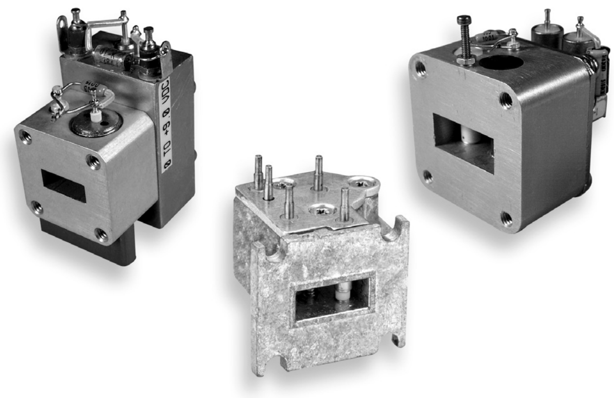


Dimensions are in inches (mm).

Voltage Controlled Transceivers

Features

- Frequency Control
- Input Voltage Available as CW or Pulsed
- High Doppler Sensitivity Levels
- Low AM and FM Noise Levels
- Direction-of-Motion Sensing
- High-Volume Design
- Compact Size



Applications

- FM Doppler Radar Systems
- Altimeters
- Police Radars
- Intrusion Alarm Systems
- Traffic Control Systems
- Industrial Control
- Direction Monitoring
- Amateur Communications
- Automotive Collision Avoidance Systems

Description

These voltage controlled transceivers are designed to provide an affordable, frequency-modulated microwave power at a discrete frequency. The varactor tuning of the transceiver permits carrier frequency modulation for ranging information.

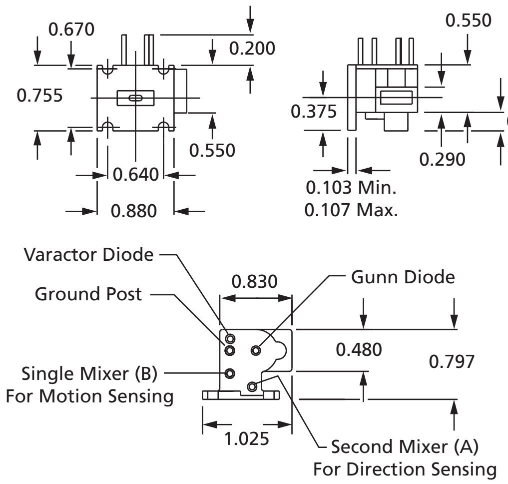
Specifications @ 25°C

Model Number	Description	Operating Voltage (V_{DC})	Output Power (mW)	Operating Current (mA)	Frequency Drift/ Temperature (KHz/°C)	Electronic Tuning Range (V_{DC})	Electronic Tuning (MHz)	Nominal Sensitivity (dBc)
X Band Voltage Controlled Transceivers								
MO87127-1	Built-In Ferrite Circulator	+8 to +10	10	200	400	+1 to +20	40	-110
MO87127-2	Built-In Ferrite Circulator	+8 to +10	20	600	400	+1 to +20	40	-110
MO87127-3	Built-In Ferrite Circulator	+8 to +10	35	600	400	+1 to +20	40	-110
K Band Voltage Controlled Transceivers								
MO9071		+5	5	150	1000	+1 to +20	50	-90
MO9072	Dual IF Output	+5	5	150	1000	+1 to +20	50	-90
MO87849		+5 to +8	5	400	500	+0.5 to +20	150	-95
MO87930	Broadband Electronic Tuning	+5 to +8	5 to 10	400	500	0 to +9	350	-95

X band frequency = 10.300 GHz.
K band frequency = 24.125 GHz.
Other frequencies and power levels available upon request.

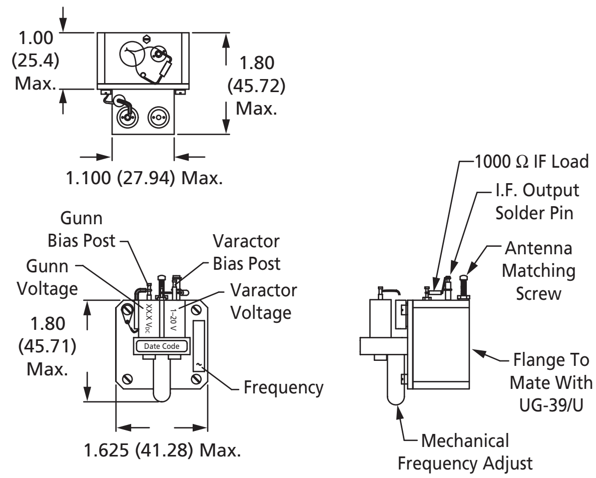
Maximum operating temperature is -30°C to +70°C.
Maximum storage temperature is -40°C to +85°C.

MO9072



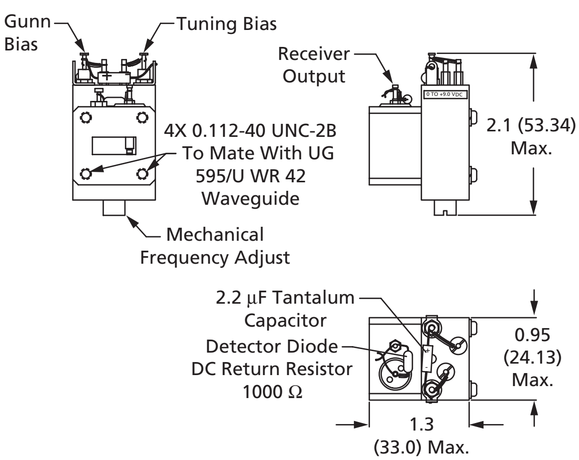
Dimensions are in inches (mm).

MO87127-1 thru 3



Dimensions are in inches (mm).

MO87930



Dimensions are in inches (mm).

Fundamentals Of Commercial Doppler Systems

Speed, Motion and Distance Measurements

I. Introduction

MDT manufactures a large variety of microwave oscillators, transceivers, and other components for the motion-detection market.

These components have been designed for use in microwave systems that measure vehicle speed — (police radar and true ground speed for agricultural vehicles), detect motion (intrusion alarms), and measure range (braking systems) or direction of motion (stereo systems). The microwave Doppler sensors are also used in industrial control applications, such as counting objects moving on a conveyor belt, measuring vibration in machine parts or measuring levels of liquid products, etc. Another major use is for automatic door openers for public buildings.

The following Sections (II–VII) discuss some of the most important considerations when designing a commercial Doppler radar system.

II. Principles of Doppler Radar

When microwave energy is reflected by a moving target, there is a shift in frequency. All Doppler radars utilize this principle. The amount of frequency shift is directly proportional to the target's velocity relative to the radar's transmitter. A similar effect at audible frequencies occurs when an automobile horn is moving with respect to a stationary observer. The sound pitch is higher when the horn is moving toward the observer and decreases as it moves away from him. Figure 1 snows the situation of a target vehicle approaching a Doppler radar. The Doppler shift frequency (F_D) is given by:

$$F_D = 2V\frac{(F_0)}{C}\cos \varnothing$$

where

F_0 = transmitter frequency in hertz

C = velocity of light (3×10^8 meters per second)

V = velocity of the target (meters per second)

$\varnothing$ = angle between microwave beam and target's path

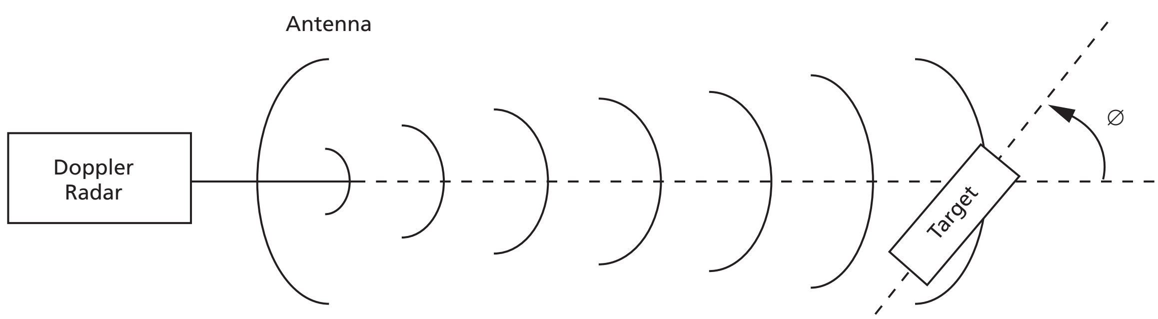
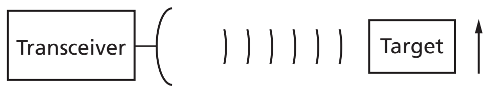


Figure 1. Doppler Shift Caused by Relative Motion of the Target

If ∅ = 90 degrees (target moving perpendicular to microwave beam) $F_D = 0$, there is no Doppler shift, i.e.,

A


If ∅ – 0 degrees (target moving parallel to microwave beam), $F_D = 2V(F_O/C)$, which gives the maximum Doppler shift attainable. Most police radars are used at an angle of ~15° (or less) when measuring automobile speed. The error is small and normally corrected in the software of a high-quality police radar.

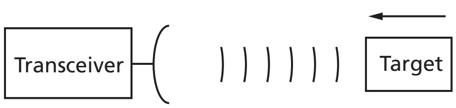
B


Figure 2 is a chart showing Doppler shift frequency (F_D vs. velocity (v)) for 10.525, 24.150 and 34.3 GHz. These are the usual frequencies used for police radars.

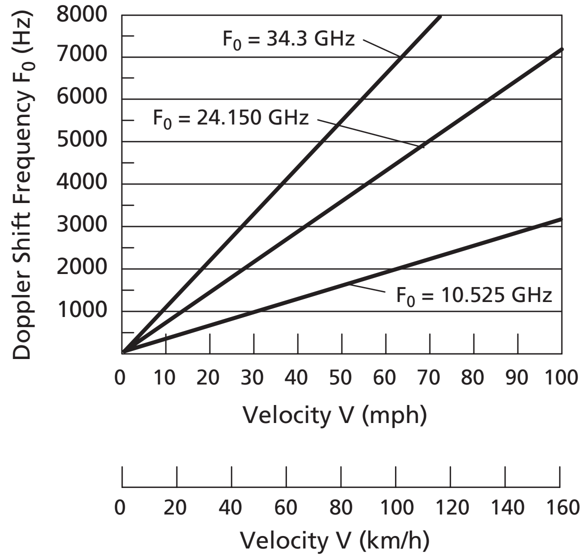


Figure 2. Doppler Frequency vs. Relative Speed of the Target

III. Typical Doppler Radar Systems

A typical Doppler radar is represented by the block diagram in Figure 3. This system consists of an RF (i.e., microwave) section, a signal processing section, and a well regulated power supply.

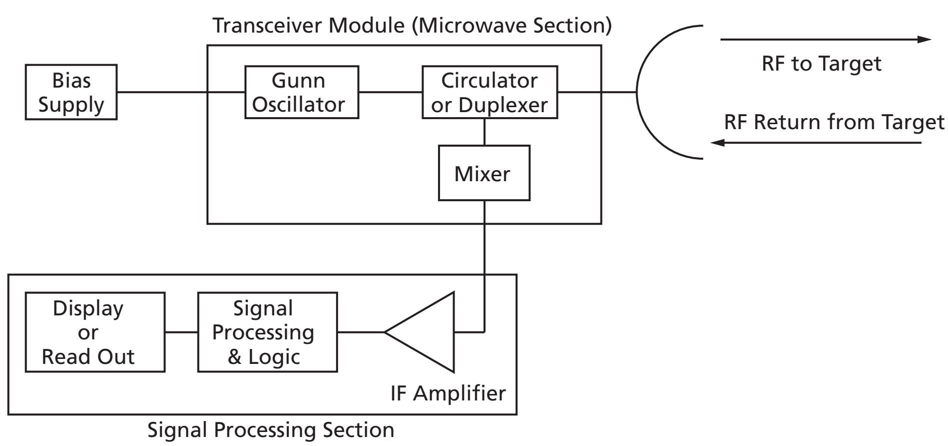


Figure 3. Typical Doppler Radar (Motion Detectors)

In order to design a Doppler radar system, one must first know:

1. The maximum range at which a target is to be detected (This determines the overall sensitivity and transmitter power required for the transceiver. It may also influence the antenna gain required.)

2. The maximum and minimum target speeds that the system is to measure (This determines the characteristics of the amplifier and its bandpass filter.)

3. The nominal radar cross section of the "target" one wishes to "observe".

4. Other environmental factors such as rain, fog or dust.

Note: These requirements are discussed in later sections. Doppler systems for police radars, intrusion alarms and most other applications usually operate with a "Zero IF". Some of the transmitter's power (Gunn Oscillator) is used as the local oscillator for the mixer. When using this technique, signal amplification occurs at the Doppler Shift Frequency.

For example, with the transmitter frequency 10.525 GHz, a vehicle traveling 50 mph causes a Doppler shift of 1568 Hz, which will be the IF frequency. This IF voltage is usually only a few microvolts RMS. at the mixer port in normal usage.

The IF amplifier's bandpass frequency for an X band police radar might allow 500–5000 Hz to pass, to include the range of target speeds expected, i.e., ~15 to ~150 mph. Police radars at K or Ka band will have higher IF frequencies (see Figure 2). The maximum target range of one mile is typical for a speed radar on a long, straight, flat road, although most are used at shorter ranges.

IV. Distance Measurement

A Stationary Target

The distance or range of a stationary target may be determined by changing the frequency of the transmitted signal during the "radar pulse" at a linear and known rate, and then comparing the frequency of the return to the transmitted signal. This can be done with a simple VCO transceiver, i.e.,

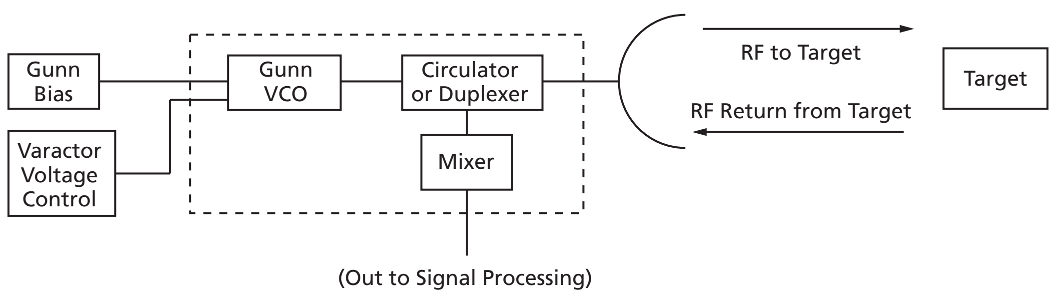


Figure 4. Voltage Controlled Transceiver

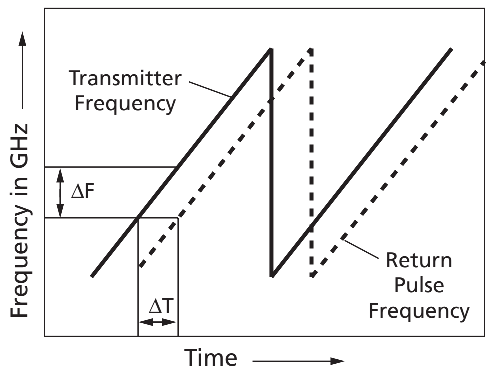


Figure 5. Gunn Voltage Controlled Oscillator Frequency vs. Time

The return signal will be shifted in frequency with respect to the initial signal transmitted. This shift (Δf) will be directly related to the amount of (ΔT) time it takes for the signal to make the round trip. We call this quantity the "transit time". The transit time (T) is approximately 1 microsecond for a target 150 meters away (~500 feet). (microwave propagation occurs at the speed of light — approximately 1 nanosecond per foot).

The range of a stationary target can then be calculated by determining the transit time of the radar signal to and from the target, and multiplying that by the speed of light (see Equation 2). The transit time in seconds is given by the absolute value of the difference in the transmitted and return signal, i.e.,

$$(1)\quad T = \frac{(F_T - F_R)}{K}$$

where
F_T = transmitter frequency in Hz
F_R = return frequency in Hz
K = rate of frequency modulation of the transmitter in Hz/sec
Note: $(F_T - F_R)$ is the IF frequency observed at the mixer's IF port.

Then: The range is given by

$$(2)\quad R = \frac{T \times C}{2}$$

where
C = speed of light in meters/sec = 3×10^8 meters/sec
T = transit time from (1) (in seconds)
R = range (in meters)

V. Direction-Sensing (Motion Detectors, Stereo) Systems

It is often very useful to be able to determine the direction of the target when using a motion detector such as an intrusion alarm or door opener.

A direction-sensing system can gate out vibrations or distinguish between approaching and receding targets. This can minimize false alarm problems caused by a vibrating surface such as a curtain blown by the wind. Energy can be conserved by quickly closing the door behind someone. Other types of background noise which can be removed are vibration of windows, moving fan blades, or incandescent light reflections.

A Doppler radar can give a target directional information by adding a second microwave mixer diode that is offset approximately 45° from the first mixer (at both the transmitted and received frequency). (See Figures 6a & 6b). The output of the 2 mixers is then fed to a phase comparator which measures the phase angle between the two detected signals.

If the target is approaching the radar, the first mixer will lead the second (see Figure 6a) i.e., the phase shift will be positive.

If the target is moving away, the first mixer will lag behind the second.

Vibrating targets, such as curtains or fans, will have periodic phase changes and can be cancelled. Incandescent lights give a periodic reflection too. This can also be determined and removed by software or a notch filter.

A stereo system can also measure velocity by determining the Doppler shift frequency in either IF Port. In a properly designed system, the Doppler frequencies will be equal.

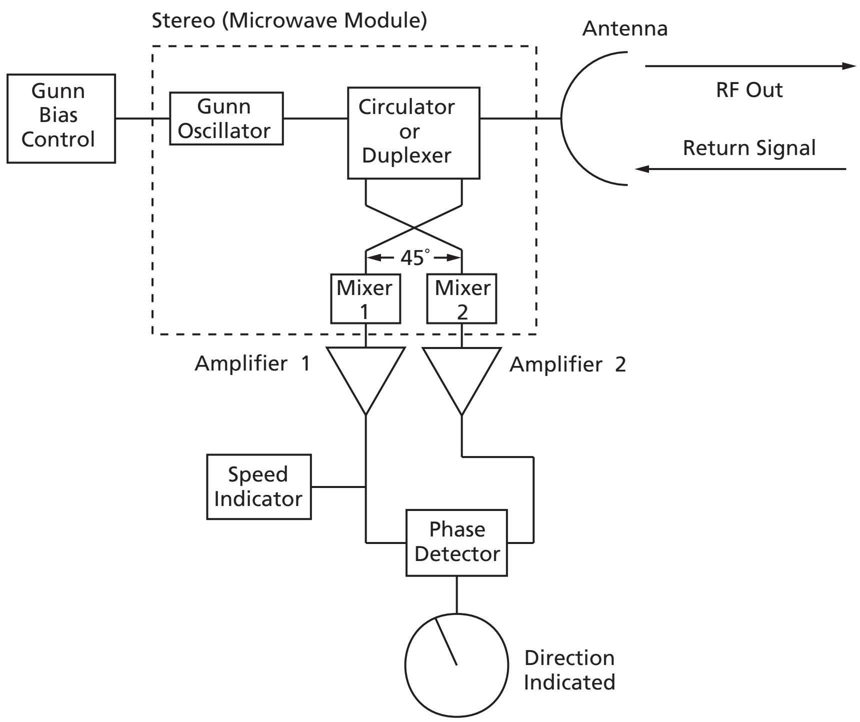


Figure 6a. Direction Sensing or Stereo Transceiver

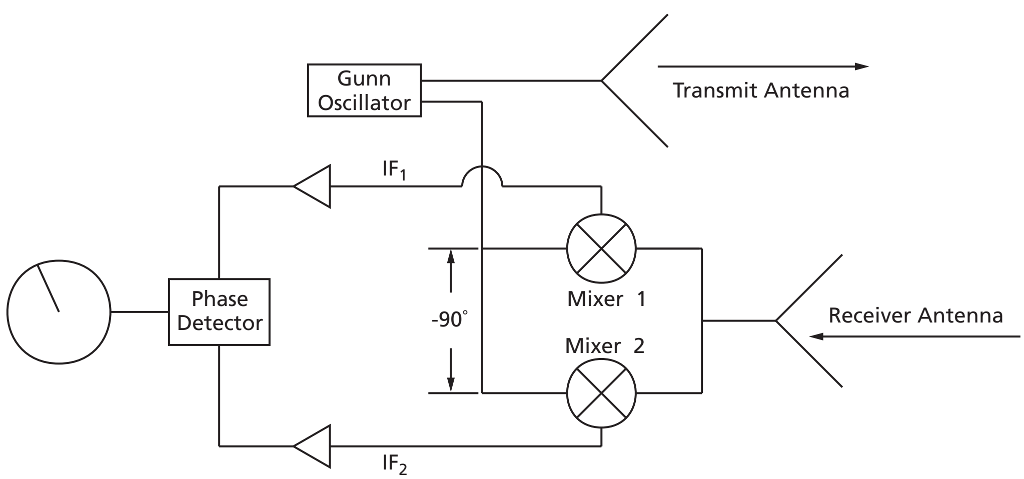


Figure 6b. Alternate Design Stereo Transceivers

VI. Range Considerations

The effective range of a Doppler system is a function of how much energy is reflected back to the transceiver from the target, and how strong that signal must be to make the receiver work properly. The major items controlling range are: 1) the transceiver's sensitivity, 2) the power output, 3) the gain of the antenna, 4) the reflection coefficient of the target and 5) the transmission or propagation loss.

When designing or using a motion detection system, the transceiver's sensitivity will be the single most important determinant of maximum range. Section VII discusses several factors that affect the receiver's sensitivity.

A second factor is the FM noise close to the carrier from its Gunn source. This can be best controlled by Gunn diode selection and proper Gunn bias conditions. MDT takes particular care to manufacture, characterize and select low-FM noise Gunn diodes for its transceivers.

Range can also be increased by increasing transmitter power — but doubling the transmitted power will only increase range up to 25% maximum. In many cases, we find that ground clutter (unwanted reflections) can result in very little practical increase in range.

The antenna gain affects the range too. In many applications, the beam shape of the antenna is more critical for proper operation than that of the gain it adds to the system. Beam shapes are usually chosen to fit particular applications. For example, a door opener placed over a door with a long, narrow entrance will require a different beam pattern than the same door opener placed in a building entrance which can be approached from both the side and the front. When a transceiver is used in a microwave barrier or fence (perimeter protection), a very thin, focused beam is required. This requires a vertical, high-gain antenna. Other custom-made antennas with different beam widths, antenna patterns and/or gains can be designed for specific requirements. All will affect range.

VII. Receiver Considerations

The characteristics and sensitivity of the receiver are normally the dominant factors in determining the range of a simple Doppler radar. Almost all commercial Doppler transceivers use low- or medium-barrier Schottky diodes for the detector/mixer. At normal L.O. bias levels, these diodes will have conversion losses of 5–8 dB (loss of return signal in the diode's mixing process).

All mixer diodes also have 1/f noise. This 1/f noise is an excess noise caused by surface states and traps in the semiconductor diode's material. The effect of 1/f noise is to increase the noise contribution of the diode as the IF or Doppler frequency is decreased. This noise increases with the reciprocal of the IF frequency, hence, the name (1/f noise).

The 1/f noise normally increases rapidly at IF frequencies below 100 KHz maximum and becomes the determinant factor in receiver sensitivity at low IF or Doppler frequencies, i.e., 10–5000 Hz as in intrusion alarms). Gunn diodes also have 1/f noise, but normally their noise contribution is much less than that of the mixer diode. This is a major reason to use higher frequencies, i.e., K or Ka band (police radars). The resultant IF Doppler frequencies are higher (see Figure 2) and the radars can be more sensitive (due to less 1/f noise).

The minimum sensitivity of the mixer diode can usually be improved by optimizing the L.O. drive (coupling of the transmitter) such that the diode's rectified current is small. (This may increase conversion loss slightly but can decrease 1 /f noise more, resulting in better signal-noise characteristics.)

In most cases, the best receiver sensitivity will be obtained when the mixer diode's rectified current is approximately 0.2–0.5 ma. We suggest using a 500–1000 Ω resistor for the diode's DC return. The detected voltage across the resistor should be approximately 0.2–0.5 V (DC). MDT's transceivers are normally factory-set for negative voltage.

It is very important that the bias resistor be a low-noise resistor. We suggest metal thin film resistors. Carbon composition resistors are not usually acceptable because their noise is too high and will degrade system sensitivity.

When the radar is detecting a target, the Doppler IF voltage from the mixer diode can be as small as 1 microvolt RMS (at the minimum system sensitivity) to ~10–100 millivolts (at the mixer's saturation). The IF amplifier (operational amplifier) must have enough gain to increase the voltage to that which is required for signal processing.

The operational amplifier should be chosen to have the lowest input noise possible, because this noise will decrease system sensitivity.

In general, the noise contribution of the amplifier should be less than 200 nanovolts RMS. (referenced to its input). This should be determined when the amplifier's input is loaded with a 500–1000 Ω resistor. It is also good practice to use a bandpass filter in front of the amplifier to restrict its bandwidth to that which is necessary for system operation. The amplifier's noise output increases with the square root of its bandwidth.

Waveguide Detectors

Features

- Low Cost
- Rugged Housings
- Low Noise
- High-Rectification Efficiency

Applications

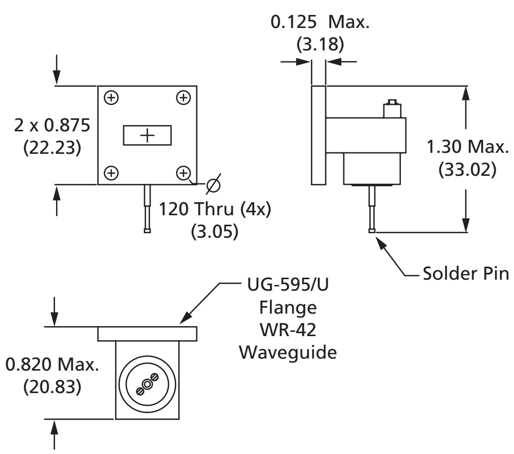
- Moisture Measurement
- Microwave Counters
- Liquid Level Indicators
- Flow/No Flow Sensors
- Microwave Perimeter Protection

Specifications @ 25°C

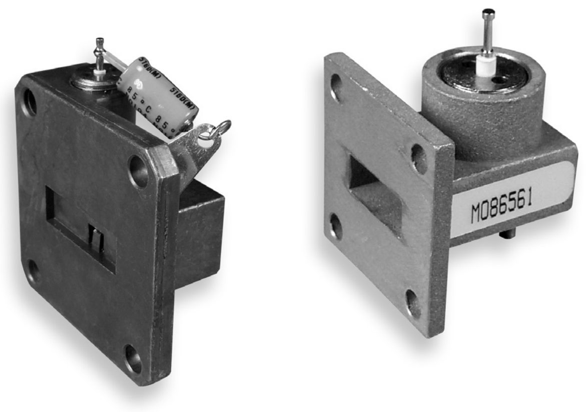
Part Number	Center Frequency (GHz)	Minimum Detectable Signal (dBm)	RF Bandwidth (MHz)
K Band Detector, Waveguide Mount			
MO86561	24.150	-45	300
X Band Detector, Waveguide Mount			
MO86571	10.525	-45	300

Other frequencies and power levels available upon request.
Maximum operating temperature is -30°C to +70°C.
Maximum storage temperature is -40°C to +85°C.

MO86561



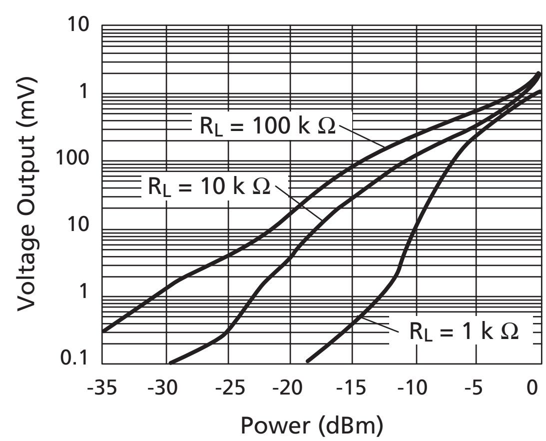
Dimensions are in inches (mm).



Description

The MO86561 and MO86571 detectors consist of Schottky barrier mixers assembled into a rugged housing suitable for use in industrial applications as a low-signal RF detector.

Performance Characteristics



Typical Performance Curve

Frequency = 24.125 GHz.
$I_F = 0\ \mu A$.
Nominal series output voltage (with zero bias).

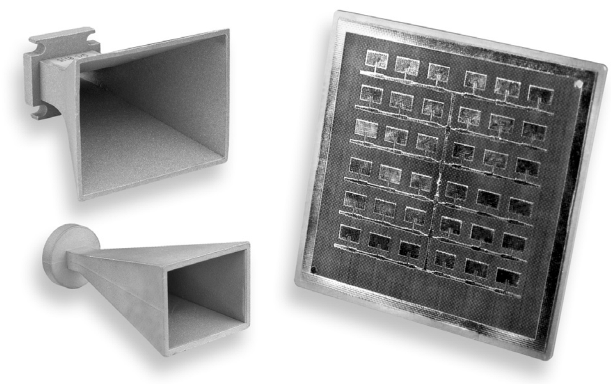
Horn Antennas

Features

- Low Cost
- Diecast Construction
- Waveguide Mounting
- Small Size

Applications

- Speed Radars
- Radar Decoys
- Intrusion Alarm Systems
- Door Openers
- Object Detection



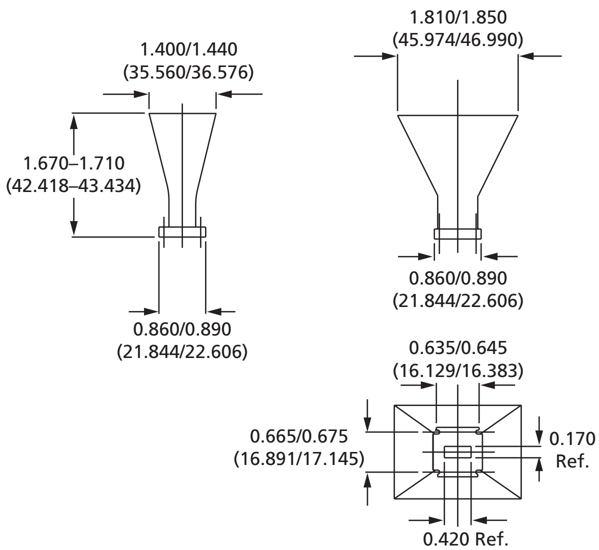
Description

The microwave antennas are designed for commercial applications as a low-cost method for transmitting microwave energy. These antennas utilize high-gain properties and shaped-beam patterns that are suitable for most applications.

Specifications @ 25°C

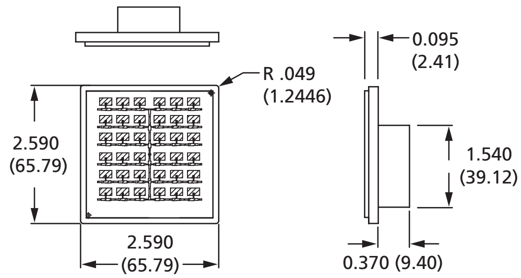
Model Number	Description	Center Frequency (GHz)	Usable Frequency Range (GHz)	E-Plane Beamwidth (Deg.)	H-Plane Beamwidth (Deg.)	Gain (dB)
X Band Antennas						
MDT86554	Pyramidal Horn Ant.	10.525	8–12	70	30	12 Nominal
K Band Antennas						
MDT86552	Pyramidal Horn Ant.	24.150	18.0–26.5	20	30	17 Nominal
MDT5864	Planar Array Ant.	24.125	24.00–24.25	14	14	18
V Band Antennas						
MHA4200	Pyramidal Horn Ant.	77.000	76–78	20	15	20

MO86552



Dimensions are in inches (mm).

MO5864

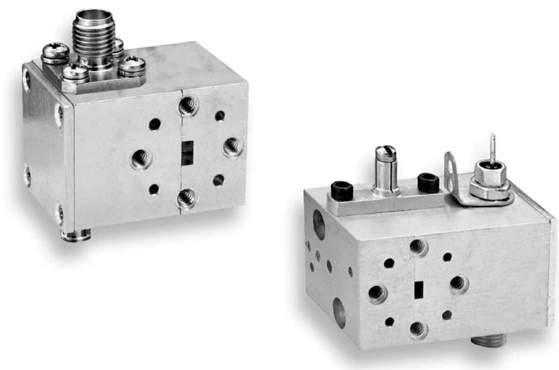


Dimensions are in inches (mm).

Millimeterwave Series Gunn Oscillators

Features

- Low Cost
- High Reliability
- Low Frequency and Power Drift
- Wide Mechanical Tuning With No Fold-Back
- Low-Phase Noise
- Unconditionally Guaranteed



Applications

The oscillators can be used as transmitters and local oscillators in microwave radio applications. They also find use as drivers for frequency multipliers. The varactor-tuned oscillators may also be used in FM CW radars and transceivers.

Description

The MGM and MGE series of Gunn oscillators have been designed to cover the frequency range from 60 GHz through 100 GHz. The oscillators have outstanding low-phase noise characteristics. A wide range of frequency tuning bandwidths — both mechanical and electronic — is available to suit specific applications. The oscillators have been specifically designed to minimize frequency and power drift over temperature. Several options are available, including integral isolators and heaters to improve stability. The oscillators are burnt-in prior to shipment to ensure long reliability.

MGM Specifications @ 25°C

Waveguide Size (WR)	Frequency Range (GHz)	Maximum Power (mW)	Tuning Bandwidth Max. (MHz)	Frequency Stability Typ. (MHz/°C)	Power Stability Typ. (dB/°C)	Bias Voltage Typ. (V)	Bias Current Typ. (Amps)
12 or 15	60–65	80	400	-3	-0.03	Note 1	Note 2
12 or 15	65–70	60	400	-3	-0.03		
12 or 15	70–75	60	300	-3	-0.03		
10 or 12	75–80	60	200	-4	-0.05		
10 or 12	80–85	60	200	-4	-0.05		
10 or 12	85–90	50	200	-5	-0.05		
8 or 10	90–95	40	200	-5	-0.05		
8 or 10	95–100	30	200	-6	-0.05		
8 or 10	100–110		consult	factory			

[1] Usual range is 3–7.5 V.
[2] Operating current depends on the required output power.

Note:
Tables show typical capabilities. Please call factory with your specific requirement.

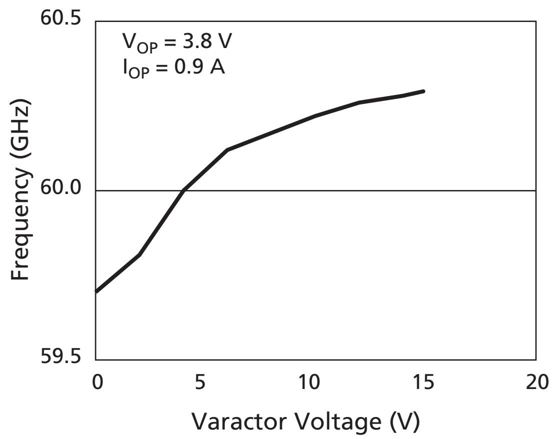
MGE Specifications @ 25°C

Waveguide Size (WR)	Frequency Range (GHz)	Maximum Power with Elec. Tuning 50 MHz (mW)	Maximum Power with Elec. Tuning 500 MHz (mW)	Frequency Stability Typ. (MHz/°C)	Power Stability Typ. (dB/°C)	Bias Voltage Typ. (V)	Bias Current Typ. (Amps)	Varactor Tuning Voltage Typ. (V)
12 or 15	60–65	80	35	-5	-0.06	Note 1	Note 2	0–20
12 or 15	65–70	60	25	-5	-0.05			
12 or 15	70–75	60	25	-5	-0.05			
10 or 12	75–80	50	25	-7	-0.05			
10 or 12	80–85	50	25	-7	-0.05			
10 or 12	85–90	40	25	-7	-0.05			
8 or 10	90–95	40	20	-7	-0.06			
8 or 10	95–100	30	20	-8	-0.06			
8 or 10	100–110		consult	factory				

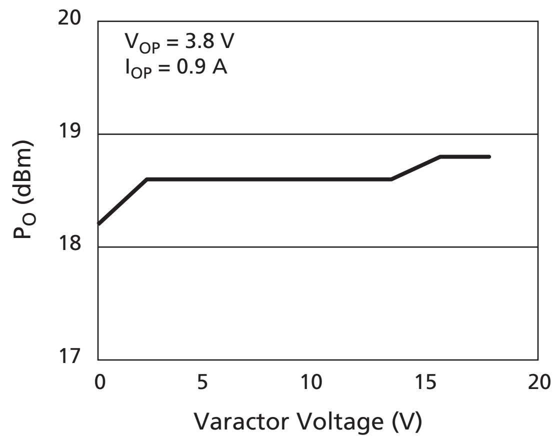
[1] Usual range is 3–7.5 V.
[2] Operating current depends on the required output power.

Note:
Tables show typical capabilities. Please call factory with your specific requirement.

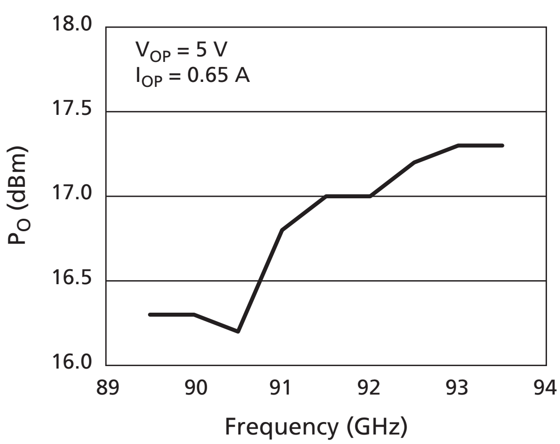
Performance Characteristics



Tuning Characteristics of MGE60.0251815 Gunn Oscillator



Power Output of MGE60.0251815 Gunn Oscillator



Power Output of MGM90.0701610 Gunn Oscillator

Typical Applications

Gunn diode oscillators are used for many purposes and typical applications include local oscillators; klystron replacement; transmit and receive oscillators for radio communications; military and commercial radar sources; police radar; sensors for detecting velocity, direction, proximity, or fluid levels; alarms; pumps for parametric amplifiers; wireless LANs; collision avoidance and intelligent cruise control; and others.

Theory Of Operation

Gunn oscillators are categorized as transferred electron oscillators (TEO) using the negative resistance property of bulk Gallium Arsenide. When an electric field of 3.2 KV/cm is present, the electrons in N type GaAs move from a high-mobility to another lower-mobility valley. Consequently, the net electron velocity is lower. This “negative resistance” phenomenon is used for converting DC into microwave power.

The charts at the end of this application note show typical voltage vs. current characteristics of a Gunn diode. As the bias across the Gunn diode is increased, the current proportionately increases. However, at a bias voltage called the threshold voltage — corresponding to the threshold electric field of 3.2 KV/cm — the current reaches a maximum known as the threshold current. As the bias across the Gunn diode is increased further, the current begins to decrease due to the negative resistance property. The current will continue to fall as the voltage is increased until a condition known as the breakdown voltage is reached. The diode will be catastrophically destroyed as the voltage is increased beyond the breakdown. The operating voltage is usually about 3 times the threshold voltage for CW operations, and about 10 times the threshold voltage for pulsed operations.

The charts at the end of this application note show typical bias voltage vs. power output of a Gunn oscillator. As bias is first applied to the Gunn diode, no output in the desired band is seen; then low-power random noise is generated. These low-level, low-frequency signals interfere with the proper operation of the oscillator and can cause damage to the diode, so suppression networks are used to minimize them. When the “turn on” voltage level is reached, the desired frequency is generated with low levels of power rising with increased voltage until “voltage power peak” or V_{PP} is reached. Voltage power peak is the bias level at which maximum RF power is generated. Best performance over operating temperature for power, turn on, and phase noise is usually obtained at a bias level 10–20% below the room temperature power peak. As an example, a 23 GHz oscillator may “turn on” at 3.5 V, be operated at 7 V, and have a power peak of 8 V.

The charts at the end of this application note show the temperature characteristics of turn on, power peak and breakdown voltages of a Gunn diode. In general, the turn on voltage and the power peak voltage decrease with increasing temperature while the breakdown voltage increases with increasing temperature. At lower temperatures, the turn on and the power peak voltages are higher than at room temperature. Conversely, the turn on and the power peak voltages are lower at higher temperatures. As an example, the turn on and the power peak voltages at room temperature may be 3.5 V and 7 V. At -30°C, the turn on and the power peak voltages will be 5 V and 8.5 V while at + 70°C turn on and the power peak voltages will be 2.5 V and 6 V. The choice of the operating voltage, for a single voltage operation, becomes crucial and has to be between the turn on voltage at the coldest temperature and the power peak voltage at the highest temperature. In the case of the pulsed operation, the operating voltage has to be lower than the breakdown voltage at the lowest temperature.

General Oscillator Designs

In general, there are 3 types of oscillator designs that are used in microwave and millimeter frequencies. These are:

- Coaxial
- Waveguide and
- Microstrip or planar

The output circuits of these 3 types may be either coaxial or waveguide.

Oscillators of all these types, covering the frequency range 5–140 GHz for CW and pulsed operation, are manufactured at MDT. Our own GaAs diodes are used in these designs.

The choice of a particular design for a given application depends on several factors such as: power, frequency, frequency stability, power, power stability, mechanical tuning, voltage tuning, cavity material, size, weight and cost. The design considerations for these oscillator types are discussed below.

In general, simple coaxial and planar circuits have a low Q. Consequently, the active device dominates the performance. Consequently, stabilization with temperature is difficult. However, high stability may be achieved by fabricating the cavity with low-temperature coefficient Invar and the proper choice of diode. On the other hand, waveguide- and dielectric-resonator stabilized circuits have higher Q and hence temperature stabilization may be relatively easier.

Again, in general, coaxial designs are preferred in the frequency range 5–65 GHz because of the ease of mechanical tuning over a 10–20% range.

Coaxial Cavity

A coax cavity with coax output is often the cavity of choice below about 15 GHz. A typical coax cavity with coax output, coax coupling is shown in Figure 1. Coax oscillators have lower Q than waveguide cavity oscillators, making them easier to tune. This type of cavity is mechanically tuned 10–20% and can be electrically tuned with bias pushing of the Gunn diode or with varactor tuning. This lower Q results in lower stability and higher frequency drift. The Gunn diode dominates the cavity, preventing cavity stabilization efforts typically used in waveguide cavities from being effective. Typical frequency stability with temperature @ 15 GHz would be 1 MHz/°C with aluminum as the body material.

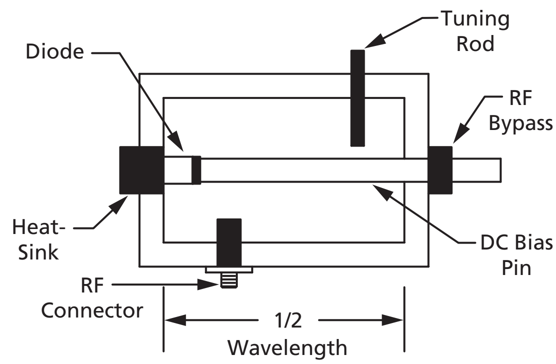


Figure 1. Coax Cavity with Coax Output

A variation on this design is the waveguide slot coupled coax cavity, which is typically used at frequencies between 15 and 65 GHz. This design is used for varactor tuning where large tuning bandwidths are needed and stability is not as critical. Figure 2 shows an example of this design. These are the most efficient cavities at millimeterwave frequencies for power generation. Typical stability @ 35 GHz would be 1.8 MHz/°C with aluminum.

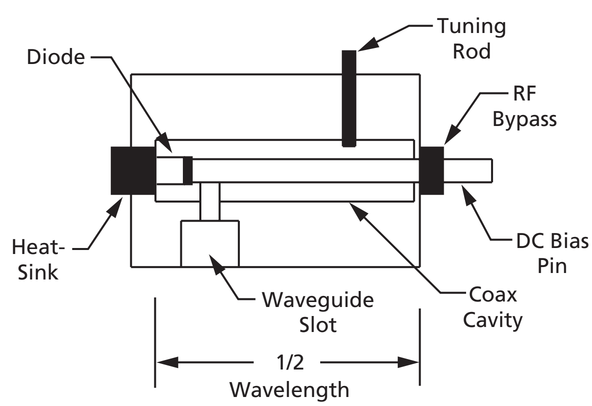


Figure 2. Coax Cavity with Waveguide Slot Coupling

Waveguide Cavity

Waveguide iris-coupled cavities are the most common types used at microwave through millimeterwave frequencies. These are simple to fabricate and are the cavity of choice for CW and Pulsed oscillators. Iris-coupled cavities have the highest Q and best frequency stability. They can be bias-tuned, or varactor-tuned, but over a much smaller bandwidth than a coax cavity. Waveguide cavities can be stabilized with the use of chimney or differential material expansion methods or by using a family of ceramics. Typical stability @ 35 GHz would be 1 MHz/°C in an unstabilized cavity. An example of an iris-coupled cavity is shown in Figure 3. With ceramic rod temperature compensation, stability of 200 KHz/°C @ 35 GHz are easily realizable.

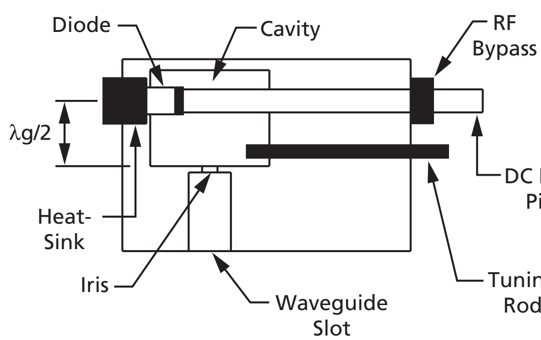


Figure 3. Iris-Coupled Waveguide Cavity

Waveguide iris-coupled cavities are used typically to 50 GHz. Above this, coax or 2nd harmonic cavities are commonly used. One type of 2nd harmonic cavity design is the resonate top hat structure. This circuit is used for CW and Pulsed oscillators as well as VCO-tuned oscillators of moderate bandwidth at frequencies up to 110 GHz. Typical stability @ 95 GHz would be 6 MHz/°C. An example of this circuit is shown in Figure 4.

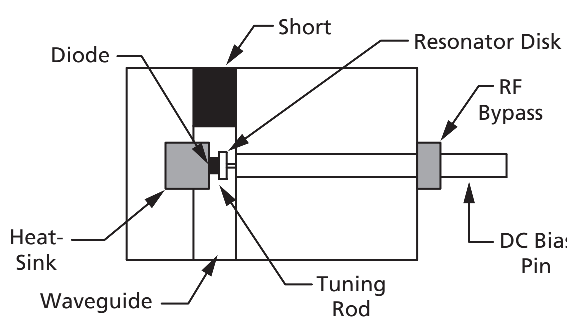


Figure 4. 2nd Harmonic Waveguide Cavity

A different type of 2nd harmonic cavity is used when frequency stability or increased varactor tuning is needed. This is a 2nd harmonic cutoff cavity where 1/2 the desired F_O is generated in the cavity and is filtered out to enhance the 2nd harmonic. An example of this cavity is shown in Figure 5. Typical stability or F_S @ 77 GHz would be 3 MHz/°C.

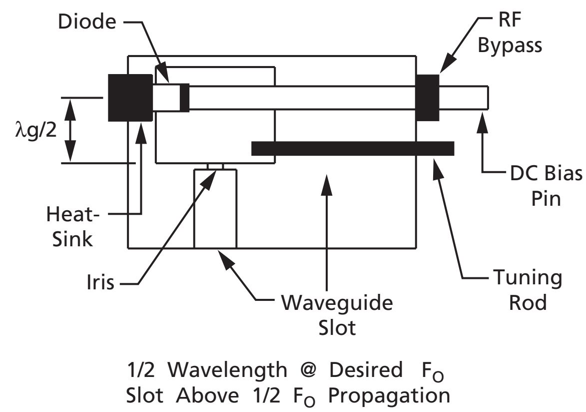


Figure 5. 2nd Harmonic Cut-Off Waveguide Cavity

Planar Microstrip Oscillators

Planar microstrip oscillators are now developed to operate at millimeter wave frequencies. These have an advantage of small size and low cost at production quantities since no cavity is required. Designs include a DRO (or dielectric resonator oscillator) and a planar microstrip Gunn oscillator. An example is shown in Figure 6.

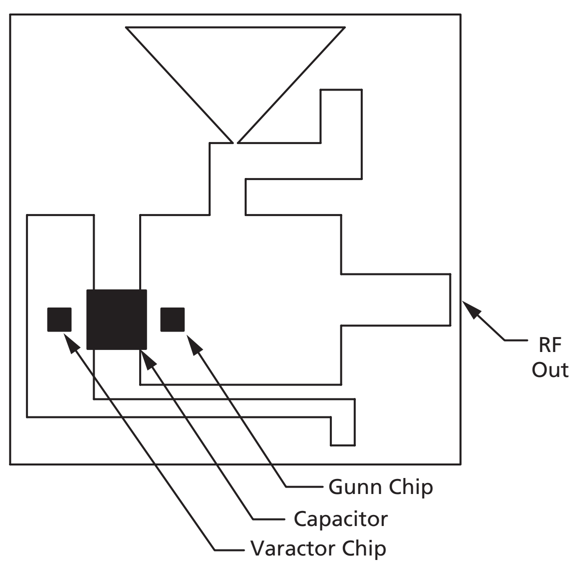
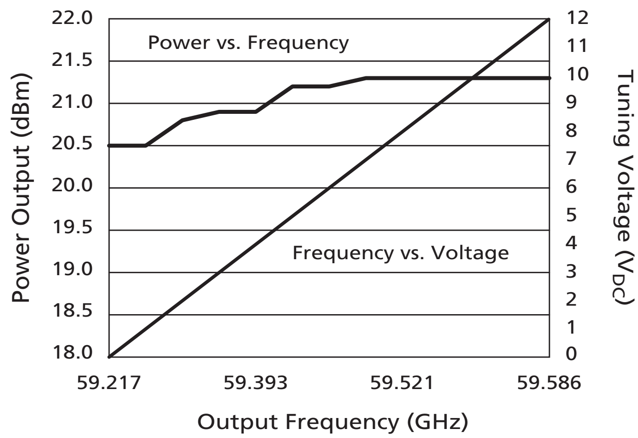


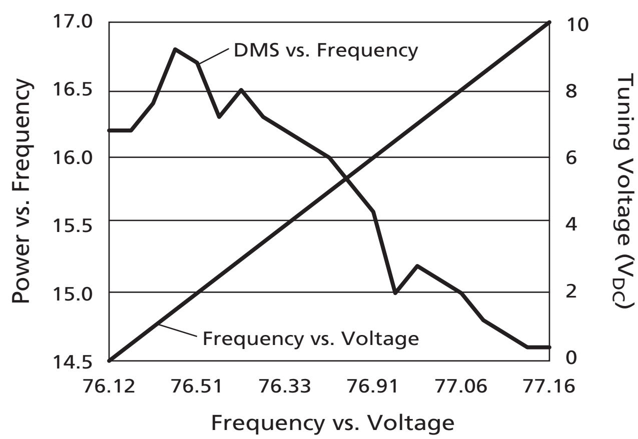
Figure 6. Planar Gunn Oscillator

Conclusions

The Gunn cavity is chosen to match the customer requirements with higher Q cavities selected when stability is most important, and lower Q when maximum tuning is required. Waveguide cavities can be stabilized with the use of chimney or differential material expansion methods or by using a family of ceramics. Typical frequency stability @ 35 GHz would be 1 MHz/°C for an unstabilized cavity. This can be improved to 0.1 MHz/°C with the combination of chimney or differential material expansion methods and ceramic compensation. Hybrid heaters can be used to hold the operating temperature to a 10°C window, further improving frequency stability and can be used alone or in combination with the above methods. Voltage regulators can be used to protect the oscillator from line variations and minimize bias pushing. Many options can be combined to meet a variety of performance specifications. The following data and charts are only a representation of available oscillators manufactured at MDT.



60 GHz VCO with 20 dBm Output with Isolator



76.5 GHz VCO with 1000 MHz V_{tune} 30 MW

Reliability and Screening for Military and Space Applications

Introduction

From our inception, Microwave Device Technology (MDT) Corporation has placed a significant emphasis on the long-term reliability of our products, whether for commercial, military or space applications. We have made a strong commitment to design quality into each one of our products. For military and space applications, we thoroughly screen the devices to ensure that they can withstand the electrical, thermal and environmental stresses in their operating environments. These screening tests are described later.

Long-term reliability is particularly important for power generation devices such as Gunn diodes, IMPATT diodes and multiplier diodes, which have significant power dissipation. For power generation devices, the thermal resistance is an important parameter. At MDT, we have developed techniques and measurement equipment to measure the thermal resistance of these devices.

In addition, for critical devices such as high-power Gunn diodes, it is necessary to know the safe maximum operating temperature at the highest ambient (case) temperature. We at MDT have analyzed the reliability of these high-power devices by "Step-Stress" techniques. These techniques are described later.

The long-term reliability of the semiconductor products is ensured by carefully controlling each step of processing, from epitaxial growth through chip fabrication to final assembly. This manufacturing control is made possible by our vertical integration and the dedication of our staff.

In this section, we will describe all the controls in place at MDT to assure long term reliability.

1.0 Controls

1.1 Lot Traceability

All the incoming materials from the chemicals used in semiconductor processing such as Arsenic Trichloride, Acetone, and Isopropyl Alcohol, to the Gallium Arsenide substrates and precious metals such as Gold, Platinum, and Gold-Germanium, have an allotted lot number. Whenever and wherever these materials are used, the lot number is noted in the "Process Flow Sheet", thus ensuring lot traceability to individual wafers used in the fabrication of diodes. Similarly, lot traceability is maintained for the finished diodes as well.

1.2 Process Documentation

All the processes used at MDT have been documented with a unique process number. These documents cover the processes from epitaxial growth through chip fabrication to chip inspection. The documentation describes in detail the equipment used in the process, with a step-by-step description of the process. These documents are available at MDT for inspection by our customers.

1.3 Documentation

All documentation, including establishment of, revisions, and distribution, is controlled. Each area in operations has its own unique documentation to produce its product. All products have, as a minimum, a product specification and an outline drawing. Documentation records are maintained for a defined period (e.g., manufacturing and shipping records are maintained for 10 years) to ensure traceability.

1.4 Custom Assigned Part Numbers

For any diode product that is unique to the customer, MDT assigns a custom part number and develops a test procedure that describes in detail the electrical and environmental requirements of that particular product to assure conformance to the specifications.

1.5 Wafer Approval and Wafer Reservation

MDT is always willing to supply diodes for wafer qualification purposes, and reserves diodes from that wafer for a reasonable period of time for customers who require such an approval.

1.6 Electrical screening

The diode electrical specifications published in the catalog are adequate for most applications. MDT is capable of screening the diodes when the customer requires that they meet performance specifications at an operating environment different from that in the catalog. For example, the customer may require that the diodes be tested at -54°C to meet the electrical performance requirements at -54°C. In such a case, MDT assigns a unique P/N for this customer, and only that customer can buy that product.

2.0 Environmental Screening

The purpose of environmental screening is to assure the customers that the devices are capable of withstanding the electrical, mechanical and thermal stresses that they may be subject to in the course of their operating lives.

Additional tests such as X-ray examination and Particle Impact Noise (PIN) may also be included as part of environmental screening to determine the physical condition of the device after the package has been hermetically sealed, and to detect the presence of loose material within the packages that may lead to device failure in the future.

The screening procedures are designed to test the integrity of the semiconductor chip processing, the chip assembly (if packaged), and the package itself under a variety of conditions emulating the actual operating environment. These are described below:

2.1 Thermal Stresses:

a. Storage in a non-operating condition:

The time and temperature are chosen to accelerate any incipient or latent defects. Usually, for Gallium Arsenide diodes, the temperature is chosen to be between 175–225 °C and the time to be between 48 to 96 hours.

b. Thermal shock:

The purpose of this test is to test the integrity of the die bond and the package. Repeated cycles of thermal shock, usually from -65°C to + 175°C, subject the chip and the package to sudden expansion and contraction. Any weakness in the bond between the chip and the underlying package will result in bond breakage.

2.2 Mechanical Stresses:

a. Constant acceleration:

The purpose of this test is to examine the integrity of the bond between the wires or straps and the chip. The test is done in a centrifugal chamber in such a way that there is a force trying to pull the straps or wires away from the semiconductor chip. The normally used acceleration is 20,000 g's. For the wires and straps that are commonly used in microwave semiconductor devices (0.001" wires and 0.00025" X 0.003" straps), the force produced by this acceleration is inadequate to cause any bond breakage. Bond pull tests in sample devices are more reliable.

b. Mechanical shock:

Microwave semiconductor diodes are not normally subject to mechanical shock tests because of their small mass.

c. Mechanical vibration (sinusoidal and non-sinusoidal):

Again, because of the small mass, the microwave semiconductor devices and the associated bond wires or straps are not tested for bond integrity by mechanical vibration tests. However, in certain applications such as in missiles where microphonic noise may pose a problem during launch, operational tests may be conducted under mechanical vibration. Microphonic noise may be caused by the strap or wire movement under vibration, causing frequency modulation of the oscillator. Such tests are time consuming and very costly.

d. Shear test:

The purpose of this test is to examine the shear strength of the ceramic-to-metal interface.

2.3 Electrical Stresses

a. DC burn-in:

The purpose of this test is to detect and eliminate devices prone to early failure. This infant mortality may be due to a poor bond between the chip and the underlying package, or between the chip and the bond wires/straps or any crack induced in the chip by the assembly operations.

The test is conducted by applying rated DC power at an elevated temperature for a period of 24 hours to 1000 hours to accelerate the failure mechanism. Pre- and post- burn-in electrical data are taken to identify and eliminate failed devices.

b. High Temperature Reverse Bias (HTRB) test:

For varactors and other control devices with a P-N junction, a test similar to the DC Burn-in test called HTRB is conducted. This test is performed by applying a DC reverse bias, which is 80% of the rated breakdown voltage of the diode at an elevated temperature for a period of 48 hours or higher. The purpose of this test is to accelerate any defects caused by unwanted metallic ions along the semiconductor surface or fast diffusing dopants within the semiconductor.

c. AC burn-in:

This test is similar to the HTRB test, except the applied bias is 60 Hz voltage. During one-half of the swing, the peak applied voltage to the device is 80% of the nominal breakdown voltage, and during the other half of the swing a positive bias is applied to the device to draw a rated AC current. Again, the purpose of this test is to accelerate any impurity movement by time, temperature and electric field. In particular, the forward current accelerates the impurity movement near the junction.

2.4 Package Integrity Tests

These tests are designed to detect the hermeticity of the packages after thermal, mechanical and electrical tests.

a. Gross leak test:

The test is conducted by immersing the devices in Perfluoropolyether under pressure for a few hours. Subsequently, any leak is detected by immersing the devices in hot Perfluoropolyether.

b. Fine leak test:

The test is conducted by immersing the devices under test in Helium in a pressurized chamber. Subsequently, any leak is detected using a He leak detector.

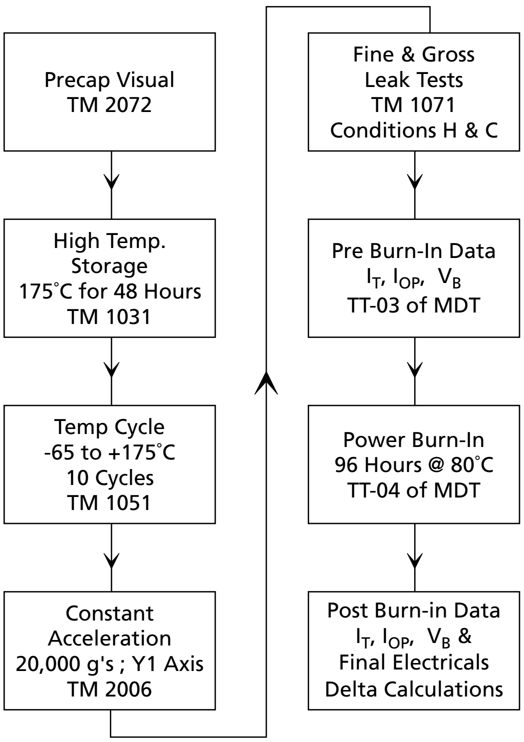
2.5 Standard Screening Sequence

All of MDT's products are designed and processed to an exacting standard for high reliability, whether the end use is for commercial, industrial, military or space applications. However, to assure our customers that the devices can withstand the stresses in their operating environments, the following standard screening tests may be performed in the sequence shown:

Figure 1 shows a typical sequence of tests that are conducted to satisfy JAN TX and JAN TXV military screening requirements for power generation devices such as Gunn diodes and IMPATT diodes.

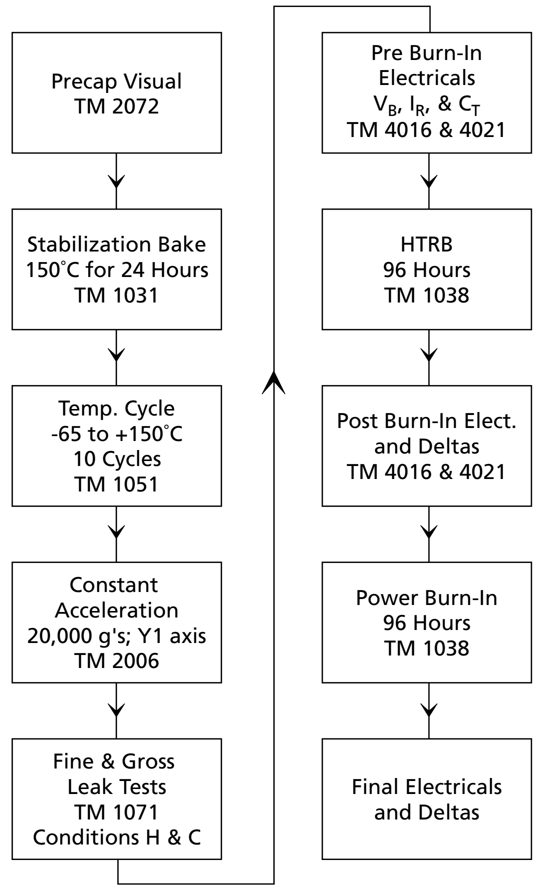
Figure 2 shows a typical sequence of tests that are conducted to satisfy JAN TX and JAN TXV military screening requirements for varactors.

MDT can also supply devices with higher levels of screening for Space applications. For details, please contact the factory or our representative in your territory.



All methods per Mil Std 750 except where noted.

Figure 1. Typical Screening Procedure for Gunn Diodes



Note : All methods per Mil Std 750.

Figure 2. Typical Screening Procedure for Varactors

3.0 Accelerated Life Testing and Reliability Physics

In life-test experiments, it is usual to subject a number of devices or units to some tests under certain stress conditions. Data is generated on the lives of these units and recorded. It is generally found that the failure rate follows the familiar bathtub curve shown in Figure 3.

Initially, the failure rate is high and drops rapidly with time (I region) to reach an approximately constant low rate for a long period (II region). Subsequently, the failure rate increases with time (III region). Each of the regions is indicative of a particular failure mode of the devices.

The first region is the infant mortality or the freak-failure region. The failure in this region in properly designed devices could be due to several reasons: mostly, they are due to poor assembly, cracked chips during assembly, etc. They can hopefully be weeded out by proper visual or other inspection and screening procedures. The freak failures may also depend on some stress parameter such as temperature. As an example, if the bond to the chip is poor, the chip could become open in time. The process may be accelerated with temperature. resulting in failure-rate dependence on the stress parameter — temperature.

The second region where the failure rate is low is the normal operating life of the devices. The failure is random, and cannot be attributed to any particular cause.

The third region is the wear-out failure region. The failure in this region is characteristic of the metallization scheme, diffusion of impurities in the device, etc. The failure in this region is typically due to a dominant failure mechanism and assumed to be characterized by a single activation energy (E_a).

It has been found (Ref.:1) that the probability density function, f(t), of the lifetimes of semiconductor devices follows log normal distribution, i.e., the logarithm of the life time is normally distributed. The probability of failure before time (t), or the cumulative failure fraction (P(t)) is:

$$P(t) = \int f(t)\,dt = [1 + \text{erf}\ h/(\sqrt{2} * \sigma)]/2 \ldots\ldots\ldots\ldots(1)$$
with $h = \log(t/\underline{t})$

A plot of P(t), the cumulative failure fraction (or percentage), as a function of log (t), using a probability graph will be a straight line with a slope of 1/σ as shown in Figure 4.

From this equation, we get:

h/σ	P(t)
0	0.5
1.0	0.84
-1.0	0.16

Thus, the time ($t_{0.5}$) to realize a cumulative failure of 50% of the units is the median life ie., $t_{0.5}$ = t. The standard deviation or the dispersion may also be obtained from the figure when the cumulative failure percentage is 84% or 16%. ie., $\sigma \approx \log(t_{0.84}/t_{0.5}) \approx \log(t_{0.5}/t_{0.16})$.

This property of the cumulative distribution function viz. that when plotted against log (t), in a probability paper results in a straight line, may be used as a criterion to judge whether a sample population failure density function follows the log normal distribution.

To study the reliability of an unknown device, it is necessary that a sufficiently large number of the devices be subject to a maximum stress that it is likely to encounter during its useful lifetime for adequate time for the device to fail. Of course, we have to define the criterion for failure for one or more measurable parameters of the device. Since the useful lifetimes are usually several years, it is impractical to conduct such a study especially considering that the device is an unknown. In this case, it will be necessary to obtain meaningful data on the useful lifetime as rapidly and as economically as possible. The lifetime data may be obtained by thermally accelerating the failure mechanism.

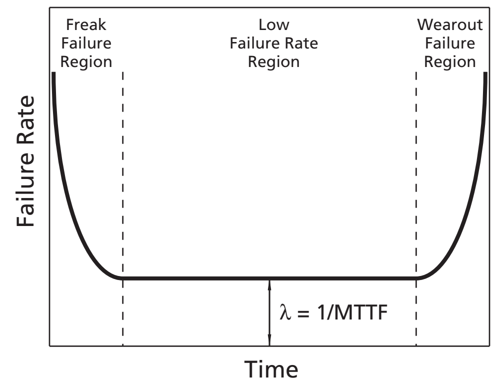


Figure 3. Generalized Failure Rate vs. Time Characteristics

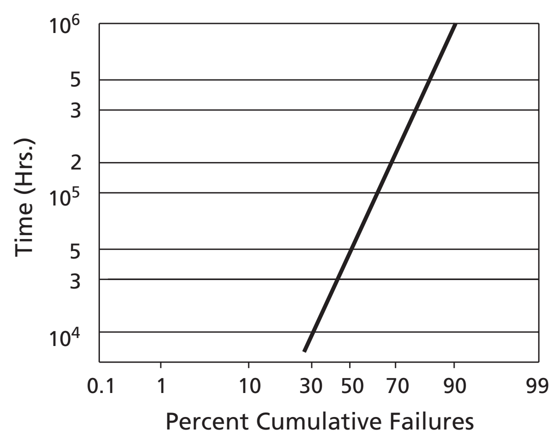


Figure 4. Cumulative Failures vs. Time

Arrhenius Equation

Failure mechanism of the devices may be considered as a physical process, and as such should depend on temperature and an activation energy (E_a), characteristic of the process. In general, the time (t), to wear-out failure region may be described by the Arrhenius rate equation:

t/τ = a constant
$\tau = \tau_o * \exp(E_a / (k * T))$..........................(2)

where
τ_o = a constant
E_a = activation energy in joules
k = Boltzmann constant = 1.38 E -23 Joules/°K
T = Absolute temperature in °K

The activation energy may be obtained by plotting log of time to failure as a function of the reciprocal temperature for a known cumulative failure percentage.

Accelerated Device Testing

Assuming that the measurable parameter values of the device under test are normally distributed, and that the standard deviation of the normally distributed parameter values is independent of temperature, it can be shown (Ref.:3) that:

$h = \log t - [E_a/(k * T)] - \log \tau - y'/a$.............(3)

where
y' = the failure criterion for the measurable parameter of the device
$t = \tau * \exp(y'/a)$.......................................(4)
a = a constant

Equation (3) together with Equation (1) show that the cumulative distribution depends on the device temperature. Also, Equation (4) shows that the median life depends exponentially on the measurable parameter of the device. This implies that by elevating the device temperature, the median life and the time-to-fail may be reduced to practical and reasonable hours. However, we still do not know the elevated temperature at which the constant stress test should be conducted.

Step-Stress Testing

To arrive at the desired constant stress level(s), it is necessary to know the activation energy for the failure mechanism. An approximate value of the activation energy may be obtained by conducting preliminary tests in a non-operating condition in which the stress level is maintained for a duration of time and then progressively increased by a known value at the end of the chosen duration. The cumulative failure percentage is recorded as a function of time. The tests are repeated for a different duration of time with similar stress-level steps. Figure 5 shows a plot of the cumulative failure fraction (or percentage) as a function of 1/T for two different dwell times. Thus, the dwell time equals the median life at 50% cumulative failure level according to Equation (1). The activation energy may be obtained from Equation (2) as follows:

$\ln(t_{d1} / t_{d2}) = (E_a/k) * [(1/T_1) - (1/T_2)]$.......... (5)

where
T_1, T_2 are the temperatures corresponding to the dwell times t_{d1}, t_{d2} for any chosen cumulative failure level.

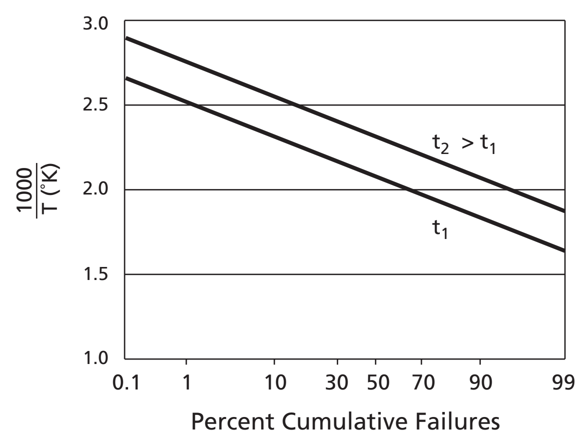


Figure 5. Cumulative Failures vs. Reciprocal Temperature

Stress-Level Selection

Knowing the activation energy, it is easy to calculate from Equation (2) the stress levels (temperatures) needed for constant stress-life testing of the devices in an operating condition.

In step-stress testing, especially at high-stress levels, it is likely that failure modes other than the one that the device is likely to encounter in its serviceable life may be activated and thus lead to an erroneous conclusion regarding the lifetime. Thus, selection of stress levels for constant stress-life testing should be done carefully. The selection is a compromise between the necessity to obtain life-test data in a reasonable time, and the closeness of the stress level to the actual one encountered by the device in its useful life. The choice is also governed by the lifetimes of the components in the life-test racks.

Number of Devices for Life Test

Ideally, a large number of devices will have to be chosen to get accurate data. However, the cost of conducting life tests will become prohibitive, not only because of the cost of the devices but also because of the cost of the life-test racks and the cost of recording and analyzing data.

Normally, it is enough to use 20 devices for each dwell time in the step-stress testing. This will provide the activation energy of the failure mechanism with reasonable accuracy. Once the activation energy is known, we can calculate, for a measurable life time of say 100 hours, the constant stress level needed. Additionally, to establish the predicted lifetime with any level of confidence, we need at least two other measured lifetimes. We can choose 50 hours and 250 hours. We can calculate the constant stress levels needed for these lifetimes also. These three stress levels may be used with a sample lot of at least 20 devices for each level to generate the actual life-test data.

Validation of Assumptions

The experimentally determined logarithms of the lifetimes should be normally distributed. This means that a plot of cumulative failure percentage as a function of log (t), should be a straight line on a probability paper. Such a plot will be meaningful if the number of devices in the sample lot is at least 20. If, for some reason, there are many freak failures, then it may be difficult to draw a conclusion from a smaller lot. In such a case, there are tests such as D'Agostino's (Ref.: 4) which can predict with a certain level of confidence the log-normality of the lifetimes.

MTTF

An extensive study of the reliability of high-power Gunn diodes was conducted at MDT in 1991 using the Step-Stress technique. From that study, it was concluded that the activation energy for failure was 3.49 eV. Also, from the Step-Stress data, the measured MTTF (Mean Time to Failure) was 48 hours at 290°C. From these data, the MTTF at any other temperature may be readily calculated:

As an example, the MTTF at 250°C junction temperature is: 1.3 E6 hours for the example quoted above.

References

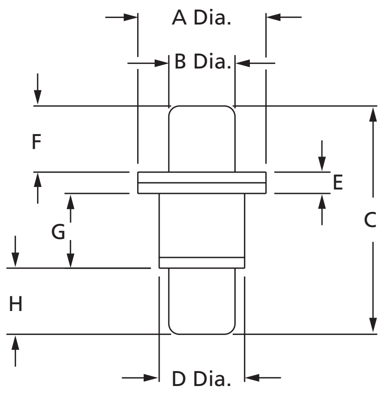
Ref.: 1 Peck, D.S. and Zierdt, C.H.
"The Reliability of Semiconductor Devices in the Bell System"; Proc. IEEE, Vol. 62, No. 2 pp. 185–211 Feb. 1974.

Ref.: 2 Sinha,S.K., and Kale, B.K.
"Life Testing and Reliability Estimation", Wiley Eastern Ltd., New Delhi, India. 1980.

Ref.: 3 Reyolds, F.H.,
"Thermally Accelerated Aging of Semiconductor Components" Proc. IEEE, Vol. 62, No. 2 pp. 212 - 222, Feb. 1974.

Ref.: 4 Zar, J.H. "Biostatiscal Analysis"
Prentice Hall, NJ. 1974

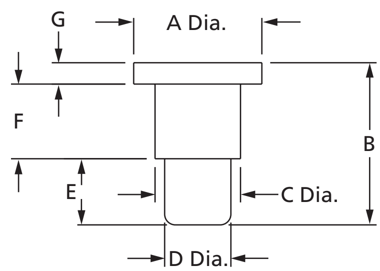
M11



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.119	0.127	3.02	3.23
B	0.060	0.064	1.52	1.63
C	0.205	0.225	5.21	5.72
D	0.079	0.083	2.01	2.11
E	0.016	0.024	0.41	0.61
F	0.060	0.064	1.52	1.63
G	0.069	0.073	1.75	1.85
H	0.060	0.064	1.52	1.63

L_P = 0.40 nH typ.
C_P = 0.17 pF typ.

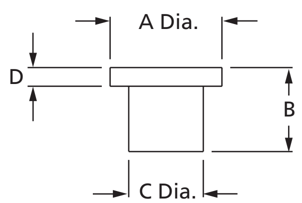
M12



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.119	0.127	3.02	3.23
B	0.143	0.163	3.63	4.14
C	0.077	0.083	1.96	2.11
D	0.060	0.064	1.52	1.63
E	0.060	0.064	1.52	1.63
F	0.066	0.076	1.68	1.93
G	0.015	0.025	0.38	0.64

L_P = 0.40 nH typ.
C_P = 0.17 pF typ.

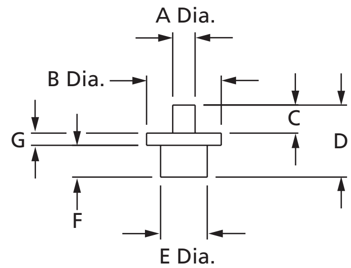
M13



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.119	0.127	3.02	3.23
B	0.085	0.097	2.16	2.46
C	0.077	0.083	1.96	2.11
D	0.016	0.024	0.41	0.61

L_P = 0.40 nH typ.
C_P = 0.18 pF typ.

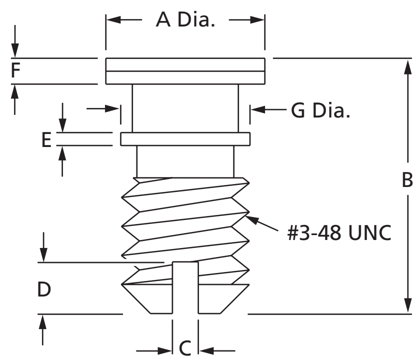
M14



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.024	0.026	0.61	0.66
B	0.078	0.086	1.98	2.18
C	0.027	0.033	0.69	0.84
D	0.070	0.080	1.78	2.03
E	0.047	0.053	1.19	1.35
F	0.029	0.038	0.74	0.97
G	0.011	0.015	0.28	0.38

L_P = 0.17 nH typ.
C_P = 0.14 pF typ.

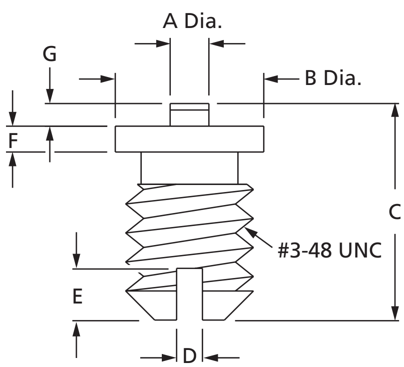
M15



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.119	0.127	3.02	3.23
B	0.188	0.208	4.78	5.28
C	0.015	0.025	0.38	0.64
D	0.025	0.045	0.64	1.14
E	0.009	0.011	0.23	0.28
F	0.016	0.024	0.41	0.61
G	0.098	0.102	2.49	2.59

L_P = 0.30 nH typ.
C_P = 0.25 pF typ.

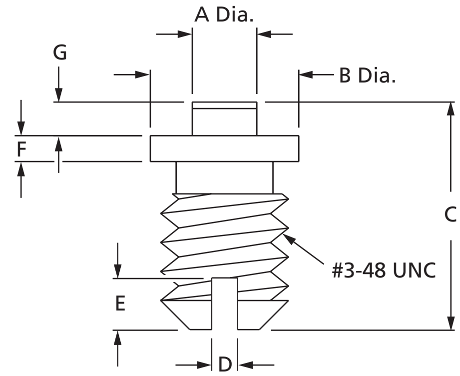
M16



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.027	0.034	0.69	0.86
B	0.113	0.118	2.87	3.00
C	0.156	0.164	3.96	4.17
D	0.015	0.025	0.38	0.64
E	0.025	0.045	0.64	1.14
F	0.018	0.022	0.46	0.56
G	0.016	0.019	0.41	0.48

L_P = 0.10 nH typ.
C_P = 0.15 pF typ.

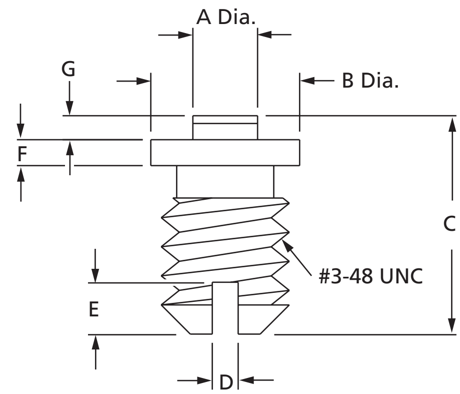
M17



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.048	0.052	1.22	1.32
B	0.113	0.118	2.87	3.00
C	0.167	0.187	4.24	4.75
D	0.015	0.025	0.38	0.64
E	0.035	0.045	0.89	1.14
F	0.018	0.022	0.46	0.56
G	0.022	0.030	0.56	0.76

L_P = 0.16 nH typ.
C_P = 0.24 pF typ.

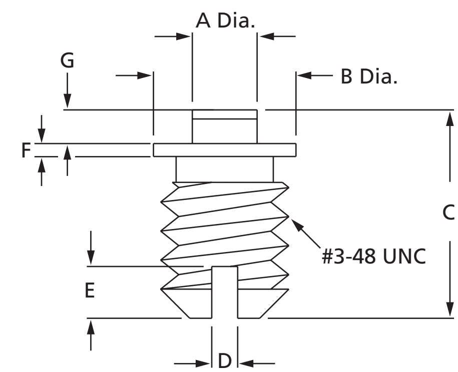
M18



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.048	0.052	1.22	1.32
B	0.113	0.118	2.87	3.00
C	0.159	0.179	4.04	4.55
D	0.015	0.025	0.38	0.64
E	0.035	0.045	0.89	1.14
F	0.018	0.022	0.46	0.56
G	0.015	0.022	0.38	0.56

L_P = 0.20 nH typ.
C_P = 0.36 pF typ.

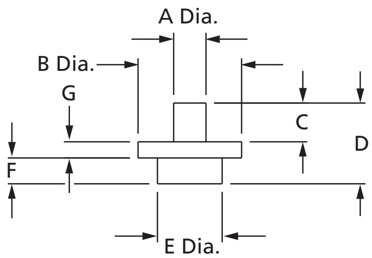
M19



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.048	0.052	1.22	1.32
B	0.098	0.102	2.49	2.59
C	0.165	0.185	4.19	4.70
D	0.015	0.025	0.38	0.64
E	0.030	0.045	0.76	1.14
F	0.009	0.011	0.23	0.28
G	0.022	0.030	0.56	0.76

L_P = 0.16 nH typ.
C_P = 0.23 pF typ.

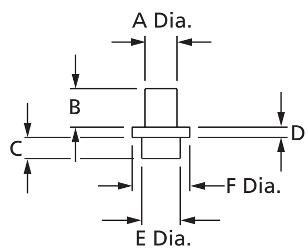
M20



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.022	0.028	0.56	0.71
B	0.077	0.083	1.96	2.11
C	0.025	0.035	0.64	0.89
D	0.055	0.068	1.40	1.73
E	0.047	0.053	1.19	1.35
F	0.018	0.022	0.46	0.56
G	0.010	0.015	0.25	0.38

L_P = 0.20 nH typ.
C_P = 0.25 pF typ.

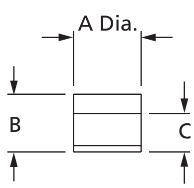
M21



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.024	0.026	0.61	0.66
B	0.026	0.034	0.66	0.86
C	0.014	0.019	0.36	0.48
D	0.007	0.010	0.18	0.25
E	0.028	0.032	0.71	0.81
F	0.043	0.047	1.09	1.19

L_P = 0.17 nH typ.
C_P = 0.14 pF typ.

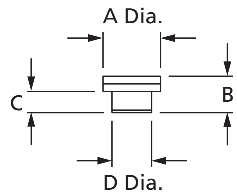
M22



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.051	0.055	1.30	1.40
B	0.040	0.050	1.02	1.27
C	0.025	0.035	0.64	0.89

L_P = 0.40 nH typ.
C_P = 0.12 pF typ.

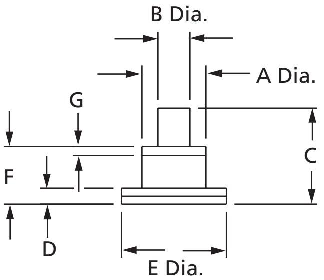
M23



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.043	0.047	1.09	1.19
B	0.028	0.032	0.71	0.81
C	0.014	0.019	0.36	0.48
D	0.029	0.033	0.74	0.84

L_P = 0.16 nH typ.
C_P = 0.14 pF typ.

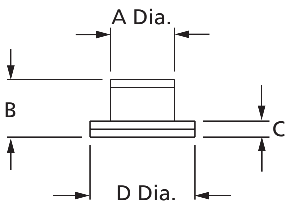
M24



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.047	0.053	1.19	1.35
B	0.024	0.026	0.61	0.66
C	0.070	0.080	1.78	2.03
D	0.010	0.015	0.25	0.38
E	0.078	0.086	1.98	2.18
F	0.040	0.050	1.02	1.27
G	0.004	0.010	0.10	0.25

L_P = 0.17 nH typ.
C_P = 0.14 pF typ.

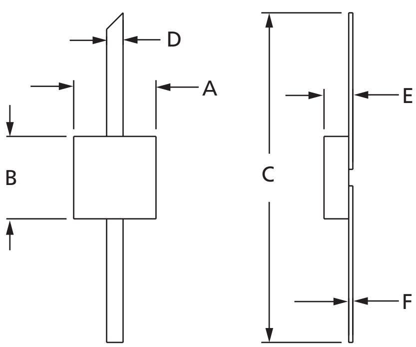
M25



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.047	0.053	1.19	1.35
B	0.040	0.050	1.02	1.27
C	0.010	0.015	0.25	0.38
D	0.078	0.086	1.98	2.18

L_P = 0.25 nH typ.
C_P = 0.14 pF typ.

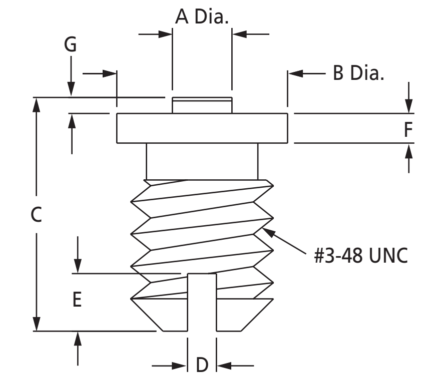
M26



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.092	0.108	2.34	2.74
B	0.092	0.108	2.34	2.74
C	0.452	0.570	11.48	14.48
D	0.017	0.023	0.43	0.58
E	0.028	0.052	0.71	1.32
F	0.003	0.007	0.08	0.18

L_P = 0.40 nH typ.
C_P = 0.10 pF typ.

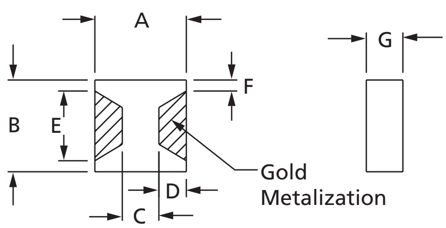
M27



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.048	0.052	1.22	1.32
B	0.113	0.118	2.87	3.00
C	0.167	0.187	4.24	4.75
D	0.015	0.025	0.38	0.64
E	0.035	0.045	0.89	1.14
F	0.018	0.022	0.46	0.56
G	0.020	0.030	0.51	0.76

L_P = 1.6 nH typ.
C_P = 0.22 pF typ.

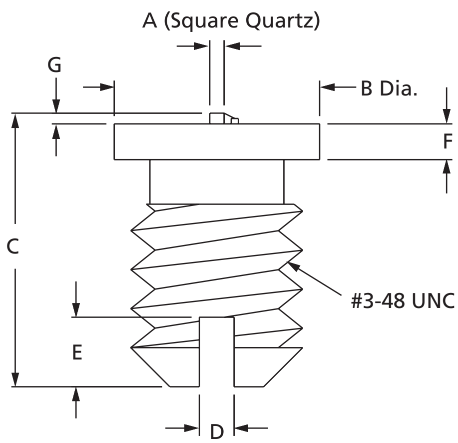
M28



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.095	0.101	2.41	2.57
B	0.095	0.101	2.41	2.57
C	0.038	0.044	0.97	1.12
D	0.027	0.033	0.69	0.84
E	0.071	0.079	1.80	2.01
F	0.009	0.015	0.23	0.38
G	0.035	0.045	0.89	1.14

L_P = 0.50 nH typ.
C_P = 0.10 pF typ.

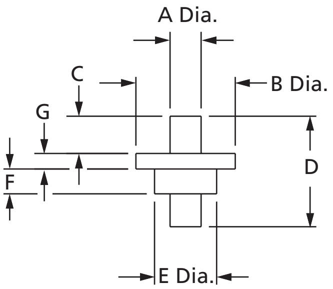
M29



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.006	0.010	0.15	0.25
B	0.113	0.118	2.87	3.00
C	0.144	0.154	3.66	3.91
D	0.015	0.025	0.38	0.64
E	0.025	0.045	0.64	1.14
F	0.018	0.022	0.46	0.56
G	0.004	0.008	0.10	0.20

L_P = 0.18 nH typ.
C_P = 0.01 pF typ.

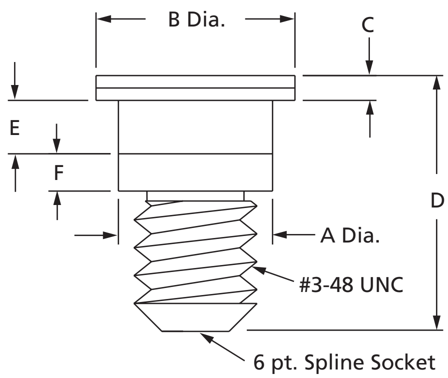
M30



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.022	0.028	0.56	0.71
B	0.077	0.083	1.96	2.11
C	0.025	0.035	0.64	0.89
D	0.080	0.098	2.03	2.49
E	0.047	0.053	1.19	1.35
F	0.017	0.023	0.43	0.58
G	0.010	0.015	0.25	0.38

L_P = 0.20 nH typ.
C_P = 0.23 pF typ.

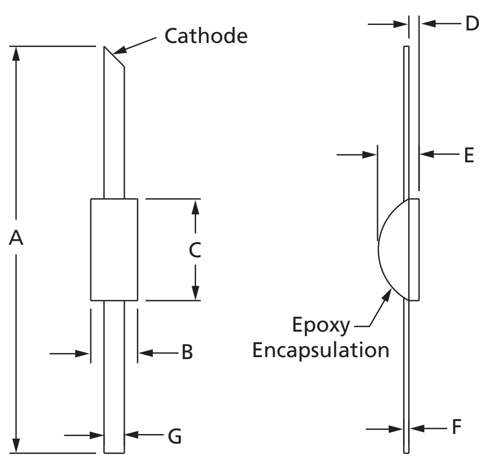
M31



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.118	0.130	3.00	3.30
B	0.155	0.165	3.94	4.19
C	0.017	0.023	0.43	0.58
D	0.190	0.220	4.83	5.59
E	0.038	0.048	0.97	1.22
F	0.026	0.034	0.66	0.86

L_P = 0.60 nH typ.
C_P = 0.44 pF typ.

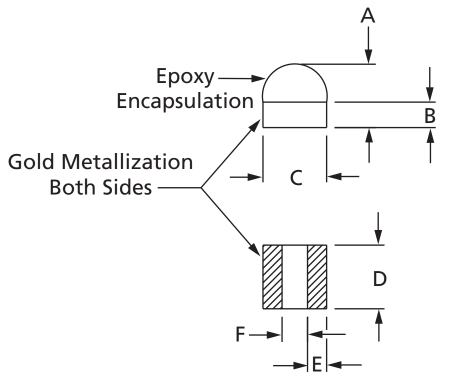
M35



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.540	0.560	13.72	14.22
B	0.042	0.048	1.07	1.22
C	0.088	0.094	2.24	2.39
D	0.008	0.012	0.20	0.30
E	-	0.040	-	1.02
F	0.003	0.006	0.08	0.15
G	0.018	0.022	0.46	0.56

L_P = 0.35 nH typ.
C_P = 0.10 pF typ.

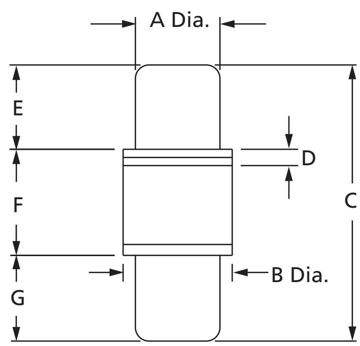
M36



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	-	0.050	-	1.27
B	0.017	0.023	0.43	0.58
C	0.047	0.053	1.19	1.35
D	0.047	0.053	1.19	1.35
E	0.012	0.019	0.30	0.48
F	0.012	0.018	0.30	0.46

L_P = 0.35 nH typ.
C_P = 0.12 pF typ.

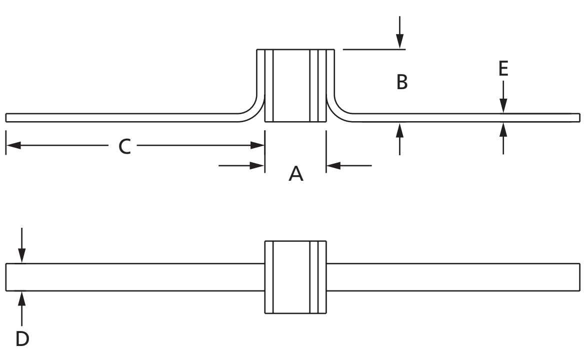
M38



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.059	0.064	1.930	2.134
B	0.076	0.084	1.499	1.626
C	0.190	0.210	4.826	5.334
D	0.007	0.015	0.178	0.381
E	0.059	0.065	1.499	1.651
F	0.069	0.087	1.753	2.210
G	0.059	0.065	1.499	1.651

L_P = 0.50 nH typ.
C_P = 0.15 pF typ.

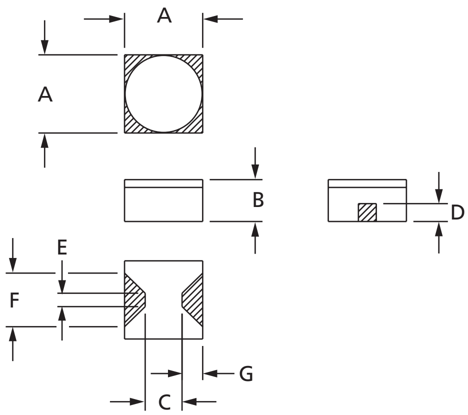
M39



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.040	0.050	1.016	1.270
B	0.051	0.055	1.295	1.397
C	0.200	-	5.080	-
D	0.019	0.021	0.483	0.533
E	-	0.005	-	0.127

L_P = 0.40 nH typ.
C_P = 0.14 pF typ.

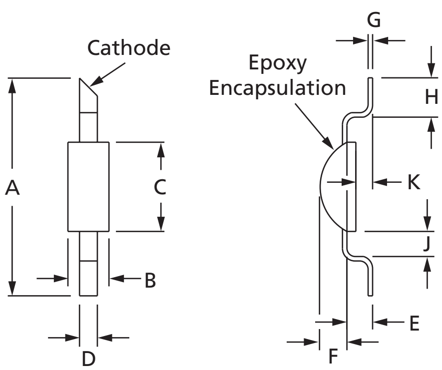
M40



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.065	0.075	1.651	1.905
B	0.034	0.041	0.864	1.041
C	0.030	0.036	0.762	0.914
D	0.013	0.017	0.330	0.432
E	0.013	0.017	0.330	0.432
F	0.043	0.053	1.092	1.346

L_P = 0.45 nH typ.
C_P = 0.15 pF typ.

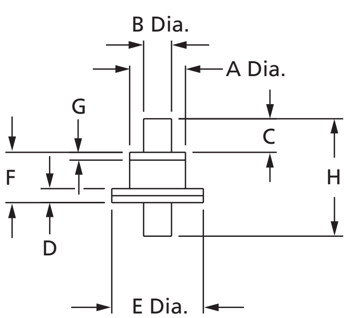
M41



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.175	0.195	4.445	4.953
B	0.040	0.050	1.016	1.270
C	0.085	0.095	2.159	2.413
D	0.015	0.025	0.381	0.635
E	0.010	0.015	0.254	0.381
F	0.015	0.020	0.381	0.508
G	0.004	0.006	0.102	0.152
H	0.020	0.030	0.508	0.762
J	0.013	0.033	0.330	0.838
K	0.003	0.005	0.076	0.127

L_P = 0.50 nH typ.
C_P = 0.13 pF typ.

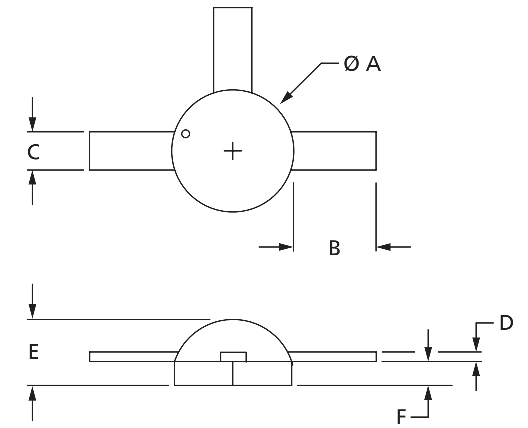
M42



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.047	0.053	1.194	1.346
B	0.024	0.026	0.610	0.660
C	0.027	0.033	0.686	0.838
D	0.010	0.015	0.254	0.381
E	0.078	0.086	1.981	2.184
F	0.040	0.050	1.016	1.270
G	0.004	0.006	0.102	0.152
H	0.100	0.110	2.540	2.794

L_P = 0.17 nH typ.
C_P = 0.15 pF typ.

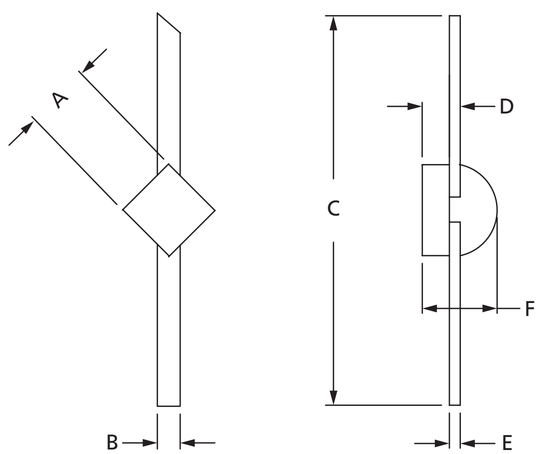
M43



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.090	0.110	2.29	2.75
B	0.090	0.110	2.29	2.75
C	0.018	0.022	0.48	0.56
D	0.003	0.006	0.08	0.15
E	0.030	0.035	0.08	0.09
F	0.010	0.014	0.03	0.36

L_P = 0.30 nH typ.
C_P = 0.10 pF typ.

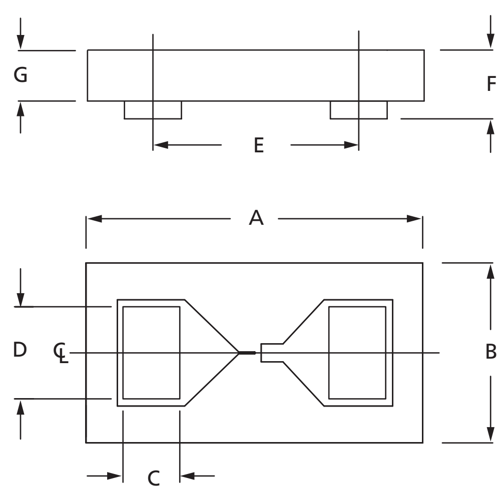
M44



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.048	0.052	0.123	0.133
B	0.013	0.017	0.033	0.043
C	0.300	0.340	0.771	0.873
D	0.008	0.012	0.020	0.031
E	0.003	0.005	0.008	0.013
F	0.024	0.028	0.062	0.071

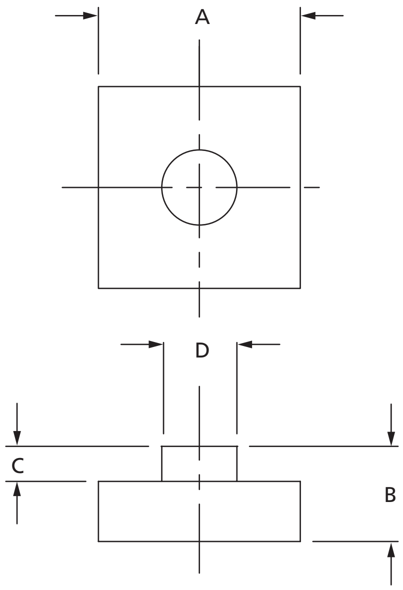
L_P = 0.30 nH typ.
C_P = 0.12 pF typ.

P2613



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.0255	0.0265	0.648	0.673
B	0.0125	0.0135	0.318	0.343
C	0.0046	0.0056	0.117	0.142
D	0.0075	0.0085	0.191	0.216
E	0.0170	0.0180	0.432	0.457
F	0.0050	0.0060	0.127	0.152
G	0.0045	0.0055	0.114	0.140

P10



DIM	INCHES		MM	
	MIN.	MAX.	MIN.	MAX.
A	0.009	0.011	0.023	0.028
B	0.003	0.006	0.008	0.015
C	0.008	0.010	0.020	0.026
D	0.001	0.007	0.003	0.018

Standard Waveguide and Flange Designations

Letter Desig.	U.S.A. EIA JAN	Europe WG R	Recom. Op. range GHz (CTE10)	Cut-off Freq. (GHz)	Waveguide Inner dim. (Inches)	Flange Type	Flange Desig. UG-
x	WR-90 RG-52/U	WG-16 R 100	8.2–12.4	6.56	0.400 x 0.900	Cover Choke	39/U 4OB/U
	WR-75 RG-346/U	WG-17 R 120	10.0–15.0	7.87	0.375 x 0.750	–	–
Ku	WR-62 RG-91/U	WG-18 R 140	12.4–18.0	9.48	0.311 x 0.622	Cover Choke	419/U 541/U
	WR-51 RG-352/U	WG-19 R 180	15.0–22.0	11.57	0.255 x 0.510	–	–
K	WR-42 RG-53/U	WG-20 R 220	18.0–26.5	14.05	0.170 x 0.420	Cover Choke	596/U 596/U
	WR-34 RG-3-54/U	WG-21 R 260	22.0–33.0	17.33	0.170 x 0.340	–	–
A	WR-28 RG-271/U	WG-22 R 320	26.5–40.0	21.08	0.140 x 0.280	Cover Choke Cover Pin	599/U 600/U 381/U
B	WR-22 RG-272/U	WG-23 R 400	33.0–50.0	26.34	0.112 x 0.224	Cover Pin	383/U
u	WR-19 RG-358/U	WG-24 R 500	40.0–60.0	31.36	0.094 x 0.188	Cover Pin	383/U-M
v	WR-15 RG-273/U	WG-25 R 620	50.0–75.0	39.86	0.074 x 0.148	Cover Pin	385/U
E	WR-12 RG-274/U	WG-26 R 740	60.0–90.0	48.35	0.061 x 0.122	Cover Pin	387/U
w	WR-10 RG-359/U	WG-27 R 900	75.0–110.0	59.01	0.050 x 0.110	Cover Pin	387/U-M
F	WR-8 RG-278/U	WG-28 R 1200	90.0–140.0	73.84	0.040 x 0.080	Cover Pin	387/U-M
D	WR-7 RG-276/U	WG-29 R 1400	110.0–170.0	90.84	0.0325 x 0.065	Cover Pin	387/U-M
G	WR-5 RG-275/U		140.0–220.0	115.75	0.0255 x 0.051	Cover Pin	387/U-M

Waveguide available in various non-ferrous materials.
Flanges meet standard military designations.

Terms and Conditions

The term "Seller" in this document refers to "Microwave Device Technology Corporation (MDT)."

1. Acceptance
This order contains all of the terms of the purchase and sale between the Seller and the Buyer, and supersedes all prior correspondence, offers, representations and negotiations between them to the extent that they will conflict or are in addition to the terms contained herein, being intended as a final expression and complete and exclusive statement of the terms of the agreement. Acceptance by the Seller of the Buyer's purchase order is expressly made conditional to the Buyer's assent to the terms of this sales order. Acceptance of the products described on the reverse side hereof ("product") shall constitute acceptance of the terms hereof, but this shall not preclude the formation of a contract to buy and sell the products in any other lawful manner.

2. Warranty
Seller warrants for a period of twelve (12) months from the date of original shipment that the products will be free from defects in material and workmanship, and will be in conformity with applicable specification; provided, however, that this warranty shall not apply to any product which shall have been abused or misused physically or electrically, or on which the trademark shall have been defaced or obliterated. Seller shall be liable under this warranty only if Buyer requests written return authorization within the warranty period and otherwise fully complies with the procedures relating to warranty adjustments set forth below. In no event shall Seller be liable for special, indirect or consequential damages nor for an amount in excess of the net price of the products found to be defective or not in conformance with applicable specifications. All products are guaranteed to operate in complete conformance with the applicable manufacturing specification providing the item is placed in operation within one year from the date of original shipment by Seller, if a product is found defective or not in conformance with applicable specification, it will be subject to adjustment only if written authorization is requested within a period of twelve (12) months from the date of original shipment by Seller. Authorization for return must be secured from Seller and will not commit Seller to the making of any adjustment with respect thereto. Requests for return authorization must list types and quantities of products involved, the reason for the request, information concerning operating conditions involved, and the period of use. In addition, the customer's purchase order number and, where possible, the original invoice number covering the original purchase of the products involved must be shown. Returned products must be shipped, transportation prepaid, by the most economical method of shipment. Shipping costs will be credited on all products found subject to warranty adjustment. Excess transportation costs resulting from the employment of other than the most economical carrier will not be allowed. Seller can accept no billing for packing, inspection, labor charges, or other incidental costs in connection with any products returned for adjustment. Unless otherwise requested by the customer, defective returned products found not subject to warranty adjustment will be sent back to the customer, transportation collect. In all cases, Seller's inspection will be final. With respect to products found defective or not in conformity with applicable specifications, an equitable adjustment will be made taking into account the nature of the defect or nonconformance, the period of use, and the price of the product prevailing at the time of adjustment. Adjustment will take the form, at Seller's option, of a replacement or repair of the defective or nonconforming product. In the event that it is uneconomical to replace or repair warranted items, Seller may, at its sole option, remit the dollar equivalent based upon the original product sales price and said remittance will be calculated by applying the pro rata percentage of the unexpired warranty to the original product sales price. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES WHETHER WRITTEN, ORALLY EXPRESSED OR IMPLIED (INCLUDING WITHOUT LIMITING THE GENERALITY OF THE FOREGOING, ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR PURPOSED), IN NO EVENT WILL SELLER BE LIABLE FOR SPECIAL CONSEQUENTIAL OR INCIDENTAL DAMAGES ARISING FROM BREACH OF THIS WARRANTY. In the event of replacement pursuant to the foregoing warranty or at Buyer's expense, such warranty shall apply to the replaced product. In the event of repair pursuant to the foregoing warranty or at Buyer's expense, the validity of the foregoing warranty will be one year from the date of shipment of the repaired product less the period of time between the date of original shipment and the date on which Seller received return of the product for repair.

3. Title and Risk of Loss
Passage of title and right to possession to the products shall remain with the Seller until all payments hereunder shall have been made in full, in cash. Payment shall be for the full amount stated on the reverse side hereof unless agreed to the contrary in writing by the Seller. The Seller reserves the right to decline to make deliveries hereunder except for cash whenever the Seller in its absolute discretion determines that the Buyer is not financially responsible; and in such event the Seller shall not be liable for the failure to deliver in whole or in part. Partial shipments shall be permitted, and if delivery is to be made in installments, no breach with respect to any installment shall be deemed to be a breach of the entire contract. The Buyer may not cancel this contract except upon the written consent of the Seller. The risk of damage to or destruction of the products shall be borne by the Buyer at all times after delivery by the Seller to a carrier for shipment. The Seller shall not be liable by reason of any delays in delivery caused by war, fire, strikes, floods, accidents, Government priorities or regulations, shortages of material or causes beyond its reasonable control. It is understood that the nonoccurrence of such events is among the basic assumptions upon which commitments by the Seller hereunder are made. The Seller will use its best efforts to meet the time for delivery specified on the reverse side hereof, but does not assume a firm obligation for delivery at that time.

4. Governing Law
The contract shall be subject to, governed by and construed in accordance with the law of the Commonwealth of Massachusetts. A waiver by the Seller of any of the terms and conditions of the contract shall not be deemed to be a continuing waiver but shall apply solely to the instance to which the waiver is directed. No action shall be brought for any breach of this contract more than one year after the accrual of the cause of action therefor.

5. Invalidity of any Provision
If any term or provision of this agreement, or the application thereof to any circumstance shall be invalid or unenforceable, the remainder of this agreement, or the application thereof to any circumstances other than those to which it is invalid or unenforceable, shall not be effected thereby, and each term and provision of this agreement shall be valid and enforced to the fullest extent permitted by law.

6. Taxes
Buyer agrees to furnish the Seller with an exempt purchase or resale certificate or, in the absence of same, assume all liabilities for all Federal, state and local taxes and duties.

7. Patent Indemnity
Seller shall provide patent indemnification for only those standard components which have been offered for sale to the public on the commercial open market. Additionally, if a U.S. Government prime contractor subcontract is involved, the provisions of FAR 52.227-1, Authorization and Consent, shall apply.

8. General
In no event shall the Seller be liable for special, indirect or consequential damages. Seller's liability on any claim for loss, cost, damage, expenses, or other liability arising out of or connected with this contract, or any obligation resulting therefrom, or the manufacture, sale, delivery, resale, repair or use of any product covered by this contract (including but not limited to, loss or liability arising from breach of contract) shall in no case exceed the unit price of such equipment or part thereof involved in such claim.

9. U.S. Government Regulations
When the items purchased under this purchase order are for use in connection with U.S. Department of Defense prime contract or subcontract; the inclusion of any Federal Acquisition Regulation, Defense Acquisition Regulation shall not operate to increase Buyer's rights with respect to audit, patent rights, and rights in technical data. The Books and Records of Seller shall only be made available to representatives of the U.S. Government. However, with respect to Buyer evaluation of contract cost proposals (SF1411), Seller's policy is to allow Buyer review of the basis for the proposed quantities of material and labor hours, including any pertinent historical data, and the quotes and/or historical pricing data.

10. Notwithstanding the Terms and Conditions herein, Seller's Terms and conditions of offer shall prevail.

Domestic:

Arizona

Sun-Tech Marketing
7307 E. Indian Plaza
Suite 113
Scottsdale, AZ 85251
Main Contact: Joe Corvino
Ph: (480) 483-1082
Fax: (480) 483-1083
E-mail: sunpow88@aol.com
Web:
www. Suntechmktg.com

Eastern Pennsylvania

Scientific Devices - Phila., Inc.
1107 Bethlehem Pike,
Suite 209
Flourtown, PA 19031
Main Contact: John Schultz
Ph: (215) 836-0780
Fax: (215) 836-0783
E-mail: SciDevJS@aol.com
Web: www.SciDev-Phila.com

NY, NJ, Fairfield County CT

RF Electronic Sales
1035 Oyster Bay Road
East Norwich, NY 11732
Main Contact: Ken Bardon
Ph: (516) 624-3800
Fax: (516) 624-2920
E-mail: sales@rfsales.com

Canada

GIGA-TRON Associates Ltd.
968 St. Laurent Blvd.
Ottawa, Ontario
Canada K1K 3B3
Main Contact: Greg Michaud
Ph: (613) 747-4114
Fax: (613) 747-3474
Mobile: (613) 795-1208
E-mail: sales@gigatron.com
E-mail: greg@gigatron.com

GIGA-TRON East (Montreal)

Ph: (514) 620-7798
Fax: (514) 620-7812
Main Contact: Greg Michaud, Michelle Rennie

GIGA-TRON West (Calgary)

Ph: (403) 257-0636
Fax: (403) 257-0569
Main Contact: Ron Stewart, Karen White

GIGA-TRON (Toronto)

Ph: (519) 744-2082
Fax: (519) 744-4155
Main Contact: Dana Prince, Greg Payne

International:

France

MB Electronique
606 Rue Fourney Z.I. - B.P. 31
78533 BUC CEDEX, France
Main Contact: Bernard Gerber, Dir Sales
Alain Rapaport
Ph: 33/1 39 67 67 67
Fax: 33/1 39 56 53 44
E-mail: a.rapaport@
mbelectronique.fr

Germany/ Austria/ Switzerland

E.R.M.
Mikrowellentechnik
Pirchingerstr, 22
D-81929 Munchen - Germany
Main Contact: Eva Renz, Pres; Erich Renz, VP Sales
Ph: 49 89 93 6788
Fax: 49 89 93 05674
E-mail:
ERM.Renz@t-online.de

Hong Kong/ China

Pangaea (HK) Limited
Room 1702, Taai Yau
Building
181 Johnston Road
Wan Chai, Hong Kong
Main Contact: Richard Fung
Ph: 852 2836 3301
Fax: 852 2834 7340

US Location

Pangaea Associates
3 Uplands Drive
Littleton, MA 01460
Main Contact: Marc Saucier
PH: (978) 486-0942
FAX: (978) 486-4647
E-mail:
Pangaeaus@internetMCI.com

India

Elkay International Inc.
15 Commerce Boulevard
Succasunna, NJ 07876
Main Contact: T. V. Krishna
Ph: 973-927-8647
Fax: 973-927-5370
E-mail:
elkay_usa@elkayintl.com

Affiliate

Aarjay International PVT Ltd.
No 583, 12 "A" Cross
J.P.NAGAR 2nd Phase
Bangalore 560 078 India
Main Contact:
P.K. Ramachandran
Ph: 91 80 6586844
Fax: 91 80 6586845
E-mail: aarjay@aarjay.com

Israel

Tritech Ltd.
4 Hayetzira Street
PO Box 2436
Ra'anana 43100
Israel
Main Contact:
Rami Galberson, Director
Perach Mashiach
Ph: 972-9-741-7277 x289
Fax: 972-9-748-2616
E-mail: Perach@tritech.co.il

Italy

MicroElit S.P.A.
Via Sardegna, 1
0146 Milano, Italy
Main Contact:
Achille Manfredi, Pres
Franco Cugusi, VP Sales
Ph: 39 02 4817900
Fax: 39 02 4813594
E-mail: f.cugusi@microelit.it

Rome Location

MicroElit S.P.A.
Via Nicola Marchese, 10
00141 Rome, Italy
Main Contact:
Massimo Martinuzzi
Ph: 39 06 86894323
Fax: 39 06 8275270

Norway

Datamatik as
Postboks 12, Lindeberg Gard
1007 Oslo
Norway
Main Contact: Tronn Lervik
Bjorn Backe
Ph: 47 22301730
Fax: 47 22300273
E-mail:
bjorn.backe@datamatik.no

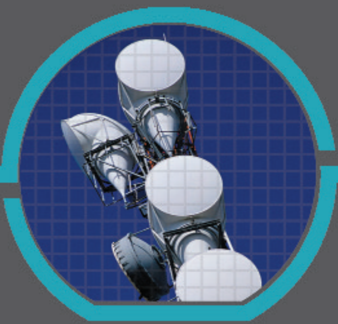
Sweden

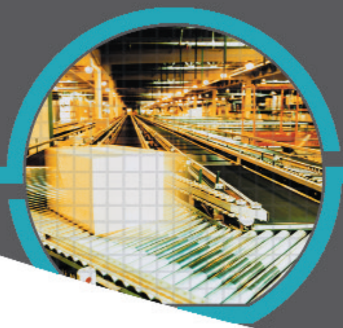
Nordimar
Box 49 S-182 05 Djursholm
Sweden
Main Contact:
Lennart Eriksson
Ph: 46 8 753 3760
Fax: 46 8 622 6304
E-mail:
lennart@nordimar.se

United Kingdom

Admiral Microwaves LTD
Admiral House
30 Watling Street
Radlett, Herts WD7 7NN
Main Contact: Stan Cohen
Ph: 1923 859300
Fax: 1923 857120
E-mail: sales@admiral-
microwaves.co.uk
Web: www.admiral-
microwaves.co.uk

Preliminary document. Specifications subject to change.





MDT

Better by Design.

Microwave Device Technology Corporation
4 Lyberty Way • Westford MA 01886
Telephone (978) 692-7800 • Fax (978) 692-9400
www.mdtcorp.com