Gunn oscillator design

for the 10-GHz band

Gunn oscillators are an attractive alternative to *reflex klystrons as a signal source in the* Amateur microwave bands. However, to some, the design of stable Gunn oscillators is considered to be somewhat empirical. In practice a particular design approach is tried then perfected through cut-and-try. Much research has been done with Gunn devices as described in the literature,[1,2] leading to high-quality commercial units.

In an effort to dispel some of the mystery surrounding Gunn oscillator design, I'll set down some ground rules for a certain design approach that produced good results. I wish to emphasize at this point that what follows is only *one* of several approaches that will give results. The oscillators were designed for 10 GHz, but this design could be used and modified for any microwave band between 5 and 90 GHz. Gunn devices can be made to oscillate in a number of configurations. These can be in the form of coaxial resonators, waveguide cavities, and microstrip circuitry.[3] They can be tuned mechanically or electrically. The theory of how Gunn devices oscillate is covered in other literature.[4,5,6]

The type of Gunn oscillator presented in this article is a waveguide cavity oscillator. If you wish to tune a waveguide cavity oscillator over a wide range, the cavity volume formed between the diode mount and a movable back wall, in the form of an rf choke, is changed. D. Evans,[7] and Tsai, Rosenbaum, and Mac Kenzie[8] describe wideband mechanically tunable waveguide cavity oscillators. However, the other approach to waveguide cavity oscillator design is to use an iris-coupled waveguide cavity. Here the resonant cavity is formed by the iris and the diode mount. The backwall is adjusted close to the diode mount for optimum operation. The design is inherently narrowband, tunable over 100-300 MHz. Since operation is permitted between 10.0 and 10.5 GHz, this type of oscillator presents a practical approach. Other features of the oscillator are that it is fairly straightforward in design and can be easily reproduced.

Following is a presentation of some of the ground rules for iris-coupled waveguide oscillator design. From these, a design procedure is presented followed by testing techniques and precautions to be taken when putting the oscillator into operation.

The iris-coupled waveguide cavity oscillator is shown in **fig. 1**. The diode is mounted across the center of the broad dimension of the waveguide. Dc bias is coupled to the diode through an rf choke. The backwall, which can be moved, is usually close to the diode mount and can be adjusted for stable operation. The function of the iris is to complete the waveguide cavity while providing coupling between oscillator and load. The tuning screw located between the diode post and the iris provides a limited tuning mechanism for the oscillator.

Since the Gunn oscillator is a negative-resistance device, it will have a tendency to oscillate at more than one frequency. The idea is to reduce the number of spurious resonances and make it oscillate where you want it to. The first step in this direction is to examine what makes up the main oscillating cavity of the oscillator.

Waveguide cavity. The fundamental resonant mode of the cavity occurs when the distance between the iris and the effective backwall is one-half the guide wavelength. If the diode is mounted near a sidewall of the cavity, the effective backwall is somewhere between the diode post and the backwall. If, however, the diode is mounted in the cavity center, the effective backwall is in the plane of the diode mount.[9] This is verified by slotted-line measurements looking at the normalized impedance in the plane of the diode mount.

One end of the cavity is now defined. The other end is defined by the iris. The iris reactance can be either inductive or capacitive. **Fig. 2** shows an equivalent circuit of an iris-coupled cavity. If the iris is capacitive, the physical length of the cavity is longer than $\frac{\lambda_g}{2}$ as shown in **fig. 2(a)**. If the iris is inductive as in **fig. 2(b)**, the actual cavity length is shorter than $\frac{\lambda_g}{2}$. The relationship between cavity length and iris susceptance is:[10]

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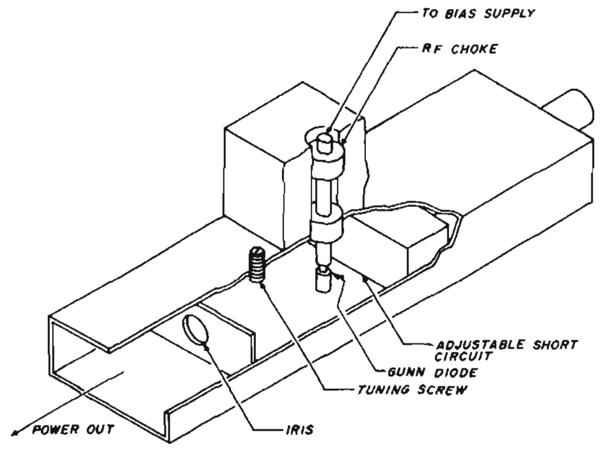


fig. 1. Simple waveguide iris-coupled oscillator. With the diode mounted across the guide center, the distance between iris and diode post is approximately one-half guide wavelength. Iris size is optimized for maximum power output while providing isolation from load mismatches. The rf choke minimizes power loss through the bias line. Backwall is adjusted to provide a stable operating point.

$$\ell = \frac{\lambda_g}{2\pi}\left[n\pi + \tfrac{1}{2}\tan^{-1}\frac{2}{|b_e|}\right] \text{(cap.)} \quad (1)$$

$$\ell = \frac{\lambda_g}{2\pi}\left[n\pi - \tfrac{1}{2}\tan^{-1}\frac{2}{|b_e|}\right] \text{(ind.)} \quad (2)$$

where ℓ = cavity length

λ_g = guide wavelength

$$= \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}}$$

n = integral number

$|b_e|$ = absolute value of normalized iris susceptance

λ = operating wavelength

a = wide dimension of waveguide

In most cases $n = 1$ to reduce the possibility of the oscillator operating at a lower frequency. Once the value for b_e is found, the appropriate expressions (**eqs. 1** or **2**) give a value for the cavity length, ℓ.

The estimated value of loaded Q for an iris-coupled cavity is given by:[11]

$$Q_L \simeq b_e^2 \frac{\pi}{2} \frac{1}{\left(1-\frac{f_c}{f}\right)^2} \quad (3)$$

where b_e = normalized value of iris susceptance

f_c = guide cutoff frequency, TE_{10} mode

f = operating frequency

From the previous discussion, the cavity length, ℓ, and the cavity loaded Q depend on the value given to the normalized iris susceptance.

Iris. An iris is an obstruction placed into a waveguide system that electrically has a value of reactance or its inverse, susceptance. Irises can take various shapes (**fig. 3**) and can be inductive, capacitive, or resonant. From the standpoint of ease of construction, a centered circular aperture is the simplest form to make. The circular iris is inductive and its value can be calculated; however, it's easier to use the graph[12] in **fig. 4**.

The graph gives a good approximation for the value of normalized susceptance, $\frac{B}{Y_0}$ (that is, b_e) as a function of the ratio of iris diameter to the broad dimension of the waveguide. This is done for various waveguide aspect ratios and various ratios of operating-wavelength-to-guide width. The values of b_e from the chart are in good agreement with measured values. Now that the iris susceptance is calculated using **fig. 4**, cavity length can be found.

The question is raised as to how large a hole should be made in an iris plate. Critical coupling, the point where power output is maximum, occurs when the iris area is about 25 per cent of the waveguide cross-sectional area.[13,14] If the hole is further enlarged, the oscillator cavity will be overcoupled with a resultant drop in output power and poor stability. On the other hand, by making the hole smaller, the cavity will become undercoupled resulting in a drop in oscillator output power.

So in determining cavity length, choose an iris area between 20 and 25 per cent of the waveguide cross-sectional area. Since the circular iris area is $\pi d^2/4$, the diameter can be found. The next step is to design the cavity to operate at the highest frequency of interest. The cavity can always be tuned downward by a dielectric screw tuner. The operating frequency determines the wavelength. Knowing the a and b dimensions of the guide, the value of the normalized susceptance, b_e, can be found from **fig. 4**. This value is then substituted into **eq. 2** to find cavity length ℓ.

Rf bias-choke system. Erratic operation, spurious responses, and power loss can be caused by an improper bias-choke design. The diode must be operated with a dc bias while decoupled from the

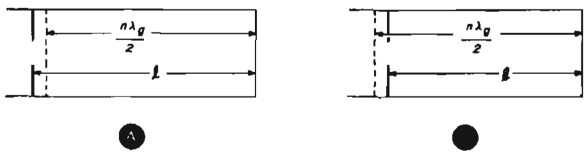


fig. 2. Equivalent circuit of an iris-coupled cavity. When the iris is capacitive, A, the actual cavity length is longer than multiples of one-half guide wavelength; when inductive, B, the actual cavity legnth is shorter than multiples of one-half guide wavelength.

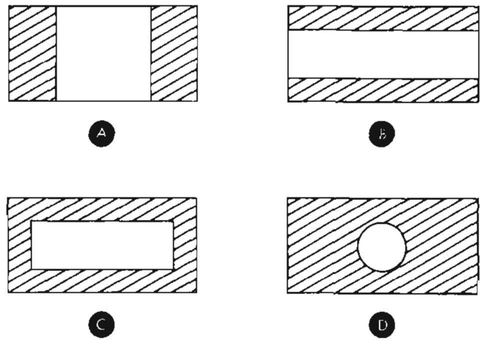


fig. 3. Various iris configurations. A and D are inductive; B and C are capacitive and resonant respectively. The circular iris in D is easiest to make.

bias supply. Early designs operated erratically and even had diode failure because of poor bias-choke design. Two common types of chokes are the radial-line choke and "dumbbell" choke. The radial-line choke requires a large circular plate parallel to the broad side of the waveguide with small separation. The radius of the radial line is approximately $\lambda/4$, with a configuration of an open-ended quarter-wave transmission line. The feedpoint impedance at the diode end becomes very low.

Although this type of bias-choke system is easy to build, some radiation occurs from the open end. A more popular choke arrangement is the "dumbbell" choke, **fig. 5**. As the name implies, sections A, B, and C resemble a dumbbell. This choke design is basically a series of quarter-wave-long coaxial line transformers, alternating between low and high Z_0 sections. The design transforms a wide variety of impedances at the feed point to an extremely low impedance at the Gunn-diode mounting point. This is necessary since the waveguide wall is a current-carrying surface.

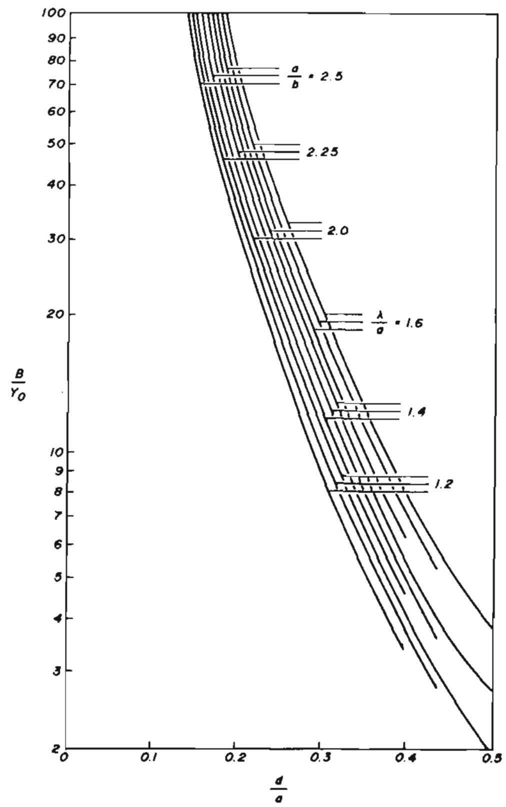


fig. 4. Relative susceptance of a centered circular aperture as a function of the ratio of iris diameter to waveguide broad dimension.

The characteristic impedance of a coaxial line is:

$$Z_0 \simeq \frac{60}{\sqrt{\epsilon_r}} \ln \frac{r_2}{r_1} \qquad (4)$$

where r_2 = inside radius, outer conductor
r_1 = outside radius, inner conductor
ϵ_r = relative dielectric constant

Since sections A and C must have close spacing with respect to the wall, a dielectric material such as Mylar tape can be used to prevent the choke from shorting the bias supply. Sections A and C will be shorter in length than section B to account for the difference in phase velocity caused by the different dielectric constant of the tape. The velocity that the wave propagates is given as:

$$v = \frac{c}{\sqrt{\epsilon_r}} \qquad (5)$$

where v = velocity of propagation
c = speed of light = $3(10^8)$ meters/second
ϵ_r = relative dielectric constant

To calculate the $\lambda/4$ sections, operating wavelength, λ, is found from:

$$\lambda = \frac{v}{f} \qquad (6)$$

where λ = operating wavelength
v = propagation velocity
f = operating frequency

Eqs. 5 and **6** will allow you to calculate the lengths of sections A, B, and C, while **eq. 4** gives the characteristic impedance of each section. The diameter of the cylindrical hole into which the choke section slides can be between 1/4 inch (6.35 mm) to 1/2 inch (12.7 mm) for X band. A compromise is to use 3/8 inch (9.5 mm).

Diode-mounting configurations. The diode can be mounted on a post centered in the waveguide. The post and mounted diode can excite TEM modes in the vicinity of the post, resulting in spurious responses that can cause oscillator turn-on problems. Post reactance can be eliminated if guide height is reduced to that of the diode package. However, results have shown that the tuning range is narrowed and power output drops.[15] If it's desirable to broadband the oscillator, a tapered or stepped post can be used. Again, because the device is a negative-resistance oscillator, broadbanding in this manner can lead to oscillation in unwanted modes and turn-on problems.

The resonant frequency of the TEM modes can be equated to post and diode height, being approximately a half-wavelength long. Mode frequency can be doubled by centering the diode on the post. The diode will cause a null in the fields at the point that makes the original post-height sections halved. However output power will drop, since mounting the diode in the post center decouples the diode. In many cases diode location on the post is left up to the experimenter.

Optimum post diameter is discussed in the literature.[16] Theoretical calculations verified by experimental results show that a post 0.125 inch (3 mm) in diameter gives the oscillator the broadest bandwidth. Post diameters greater than 0.150 inch (3.8 mm), reduce bandwidth over which the oscillator can operate. The power output, however, increases with post diameters greater than 0.150 inch (3.8 mm).

Cavity backwall. In some Gunn-oscillator designs the cavity backwall is fixed and located approximately one-half guide wavelength behind the diode post. For this configuration, some form of matching network is ahead of the diode. In the iris-coupled waveguide oscillator the backwall can also be fixed; however, this must be done by experimentation to obtain optimum results.

Once the backwall position is determined for optimum power output and stability, the position can then be fixed. From a flexibility standpoint, I found that a movable backwall permitted greater freedom of adjustment. This is particularly evident when different Gunn diodes are used in the same cavity.

Fig. 6 illustrates different movable backwall designs. **Figs. 6A** and **B** are quarter-wave choke sections, while **fig. 6C** is a close-fitting block that can be secured by locking screws once optimum operation is established. In **fig. 6A**, the quarter-wavelength sections are separated from the wall by nylon bearings. The mechanism is spring loaded, so that a constant pressure is exerted onto the choke assembly. An adjusting knob, riding on a threaded shaft, moves the choke assembly in and out.

Fig. 6B is identical to that of **fig. 6A**, except a dielectric is used around the entire sections that come in close contact with the waveguide walls. Note that these sections are narrower than the corresponding sections in **fig. 6A** because the insulated sections form a dielectric loaded guide.

Fig. 6C shows a simple block that is close-fitted in the guide. No attempt is made to insulate here; wall contact is desired with this design. In many cases, the block is cut to a depth of a quarter guide wavelength. A threaded rod acts as a handle for block adjustment.

The choke-section depth is based upon the idea that the space between guide sidewall and choke can be considered as a guide beyond cutoff (assuming TE_{10} mode). The space between the guide broad wall and choke is basically a reduced-height guide propagating in the TE_{10} mode. The relationship for λ_g is the same regardless of guide height. The choke depth is one-quarter guide wavelength. When air is in the dielectric, $\lambda_g/4$ is computed from:

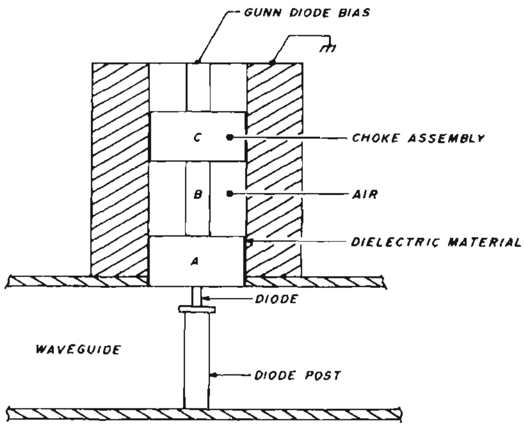


fig. 5. Cross section of the dumbbell rf choke. Sections A and C are identical. The dielectric insulates the center section from the wall. Sections A, B, and C form a coaxial transmission-line system of quarter-wavelength transformers with different characteristic impedances.

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}} \; for \; TE_{10} \; mode \qquad (7)$$

where λ_g = guide wavelength
λ = operating wavelength
a = broad guide dimension

From **eq. 7** the value for λ_g is divided by four, and each section in **fig. 6A** is $\lambda_{g/4}$ long.

In **fig. 6B**, the value of λ_g for the two sections having dielectric tape wrapped around them is:

$$\lambda_{gd} = \frac{\lambda}{\sqrt{\epsilon_r - \left(\frac{\lambda}{2a}\right)^2}} \; for \; TE_{10} \; mode \qquad (8)$$

where λ_{gd} = guide wavelength in dielectric guide
ϵ_r = relative dielectric constant

Here the first and third choke sections are $\lambda_{gd}/4$,

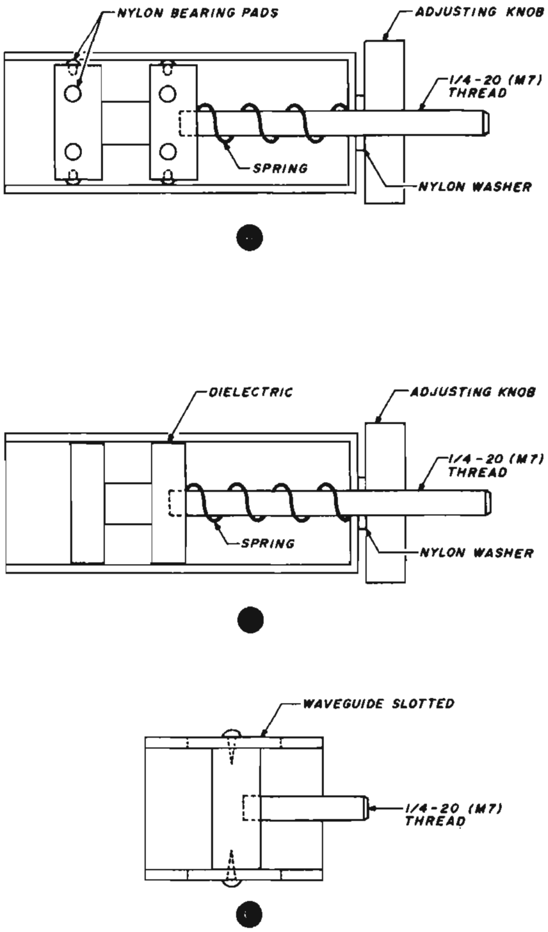


fig. 6. Different moveable backwall designs. An adjustable backwall choke assembly, using nylon pads for isolation, is shown in A. B shows a design using dielectric tape around the two sections. Wall contact is desired in the block design in C. The close-fitting adjustable backwall is locked into place by locking screws on each side of the waveguide.

while the middle section is $\lambda_g/4$. **Eq. 8** is an approximate solution, assuming that a dielectric with a low-loss tangent is used.

Matching section. This device is an adjunct to the oscillator in that, if there's a considerable mismatch between oscillator and load, some sort of matching device is needed. Several techniques are used in impedance matching. Devices such as E-H tuners and slide-screw tuners, have been fairly common. However, they've been replaced in many applications by a ferrite isolator. This device exhibits low attenuation in the forward direction and high attenuation in the reverse direction. They can be made broadband and present a constant load to the oscillator despite wide variation of load mismatch. However, they're rather expensive, so a simple approach is used.

While it's narrow band, a three-screw tuner will match over a limited range of mismatch conditions. **Fig. 7** is an example of a three-screw tuner. The screws are one-quarter guide wavelength apart and are placed along the center line of the broadwall of the guide. If a wider range of impedances is to be matched, 3/8 and 5/8 guide wavelength separations can be used if space permits. The distance between the iris and the first screw of the tuner can be made 3/8 guide wavelength.

oscillator design and assembly

Since an iris-coupled waveguide cavity oscillator can tune only over a portion of the 10-GHz band, several factors affect the choice of frequency. First, the frequency will tune downward with increasing bias for most diodes. Diodes are available where frequency increases with bias; these are employed where temperature compensation is required. Second, the frequency will tune downward as the tuning screw penetrates the cavity. Third, the frequency decreases with increasing temperature.

Because the effects of bias, temperature, and mechanical tuning lower the frequency, choose a frequency of, say, 50 MHz or so above the desired operating frequency. With an AFC system, the oscillator can stay locked onto either the incoming received signal or a reference signal.

Design example. In the following example an operating frequency of 10.350 GHz was chosen. To compensate for the effects mentioned previously 10.400 GHz became the design frequency. An iris diameter of 0.25 inch (6.35 mm) was used. Before the cavity length can be calculated from **eq. 2**, λ_g and b_e must be found:

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 m/s}{10.4 \times 10^9 Hz} = 1.13 \text{ inch}$$

$$(0.02885 \text{ meters or } 28.85 \text{ mm})$$

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}} = \frac{28.85 \text{ mm}}{\sqrt{1 - \left(\frac{28.85 \text{ mm}}{2 \times 22.86 \text{ mm}}\right)^2}} = 1.464 \text{ inch } (37.18 \text{ mm})$$

From **fig. 4**, the value for b_e can be found, providing the following ratios are calculated:

$$\frac{d}{a} = \frac{6.35 \text{ mm}}{22.86 \text{ mm}} = 2.8$$

$$\frac{a}{b} = \frac{22.86 \text{ mm}}{10.16 \text{ mm}} = 2.25$$

$$\frac{\lambda}{a} = \frac{28.85 \text{ mm}}{22.86 \text{ mm}} = 1.26$$

Using these numbers in **fig. 4**, b_e is 14. Next substitute the values for b_e and λ_g in **eq. 2** and calculate cavity length:

$$\ell = \frac{\lambda_g}{2\pi}\left[\pi - \frac{1}{2}\tan^{-1}\frac{2}{|b_e|}\right]$$

$$\ell = \frac{37.18\ mm}{2\pi}\left[\pi - \frac{1}{2}\tan^{-1}\frac{2}{14}\right]$$

$$0.717\ inch\ (18.2\ mm)$$

The tuning screw can be placed anywhere between the diode post and the iris; however, a position of 0.22 inch (5.6 mm) from the iris was chosen, since placing it too close to the diode post would cause unstable operation.

Bias choke and diode post. Referring to **fig. 5**, the lengths of sections A, B, and C are calculated. Since sections A and C are sections of coaxial line with Mylar insulation, propagation velocity will be altered by $\sqrt{\epsilon_r}$ of the Mylar. Using **eqs. 5** and **6**:

$$v = \frac{c}{\sqrt{\epsilon_r}} = \frac{3 \times 10^8\ m/s}{\sqrt{2.8}} = 5.9 \times 10^8\ feet/second\ (1.79 \times 10^8\ meters/second)$$

$$\lambda = \frac{v}{f} = \frac{1.79 \times 10^8\ m/s}{10.25 \times 10^9 Hz} = 0.688\ inch\ (17.5\ mm)$$

In the above instance, the frequency for the middle of the 10-GHz band was chosen, i.e., 10.25 GHz. The length of sections A and C are $\lambda/4$, therefore:

$$\frac{\lambda}{4} = \frac{17.5\ mm}{4} = 0.17\ inch\ (4.4\ mm)$$

Section B (**fig. 5**) has air dielectric, therefore $\sqrt{\epsilon_r} = 1$ and its length becomes:

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8\ m/s}{10.25 \times 10^9\ Hz} = 1.15\ inches\ (29.27\ mm)$$

$$\frac{\lambda}{4} = \frac{29.27\ mm}{4} = 0.28\ inch\ (7.3\ mm)$$

The characteristic impedance must be low for section A and C and high for section B. Based on choke design appearing in D. Evan's articles,[17,18,19] the outer diameter of the choke cylinder is 0.375 inch (9.525 mm). Sections A and C are chosen so that the spacing accommodates one or two layers of Mylar tape. The diameters of A and C are then 0.360 inch (9.144 mm). The diameter of B is approximately 1/3 of that of A and C. Section B diameter is chosen as 0.125 inch (3.175 mm). Using these diameters in **eq. 4**, the characteristic impedances of the sections are:

Sections A and C:

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}}\ \ell n \frac{r_2}{r_1}$$

$$Z_0 = \frac{60}{\sqrt{2.8}}\ \ell n \frac{9.525\ mm/2}{9.144\ mm/2} = 1.46\ ohms$$

Section B:

$$Z_0 = \frac{60}{\sqrt{1}}\ \ell n \frac{9.525\ mm/2}{3.175\ mm/2} = 65.9\ ohms$$

The section above C maintains the same diameter as in section B and is made long enough to connect to a BNC connector. The Gunn diode connects to section A. **Fig. 8** is an outline dimension for a typical low-to-medium power Gunn diode package. Each end is 0.061 inch (1.56 mm) in diameter. The mating hole in section A is made slightly larger; i.e. 0.0625 inch (1.59 mm) in diameter and at least as deep. The diode post is made from a 10-32 (M5) screw. The end opposite the head has a hole drilled out to 0.0781 inch (1.98 mm) diameter. The depth of the hole is at least 0.0625 inch (1.59 mm). The larger hole is needed to avoid fracture of the diode caused by misalignment errors.

The quarter-wave dimensions for movable backwall choke assembly are based on the design shown in **fig. 6B**. Here the first and third sections are loaded with Mylar tape. The inner guide dimension is 0.9×0.4 inch (22.86 mm×10.16 mm). The choke

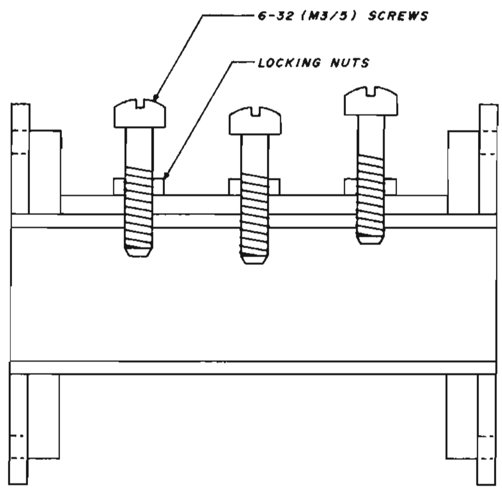


fig. 7. Cross section of the triple-screw matching section. Screws are one-quarter guide wavelength apart and are placed along the centerline on the guide broad wall. Spacings of 3/8 and 5/8 guide wavelengths can be used if space permits, since such spacings match a wider range of impedances.

block must be made smaller by the amount of the Mylar tape. If 5-mil-thick tape is used, the choke block is made with at least a 7-mil clearance on each side. These blocks then become 0.886 × 0.386 inch (22.50 mm × 9.80 mm) in their cross-sectional dimensions. Their length is computed from **eq. 8**:

$$\lambda_{gd} = \frac{\lambda}{\sqrt{\epsilon_r - \left(\frac{\lambda}{2a}\right)^2}}$$

$$= \frac{28.85\ mm}{\sqrt{2.8 - \left(\frac{28.85\ mm}{2 \times 22.86\ mm}\right)^2}}$$

$$= 0.733\ inch\ (18.62\ mm)$$

$$\frac{\lambda_{gd}}{4} = \frac{18.62\ mm}{4} = 0.183\ inch\ (4.66\ mm)$$

This value is the length of the first and third sections. The middle section length is computed from **eq. 7**:

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}}$$

$$= \frac{28.85\ mm}{\sqrt{1 - \left(\frac{28.85\ mm}{2 \times 22.86\ mm}\right)^2}}$$

$$= 1.464\ inch\ (37.18\ mm)$$

$$\frac{\lambda_g}{4} = \frac{37.18\ mm}{4} = 0.37\ inch\ (9.30\ mm)$$

The remaining calculation is that of the matching transformer or tuner. The first screw of the three-screw tuner shown in **fig. 7** is approximately 3/8 λ_g away from the iris. The distance between the screws is $\lambda_g/4$. Using 10.25 GHz, a band center, $\lambda_g = 1.5$ *inches* (38.10 mm). The distance between screws is 0.375 inch (9.5 mm), and between screw and iris is 0.563 inch (14.3 mm). When the sections were built, this dimension was closer to 0.590 inch (15 mm). The discrepancy produced no apparent problem.

construction

Now that all critical dimensions have been calculated, **figs. 9A** and **B** show the oscillator assemblies. The oscillators operate around 10.4 GHz and 10.3 GHz respectively. **Fig. 9B** differs from **A** mainly in backwall design. The construction of the oscillator follows a sequence of steps.

Cavity. Referring to **fig. 9A**, the cavity assembly is made from a piece of WR-90 waveguide about 2.5 inches (63.5 mm) long. If you have a drill press, milling machine, and lathe, the job becomes easier. However, much of the construction can be done if

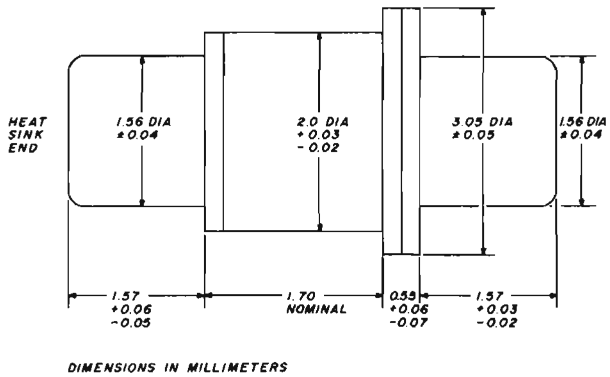


fig. 8. Outline dimensions of a typical low-power Gunn diode encapsulation. Diodes with output power ratings greater than 50 mW (such as the Alpha Industries DGB-6835C) have the cathode on the heatsink end. Those with less than 50 mW output power ratings (such as the Microwave Associates MA-49508) have the anode on the heatsink end.

you have some hand tools and a drill press.

Square off both ends of the guide and deburr. Obtain a piece of brass stock 0.75 × 1 × 1 inch (19 × 25.4 × 25.4 mm) and another 0.125 × 0.75 × 1 inch (3.175 × 19 × 25.4 mm). Fit a UG-39/U cover flange over one end of the guide and clamp the two brass pieces on each side. Make a waveguide cap for the other end of the guide out of a piece of 1 × 0.5 inch (25.4 × 12.7 mm) flat stock 60 mils thick. Place this assembly vertically on a fire brick. Rest the waveguide cap over the open waveguide. The flange end should be flush with the brick. Solder the assembly using a torch and let cool. File the flange end smooth; or if a milling machine is available, mill it smooth.

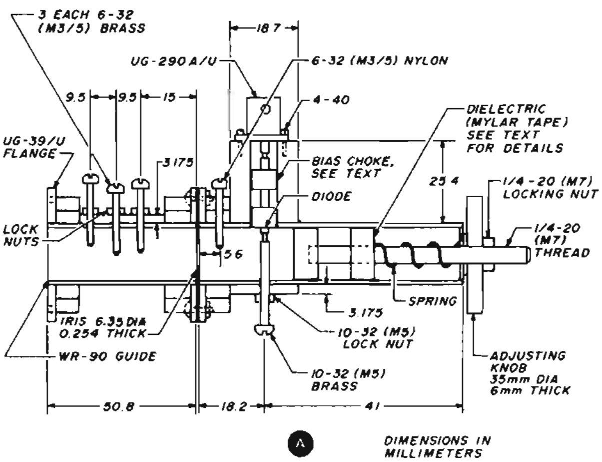
Measure a point 0.717 inch (18.2 mm) back from the flange and center it on the broad dimension of the guide on the 1 inch (25.4 mm) high block behind the flange. Drill a small pilot hole through the entire assembly using a 3/32-inch (2.38 mm) diameter drill. This ensures the alignment of the bias choke with the diode post. On the bottom side, drill and tap for a 10-32 (M5) thread. On the choke block, drill a 3/8-inch (9.525 mm) diameter hole.

A word of caution here — start by drilling progressively larger holes until the required diameter is reached. Use a slow drill speed and oil. The drill has a tendency to grab, and you may have to anchor the assembly to the work table on the drill press.

Next, locate the holes of a UG-290/A BNC connector on the top of the bias-choke housing. Drill and tap four 4-40 (M3) screws 0.5 inch (12.7 mm) deep. Drill and tap a 6-32 (M3/5) hole 0.22 inch (5.6 mm) back from the flange face and centered on the broadwall in front of the bias block for a 6-32 (M3/5) nylon tuning screw. Drill a 1/4-20 (M7) clearance hole centered on the waveguide cap to accommodate the shorting choke assembly screw mechanism.

Iris. The iris is made from thin copper foil at least 10 mils thick. One of the UG-39/U flanges can be used as a pattern as an outline to locate the center. Cut out the iris and scribe a mark locating the center of the iris hole. Carefully drill a 0.25-inch (6.35 mm) diameter hole. Then drill out the four corner holes to clear 8-32 (M4) screws. (Later, the iris plate will be clamped between the oscillator assembly and the tuner assembly.)

Bias choke. To make the bias choke, a lathe is handy since it makes the job easier but isn't absolutely necessary. Obtain a 3/8-inch (9.525 mm) diameter brass rod about 4 inches (101.6 mm) long and square off one end. Referring to **fig. 5**, mark off sections A, B, and C. These will be 0.172 inch (4.4 mm) 0.288 inch (7.32 mm), and 0.172 inch (4.4 mm) respective-



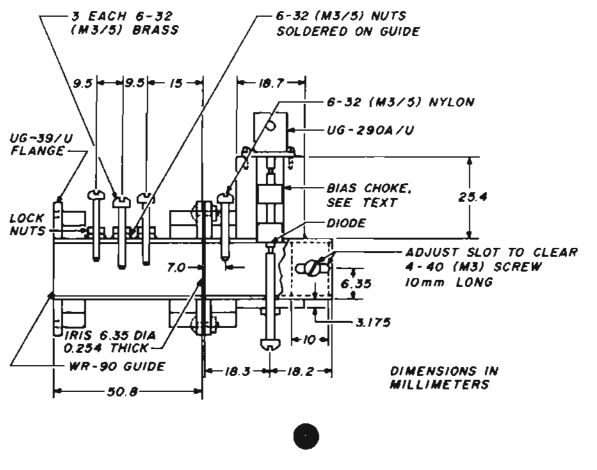


fig. 9. Assembly drawings of two Gunn oscillators. A design using an adjustable choke plunger backshort is shown in A. The oscillator in B has an adjustable contacting backshort that can be locked into place.

ly. Above section C, a length of 0.236 inch (6 mm) can be cut back and attached to the bias connector.

Sections A and C are reduced in diameter 0.360 inch (9.144 mm) and B and the section above C to 0.125 inch (3.175 mm) in diameter. A 0.0625 inch (1.59 mm) diameter hole is drilled on center in the end of section A. Wrap a layer of Mylar tape around A and C. Fit the bias choke into the bias block and set it flush with the inside top of the waveguide. Cut the section of the choke above section C to mate up with the center conductor on the BNC connector and solder. The assembly is secured into place by four 4-40 (M3) screws.

Diode post. The diode post is made from a 10-32 (M5) screw with a 0.078 inch (1.98 mm) diameter hole drilled into the center of the screw opposite the head. When the diode post is put into position, a 10-32 (M5) locking nut secures it.

Backwall. The movable backwall is made from two brass blocks 0.886 × 0.386 inch (22.50 × 9.80 mm) in cross section by 0.183 inch (4.66 mm) long, and a 2.5 inch (63.55 mm) long 1/4-20 (M7) threaded rod. Drill a hole, centered on the face of the block, and tap it for 1/4-20 (M7) thread through one block and half way through the other. Screw the rod into one block. Screw down the other block until it's about 0.366 inch (9.30 mm) from the first block. Wrap a layer of Mylar tap around each block. Slide a spring over the free end of the 1/4-20 (M7) rod.

The assembly is backed into the flange end of the oscillator cavity, and the rod goes through the clearance hole in the cap end of the waveguide. An adjusting knob, threaded for 1/4-20 (M7) is screwed on and used to move the choke assembly. A 1/4-20 (M7) is screwed on and used to move the choke assembly. A 1/4-20 (M7) locking nut is secured when the optimum position for the choke is found.

Place the diode, with heat-sinking compound, into the diode post screw. Carefully insert the screw and diode and lock into place. Do not exert too much pressure (see "**precautions**"). Lock into place with the locking nut. Insert the 6-32 (M3/5) nylon tuning screw at this point.

Tuner. The triple-screw tuner is made from a 2-inch (50.8 mm) section of WR-90 guide. The ends should be squared off and deburred. Solder a brass section 1.125 inch (28.58 mm) long by 1 inch (25.4 mm) wide by 0.125 inch (3.175 mm) thick onto the broad side of the waveguide between the two flanges. Clamp the plate to the waveguide, slide the flanges over each end of the waveguide and solder the assembly. Drill and tap three 6-32 (M3/5) holes centrally along the broad waveguide face through the block according to the locations in **fig. 9A**. Deburr the holes and *insert three 6-32 (M3/5) screws 0.75 inch (19.05 mm)* long with locking nuts. Connect the tuner to the oscillator section. Place the iris plate as shown and use four 8-32 (M4) screws and nuts to hold the assembly together.

This completes the oscillator assembly. The unit in **fig. 9B** is constructed in the same manner except for the backwall. Here a block closely fitting the inside of the guide is clamped into place on each side by a 4-40 (M3) screw.

test techniques and results

The type of tests that can be made depends on what equipment is available. If you've been able to *obtain a fair amount of X-band test equipment,* including a frequency meter and a slotted line from surplus dealers or flea markets, you're in good shape. Otherwise, a minimum of test equipment can be borrowed or made. For making some of your X-band test equipment consult reference 20.

Reflectometer test. For those who have access to *an X-band reflectometer, looking at the reflected* power from the cavity will show where the oscillator cavity resonates and where any spurious resonances occur within the 8.5-12.4-GHz band. Moving the backwall and tuning screw gives an indication of the tuning range. However, when power is applied to the oscillator, these frequencies will shift slightly. If a coaxial-to-waveguide transition is available, a transmission test is made to determine 10-GHz leakage out of the bias choke. The results on both oscillators of **fig. 9** indicate the leakage is down by 60 dB or more.

Slotted line measurements. If a slotted line is available, the reactance of the iris can be measured. I built several irises and the differences between calculated and measured reactance were within 5 per cent. If the values of normalized reactance are calculated carefully from **fig. 4**, they should be within 5 per cent of the actual values.

Swept-bias tests. Probably the most important testing technique used on Gunn oscillator design is

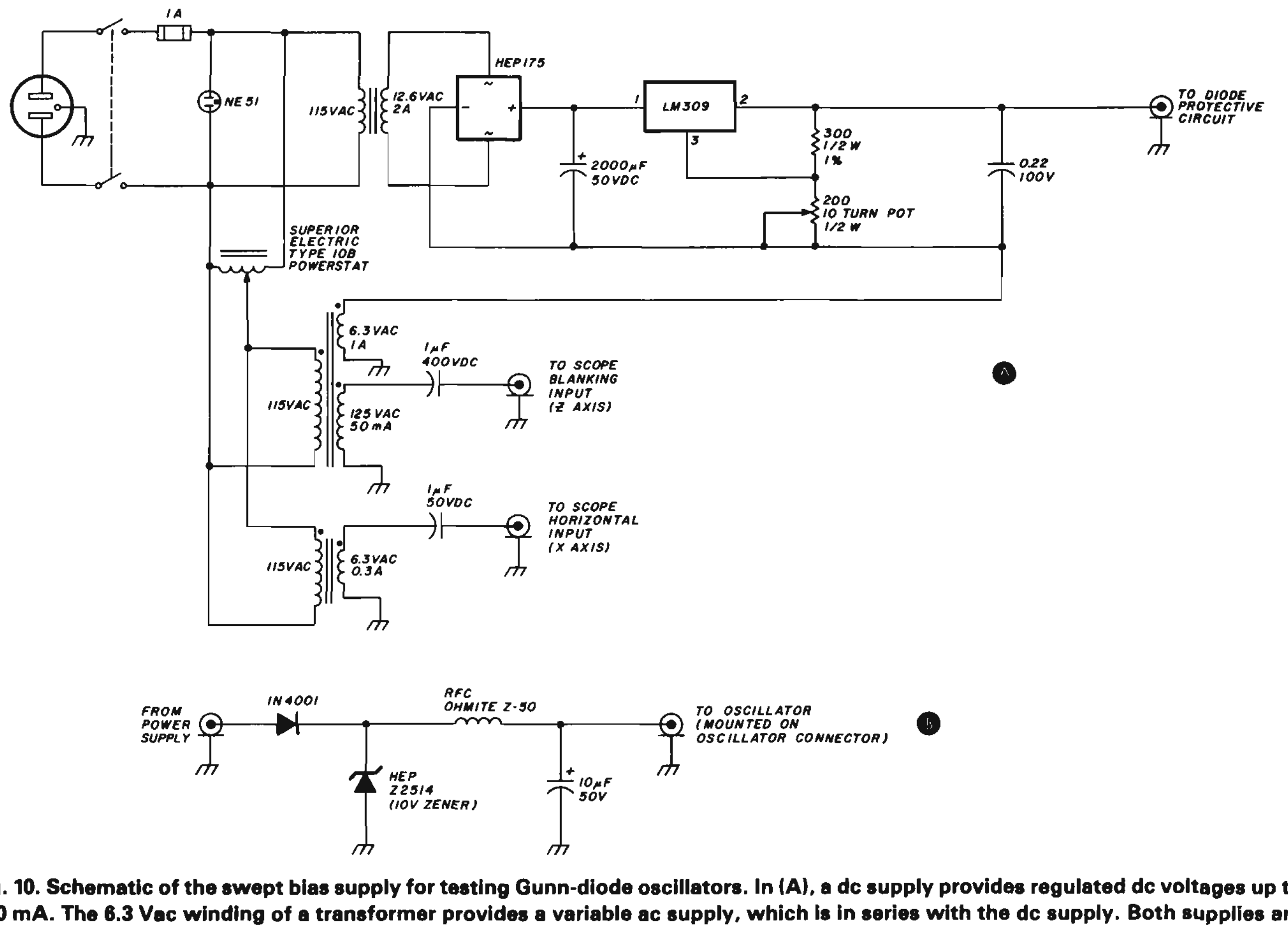


fig. 10. Schematic of the swept bias supply for testing Gunn-diode oscillators. In (A), a dc supply provides regulated dc voltages up to 500 mA. The 6.3 Vac winding of a transformer provides a variable ac supply, which is in series with the dc supply. Both supplies are connected to the Gunn oscillator through the protective circuit in (B).

the swept-bias test setup. A variable bias voltage is applied to the oscillator while its output is monitored with a detector and frequency meter. The swept response is displayed on an oscilloscope. Using such a test setup, the oscillator can be made to look into various loads while making different adjustments toward a stable operating point.

Connect the oscillator and tuner to a load through a directional coupler. Connect a frequency meter and detector to the directional-coupler coupling arm.

The swept-bias supply circuit shown in **fig. 10A** is made of several supplies. A dc supply provides a regulated 5-10 volts dc. The supply can also provide up to 500 mA of current. The 6.3 Vac winding of a transformer, providing a variable ac supply, is in series with the dc supply. Both are connected across the Gunn diode oscillator through the protective circuit, **fig. 10B**. Provisions are made for synchronized sweep voltage and a blanking voltage. Correct winding sense must be observed on the transformer windings to ensure proper sweep direction and blanking.

The protective circuit has a diode in series to protect the Gunn diode from reverse bias voltages and a zener diode to protect it from overvoltage in the forward-bias direction. The Z-50 choke and electrolytic capacitor ensure that a low impedance is presented to the oscillator and prevents buildup of dangerous voltage levels from parasitic resonances.

The protective circuit is connected to the swept source through a coaxial cable. A dummy load is then connected to the protective circuit. The dc voltage is set to 5 volts, and the sweep voltage is adjusted for 6 volts peak-to-peak if the MA-49508 diode is used, or 10 volts peak-to-peak if the DGB-6835C diode is used.

Note the powerstat settings for these ac voltages. Set the ac voltage to zero, turn off the supply, and remove the dummy load. Note: The protective circuit parts mount onto the Gunn oscillator. A matched load is used on the Gunn oscillator setup, and the nylon screw is backed out so that it's even with the inside top wall of the waveguide. The protective circuit box is connected to the oscillator. Turn on the power and advance the swept voltage to the preset position. Move the backshort until a stable swept response, shown in **fig. 11D**, is obtained. (**Figs. 11A** through **11C** show various stages of *misadjustment*.) The screws on the tuner can be adjusted for optimum output power while maintaining oscillation. If a particular antenna is to be connected, turn off the supply, connect the antenna, turn on the supply and make adjustment.

Fig. 11D shows that, under proper operation, the onset of oscillations starts abruptly once the bias voltage exceeds the Gunn-diode threshold voltage.

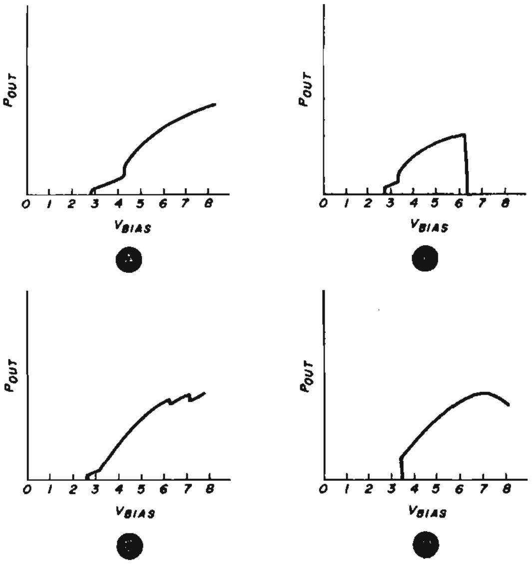


fig. 11. What to expect while running tests. Graphs A through C show respectively poor starting characteristics, oscillator-to-load mismatch, and backwall partially under the bias choke. Graph D shows the proper relationship between power output and bias.

As the bias voltage increases, output power increases to a peak and drops suddenly. Frequency usually decreases with increased bias voltage.

Modulation sensitivity tests were performed on the two types of Gunn diodes. The MA-49508 diode modulation sensitivity measurement was 15.6 MHz/volt, while the DGB-6835C modulation sensitivity measurement was 11.7 MHz/volt (both at room temperature).

For comparison, the published data on these diodes indicate an average modulation sensitivity around 7 MHz/volt at room temperature. The current through the diode remained fairly constant during these measurements.

I made a rough check of temperature effect on the oscillation frequency. The MA-49508 diode frequency drift with temperature was measured at −290 kHz/degree C compared to the maximum of −350 kHz/degree C on the data sheet. The DGB-6835C diode measured −0.87 MHz/degree C to the maximum −1 MHz/degree C on its data sheet.

some precautions

The Gunn diode, like any semiconductor device, can be damaged by an electrostatic discharge. Therefore, use care when handling the diodes. Mechanically, the diodes are fairly rugged upon compression. However, they can be damaged by shear fracture. This particular failure mode occurs when placing the diode into the oscillator cavity and tightening the diode post screw too much, especially if some axial misalignment exists in the diode-socket holes.

Check diode polarity before power is applied. In many cases positive bias with respect to ground is used. The medium- and higher-power diodes, such as the Alpha DGB-6835C, are heat sinked at the cathode end. The diode cathode end makes firm contact with the diode post, which is usually a good heatsink.

On the other hand, a lower-power diode, such as the MA-49508, is constructed with the heatsink on the anode end. It's important to note that, with this type of diode configuration, the diode is physically reversed inside the package. Therefore, if the cathode end is the grounded electrode, the package must be *physically reversed* before mounting it into the oscillator. If this is not done, the diode will be reversed-biased and will be damaged.

Another cause of diode damage is parasitic oscillation. Since the Gunn oscillator is a negative resistance device, oscillations will occur at any spurious resonance that exists from hf to the microwave frequencies. Oscillations can exceed the maximum bias voltage on the diode. If not by-passed at the bias choke cold end, any length of bias line can form a resonant system, and the oscillator may put out power at that particular frequency.

For this reason, it's desirable to mount any modulation/bias circuitry close to the oscillator. Any bias modulation circuit should present a low impedance to the Gunn oscillator. Check with the Gunn diode manufacturer for their recommended protection circuit.

One very important precaution must be mentioned regarding Gunn oscillators (or any microwave oscillator). *Do not* look into the open end of the waveguide while power is applied to the oscillator. Close up, rf power density can exceed OSHA's *10mW/cm²* safety limit. Fortunately, the rf power density falls off to a safe level a short distance from the oscillator. Your eyes are especially susceptible to damage from rf power radiation, so never look into an open waveguide or stand in front of a microwave antenna!

conclusion

I've presented some of the details in the design of a Gunn oscillator. Some of the parameters and conditions for building a working oscillator are given. Also presented is a detailed design and assembly description of the oscillator. Test results are given, and some precautions are stated since it's possible to damage these devices if not properly treated.

Detailed circuits to drive and modulate the diode were not presented, since this is a different subject. Further information can be found in references 21-27. The main purpose of this article was to present how a Gunn oscillator can be built and tested.

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references

1. How to Build a Gunn Oscillator, *Micronotes*, Microwave Associates, Vol 11, No. 2, March, 1974.
2. A.A. Sweet, "How to Build a Gunn Oscillator," *Microwave System News*, October/November, 1973, pages 28-32.
3. *Gunn Effect Technology*, Plessey Optoelectronic and Microwave Application Notes, Publication PS1875, 1980.
4. S.Y. Narayan and F. Sterzer, "Transferred Electron Amplifiers and Oscillators," *IEEE Transactions MTT*, Vol. MTT-18, No. 11, November, 1970, pages 773-783.
5. H. Pollman, et al, "Load Dependence of Gunn-Oscillator Performance," *IEEE Transactions MTT*, Volume MTT-18, No. 11, November, 1970, pages 817-827.
6. W. Tsai and F.J. Rosenbaum, "Amplitude and Frequency Modulation of Waveguide Cavity CW Gunn Oscillator," *IEEE Transactions MTT*, Volume MTT-18, No. 11, November, 1970, pages 877-884.
7. D. Evans, G3RPE, "Practical 10-GHz Gunn Oscillators," *Radio Communication*, May, 1974, pages 288-295.
8. W. Tsai, et al, "Circuit Analysis of Waveguide Cavity Gunn-Effect Oscillator," *IEEE Transactions MTT*, Volume MTT-18, No. 11, November, 1970, pages 808-817.
9. See reference 1, page 10 and reference 2, page 35.
10. J. Altman, *Microwave Circuits*, D. Van Nostrand and Co., Inc., New York, 1964, pages 233-236.
11. See reference 3, page 8.
12. N. Marcuvitz, *Microwave Handbook*, MIT Radiation Laboratory Series, Volume X, Chapter 5, 1948, pages 238-243.
13. See reference 2, page 35.
14. See reference 3, page 8.
15. See reference 2, page 35.
16. See reference 8, page 813.
17. See reference 7, pages 289-291.
18. D. Evans, G3RPE, "A Simplified 10-GHz Gunn Oscillator," *Radio Communication*, February, 1976, page 123.
19. D. Evans, G3RPE, "Getting Started on the 10-GHz Band," *VHF Communications*, January, 1977, pages 19-29.
20. *VHF-UHF Manual*, Chapter 8, Radio Society of Great Britain, 3rd Edition.
21. H.V. Schurmer, *Microwave Semiconductor Devices*, Wiley-Interscience Series, Chapter 8, *Gunn-Effect Devices*, John Wiley and Sons, Inc., New York, 1971.
22. J.R. Fisk, W1HR, "Solid State Microwave RF Generators," *ham radio*, April, 1977, pages 10-22.
23. K.H. Hirschelmann, DJ7OO, "10-GHz Transceiver for Amateur Microwave Communications," *ham radio*, August, 1978, pages 10-15.
24. J.R. Fisk, W1HR, "10-GHz Gunnplexer Transceivers — Construction and Practice," *ham radio*, January, 1979, pages 26-42.
25. D.G. Fink, *Electronic Engineer's Handbook*, First Edition, McGraw-Hill Co., New York, 1975, pages 9-60, 9-68 to 9-70.
26. M.J. Lazarus, et al, "Having a High-Quality V-Band Link and Low Cost Too," *Microwaves*, November, 1972, pages 52-53.
27. M.R. Inggs, "Self-Oscillating Mixer Cuts Antenna Test Costs," *Microwaves*, April, 1978, pages 100-102.

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