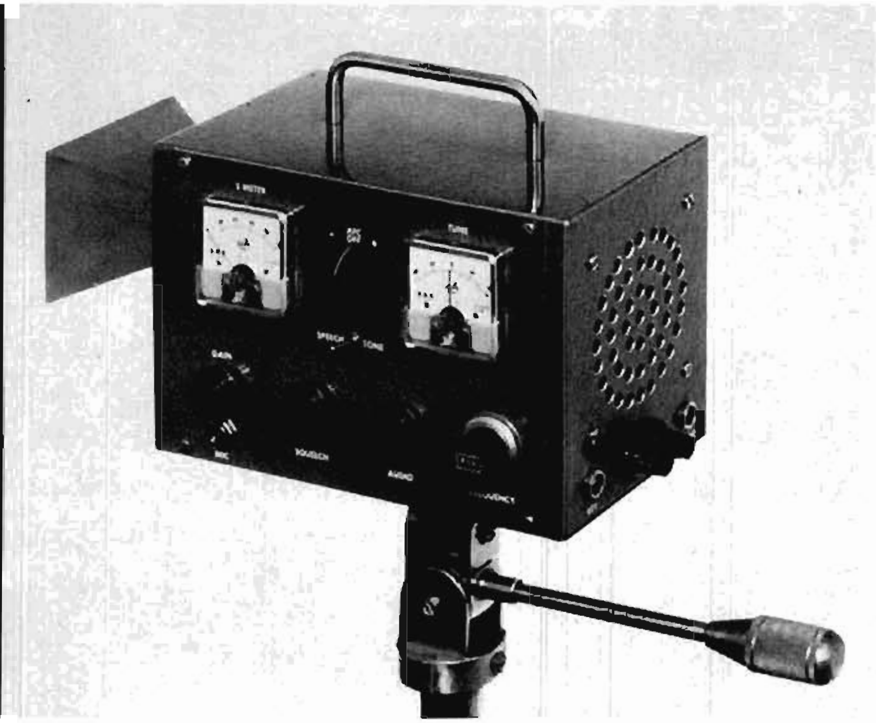


10-GHz Gunnplexer transceivers — construction and practice

Discussion of the various aspects of Gunnplexer transceiver construction and operation, including two practical transceiver designs

Microwave communications is one of the last frontiers of Amateur Radio; thanks to the Gunnplexer transceiver module offered by Microwave Associates, it's now easier than ever to put together a practical station for amateur operation on the 10-GHz band. Only a few years ago a "simple" microwave setup required a rack-full of equipment and friends in the industry who could provide hard-to-find parts. With the Gunnplexer, an entire microwave system can now be held in one hand. It can be easily backpacked to the highest mountain tops, and it can be operated from a single 12-volt battery.

As you receive it, the Gunnplexer module is not a complete transceiver; to put it on the air you need a dc power supply, a simple speech amplifier, and an fm receiver. You can put together a working system in one evening. To build a complete transceiver like that described in this article will take a little longer.

what is a gunnplexer?

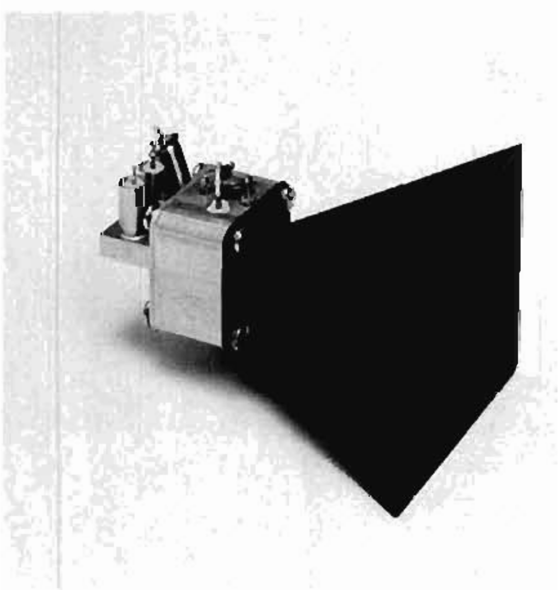
The heart of the Gunnplexer is the Gunn diode oscillator, named after the IBM engineer who invented it in 1963, John Gunn. While measuring the resis-

By James R. Fisk, W1HR, *ham radio*, Greenville, New Hampshire 03048

tance of gallium arsenide (GaAs), Gunn found that when the voltage across a thin wafer of the material was increased above a certain point, the current fluctuated at *microwave frequencies.* The mechanism which caused this was a mystery at first, but Gunn suspected a negative resistance due to electron movements within the gallium arsenide. This eventually proved to be the case (a detailed description of the Gunn diode phenomenon is contained in reference 1).

When a Gunn diode is placed in a resonant microwave cavity, small amounts of power can be obtained at the desired frequency. The cavity can be tuned mechanically, or a voltage-variable capacitor (varactor) may be used to change the resonant frequency of the cavity. The Gunnplexer (**fig. 1**) uses both a mechanical tuning screw and a varactor diode; frequency modulation is obtained by placing a small modulating voltage across the varactor. Power is coupled out of the cavity through an iris. The size of the iris must be determined experimentally for the best compromise between maximum power output and isolation from changes in diode impedance and load.

In the Gunnplexer the Gunn oscillator provides both the transmit power and the local-oscillator injection for the mixer diode. The ferrite circulator couples a small amount of energy into the low-noise Schottky mixer diode and isolates the transmit and receive functions. Since the Gunn oscillator functions as both the transmitter and receive local oscillator, the i-f receiver at each end of the communications link must be tuned to the same frequency, and the frequencies of the Gunn oscillators at each end of the link must be separated by the i-f.



Microwave Associates 10-GHz Gunnplexer.

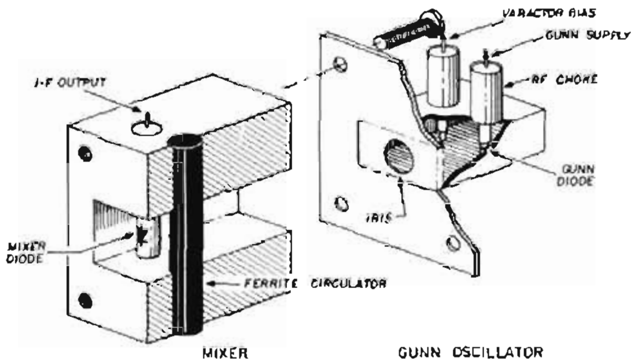


fig. 1. Cutaway view of the Microwave Associates Gunnplexer. The Gunn diode is mounted in a resonant cavity which is tuned by a tuning screw (coarse tuning) and a varactor (fine tuning). Microwave energy is coupled out of the cavity through an iris. The ferrite-rod circulator couples a small amount of rf energy into the Schottky mixer diode; the circulator also isolates the transmit and receive functions and allows full-duplex operation.

Confused? Take a look at **fig. 2**. Here Gunnplexer 1 is tuned to the center of the 10-GHz amateur band at 10250 MHz. If a 30-MHz i-f receiver is used, Gunnplexer 2 must be tuned either 30 MHz higher or lower than Gunnplexer 1. Assume it's tuned 30 MHz higher at 10280 MHz; its signal will mix with the 10250-MHz LO in Gunnplexer 1 to provide an output to the receiver at 30 MHz. Conversely, the 10250-MHz transmit signal from Gunnplexer 1 will mix with the 10280-MHz LO in Gunnplexer 2 to provide an output at 30 MHz.

gunnplexer communications range

One of the first and most asked questions about Gunnplexers is, what is their maximum range? Since most microwave communications systems are based on line-of-sight transmission, it's a relatively easy matter to determine the effective communications range of any Gunnplexer system. When the distance between the two stations is known, path loss in dB is given by:

$$92.5\ dB + 20 \log f\ (GHz) + 20 \log D\ (kilometers)$$

$$96.6\ dB + 20 \log f\ (GHz) + 20 \log D\ (miles)$$

where f is the operating frequency and D is the distance between transmitting sites. Note that each time the frequency is doubled, the path loss increases by 6 dB. This is shown graphically in **fig. 3**, which shows the path loss *vs* distance for each of the amateur bands above 1000 MHz. At 10250 MHz, the center of the 10-GHz amateur band, the path loss equation can be simplified to:

$$112.7 + 20 \log D\ (kilometers)$$

$$116.8 + 20 \log D\ (miles)$$

In other words, the path loss over a distance of 1 km is 112.7 dB; it increases 6 dB each time the path length is doubled. The objective is to build enough gain and sensitivity into the microwave system to overcome the loss over the desired path. This is a function of transmitter power, antenna gain, receiver sensitivity (noise figure), and receiver bandwidth, but it's not as complicated as it sounds because all these factors can be easily translated into dB.

The graph of **fig. 4** has been designed to simplify the calculation of communications range at 10250 MHz and is normalized to a power output of 15 mW, receiver bandwidth of 200 kHz, 12-dB noise figure, and 17-dB gain antennas at each end of the link. This is what I consider a minimal Gunnplexer system. The horizontal line labelled THRESHOLD is the beginning of reception of intelligible speech and allows no margin for fading due to rainfall, multipath propagation, or other environmental effects. With the minimal Gunnplexer system, threshold occurs at a distance of about 127 kiliometers (76 miles). Since a carrier-to-noise ratio of 8-10 dB is recommended for reliable communications, about one-third this distance could be used for successful communications.

There are four major things which can be done to increase range: use higher transmitter power, reduce receiver bandwidth, improve receiver sensitivity, or increase antenna gain. The effects of power output and receiver bandwidth are shown in the chart on **fig. 4**. Each improvement in system performance adds the stated number of dB to the carrier-to-noise ratio. A 40-mW Gunnplexer with a receiver bandwidth of 25 kHz, for example, improves the carrier-to-noise ratio by 13.3 dB (4.3 dB for 40 mW transmitter power, plus 9.0 dB for reduced bandwidth). This system would provide a carrier-to-noise ratio of 8 dB at a line-of-sight distance of 233 kilometers (145 miles).

When calculating the communications range of a microwave system, all the gain and loss components of the system must be considered, as shown in **fig. 5**. Here a distance of 50 km (30 miles) is assumed, so the path loss is 146.7 dB. The other item which is fixed is the thermal noise floor, at − 144 dBm, which is set by the laws of nature and determines the ultimate sensitivity of the receiver.[2]

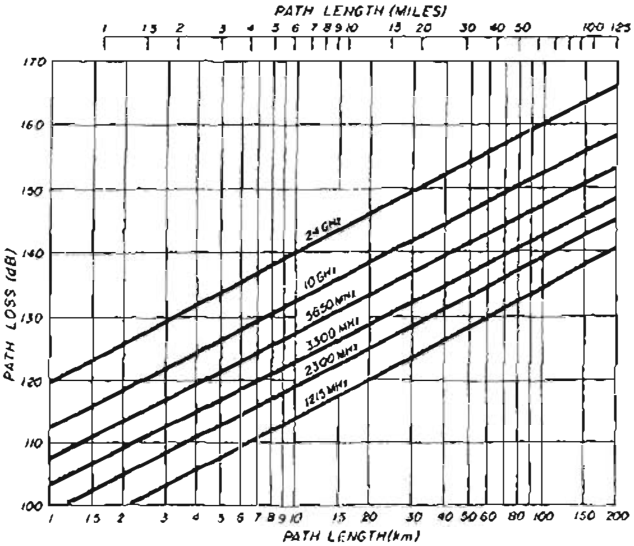


fig. 3. Path loss vs distance for each of the six amateur microwave bands. Note that path loss increases 6 dB each time the frequency or path length is doubled. Loss over a 61.7-km path at 1215 MHz, for example, is 130 dB; at twice the frequency (2430 MHz) the loss is 6 dB greater; at 8 times the frequency, near the 10 GHz band, loss is more than 18 dB greater. This graph assumes line of sight with no obstructions of any kind.

Beginning at the transmitting end of the link, we have 15 mW power output (+ 11.8 dBm). To this is added the 17-dB gain of the antenna. When the path loss is subtracted, the signal level at the receiving site is − 117.9 dBm. The 17-dB-gain receiving antenna increases the signal to − 100.9 dBm. From this must be subtracted the 12-dB noise figure and the 200-kHz bandwidth factor (23 dB), for a signal level of − 135.9 dBm. The difference between this and the thermal noise floor at − 144 dBm is the carrier-to-noise ratio. For this link, + 8.1 dB.

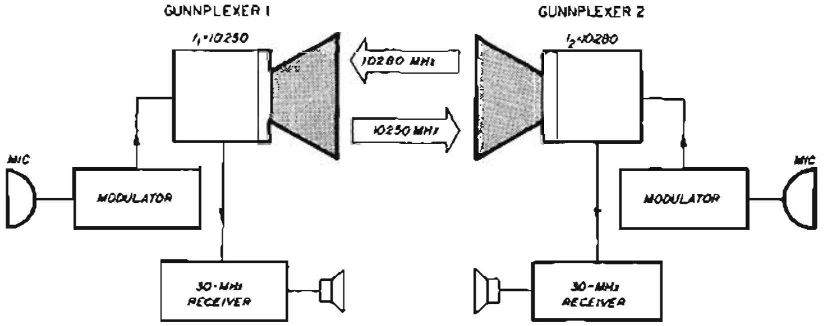


fig. 2. Gunnplexer operation. Since the same oscillator is used as both a transmitter and local oscillator for the mixer, the i-f at each end of the link must be at the same frequency, and the Gunn oscillator frequencies must be separated by the i-f. In the example shown here, Gunnplexer 1 is tuned to 10250 MHz; 30-MHz receivers are used, so Gunnplexer 2 at the other end of the link must be tuned either exactly 30 MHz higher or lower (to 10280 or 10220 MHz).

The easiest way to improve range is to use a higher

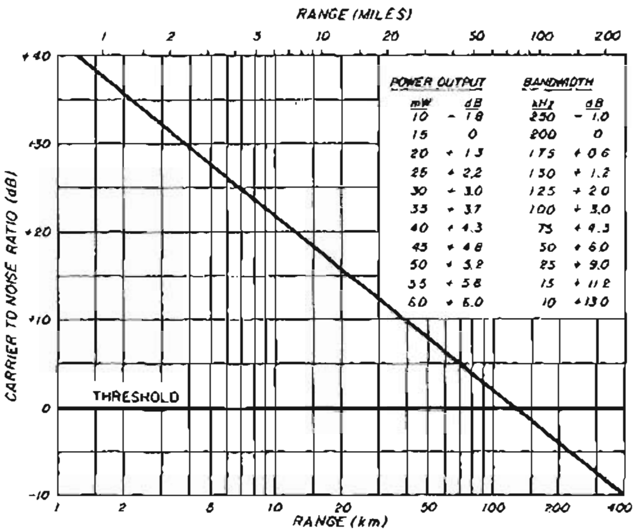


fig. 4. Carrier-to-noise ratio vs distance for two 15-mW Gunnplexers at 10250 MHz, equipped with 17-dB-gain horn antennas; receiver noise figure is assumed to be 12 dB with 200 kHz bandwidth. The THRESHOLD line is the beginning of the reception of intelligence. At a distance of 127 km (76 miles) the carrier is at the noise level or threshold; at a distance of about 40 km (25 miles) the carrier-to-noise ratio is 10 dB, the minimum signal level recommended for reliable voice communications. Range can be lengthened by increasing transmit power, decreasing bandwidth, or adding antenna gain (see text). Improvements in dB for increased output and narrower bandwidth are shown.

gain antenna. Unlike the lower frequencies, where antenna gain is hard to come by, on the microwave bands it's relatively easy. A 24-inch (61-cm) parabolic reflector, for example, yields 32 dBi gain. If used at only one end of the system shown in **fig. 5**, this would have the effect of increasing the range to

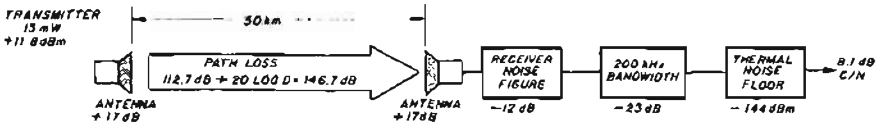


fig. 5. Example of a path-loss calculation at 10250 MHz. With two 15-mW Gunnplexers equipped with 17-dB gain antennas, and 12-dB noise figure in 200-kHz bandwidth, the carrier-to-noise ratio at 50 km is 8.1 dB.

Transmitter power, 15 mW	+ 11.8 dBm	+ 11.8 dBm
Add transmitter antenna gain	+ 17.0 dBi	+ 28.8 dBm
Subtract path loss	+ 146.7 dB	− 117.9 dBm
Add receiver antenna gain	+ 17.0 dBi	− 100.9 dBm
Subtract receiver noise figure	− 12.0 dB	− 112.9 dBm
Subtract 200 kHz bandwidth factor	− 23.0 dB	− 135.9 dBm
Thermal noise floor		− 144.0 dBm
	Carrier-to-noise ratio:	+ 8.1 dB

nearly 2000 km (1200 miles) for the same 8.1 dB carrier-to-noise level! That's obviously well beyond line-of-sight for any two earth-based locations. One disadvantage of high antenna gain is antenna alignment; the 4-degree beamwidth of a 24-inch dish leaves little room for error when pointing the antenna at another station.

You can also increase range by reducing the bandwidth of your receiving system, but because of the thermal drift of the Gunnplexer, this requires a system which phase locks the Gunn oscillator to a crystal-controlled reference oscillator. The cost of a phase-locked system is somewhat less than that of a commercial parabolic reflector, but system gain is only on the order of 12-13 dB when compared with a system with 200-kHz receiving bandwidth. On the other hand, a phase-locked system permits the use of CW, which provides reliable communications with lower carrier-to-noise ratios than voice, so there may be the equivalent of an additional 4-5 dB gain available.

For greater range you can also increase transmitter output or improve receiver noise figure, but both are expensive and limited to a certain extent by the present state of the art.

gunnplexer performance

The Gunnplexer performance measurements discussed here were made by B. Chambers, G8AGN, of the Department of Electronic and Electrical Engineering at the University of Sheffield, England, who is also a member of the Microwave Committee of the Radio Society of Great Britain. Front-end performance was not measured because, in practice, receiver sensitivity and noise figure are highly dependent on the operator's choice of i-f strip and the degree of matching between the mixer diode and the i-f preamplifier. Therefore G8AGN made measurements only to check the performance of the Gunn oscillator.

When a variable voltage was connected to the Gunn diode, it was found that rf power was produced with an applied voltage as low as 5 volts. Most of the tests, however, were accomplished with +10 volts applied to the Gunn diode and +4 volts bias on the varactor diode.

Using a Systron-Donner model 6057 frequency counter with an upper frequency limit of 18 GHz, G8AGN found that the Gunn oscillator drifted down in frequency by about 3 MHz during the initial one-hour warm-up period. A further frequency check 15

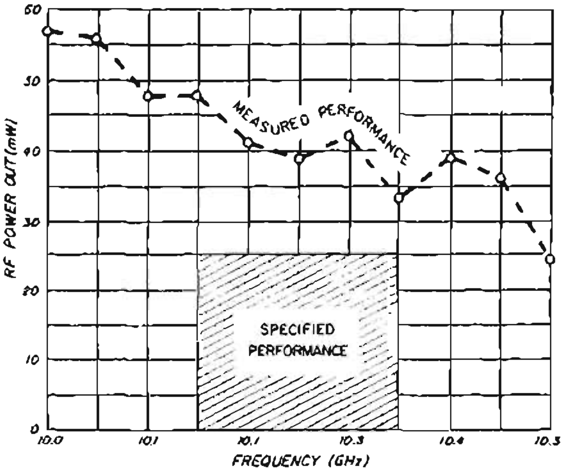


fig. 6. Typical variation of Gunnplexer output power as the frequency is tuned mechanically through the 10-GHz amateur band, as measured by G8AGN. At all frequencies the output was well above the rated 25 mW.

minutes later showed that the oscillator was drifting down in frequency by about 28 kHz per minute. This rate of drift is quite acceptable in practice unless a narrow-band system is being used and there is no provision for AFC.

The mechanical tuning range of the oscillator was checked next and found to extend from 9641 MHz up to 10764 MHz. The rf power output over this frequency range was measured with a Marconi model 6460 power meter with a coaxial head, buffered by a fixed 20-dB pad. This was preceded by a coax-to-waveguide transition and slide-screw tuner which was adjusted before each reading to ensure that the oscillator was delivering power into a matched load. **Fig. 6** shows the variation of rf output power over the frequency range from 10.0-10.5 GHz. Rf power measurements at the extremities of the tuning range showed 39 mW at 9641 MHz and 24 mW at 10764 MHz.

For a given setting of the mechanical tuning screw, the frequency of the Gunn oscillator may be tuned electrically by changing the voltage applied to either the Gunn diode or the varactor. Varying the voltage of the Gunn diode over the range from +5 to +11 volts produced a frequency change of 13.3 MHz about a preset value of 10250 MHz. This represents approximately 2.2 MHz per volt for frequency pushing and is well within the quoted specification.

With the Gunn diode held at +10 volts, the varactor bias was varied from +1 to +12 volts and measurements were made of both frequency and rf power output. Although up to +20 volts bias may be used on the varactor, measurements were made only to +12 volts because this is the maximum voltage usually available for portable operation. **Fig. 7** shows the result of these measurements. It can be seen that the maximum electronic tuning range was approximately 100 MHz, and that over this range the rf power output varied by about 3.5 dB.

The final set of Gunnplexer measurements made by G8AGN were concerned with the frequency-pulling performance of the Gunn oscillator. To make these measurements, the Gunnplexer was set up to deliver power to a load consisting of an adjustable short circuit; therefore, by varying the axial position of the short-circuit plane within the waveguide, a wide range of load impedances would be seen by the oscillator. For an axial variation of the short-circuit plane of 20 mm (0.8 inch), corresponding to a distance just greater than $\lambda_2/2$ at 10250 MHz, the total frequency variation was found to be 12 MHz.

The result of this test suggested that the ferrite circulator should be "transparent" enough for the Gunnplexer to be frequency locked using a cavity wavemeter, and this, in fact, proved to be the case. A TE_{011} mode transmission-type cavity wavemeter with a quoted Q factor of 8000 was available. This was simply bolted to the Gunnplexer assembly — the resulting separation between the wavemeter and the coupling iris to the Gunn oscillator being about 6.5 cm (2.6 inches). The wavemeter cavity had provision for attaching a waveguide diode holder, and this was

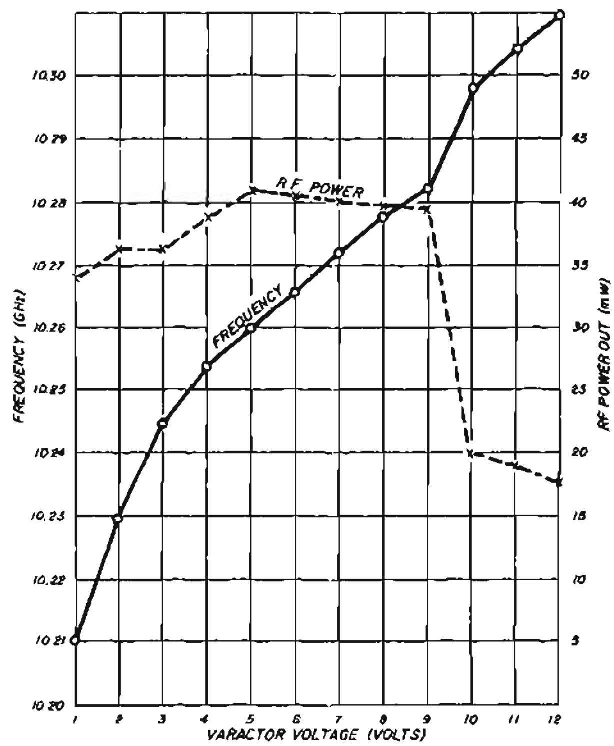


fig. 7. Frequency variation and measured power output with changes in varactor bias, as measured by G8AGN. Power output varies less than 3.5 dB over the nearly 100-MHz tuning range.

used in conjunction with a sensitive milliammeter to detect when the cavity was tuned near resonance.

With a little practice, G8AGN found that it was possible to hold the frequency of the Gunn oscillator to within 1 kHz for periods of minutes at a time. In view of this, it seems probable that the Gunnplexer could also be injection locked using a crystal controlled source, although this was not tried.

power supply

The first requirement for a Gunnplexer system is a regulated +10 volt power supply. Unfortunately, there aren't any readily available, high-current, three-terminal IC regulators with a 10-volt output (the Lambda LAS1510 meets these requirements, but is difficult to purchase in small quantities).* The answer is the Fairchild μA78MG 4-terminal regulator, which requires only two external resistors to set the regulated output voltage (see **fig. 8**). This regulator will provide in excess of 500 mA output, so it's adequate for most Gunnplexer systems.

For precise voltage adjustments, I have included a miniature 500-ohm pot between the two 4700-ohm resistors; this allows the output voltage to be set within a few millivolts of +10 volts. If you're not this fussy, you can connect the IC's control terminal (pin 4) directly to the junction of two 4700-ohm resistors — the output voltage should be within 5 per cent of the required 10 volts. This is probably close enough for most applications.

In many circuits using the μA78MG regulator the bypass capacitors may not be required. However, for stable operation of the regulator IC over all voltage and current input ranges, bypassing is recommended by the manufacturer (0.33 μF at the input and 0.1 μF at the output). The input bypass is necessary if the regulator is located far from the filter capacitor in the power supply; bypassing the output improves the transient response of the regulator.

tuning range

The frequency of the Gunnplexer is controlled by the voltage on the built-in tuning varactor, the setting of the mechanical tuning screw, and the supply voltage to the Gunn diode. Unless otherwise specified, the Gunnplexer is mechanically tuned to 10250 MHz at the factory with 10.0 volts on the Gunn diode and 4.0 volts across the varactor. The output frequency of the Gunnplexer can be adjusted ±100 MHz with the tuning screw, but I don't recommend touching the mechanical tuner unless you have access to a microwave frequency counter; you will find it difficult to accurately retune the unit to 10250, the center of most amateur activity on this band.

The Gunnplexer can also be electronically tuned by varying the voltage across the varactor from 1 to 20 volts; this is the preferred method, and a tuning range of 60 MHz is guaranteed. Electronic tuning range varies from unit to unit, but data is furnished with each Gunnplexer so you can easily estimate frequency output *vs* varactor voltage. Many units have an electronic tuning range of 100 MHz or more, so it's not necessary to touch the mechanical tuning screw for most amateur applications.

Shown in **fig. 10** is a plot of frequency output *vs* varactor tuning voltage for a 40-mW Gunnplexer that I am using at my station. The tuning curve is quite nonlinear, with the greatest frequency change — 50 MHz — occurring as the varactor voltage is increased from 1 volt to 4 volts. An increase from 4 volts to 10 volts moves the output frequency up 40 MHz, and a change from 10 volts to 20 volts increases the output frequency 46 MHz. The total frequency change is 136 MHz. The tuning range of other Gunnplexers won't exactly follow this curve, but it gives you an idea of what you can expect.

The varactor also provides a way of frequency modulating the unit. If a small modulating voltage is

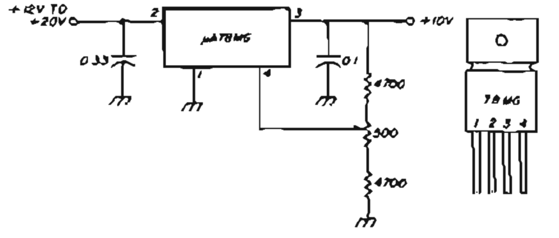


fig. 8. Regulated Gunnplexer power supply can be adjusted to exactly +10 volts; with proper heatsinking, this circuit will provide current in excess of 500 mA. The 0.33-μF capacitor at the input and 0.1 μF at the output improve circuit performance.

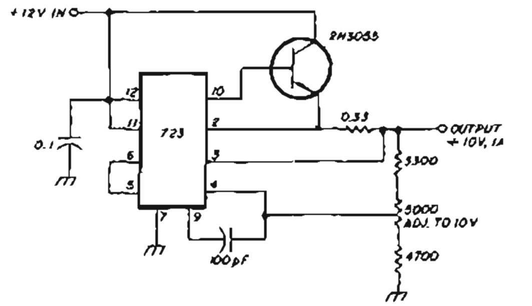


fig. 9. Simple +10 volt regulator using readily available parts, designed by W1SL, will supply up to 1 ampere. The 723 regulator is available from Radio Shack (part number 276-1740) as is the 2N3055 transistor (Radio Shack 276-1634).

*Shortly after this article was written, Fairchild Semiconductor announced the μA78C00 series of 3-terminal voltage regulators which have rated output current greater than 500 mA. A 10-volt regulator, the μA78C10C, is included in the series.

impressed on the varactor bias, the frequency will be varied at an audio (or video) rate. Because of the wide electronic tuning range, the required modulation voltage is very small; 10 mV or so for 75 kHz deviation, or less than 1 mV for 5 kHz deviation. However, don't plan on using narrowband deviation unless you have a crystal-controlled, phase-locked system for stabilizing the Gunnplexer frequency.

The output frequency also varies with changes in the Gunn diode supply voltage — 15 MHz per volt maximum — but this isn't recommended as a tuning method. In addition, the power output and efficiency of the Gunnplexer has been optimized for a 10.0-volt supply, and you don't want to risk damaging the expensive Gunn diode.

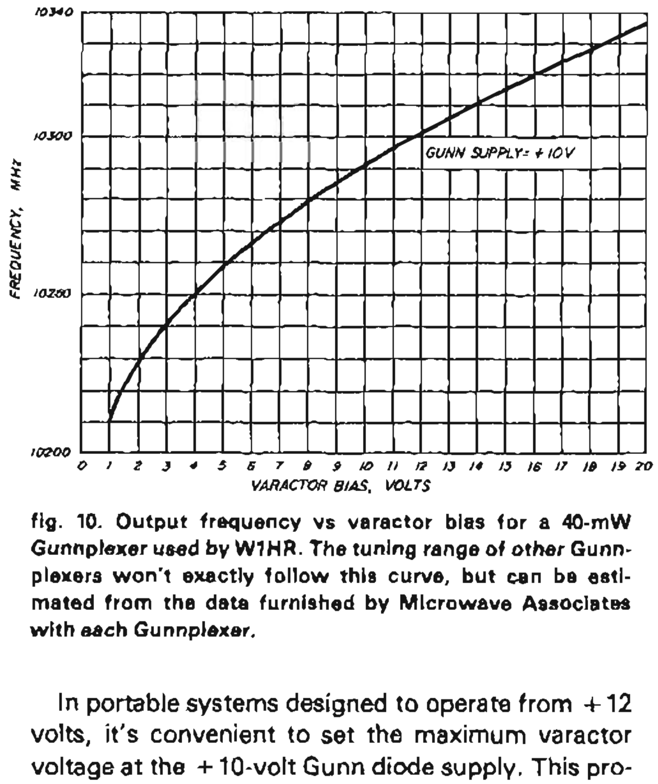


fig. 10. Output frequency vs varactor bias for a 40-mW Gunnplexer used by W1HR. The tuning range of other Gunnplexers won't exactly follow this curve, but can be estimated from the data furnished by Microwave Associates with each Gunnplexer.

In portable systems designed to operate from +12 volts, it's convenient to set the maximum varactor voltage at the +10-volt Gunn diode supply. This provides more than enough tuning range if you use a 30-MHz i-f system. Amateurs in Europe usually transmit voice on 10250 MHz and receive on 10280 or 10220; in the United States many stations have standardized 10250 for transmitting and 10280 for receiving (for full duplex operation one station transmits on 10250 and the other transmits on 10280).

If you use fm broadcast receivers at each end of the link with a 10-volt varactor supply, you may not be able to obtain sufficient tuning range to cover the required 100 MHz. However, if you use an auxiliary varactor supply that will provide up to 20 volts, you should have no difficulty obtaining the required range. In many cases the nominal 12 volts available

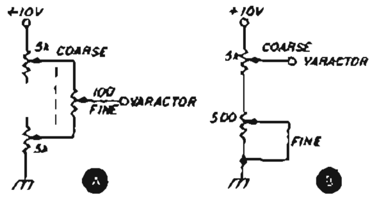


fig. 11. If a multi-turn potentiometer is unavailable, varactor bias can be controlled by one of the methods shown here. The resolution of the circuit at (A) is about four times better than with a 10-turn pot; the circuit at (B) has somewhat less resolution but is less expensive.

from an automobile battery will be sufficient. If you use an ac-powered dc supply for the varactor, however, be sure it's well regulated and filtered. Any ripple on the supply line will result in hum modulation.

varactor bias control

Since small changes in varactor bias have a large effect on the output frequency, a multi-turn potentiometer should be used for the tuning control (with a conventional 270° pot, the frequency can change 300 kHz or more for each 1 degree rotation of the pot's shaft). Sometimes you can find precision 10-turn pots on the surplus market, but, if not, there are several alternatives. One is to use a single-turn pot with a reduction unit like the Jackson Brothers 6:1 planetary drive. This may not be completely satisfactory, however, because resolution may be limited by man-

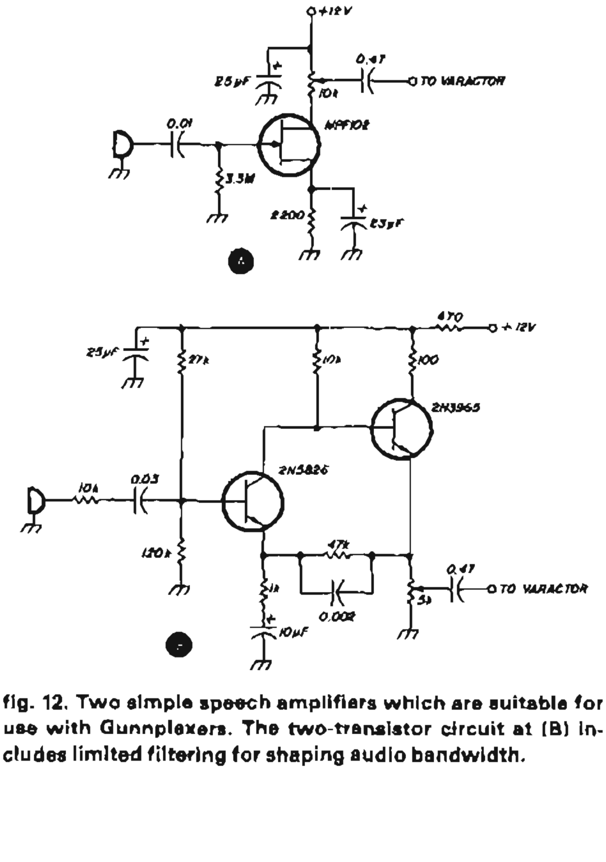
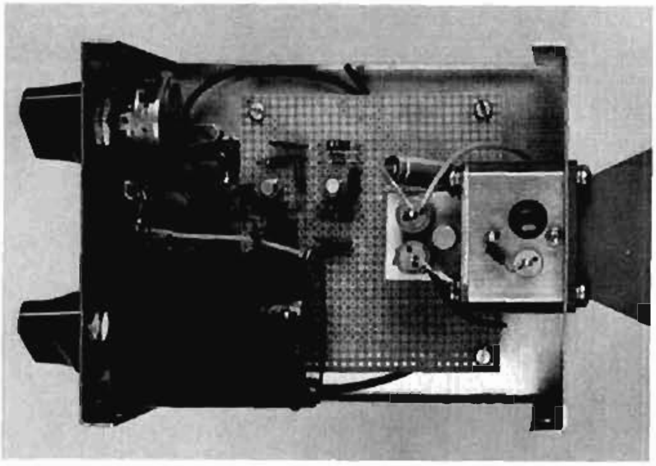
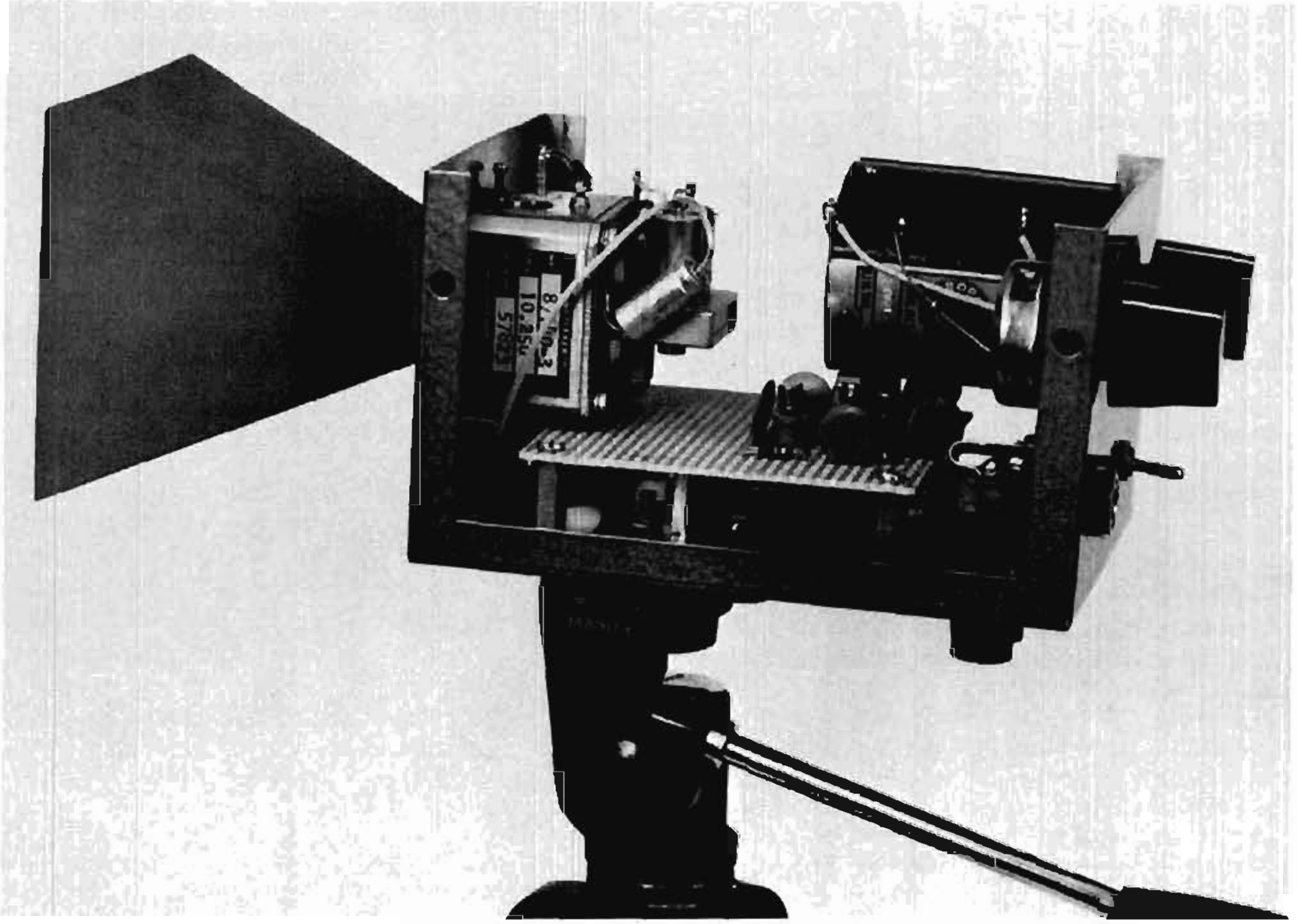


fig. 12. Two simple speech amplifiers which are suitable for use with Gunnplexers. The two-transistor circuit at (B) includes limited filtering for shaping audio bandwidth.





Minimal Gunnplexer system used by W1HR includes a 10-volt IC voltage regulator, simple speech amplifier, and tone oscillator. A phono connector on the bottom of the chassis is provided for the fm receiver. A 10-turn precision potentiometer found on the surplus market is used for frequency control.

ufacturing tolerances in the potentiometer's resistance element.

Two other possibilities for varactor control are shown in **fig. 11**. The system in **fig. 11A** uses one dual potentiometer for coarse adjustments and a single-turn pot for fine tuning. Resolution of this system is about four times better than with a 10-turn pot and is suitable for the most demanding requirements. The bias control arrangement in **fig. 11B** does not provide as much resolution but is more economical. A disadvantage is that the resolution of the fine adjustment varies, and depends upon the setting of the coarse control; when the coarse potentiometer is in the center of its range, resolution approximates that of a 10-turn pot.

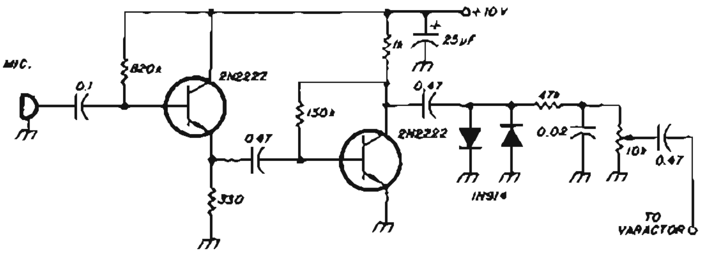


fig. 14. Two-transistor speech amplifier for Gunnplexers features high input impedance, good gain, clipping for improved audio punch, and a lowpass filter for limited audio bandwidth.

speech amplifiers

Because of the high sensitivity of the varactor, a very small modulation voltage (on the order of 10 mV p-p) is required to obtain 75-kHz deviation for wideband frequency modulation of the Gunnplexer; this greatly simplifies the design of a suitable speech amplifier. In its simplest form, the Gunnplexer speech amplifier requires only one transistor, as shown in **fig. 12A**. In this circuit the MPF102 fet exhibits high input impedance for a crystal, ceramic, or dynamic microphone, and provides more than enough voltage gain for full 75-kHz deviation at 10.25 GHz. Deviation is adjusted with the 10k potentiometer in the drain circuit.

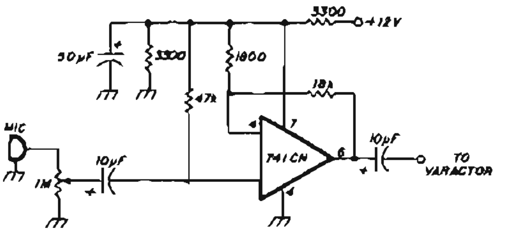


fig. 13. Speech amplifier circuit designed by G8AGN for Gunnplexer operation uses a low-cost 741 op amp and offers high input impedance.

The two-transistor speech amplifier in **fig. 12B** has an input impedance of about 20 kilohms and includes filtering to limit the speech bandwidth. For those who prefer to use ICs the circuit in **fig. 13** is recommended. This 741 speech amplifier was designed by G8AGN/G8CZO for use with a Gunn diode transmitter.[3]

In any frequency-modulation system the speech amplifier should, in addition to providing audio gain, include some form of speech processing to limit dynamic range so the audio signal doesn't exceed the maximum frequency deviation. This can be done with audio compression or by using a simple diode clipper to limit the audio peaks. The two-stage speech amplifier shown in **fig. 14** includes a clipper and lowpass RC filter (47k resistor and 0.02-μF capacitor) to reduce the harmonics produced by clipping. I used 2N2222 transistors in this circuit because I had them in my junk box, but most high-gain NPN transistors should work. If you wish, the same diode clipper and RC filter can be added to the circuits of **figs. 12** and **13**.

For most effective fm communications, the speech system should include a system for limiting bandwidth to 300-3000 Hz, and de-emphasis to correct the speech frequency characteristic. A circuit which

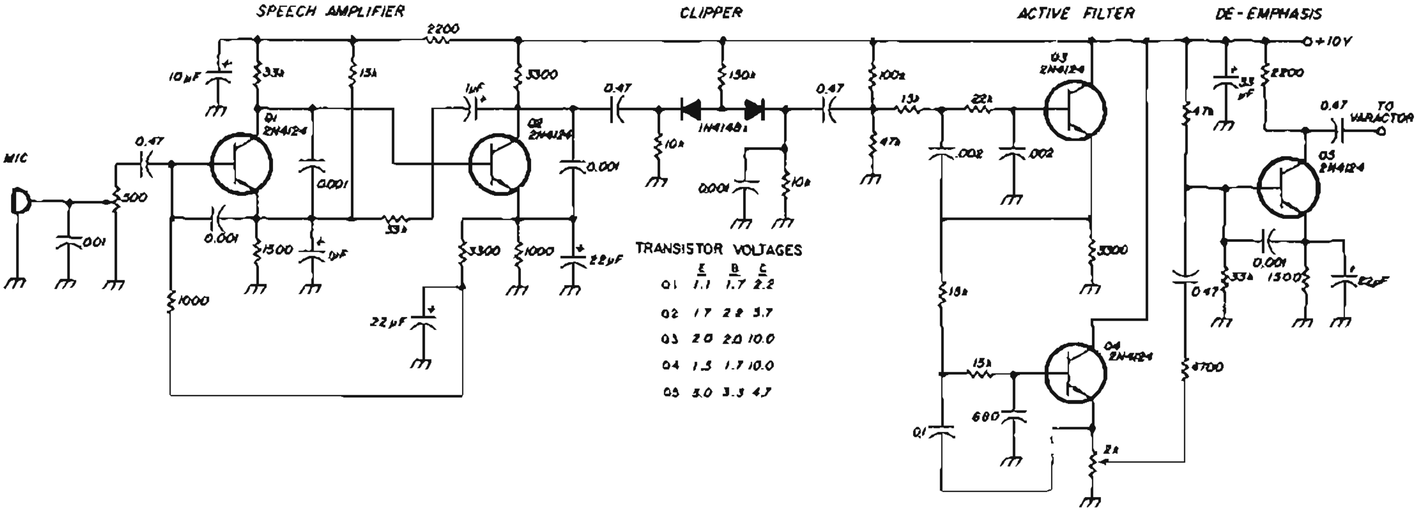


fig. 15. High-performance fm speech amplifier uses heavy feedback for reduced audio distortion. It also includes an audio clipper, 300-3000 Hz active audio filter, and de-emphasis stage. Both input and output controls are provided. Circuit board for this circuit is shown in fig. 22.

has a complete speech amplifier, clipper, active filter, and de-emphasis stage is shown in **fig. 15**.[4] The first two stages use heavy feedback to reduce distortion and improve frequency response. These stages are followed by a double-diode clipper and a two-stage active filter that has a 500-3000 Hz passband. The last stage provides de-emphasis. This amplifier gives an output of 100 mV for an input of 2 mV across 300 ohms; both input and output controls are provided. I have used this amplifier with good success at one end of a wideband Gunnplexer link.

tone oscillator

When lining up two Gunnplexer systems, particularly if you're using high-gain parabolic reflectors, it's helpful to continuously tone modulate your transmitter. There are several ways to generate an audio tone, but for minimum parts count I prefer the circuit of **fig. 16**, which uses a 555 timer IC. Total current drain with a 10-volt supply is only 10 mA. The 1-kHz squarewave output swings from ground to +10 volts; this is reduced to manageable levels for Gunnplexer use with the series 100k resistor and 200-ohm pot. The 10k resistor and 0.1-μF capacitor form a lowpass filter; in some applications the filter may not be required.

If you have a memory keyer, it can be plugged into the key jack and used to send your call sign, a series of vees, or your location. If you wish to send only your call sign, you might consider the automatic CW ID unit manufactured by Autocode.* Although this unit was designed for automatically sending CW identification for RTTY or vhf-fm transmissions, it is ideal for Gunnplexer systems.

i-f receiver

Although a 30-MHz i-f receiver is recommended if you want to work reliably over long distances, to get started with a Gunnplexer system many amateurs have used low-cost fm broadcast receivers tuned around 100 MHz. One popular unit is the Audiovox fm converter; this receiver sells for less than $20, can be completely converted to Gunnplexer use in one evening, and is a good compromise unit for getting started on 10 GHz with Gunnplexers. Complete conversion information is available from G. R. Whitehouse & Company.† The main disadvantage of an fm broadcast receiver is i-f feedthrough. For best results

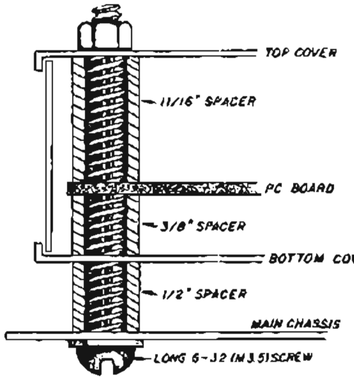


fig. 17. Method of mounting the DJ700 fm receiver with spacers and a long 6-32 (M3.5) screw. Similar mounting arrangements are used at the four corners of the fm receiver PC board.

you must pick a frequency that is clear of local fm broadcasters. If you take this system mountain-topping, your problems with i-f feedthrough will increase dramatically, but it is still a good way to get started. Also, it's a simple matter to add a better receiver to your system later — no other parts of the set-up will have to be changed.

Another low-cost approach to the i-f receiver can be found in the used two-way equipment market. Many of the fire, police, and public-service fm receivers built 10 or more years ago can now be purchased for a few dollars. The receiver you want for Gunnplexer use was originally designed to tune from 30 to 50 MHz and is built for wideband fm. Many of the newer fm receivers for this band are for narrowband fm, so they are not suitable for Gunnplexer use. A number of companies marketed solid-state receivers of this type in the 1960s, including Lafayette, Radio Shack, and Regency. Some had provisions for crystal control; this, if you can find one, is the type most suited to Gunnplexer communications. Price for a receiver of this type is typically around $5; most users have switched to more portable narrow-band receivers with scanners, so the older, tunable receivers have practically no commercial value.

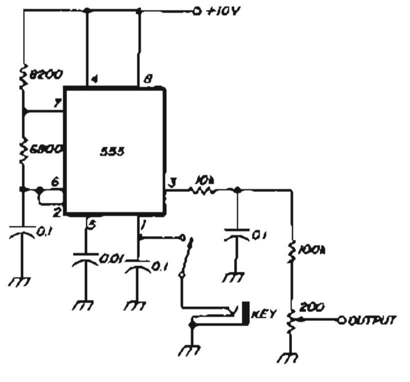


fig. 18. A 1000-Hz tone oscillator is very helpful when setting up a Gunnplexer link. It can also be used for MCW under weak-signal conditions.

*Autocode, 8116 Glider Avenue, Dept. H, Los Angeles, California 90045.

†G. R. Whitehouse stocks 15-, 25-, and 40-mW Gunnplexers; his address is Newbury Drive, Amherst, New Hampshire 03031.

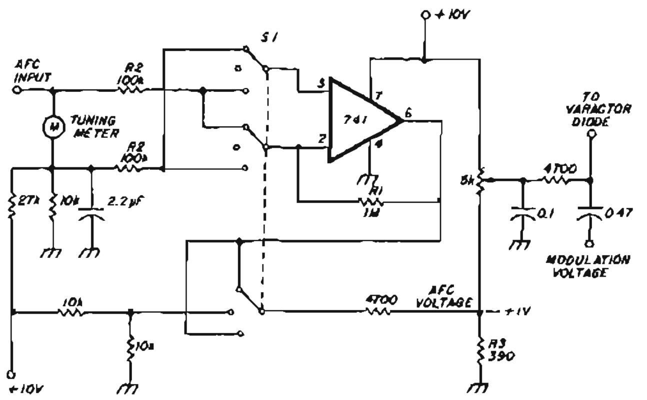


fig. 18. Gunnplexer AFC system designed by DJ7OO for use with his 30-MHz fm receiver. Circuit may be adapted to other fm receivers by changing the ratio of resistors R1 and R2. It may be desirable in some cases to replace R3 with a trimmer pot. In the center position of switch S1, the AFC is turned off, the two outer positions provide positive- and negative-going AFC voltage with increasing frequency (see text).

The choice of 30 MHz for the i-f receiver means that you can set up your Gunnplexer on 10250 MHz and tune in stations either 30 MHz above or below your center frequency. Many Gunnplexers don't have sufficient electronic tuning range to handle an i-f at 100 MHz with only +10 volts of varactor bias. If you have a +20 volt bias supply available, many Gunnplexers will tune the required 100 MHz, but that precludes most portable operation unless you provide additional batteries for the bias supply. For reasons mentioned previously, I don't recommend touching the mechanical tuning screw.

I have used both tunable and crystal-controlled 30-MHz i-f receivers in Gunnplexer links, and the difference is like night and day. Tunable receivers are fine if you're interested only in working over short distances, but if you want to communicate farther than you can shout, you have to use a crystal-controlled i-f receiver. Remember that the local oscillator for your receiver is the Gunn oscillator at the other station; for communications, the receivers at both ends of the link must be tuned to *exactly* the same frequency. Even at 30 MHz, a tunable receiver that is off frequency by only 1 per cent will be completely out of the passband of a wideband fm signal.

Automatic Frequency Control (AFC) is helpful when you first turn on your Gunnplexer, but if both stations are operating in essentially the same environment, I've found that frequency drift during warm-up is slow enough that it's an easy matter to keep the other station tuned in. Once the two Gunnplexers have reached thermal equilibrium, they'll sit on frequency for hours at a time.

The receiver I'm using in my Gunnplexer station was described by DJ7OO.[5] In addition to being crystal controlled, it has built-in provisions for a tuning meter *and* signal strength meter; both are extremely useful in setting up Gunnplexer links over marginal paths. Also, the output from the discriminator is available for AFC purposes. If you're interested in serious microwave communications, I highly recommend this receiver.

As supplied, the DJ7OO receiver is built into a tin-plated enclosure with no mounting tabs. If you wish, small L-shaped brackets could be soldered to the enclosure, or the receiver could be clamped into place. In my Gunnplexer transceiver I mounted the DJ7OO receiver with spacers and long screws; this seems to be more rugged than brackets or clamps, and, since the transceiver is designed for portable use, I wanted something that would stand up to unintentional abuse (see **fig. 17**).

If you purchase a DJ7OO i-f receiver, the only problem you may have is obtaining knobs to fit the potentiometer shafts. The diameter of these shafts is 4 mm — too large for 1/8 inch shafts, and too small for 1/4 inch! The best solution is to purchase knobs for 1/8 inch shafts and drill them out with a no. 22 or 4 mm drill. You can also wind tape around the shafts to build them up to 1/4 inch, but the knob will tend to feel sloppy and will probably be eccentric.

automatic frequency control

After a Gunnplexer is initially turned on, its output frequency drifts rapidly as the unit warms up. The typical drift rate is about 300 kHz per degree Celsius, and since the Gunnplexer temperature may go up 10 degrees per minute after it's first turned on, total frequency drift is 3 MHz or more. As the unit reaches thermal equilibrium, however, frequency drift slows, and, if the unit is shielded from wind currents, the output frequency is quite stable. If the Gunnplexers at opposite ends of a wideband fm communications link ($\Delta f = 200$ *kHz*) are in similar environments, they can be used for voice communications over long periods of time without any frequency adjustments.

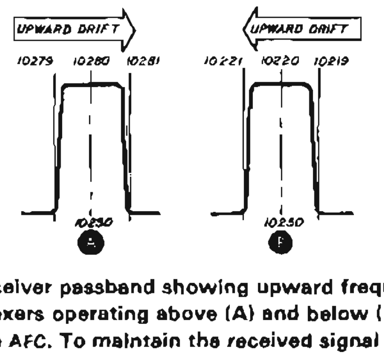


fig. 19. Receiver passband showing upward frequency drift of Gunnplexers operating above (A) and below (B) a Gunnplexer with AFC. To maintain the received signal in the center of the passband requires AFC with *positive* sense in (A) and *negative* sense in (B).

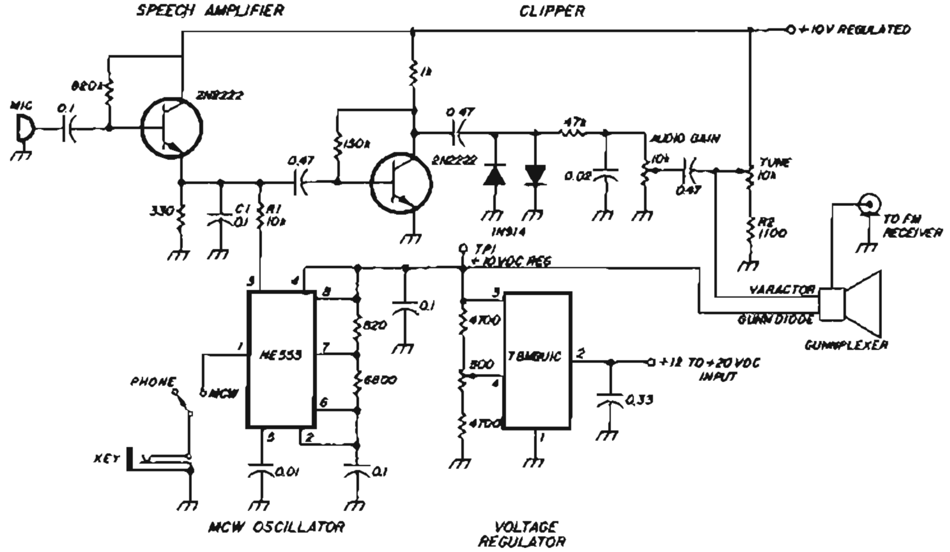


fig. 20. Circuit for a Gunnplexer transceiver without a built-in i-f receiver. In the original model, this circuit was built on perf board. Resistor R1 is adjusted for the desired tone level; R2 is set for a 1-volt drop.

(After an initial warmup of 30 minutes, two enclosed Gunnplexers in my shop remained on channel for more than a day.)

For closer frequency control you can either preheat the Gunnplexer (or use a proportional temperature control system as I suggested in an earlier article[1]) or use automatic frequency control (AFC). Gunnplexer temperature control would probably be a good choice for use at a base station, but because of the huge current drain of any heating system, AFC is better for portable use. In an AFC system any deviation in the average value of the i-f from the center frequency of the discriminator in the receiver will produce a dc voltage determined by the direction of the frequency deviation. This dc voltage is applied to the varactor in the Gunnplexer to bring it back on frequency. Note that the use of AFC must be limited to one end of a Gunnplexer link; the other end is allowed to run free.

In many cases, the AFC voltages for the Gunnplexer can be obtained from the i-f receiver. The AFC system shown in **fig. 18** was designed by DJ7OO for use with his 30-MHz receiver.[5] This same basic circuit can be used with other fm receivers by simply changing the values of resistors R1 and R2. In some cases the circuit will work as shown, but others will require more (or less) gain — which is set by the ratio of R1 to R2. The only other adjustment is R3, which should be set for a voltage drop of 1 volt.

In the center position of switch S1 the AFC is turned off; the two outer positions provide positive- and negative-going AFC voltage with increasing frequency. Which is chosen depends upon whether the frequency of the Gunnplexer with AFC is above or below the free-running Gunnplexer without AFC. Assume the Gunnplexer with AFC is set to 10250 MHz (see **fig. 19**). If the free-running Gunnplexer is at 10280 MHz and drifting higher, the incoming signal is moving *upward* through the receiver passband. Therefore, a positive AFC voltage is required to shift the 10250-MHz LO up to recenter the 10280-MHz signal on the middle of the passband. If the free-running Gunnplexer drifts downward, the opposite occurs. In either case, however, the sense of the AFC voltage is the same (positive) as the necessary frequency shift.

Now consider what happens if the free-running

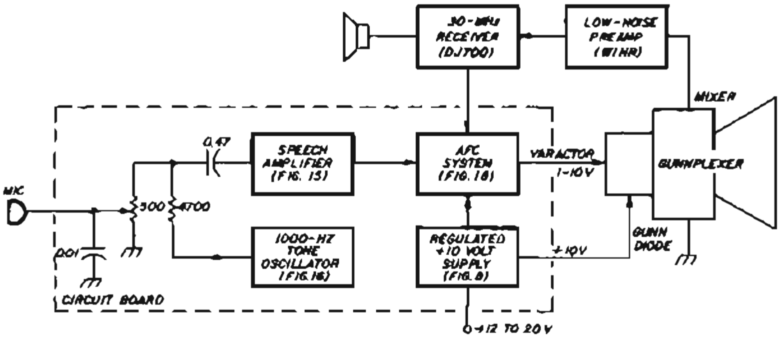
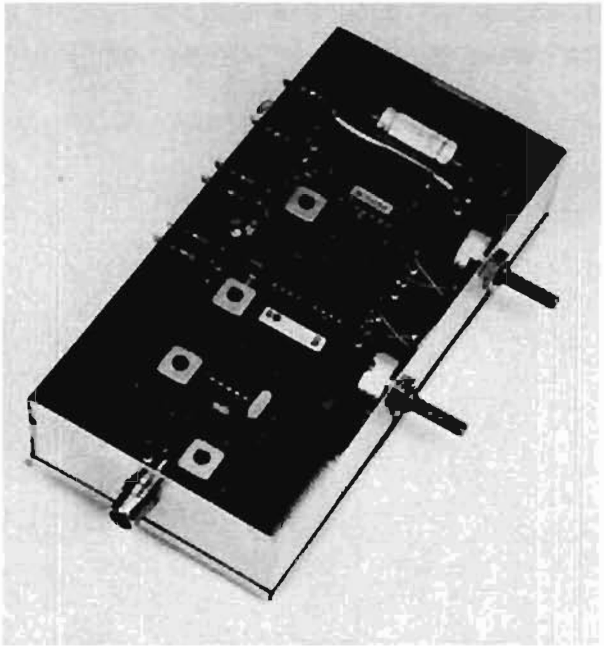


fig. 21. Complete Gunnplexer transceiver featuring high-performance speech amplifier with clipping and de-emphasis, crystal-controlled 30-MHz receiver, and low-noise preamplifier. A circuit board for the speech amplifier, tone oscillator, AFC system, and regulated power supply is shown in fig. 22.



Wideband 30-MHz fm receiver designed by DJ7OO for use with Gunnplexer systems (described in the August, 1978, Issue of *ham radio*). At the left is the mosfet input stage, followed by the SO42P crystal-controlled local oscillator and mixer, TDA1047 i-f strip, and TAA611 audio power amplifier. The two controls are for squelch and audio gain.

Gunnplexer is *below* the one with AFC at 10220 MHz. If it is drifting higher, the incoming signal is moving *down* through the receiver passband, and a *negative* AFC voltage is required to move the 10250-MHz LO down to shift the 10220-MHz signal to the center of the passband. Therefore, if the frequency of the Gunnplexer with AFC is above that of the free-running Gunnplexer, the sense of the AFC voltage is opposite (negative) to the necessary frequency shift.

Obviously, the *sense* of the AFC voltage is extremely important. If the AFC sense is incorrect, it tends to chase the received signal out of the passband. In **fig. 19B**, for example, if positive AFC is used, upward drift toward 10221 MHz will reduce the AFC voltage, moving the LO toward 10249 MHz — the wrong direction! If the AFC has the wrong sense, you'll find it almost impossible to tune in the signal; in many cases the LO will actually oscillate back and forth across the receiver passband several times per second. If you've built a Gunnplexer system with AFC and have experienced this problem, now you know what caused it.

gunnplexer transceivers

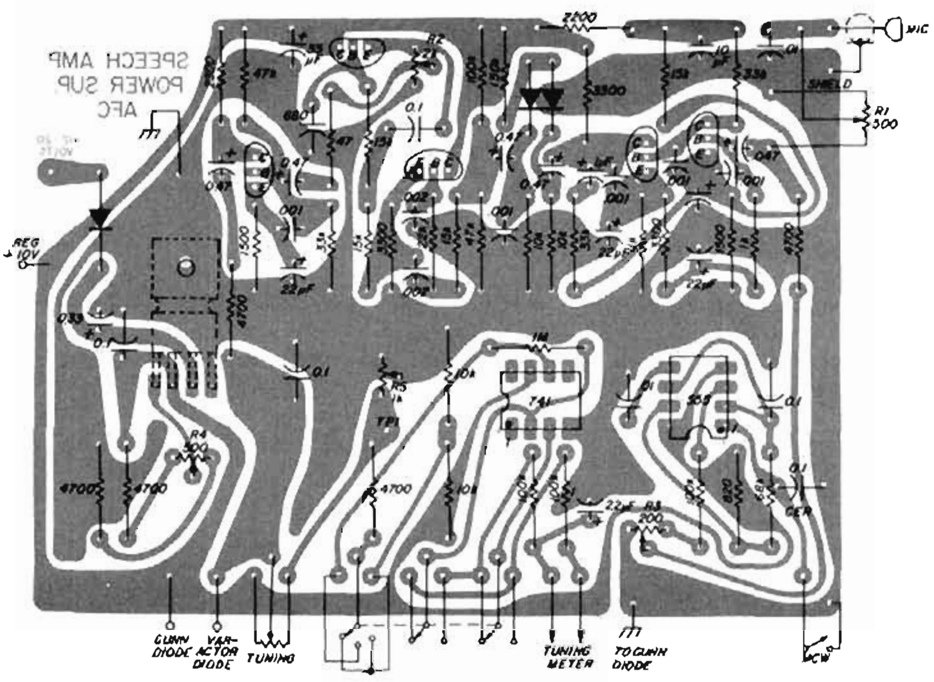
To build a complete Gunnplexer transceiver, all you have to do is combine some of the previous circuits and build them into a single enclosure. Two examples are shown in the accompanying photographs. The first, which I call the "minimal" Gunnplexer system, is built into a 125 × 100 × 75 mm (5 × 4 × 3 inch) Minibox and doesn't include the receiver (a phono jack is provided so it can be used with a variety of external receivers). The other transceiver, which is built into a 225 × 150 × 125 mm (9 × 6 × 5 inch) aluminum utility box, includes a built-in 30-MHz receiver with a low-noise preamp and speaker.

The circuit of the minimal Gunnplexer transceiver is shown in **fig. 20**. Basically, it consists of the two-transistor speech amplifier (**fig. 14**), 1000-Hz tone oscillator (**fig. 16**), and regulated dc power supply. Note that the lowpass filter at the output of the tone oscillator is combined into the speech amplifier. No receiver was included because at the time I built this transceiver I was still undecided about a receiver and wanted to try several options. Since it was built it has been used successfully with a variety of i-f receivers at 30 MHz, 100 MHz, and, more recently, 111 MHz (the New England spot for retuned fm broadcast receivers).

The Gunnplexer transceiver shown in **fig. 21** might be called the "deluxe" model. In addition to the built-in 30-MHz receiver and low-noise preamp[6], it features the high-performance speech amplifier with clipping, audio shaping, and de-emphasis (**fig. 15**),

10-GHz Gunnplexer system setup by the W1FC group on Pack Monadnock in New Hampshire during the September vhf/uhf contest. Two-way communications were established with Gunnplexer-equipped stations in Maine, New Hampshire, and Vermont.

fig. 22. Component layout for the printed-circuit board for the Gunnplexer transceiver. At the top of the board is the speech amplifier with clipping and de-emphasis. Below, right to left, are the 555 tone oscillator, 741 AFC amplifier, and 78GU1 voltage regulator. (Note that the 78GU1 is mounted on the foil side of the board.) In the speech amplifier, pot R1 sets the microphone gain: pot R2 is used to set maximum deviation. Pot R3 sets the tone voltage level into the speech amplifier; R4 is the +10 volt adjust, and R5 is set for +1 volt at TP1. The capacitors in the audio amplifier are tantalum types.*

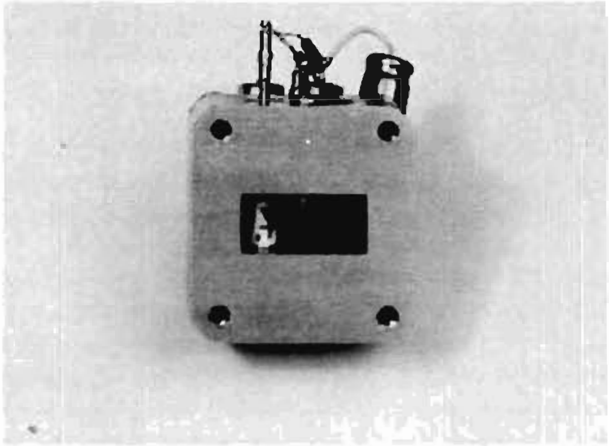


an AFC system, tone oscillator, and regulated power supply. To save space and improve reliability, these circuits are built on a printed-circuit board (**fig. 22**). For improved heatsinking of the 78GU1 voltage regulator, this IC is mounted on the foil side of the circuit board. In addition, an aluminum mounting spacer is used to conduct heat to the chassis. The result is a very cool-running voltage regulator, even with 500 mA of output current. In the transceiver this circuit board is mounted on the rear wall of the utility box. A 100 x 100 mm (4 x 4 inch) aluminum plate, 6 mm (1/4 inch) thick, is mounted in the bottom of the enclosure and tapped for a 1/4-20 screw. This is the standard thread for camera tripods sold in the United States.

When setting up this transceiver, first set the 500-ohm voltage adjust potentiometer, R4, for +10.0 volts at the Gunn diode, then adjust R5 for 1.0 volt at test point 1 (TP1). The tone output level adjustment, R3, is set for the same deviation as the microphone; this and the other audio adjustments are discussed later.

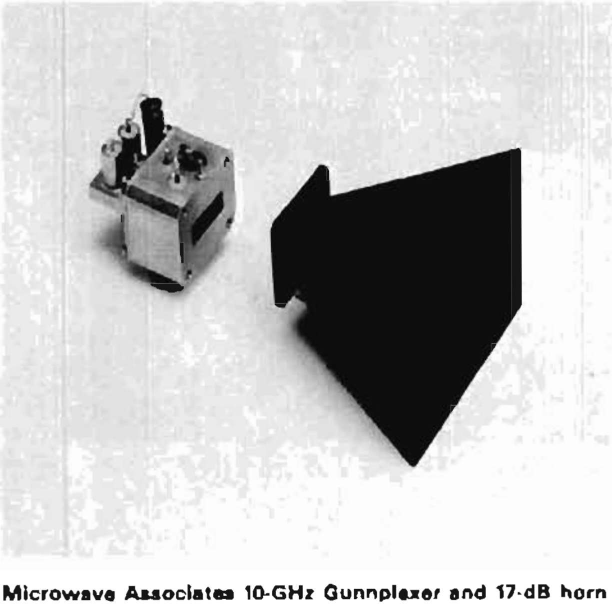
fig. 23. Full-size printed-circuit layout for the Gunnplexer speech amplifier, tone oscillator, AFC amplifier, and voltage regulator. Component layout is shown in fig. 22.

*Complete parts kits, including PC board, are available from G. R. Whitehouse, 10 Newbury Drive, Amherst, New Hampshire 03031.



Head-on view of the Gunnplexer showing the mixer diode, left, and ferrite circulator (black cylinder to right). The small screw which protrudes through the top of the waveguide is used to adjust mixer injection.

One feature of the transceiver which is not shown on the schematic should be mentioned: a small relay to turn off the speaker during voice transmissions. When communicating with a Gunnplexer system, the receiver detects both the signal from the distant station and the local transmitted signal. In addition to being annoying, this is sometimes the cause of unwanted howls and squeals because of audio feedback. To solve this problem, some builders have installed a spdt switch to transfer the audio output to a 4.7-ohm resistor. In my transceiver I installed a miniature spdt relay which is operated by the PTT switch on the microphone (most 12-volt relays work quite well on +10 volts). The speaker circuit isn't affected when the tone oscillator is used for CW, so I have a built-in CW sidetone system.



Microwave Associates 10-GHz Gunnplexer and 17-dB horn antenna. Receiver section is housed in waveguide section machined from large block of metal. This improves thermal stability of the unit.

waveguide flange layout

If you wish to mount your Gunnplexer inside an aluminum Minibox, you must match the waveguide and mounting screws to a cutout in the enclosure. There are feedthrough waveguide flanges on the market, but they're expensive and seldom make their way into the surplus market. The only alternative is to carefully lay out the mounting holes for the UG-39/U waveguide flange and then hand file a cutout to match the interior dimensions of the waveguide. This is difficult if you don't have access to a waveguide handbook because the screw holes are not at the corners of a square, as you might suppose, but are slightly offset as shown in **fig. 24**. This is done intentionally so it is impossible for a technician to cross polarize sections of waveguide.

To locate the mounting holes for the UG-39/U flange, prick punch the center and use a compass to swing an arc with a radius of 15.5 mm (0.61 inch) as shown in **fig. 24B**. Now use a carpenter's or machinist's square to draw two vertical lines which are tangent to the arc (**fig. 24C**). Using the same center point, swing another arc with a radius of 16.3 mm (0.64 inch) and use the square to draw two horizontal lines (**fig. 24D**). The screw mounting holes are located at the intersections of the straight lines. To check their location, swing an arc with a radius of 22.5 mm (0.884 inch); it should cross the center point of each of the hole locations (**fig. 24E**). When you are satisfied that the mounting holes are correctly located, drill the holes with a number 18 (4.3 mm) drill for the 8-32 mounting screws. Temporarily mount the Gunnplexer to make sure the holes mate with the tapped holes in the Gunnplexer flange.

After the screw holes have been located you can make the rectangular cutout for the waveguide. This cutout measures exactly 0.4 to 0.9 inch and is centered on the same point as the mounting holes. After scribing the outline with a square, I found the best approach was to drill out the center point with an 8 mm (5/16 inch) drill. This provides clearance for an Adel nibbling tool.

A word of warning: don't try to make the *finished* cutout with the nibbler; you're sure to botch the job. Use the nibbler only to make the rough cutout — within about 1 mm (1/32 inch) of the finished edge. Then carefully hand file the edges of the opening so they match the waveguide.

Temporarily install the Gunnplexer to check progress, but carefully wipe off the metal filings first so they don't get into the Gunnplexer. And don't leave the Gunnplexer in place while you're filing the opening — that's an open invitation to disaster!

setup and test

The easiest way to set up a Gunnplexer system is to get together with a friend and set up your 10-GHz stations at the same time. With two Gunnplexers running on the bench, it takes only a few minutes to adjust the speech amplifier and tone oscillator for best performance. Tests and adjustment of an AFC system take longer, but most work can be done in one evening.

The only problem you're apt to encounter with two Gunnplexers in the same workshop is high signal strength — if you have an S-meter, you can be sure it will be against the pin, regardless of the direction you point your Gunnplexers. However, wood makes an excellent microwave absorber, as does the conductive black plastic foam which is often used to protect CMOS integrated circuits. A small section of black foam placed across the waveguide will reduce the radiated signal by 30 dB or more; a section of 2 × 4 pine lumber in front of the Gunnplexer reduces signal strength by 10 or 12 dB. Once you have reduced signal strength to manageable levels, you can make the necessary adjustments. First set one Gunnplexer up with +10 volts on the Gunn diode and +4 volts on the varactor; unless tuned specially by the manufacturer, the operating frequency will be close to 10250 MHz. Now tune the other Gunnplexer to a frequency below the first where you hear the carrier, and carefully adjust the varactor bias for a zero reading on the carrier meter (if your receiver doesn't have a zeroing meter, adjust for maximum signal strength). Make a note of the varactor voltage; this Gunnplexer will now be tuned to 10220 MHz if a 30-MHz i-f is being used.

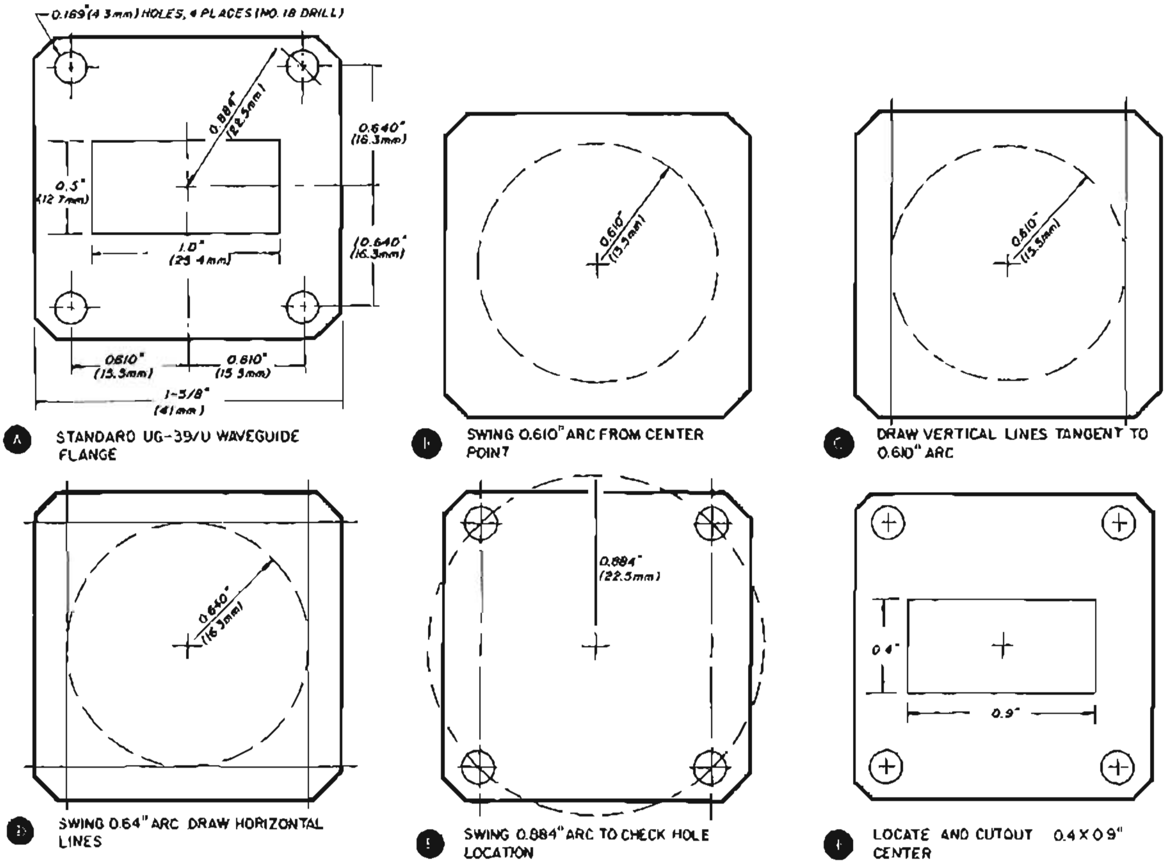


fig. 24. How to lay out the chassis to match a UG-39/U waveguide flange (used on all Microwave Associates Gunnplexers). Note that the flange holes are not symmetrical. Step-by-step instructions are given in the text.

Now tune the second Gunnplexer above the first until you hear the carrier and carefully center the carrier in the passband of the receiver. Make a note of the varactor voltage (Gunnplexer tuned to 10280 MHz with a 30-MHz i-f). If you wish, you can now set the varactor voltage on this Gunnplexer to +4 volts and make similar measurements on the other unit. If you use a turns-counting dial on the varactor bias potentiometer, it's helpful when mountain-topping to know which dial settings correspond to the operating frequencies of 10220, 10250, and 10280 MHz.

Now tune the Gunnplexers to one another and carefully center the carriers. Plug in your microphone and increase the speech gain control. You will note that the received audio signal will have excellent fidelity at a certain setting of the gain control, but, as gain is increased beyond that point, the signal becomes distorted. Back down the gain control to a setting slightly below that which causes audible distortion.

If you wish to measure the actual deviation of your signal, you can use the Bessel function relationship to determine the audio input frequencies at which the fm carrier will completely disappear; this technique is discussed in most of the popular vhf-fm books. **Table 1** lists the audio frequencies for carrier nulls at several popular deviations (use 75-kHz deviation for wideband fm receivers); it is not practical to use carrier nulls beyond the third.

In most cases it's not necessary to make an actual deviation measurement; reliable fm microwave communications can be obtained by a simple adjustment of the speech gain control for no audible distortion. Once the speech gain had been adjusted, turn on the tone oscillator and adjust the tone signal level for a signal strength approximately the same as for voice. If you have both input and output controls in your speech amplifier, set the output control for full deviation or minimum audio distortion with the microphone gain control set at about one-half full gain — this will leave plenty of leeway for microphones with higher or lower output. Set the tone oscillator level as before.

If you don't have a friend with a Gunnplexer, you can use the *Boomerang* system shown in **fig. 25**, which was originated by the San Bernadino Microwave Society. All you need is an X-band crystal mixer and a 1 to 2 mW local-oscillator source at 30 MHz (if you're using a 30-MHz i-f receiver). When setting up the mixer, be sure to provide a dc return (rf choke) for the mixer diode. Place the mixer 100 meters (300 feet) or so from the Gunnplexer. The transmitted signal from the Gunnplexer will mix with the 30-MHz LO, be re-radiated, and picked up by the Gunnplexer receiver. With this system you can make all the adjustments discussed previously.

table 1. Audio frequencies which will produce a carrier null for various amounts of frequency deviation (use 75 kHz deviation for wideband fm receivers).

modulation frequency	deviation produced 1st null	2nd null	3rd null
2717.3 Hz	± 6.53 kHz	± 15.00 kHz	± 23.52 kHz
4528.9 Hz	± 10.89 kHz	± 25.00 kHz	± 39.19 kHz
5000.0 Hz	± 12.02 kHz	± 27.60 kHz	± 43.27 kHz
8666.8 Hz	± 20.84 kHz	± 47.84 kHz	± 75.00 kHz
10000.0 Hz	± 24.05 kHz	± 55.20 kHz	± 86.54 kHz
13586.7 Hz	± 32.67 kHz	± 75.00 kHz	± 117.58 kHz

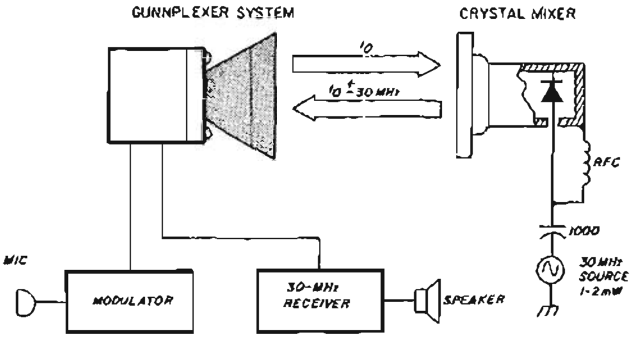


fig. 25. Boomerang system devised by the San Bernadino Microwave Society for testing microwave systems. It requires only an X-band diode mixer and 1 to 2 mW at 30 MHz. The mixer should be placed 100 meters or so from the Gunnplexer to eliminate i-f feedthrough; if the X-band mixer is too close to the Gunnplexer, radiation from the 30-MHz signal source will completely block the i-f receiver.

When using the Boomerang system don't place the X-band mixer too close to the Gunnplexer. If it is too close, primary 30-MHz radiation from the LO will feed directly through to the i-f receiver. You can tell very quickly if this is happening because the receiver will be completely blocked.

radiation hazard

Although 20 mW isn't usually considered to be very much rf power, in the Gunnplexer it's concentrated at the small, open end of the waveguide, so power density is about 6.2 mW per square cm (up to 19 mW/cm^2 for higher-powered Gunnplexers). This is considerably above OSHA's 10 mW/cm^2 safety limit. Fortunately, rf power density falls off to safe levels with a few feet (2 meters), but remember that your eyes are especially susceptible to damage from rf radiation — never look into the open end of a Gunnplexer while it's operating.

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ham radio