Microwaves for the radio amateur—4

This is the fourth in a short series of articles written in an attempt to stimulate activity by radio amateurs on the microwave bands. This month the author deals with wavemeters, ferrite devices, power generation and klystrons, and antennas.

by DES CLIFT, VK2AHC*

Frequency measurement can present problems for the amateur microwave enthusiast. Even the amateur with quite a respectable array of equipment and facilities for HF and VHF generally finds himself unable to measure microwave frequencies with sufficient accuracy to tell with certainty whether he is inside or outside the allocated band.

Microwave wavemeters and radar test units known as "echo boxes", both calibrated in terms of frequency, have appeared on the surplus market from time to time, but never in large quantities.

Those fortunate enough to possess a slotted line can obviously measure frequency directly, by a measurement of the waveguide wavelength inside the waveguide. This is then converted to free space wavelength and hence to frequency. The technique is covered in almost every text book of microwaves.

For those not in the above categories the following course of action is recommended and will confirm the conviction that it is possible to produce homemade apparatus of accuracy comparable with that of expensive commercially made items.

A wavemeter can be produced, based on a cross coupler similar to that shown last month in Fig 10 but having one coupling hole of about 20-25dB. This feeds a length of waveguide in which is a movable plunger forming one end of a cavity. The unused end of the waveguide is blanked off. Resonances occur at the frequency of the incoming microwaves, and if the difference in mechanical position of the plunger is measured for adjacent indications, this is then half the waveguide wavelength, which again can be converted to frequency.

It is reasonably easy to measure frequency to ±10MHz in 10,000MHz (ie, 0.1%) with this device. A practical unit is fully described in the RSGB Bulletin for May 1958, together with a spot frequency cavity for 9375MHz (the design frequency of a large quantity of American surplus airborne radars) and 10,000MHz, the lower band edge of the amateur band. The arrangement for the measurement is as shown in Fig 13.

A large number of educational establishments possess wavemeters which cover X band. If an absolute calibration of the above, or any uncalibrated surplus wavemeter is required, no doubt this could be organised. The writer will also be glad to assist any amateur who is in difficulty with calibration of wavemeters and other components.

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Ferrite Devices

All the waveguide pieces discussed so far are bi-directional. An exception to this rule are waveguides containing ferrite slabs or rods. The most popular components are the isolator or one way attenuator, and the circulator (see Fig 2c of first article for an example of use), in which the direction of microwave energy flow to and from a number of fixed ports is always in a known, controlled direction.

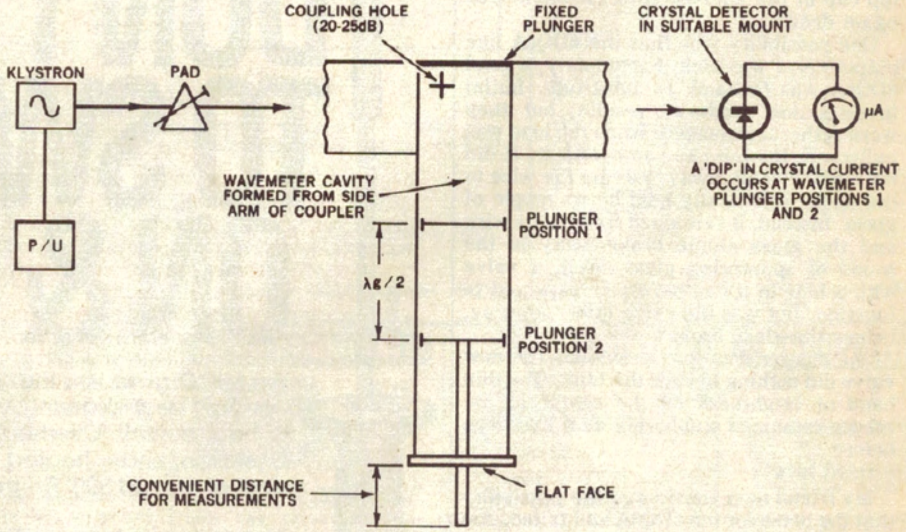


Fig. 13 USE OF HOMEMADE WAVEMETER

A ferrite material is the basis of these devices and is used with either an electromagnet or a permanent magnet. The material is a very low loss ceramic mixture of the oxides of iron and other metals, such as nickel, cobalt, magnesium, manganese and aluminium, which are fired at temperatures in the region of 1300-1400°C.

This material can be likened to lots of little magnets randomly orientated. With the application of a given magnetic field, the axes of all the particles align themselves with the direction of the applied field. This takes place in a few nano seconds, and the operation is known as precession. If, however, an RF field is also applied a condition can result where quite large non-reciprocal losses are present, so that energy can flow much more readily in one direction than another.

Isolators, by far the most widely used ferrite devices at present, operate where the RF field resonance is the same as the natural precession frequency. They are, therefore, referred to as resonance isolators. The ferrite material is either placed on opposite faces, or right across the waveguide at a distance about quarter way across the broad dimension. At this point in the guide the RF magnetic field is circularly polarised. When resolved into two components, one will be rotating in the same sense as the natural precession, and suffer loss. The other will be unaffected.

If, however, the magnetic field is not at that value at which natural precession takes place, components are produced using an effect called Faraday rotation. This is the basis of ferrite phase shifters, circulators, modulators and switches. These devices can take the form of a rod of ferrite along the axis of circular waveguide. Applied microwave energy is made to rotate through 45° by applying a suitable magnetic field. It is then either taken out, dissipated, or reflected, depending upon what the final form of the component is to be.

RF Power Generation

For the 3300, 5650, and 10,000MHz bands the reflex klystron is probably still the easiest and cheapest method of obtaining enough microwave power for amateur communication over 20-100 miles range. Suitable klystrons are the 2K25 / 723 A / B series for 10,000MHz and the 726A for 3300-MHz. These types have been available in reasonable quantities since the war, since they were used extensively in airborne radar equipment. They have internal cavities, and their output is via a short coaxial line.

More modern types such as the CV2346 suitable for both 5650 and 10,000MHz and the CV2116, sutiable for 2300 and 3300MHz require an external cavity and are, therefore, more versatile. Other modern CV types, usually of the English Electric K series have appeared in small numbers on the surplus market from time to time. Some of these operate in the 10,000MHz amateur band, others require modification, and others designed to operate between 8000 and 9000MHz do not appear to work at 10,000-MHz. An exception is CV2282 (K308). All these latter types have waveguide outputs and are thus easy to couple to the rest of the system.

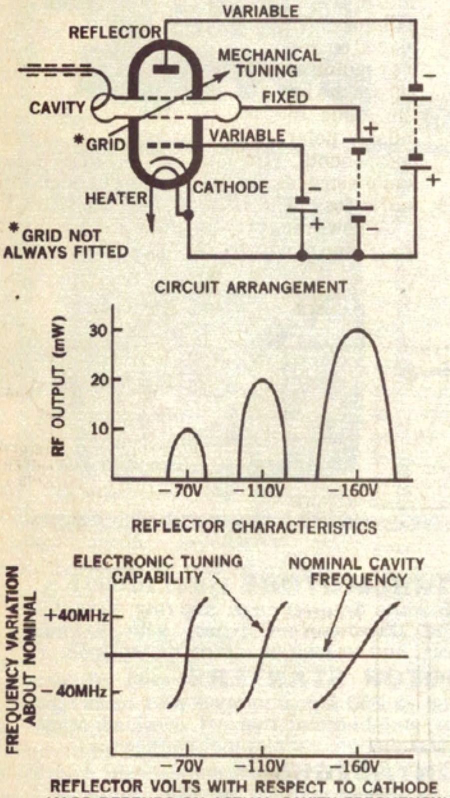


Fig. 14 TYPICAL REFLEX KLYSTRON AND ITS REFLECTOR CHARACTERISTICS

The principle of operation of all these reflex klystrons depends upon the "transit time" effect, as follows. In a typical klystron (Fig 14) electrons are emitted by the cathode, the electron stream sometimes being controlled by a negative potential on an additional grid. The electrons are accelerated through the cavity grids and repelled by the negative potential of the reflector. If the valve is assumed to be already oscillating, an RF voltage will be present across the cavity, which is mechanically tunable.

The electrons travel between the two grids spaced in the centres of opposite sides of the cavity in a time which is short compared with the period of oscillation; their velocity is altered by the RF voltage on one of these grids. From the cavity emerge "bunches" of electrons, which are repelled by the reflector and arrive back at the cavity after a short period of time. The negative voltage on the reflector determines how far the "bunches" will travel into the space between the cavity and the reflector. At a certain reflector voltage, the "bunches" will arrive back at the cavity at the correct instant to reinforce and sustain oscillation.

The "bunches" of electrons can also arrive back at the cavity after longer intervals of time, producing less favourable conditions. Thus, as the reflector voltage is varied, the valve will oscillate in various "modes", which are usually referred to as, for example, the "160 V mode" or the "110 V mode". These voltages are the approximate reflector voltages which permit oscillation.

It may be seen that only for one value of reflector voltage will the transit time be correct for oscillation at the resonant frequency of the cavity in each of the

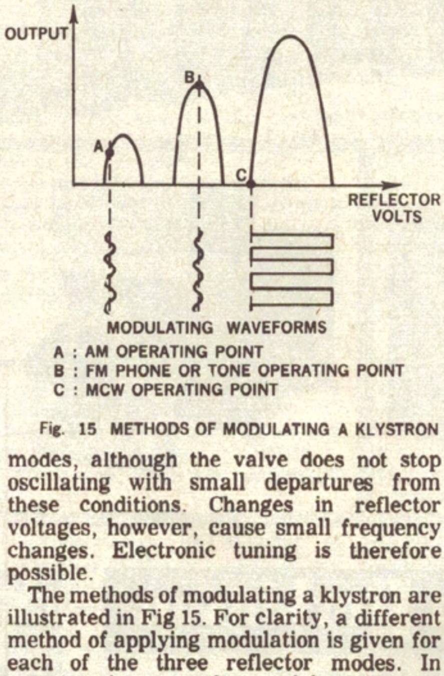


Fig. 15 METHODS OF MODULATING A KLYSTRON

modes, although the valve does not stop oscillating with small departures from these conditions. Changes in reflector voltages, however, cause small frequency changes. Electronic tuning is therefore possible.

The methods of modulating a klystron are illustrated in Fig 15. For clarity, a different method of applying modulation is given for each of the three reflector modes. In practice of course only one of these types of modulation is used on one mode at any one time.

FM phone and tone is by far the most satisfactory method for amateurs. It is secured very easily by applying a few volts of audio telephony, or keyed tone to the peak of the reflector mode. Since the slope of the reflector / frequency characteristic varies with the operating mode chosen, a choice of deviation is available for experimentation.

AM phone is obtained (together with some FM) by operating the reflector operating point on the side of the reflector mode. By using a larger amount of audio than used for FM, reasonable quality AM is produced. This method is handy for initial experiments where an FM receiver is not available, as is the case of the use of a standard radar IF strip, but suffers from the disadvantage that

(a) the klystron is only giving a fraction of its potential output.

(b) the klystron, as used without AFC

(Automatic Frequency Control), as is usually the case with amateurs, will tend to drift somewhat and therefore require frequent readjustments to be made at both ends of the microwave link.

Modulated CW or MCW can be obtained by the application of a square wave of the order of 50 volts peak to peak, so as to sweep through one mode, but not run into the adjacent mode.

Particular care has to be taken to reduce the hum on the reflector to a very low value (under 10mV seems acceptable) before the application of the audio. This is easily done by a three or four section RC filter. A typical practical arrangement, showing this, and the use of a zener diode DC heater arrangement which also reduces unwanted FM, will be described in the next article.

Klystron Mounts.

Klystron mounts are required for X band and S band klystrons such as 2K25 / 723 A / B and 726A, which have a type of coaxial output.

Although most of the text books suggest (for 9375MHz) an offset arrangement for the injection of the coaxial probe into the waveguide, the writer has found that at 10,000MHz, the best arrangement is to place the probe in the centre of the waveguide and make an adjustment of vertical injection as shown in Fig 16.

WARNING: It should be noted that the outer shell and tuner of these kylstrons is connected to the cavity. In any arrangement where the cathode of the klystron is at earth potential, the cavity will be at HT potential (ie 250V to 300V) and therefore dangerous to handle. This remark also applies to the coaxial probe, which should also be suitably isolated from the waveguide.

For reasons of maintaining thermal and hence electrical stability the klystron is usually enclosed in a box. This assists in the prevention of electric shock but nevertheless caution should be exercised when handling operating klystrons until the exact nature of the circuitry is known and understood.

Antennas

This is a subject which the average experimenter tends to treat as a problem area but which in fact need not be at all.

Surplus parabolic antenna and feeds such as the AN / APS4 (suitable for use at 10,000-MHz) have recently been available, but probably the best approach is to make up reasonably sized horn antennas from thin brass or even tin plate. These give excellent results, both from the aspect of gain and due to the fact that they are virtually non frequency sensitive over quite large frequency ranges. The writer has produced S, C and X band versions and thoroughly recommends their use for all but the longer range contacts.

The fact that all these designs are based on the use of standard sizes of waveguide tube can be used to advantage since the user can mount the klystron and the other components on the one assembly. At the lower frequencies a simple transition to coaxial cable as illustrated in Fig 8 last month can be used.

Fig 17 (a) gives construction details of four applicable designs while Fig 17(b) shows examples of some of the finished items.

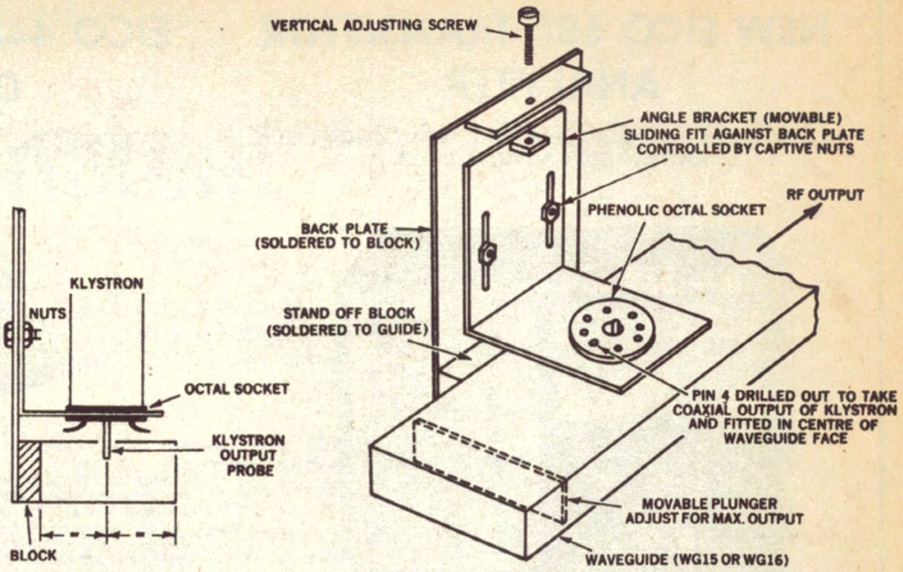
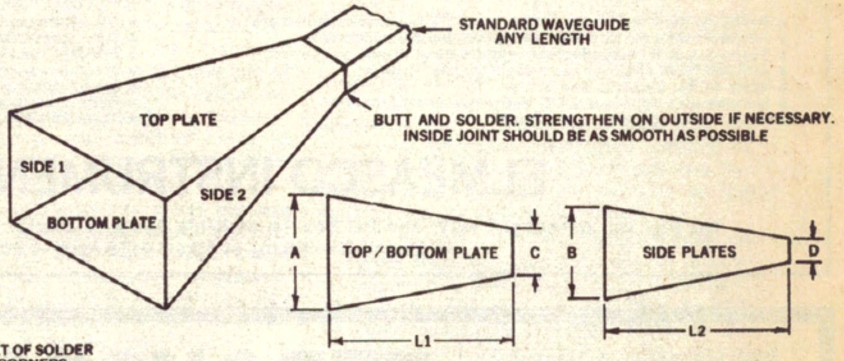
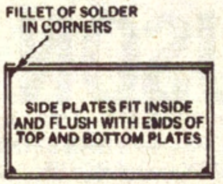


Fig 16 KLYSTRON MOUNT FOR 2K25 / 723A / B ETC. FOR 10GHz





FREQUENCY	L1	A	C	L2	B	D	FOR USE WITH
10GHz GAIN 22dB	11.71"	7.75"	1"	11.9"	5.67"	0.4"	WG16
5.65GHz GAIN 20dB	17.32"	11.48"	1.5"	17.59"	8.42"	0.62"	WG14
3.3GHz GAIN 18.6dB	14.24"	12.95"	3"	14.52"	9.45"	1.34"	WG10
2.3GHz GAIN 16.5dB	11.28"	14.5"	4.3"	11.62"	10.75"	2.15"	WG8

DIMENSIONS GIVEN ASSUME THE USE OF MATERIAL OF SIMILAR THICKNESS TO WAVEGUIDE. THIS IS NOT REALLY NECESSARY PROVIDING CARE IS TAKEN WITH MATCHING SMALL END TO WAVEGUIDE

Fig. 17 (a) HORN ANTENNAS SUITABLE FOR AMATEUR MICROWAVE BANDS

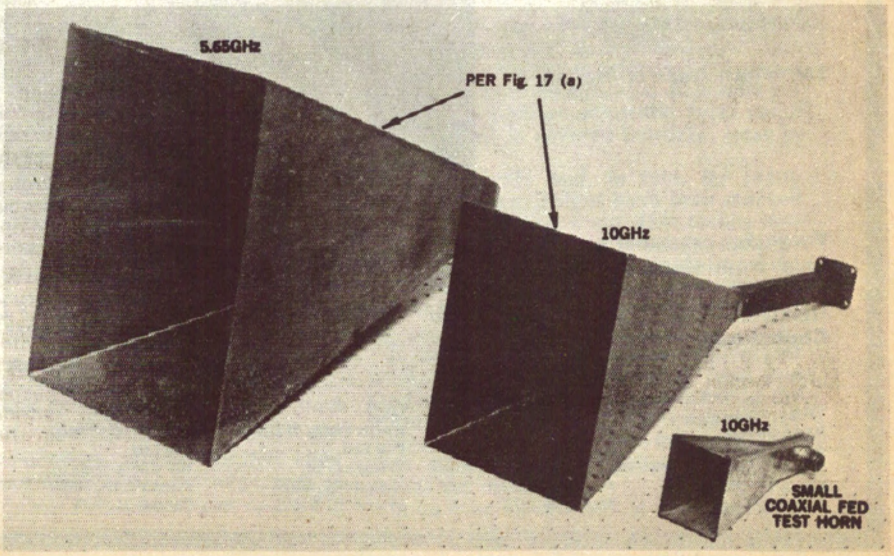


Fig. 17(a). (Right) Some examples of home-made horn antennas.

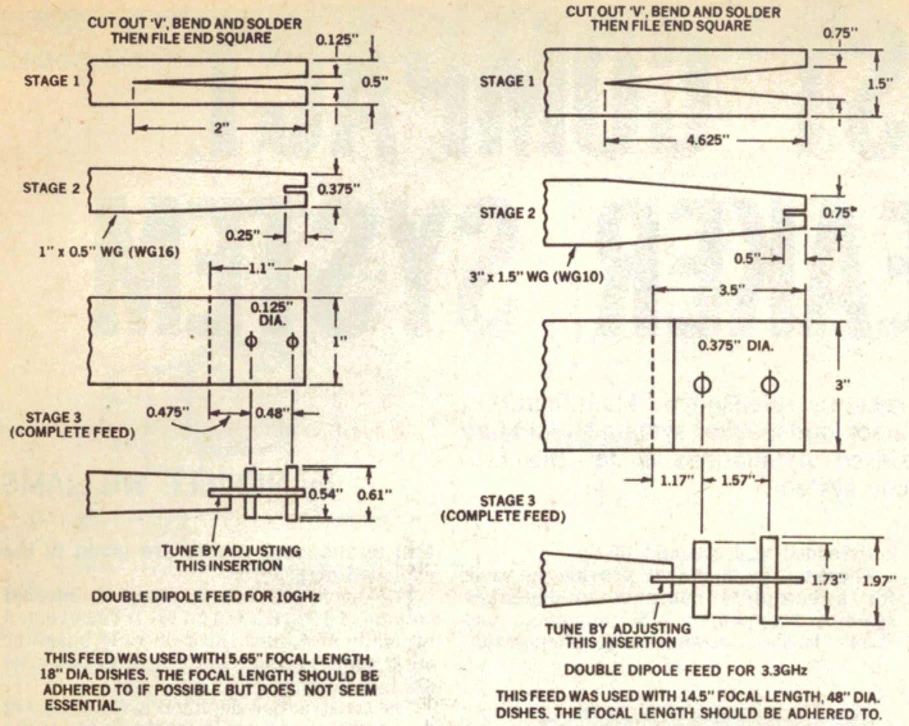


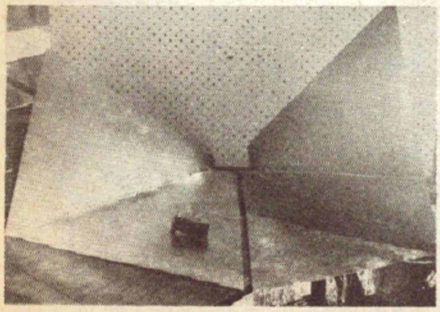
Fig. 18 DOUBLE DIPOLE FEEDS FOR USE WITH PARABOLIC ANTENNAS.

The horns can be made from four plates with dimensions as the table in Fig 17(a). These are not particularly critical except at the small end, where the inside dimensions should be carefully adjusted to mate with the waveguide. A wooden bung will assist in the location of this during assembly and also support the assembly while an outside strengthening piece is being added and soldered in place. A small blow torch is a necessity.

An alternative method of construction is to make the horn in two pieces. This makes the soldering and "holding in place" task a lot easier. In this case two plates, with "X" joined together would be cut, and bent at the point "X", a small (1/32" approx) reduction in dimensions A and B being made to compensate for the bend. Before trying this method, which is recommended, make up a trial horn with a piece of stiff paper. The extra effort involved may well be worthwhile!

For those in possession of suitable parabolic antennas, but with no suitable feeds to use with them, Fig 18 details two waveguide feeds suitable for use at 3300MHz and 10,000MHz. These require a little care in manufacture but are certainly not outside the scope of the average amateur, and they can be tuned for minimum reflection by a simple adjustment of the element supporting plate. A simple reflectometer, based on a directional coupler such as is shown in Fig 9 is all that is required for this tuning.

(To be continued)



A half-made 3300MHz horn with a tiny 10,000MHz horn for comparison.