TABLE OF CONTENTS

Page

EXPERIMENT #1 - MICROWAVE TUNER 2

EXPERIMENT #2 - USE OF COAXIAL CABLE 7

EXPERIMENT #3 - HORN ANTENNA – MICROWAVE PROPAGATION IN SPACE... 10

EXPERIMENT #4 - DOPPLER RADAR 15

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EXPERIMENT #1 - MICROWAVE TUNER

OBJECTIVES

- To be aware of the need for tuning of a mismatched load.
- To be familiar with the concept of admittance in a waveguide.
- To know how to use a slotted-line tuner to achieve a match between a load and source.

THEORY

When microwave power is being sent to a load, reflected energy is usually lost and standing waves are formed. Systems which have large standing waves in them, are much more difficult to handle and adjust than 'flat' systems (having no standing waves). Furthermore, they are much more liable to wide variations in performance when the conditions are disturbed, e.g. by temperature or other ambient changes or drift of the signal frequency.

There are therefore several reasons for wanting a load to accept all the r.f energy incident on it, without reflection. To illustrate this (ref. fig 1.2), suppose we have a waveguide terminated in a load, which is mismatched.

We could say that the load has a normalised impedance $(R+jX) / Z_0$, but it is more convenient to think of its 'admittance', which is simply the reciprocal of impedance. So let the load admittance be $Y_L=G_L+jB_L$. In a similar way the waveguide can be said to have characteristic admittance Y_0 which is simply the reciprocal of the characteristic impedance Z_0, and the normalised admittance Y/Y_0.

A convenient feature of a Smith chart is that if the normalised impedance is represented by one point, Z, on a constant mismatch circle, then the normalised admittance Y is found simply moving to the other end of the diameter through Z, (see fig 1.3). This demonstrates the relationship between Z, a normalised impedance, and $Y=1/Z$ a normalised admittance.

If we move along the waveguide, back toward the oscillator, the admittance $Y=G+jB$ will change, through values represented by the circle of constant mismatch in a Smith chart (see fig. 1.1). A point Y_1 can be found where the conductance G becomes equal to Y_0. In general the 'susceptance' jB will be non-zero. If we could put in parallel with Y at this point a susceptance –jB, the combined susceptance would be zero, and Y would simply become Y_0. A match would be thus be achieved, in the sense that no part of an incident wave must arriving at Y_1 would be reflected. All the energy of the wave must therefore go to the load.

A convenient form of susceptance, which can be connected in the waveguide line, is a capacitive screw (fig. 1.4).

This of course can only provide a capacitive (positive-valued) susceptance. What if the jB, which is to be cancelled, is also capacitive? A moment's study of fig. 1.1 will show that there is not just one point Y_1 where $G=Z_0$, but two. And the susceptance will be of opposite sign at the two points, so that one can always choose whichever kind is easier to cancel.

EXPERIMENTAL PROCEDURE

1. Connect the equipment as shown in fig. 1.5. On the Control Console, switch on the supply to the oscillator and set its left-hand switch for internal keying; set the METER READS switch to 'detector output'.
2. Unscrew the Slotted-line Tuner as far as it will go (without undue force).
3. Move the Slotted-line Detector to find a maximum in the standing wave pattern. Adjust the source Attenuator until the meter reads about four-fifths full scale.
4. Find a minimum in the pattern and adjust the load Attenuator until the meter reads about one-tenth full scale. (It may be necessary to track the minimum position as it is disturbed by the Attenuator adjustment).
5. Use the Slotted-line Detector to determine the impedance of the load there represented by the combination of the Tuner and Terminator. Write down the result and the intermediate results as in Table 1.

TABLE 1:

minimum position;	
initial conditions (X_1)	
with short-circuit representing load (X_2)	
and X_3	
$\lambda_g=2(X_2-X_3)$	
$(X_1-X_2)/\ \lambda_g$	
from the Smith chart, normalised Z_L	
Y_L (opposite end of diameter)	

6. On a Smith chart, draw the constant-mismatch circle for this VSWR and the circle G=1.
7. Choose their point of intersection (Y_1) having negative susceptance, see fig. 1.1.
8. Find the distance from the load at which it occurs. This is given (in wavelengths) by the distance along the outer scale from Y_L to Y_1, in the direction 'towards generator'. If necessary add one or more half-wavelengths to that distance (since the impedance pattern repeats every half wavelength). Record the position chosen.
9. Position the screw of the Tuner at a position along its slotted guide in accordance with your calculated position.

   ie. (distance in λ) × (λ_g in mm)

It is then necessary to adjust the depth of penetration of the screw and make a fine adjustment to the slide position, to reduce the VSWR as much as possible. Do these two adjustments in sequence, as follows:

- Make sure that the Detector is accurately at a minimum.

- Adjust the Tuner's screw penetration to raise the meter reading and carefully try a small adjustment of its longitudinal to raise the reading further.
- By moving the Detector along the pattern, check that the adjustment have reduced the VSWR.
- Repeat the sequence until further improvement becomes difficult.

Measure and record the final value of VSWR. Record the final position of the Slotted-line Tuner and compare it with that predicted from your impedance measurements.

RESULTS AND CONCLUSIONS

1. Explain how the inductive susceptance could be used for matching?
2. What are the other methods for matching load impedance to the characteristic impedance?
3. In practice, is it possible to use pure inductive or pure capacitive loads? If possible how matching could be achieved?

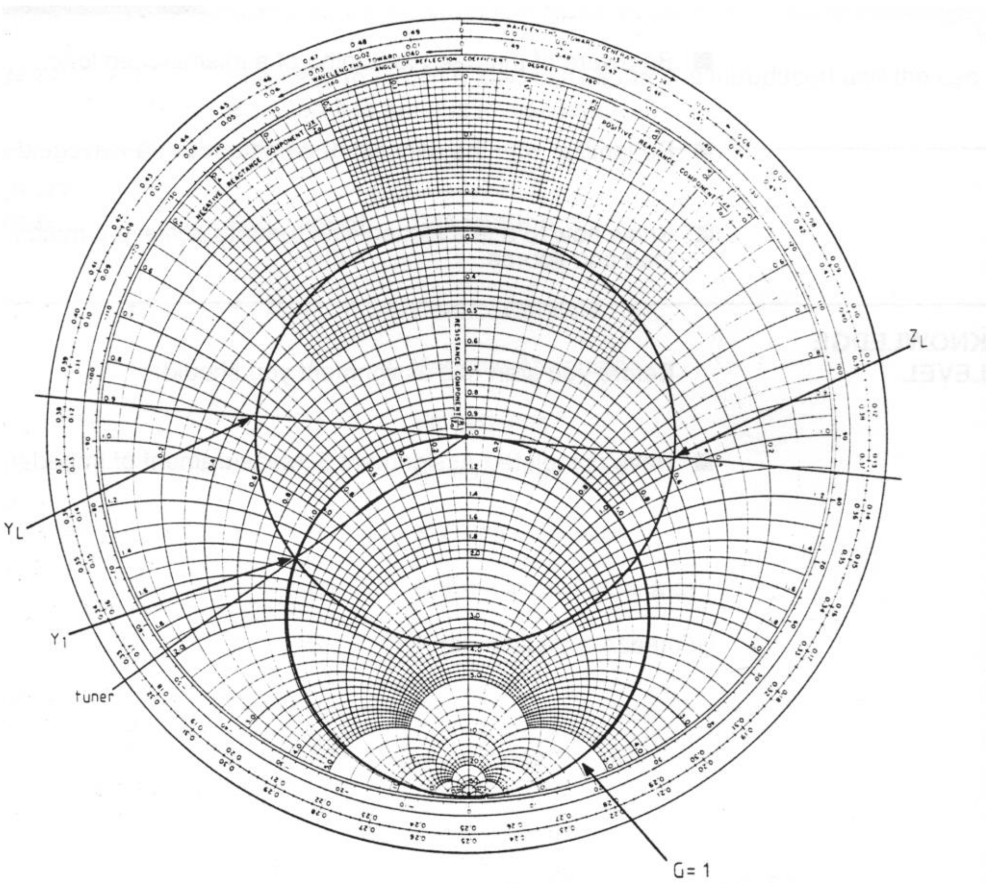

Fig 1.1

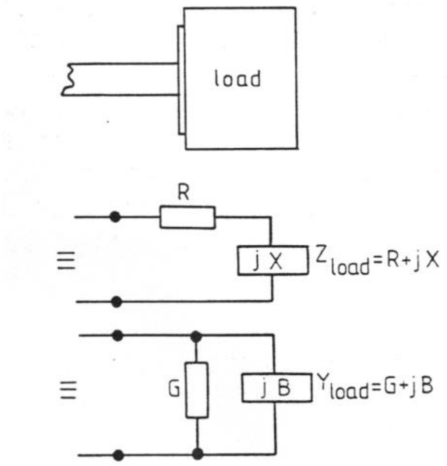

Fig 1.2

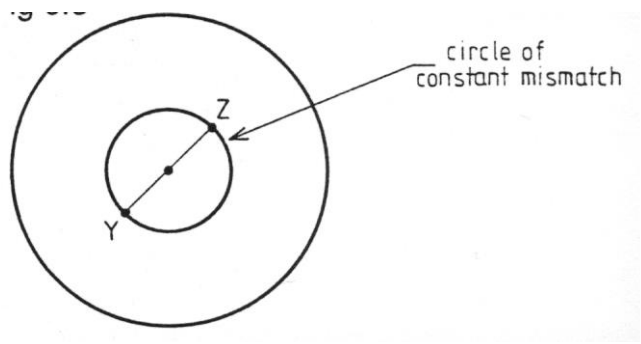

Fig 1.3

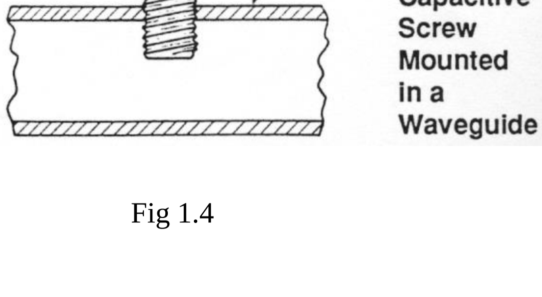

Fig 1.4

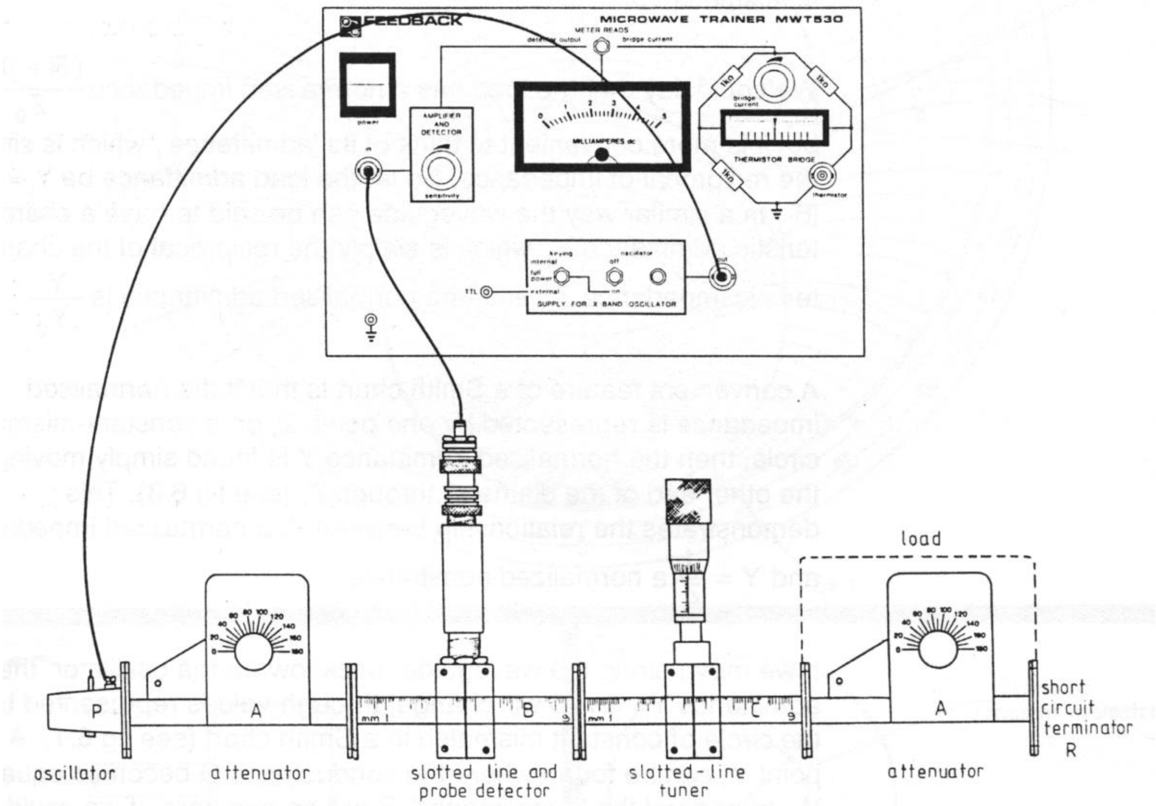
FEEDBACK
MICROWAVE TRAINER MWT530
METER READS
detector output
bridge current
power
AMPLIFIER AND DETECTOR
sensitivity
MILLIAMPERES dc
THERMISTOR BRIDGE
thermistor
keying
internal
full power
external
oscillator
off
on
TTL
SUPPLY FOR X BAND OSCILLATOR
load
P
A
B
C
A
short circuit terminator
R
oscillator
attenuator
slotted line and probe detector
slotted-line tuner
attenuator

Fig 1.5

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EXPERIMENT #2 - USE OF COAXIAL CABLE

OBJECTIVES

- To show that waveguide is not the only method of guiding microwave signals.
- To investigate the losses arising from the use of coaxial cable with those of waveguides.

THEORY

Although a waveguide is excellent from the point of view of transmitting microwave energy with low losses, it is not always convenient. Modern electronics tends to be on printed circuit boards, for which strip-line techniques are widely used (the conductors are tracks in the printed wiring). Also units are mounted in boxes, which must be easy to interconnect and disconnect, for which purpose the flexibility of cables is convenient and coaxial cable must be suitable. Both strip-lines and coaxial cables introduce fairly heavy losses, however. For this reason waveguide is generally preferred for antenna feeders, where loss of the signal spoils the signal/noise ratio in reception, or wastes expensive power in transmission.

When a signal is transferred from one mode of propagation to another, as from waveguide to cable or vice versa, some special device is needed to accept the signal in one mode and launch it in a new mode. Such a transition device must attempt to convert an electromagnetic field in one form to another electromagnetic field of different form. This often presents some problem in matching.

In this experiment the losses and matching problems in a length of coaxial cable will be examined.

EXPERIMENTAL PROCEDURE

1. Before starting, adjust the penetration of the Tuner probe to approximately zero. Then set up the apparatus as shown in fig 2.1.
2. On the Control Console, switch on the supply to the oscillator and set its left-hand switch for internal keying; set the METER READS switch to ‘bridge current’.
3. The Attenuator may be set to minimum attenuation. In this condition it should be realised that reflections from any mismatch can upset the Oscillator, possibly preventing it from working.
4. Using the Bolometer bridge, measure the power sent to the Bolometer while the Tuner is doing nothing.
5. Then use the Tuner to maximize the amount of power sent to the Bolometer. To do this, increase the probe penetration slightly, and find the position of the carriage giving greatest power; then adjust the probe depth and carriage position alternately.
6. It may be found that too much power is available for the bolometer bridge to be balanced at minimum d.c. If so, adjust the Attenuator to give a measurable power. Make sure that Attenuator setting is not disturbed during the following part of the experiment.
7. Measure the maximum power obtained in the Bolometer.

8. Next disconnect the Bolometer from the Tuner, and insert the two Waveguide/Coaxial Adaptors and Coaxial Cable per fig 2.2.
9. Without altering the Attenuator, again adjust the Tuner for maximum bolometer power. (It may be helpful to reduce the probe penetration of the Tuner first). Measure the new value of the power.

RESULTS AND CONCLUSION

1. Calculate the ratio of powers obtained with and without the cable link.
2. Calculate the cable loss in dB, which is:

   Loss = 10 $\log_{10}$ (power ratio)
3. Examine the waveguide/coaxial cable Adaptors and describe in your own words how you think they work.

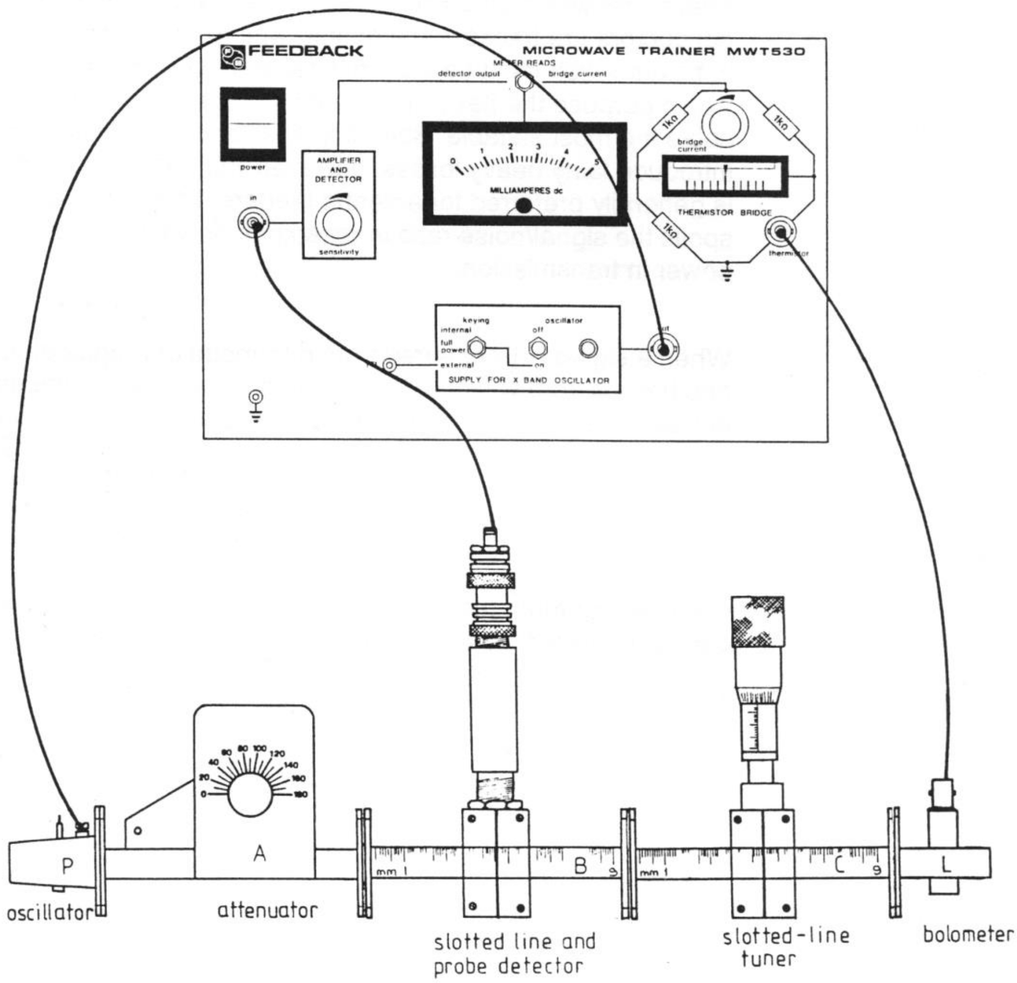

Fig 2.1

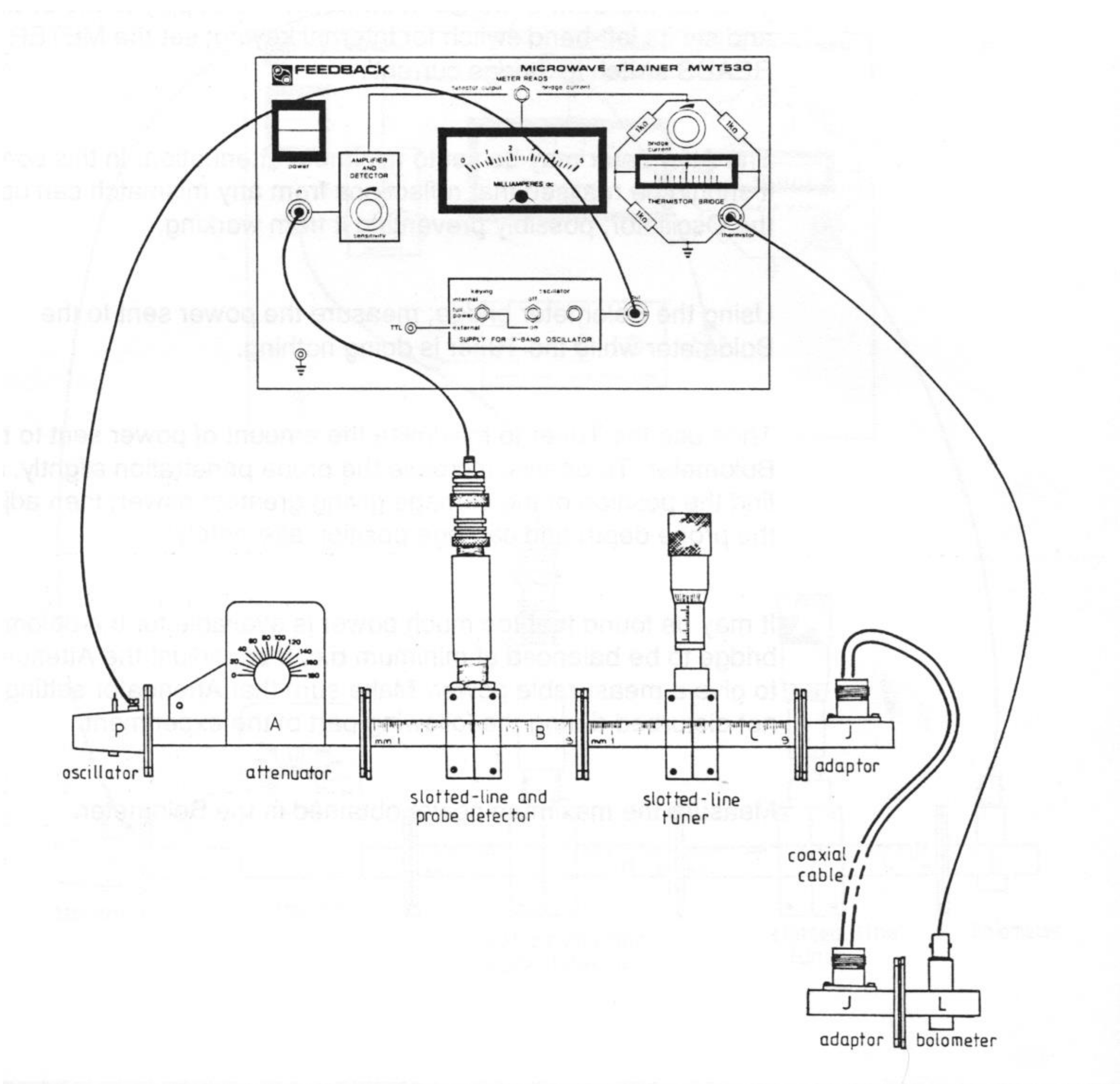
FEEDBACK
MICROWAVE TRAINER MWT530
METER READS
AMPLIFIER AND DETECTOR
MILLIAMPERES dc
THERMISTOR BRIDGE
SUPPLY FOR X-BAND OSCILLATOR
TTL
P
A
B
C
J
oscillator
attenuator
slotted-line and probe detector
slotted-line tuner
adaptor
coaxial cable
J
L
adaptor
bolometer

Fig 2.2

EXPERIMENT #3 - HORN ANTENNA – MICROWAVE PROPAGATION IN SPACE

OBJECTIVES

- To be able to describe the operation and characteristics required of a horn antenna.
- To know what is meant by beam-width and gain with reference to a horn antenna.

THEORY

If a waveguide, which is propagating a signal, is left with an open end, some of the signal energy will escape into space (Fig 3.1). Some will be reflected because the end is not well matched to free space, so a VSWR of about 2 will typically result.

Let us consider first the energy, which does get radiated or transmitted into space. Suppose the transmitted power is P_t. If it were radiated in all directions equally, then at a distance r from the source the total power P_t would be spread evenly across the surface of a sphere of surface area $4\pi r^2$. A receiving antenna occupying area A of that sphere would receive a proportional of the transmitted power.

$$P_r = P_t \frac{A}{4\pi r^2}$$

When it is required to transmit energy efficiently into space, a device called an 'aerial' or 'antenna' is used. The horn is a very simple form of antenna, being no more than a flare-out of the shape of the waveguide walls. It improves the match between the waveguide and the free space, and narrows the angle over which energy is radiated, fig 3.2.

By concentrating the radiation in a particular direction, the power radiated in that direction is increased (at the expense of reduced power in other directions). The factor by which it is increased is called the 'gain' of the transmitting antenna. Thus the power received by the receiving antenna of area A becomes:

$$P_r = P_t \frac{GA}{4\pi r^2}$$

The gain is often expressed in decibels as:

$10 \log_{10} G$ dB or dBi

(where the 'i' refers to an isotropic radiator; one which radiates equally in all directions).

An alternative definition for gain compares the antenna's performance not with an isotropic radiator, but with a half-wave dipole. The gain defined in this way is about 2.2 dB less than the gain in dBi.

In most microwave applications we require as much energy as possible to be radiated in a particular direction. This is often important not only for maximizing the power received, but also because the system (a radar, perhaps) requires directional information.

The directional characteristics of an antenna would ideally be shown as a three-dimensional graph in which, for each direction, the radius from a central point is proportional to the power density at a given distance. This is called the “radiation pattern”. For practical reasons the radiation pattern is normally shown by the two-dimensional graphs which show a section or sections of the three-dimensional pattern, like figure 3.3.

Fig 3.4 shows the planes used for a rectangular waveguide, designated TM-plane andTE-plane because they contain the directions of the electric and magnetic field respectively.

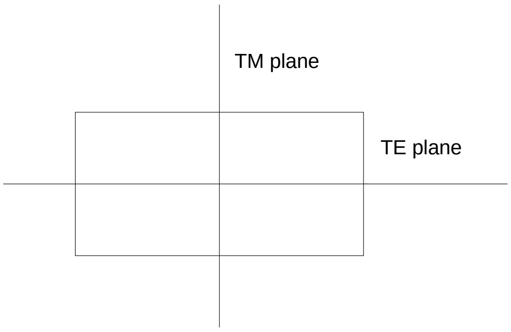

Fig 3.4 End-view of Waveguide Showing TM and TE planes

As shown in fig 3.3, a radiation pattern usually has several ‘lobes’. Generally, most energy is concentrated into the main lobe. Radiation in side and back lobes represents a waste of power. It can in some applications have serious effects by, for instance, producing false radar images.

The ‘3-dB beam width’ is often used as a measure of the directivity of an antenna. It is the angle (θ in fig 3.3) between the two points on the main lobe at which the radiated power density is half the maximum.

The gain is generally highest if the beam width is narrow and the side lobes are small, so that all the power is sent in the desired direction. An antenna, which has these characteristics, will also generally be an efficient receiver of radiation.

The radiation pattern differs when measured close to the antenna and at a distance. It is usually the latter condition, which is of interest, referred to as the ‘far field’. For practical purposes, and in the case of a simple horn antenna, the far field may be taken to start at a distance $2D^2 / \lambda_o$ from the horn, where D is its larger dimension at the opening, and λ_o is the free-space wavelength.

Radiation measurements are easily disturbed by reflections from the ground and other objects. These problems are avoided as far as possible in practice by using clear areas out of doors, or by using ‘anechoic’ rooms having walls specially designed to absorb radiation.

EXPERIMENTAL PROCEDURE

1. Connect the apparatus as shown in fig 3.5, with one sending antenna and one receiving antenna. On the Control Console, switch on the supply to the oscillator and set its left-hand switch for internal keying; set METER READS switch to “detector output”.

Results will improved if the sending and receiving antennas are each mounted so that no solid material is near the path between them. They may each for instance be mounted on the edge of a box, or on the edge of a table, leaving an open space between them. A space of about 150mm between the antennas may be tried for a start.

WARNING

Keep your eyes AWAY from the space in front of the transmitting antenna.

2. Set the amplifier to maximum sensitivity. Align the Antennas ‘0°’ direction. Adjust the attenuator to given a meter deflection near maximum. Make a note of this reading in the 0° column of Table 1. (Do not stand close to the transmission path while taking readings, as they will be affected).

TABLE 1

Meter reading (mA)	Attenuator setting				
	0°	10°	20°	30°	40°
Left side					
Right side					

3. Notice that the antennas must be similarly ‘polarised’. That is, the receiving antenna must be sensitive to electric field in the same direction as the electric field from the sending antenna. Try turning the receiving antenna on its side and note the effect.
4. Using a protractor to measure angles, rotate the receiving antenna about the centre of the broad edges of its aperture (opening). Set the angle to 10°, 20°, 30° and 40° in each direction.
5. Record the meter reading in each case. Plot them on a graph sheet like fig 3.6.
6. Use the graph to find the 3 dB beam-width of the antenna.

RESULTS AND CONCLUSION

1. Find the properties of a horn antenna with a given radiation pattern.
2. What position should the antenna be located to get the maximum gain and express the conditions to increase the gain.
3. Is that possible, for any antenna, to be used as a receiver and transmitter? What is the point of that?

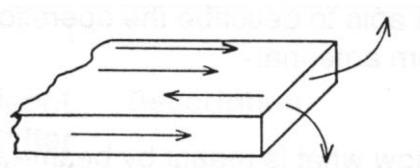

Fig 3.1

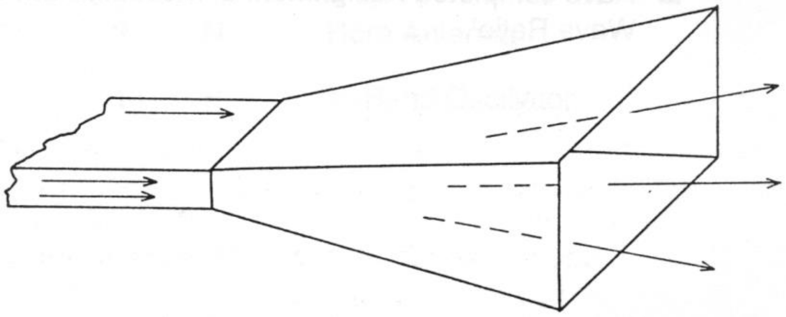

Fig 3.2

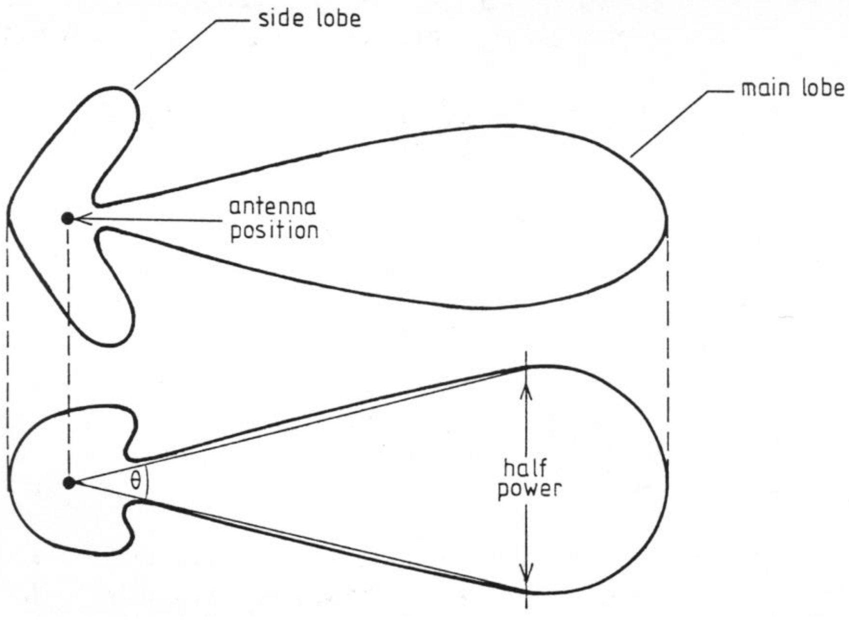

Fig 3.3

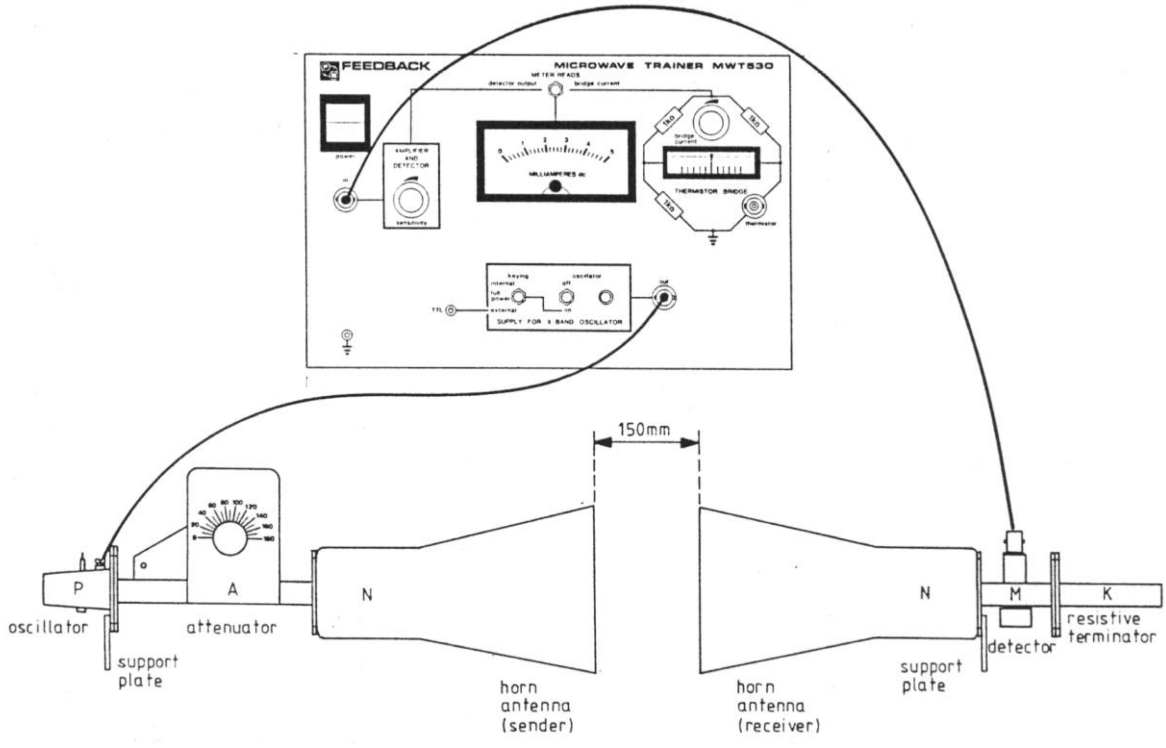
FEEDBACK
MICROWAVE TRAINER MWT530
150mm
P
A
N
N
M
K
oscillator
attenuator
support plate
horn antenna (sender)
horn antenna (receiver)
support plate
detector
resistive terminator

Fig 3.5

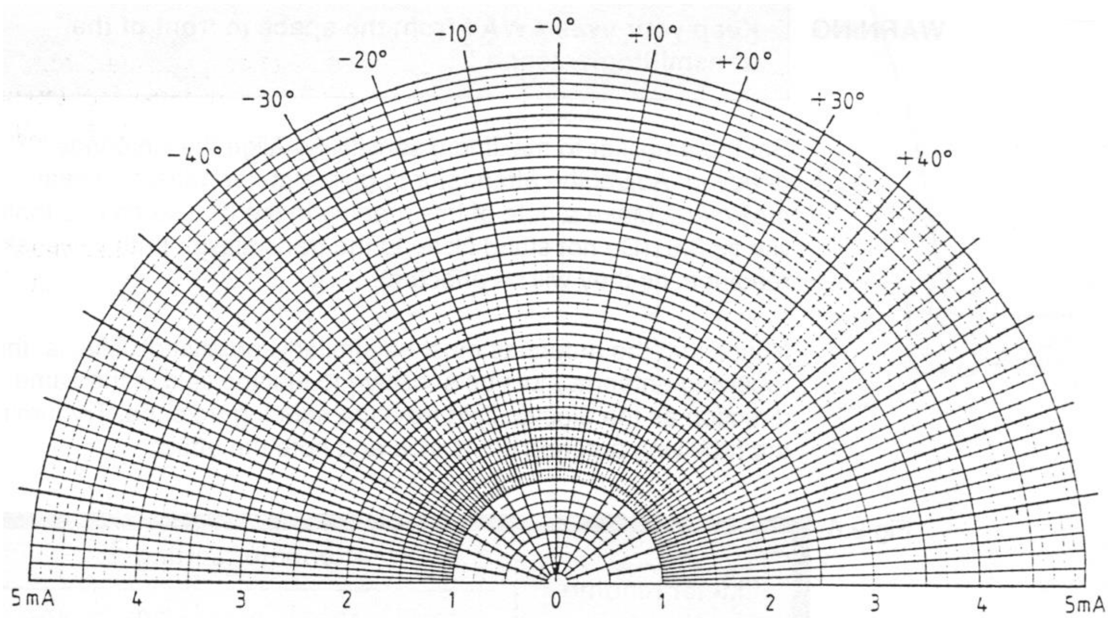
−0°
−10°
+10°
−20°
+20°
−30°
+30°
−40°
+40°
5mA
4
3
2
1
0
1
2
3
4
5mA

Fig 3.6

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EXPERIMENT #4 - DOPPLER RADAR

OBJECTIVES

- To understand the operation of Doppler radar.
- To be able to describe the construction and operation of a Hybrid Tee waveguide junction.
- To understand the use of mixer.

THEORY

If a wave is transmitted toward an object which reflects some of the wave back to the source; at a particular point on the path, the outward and reflected waves may be in phase with one another, in antiphase, or anywhere between. If the distance x between source and reflecting object increases by δx, then the total path length, out and back, changes by $2\delta x$, so the relative phase of the two signals will alter by $(2\delta x)/(2\pi\lambda)$ radians, where λ is the wavelength in the space surrounding the reflecting object. If the object is moving, the result will be a change in the frequency of the reflected wave, since, if e $\cos\omega t$ is the transmitted wave's electric field then, because of the distance 2x traveled, the reflected field will be :

$$ke\cos\left[\omega t - \frac{x}{\pi\lambda c}\right]$$

where k is a constant and c is the wave velocity.

If v is the velocity of the object away from the source, and x has the value x_0 when t=0,

then: $x = vt + x_0$

so that the reflected wave becomes:

$$ke\cos\left[\omega t - \frac{vt + x_o}{\pi\lambda c}\right]$$

which $= ke\cos(\omega_1 t - \phi)$

where the angular frequency $\omega_1 = \omega - \left(\frac{v}{\pi\lambda c}\right)$ and ϕ is a fixed phase value.

The received frequency, ω_1 is thus displaced from that transmitted, ω, by an amount proportional to the velocity v. This is known as the *' Doppler principle'*, and is similar in nature to the change in pitch of a sound, as heard by a stationary listener, which comes from an object moving past the listener at speed.

The change of frequency is detected by applying both the received and (suitably attenuated) the transmitted signals simultaneously to a 'mixer'. This is a non-linear device, such as the crystal detector.

If two signals ($e_0 \cos\omega t$) and ($e_1 \cos\omega_1 t$) are applied to a detector having the characteristic $i=Ke^2$, the output becomes :

$$i = (e_0 \cos\omega t + e_1 \cos\omega_1 t)^2$$
$$= e_0^2 \cos^2 \omega t + e_1^2 \cos^2 \omega_1 t + 2\, e_0\, e_1 \cos \omega t\ \cos \omega_1 t$$

but since $\cos^2 \theta = \frac{1}{2}\ (1+2\cos 2\theta)$

and $2 \cos A \cos B = \cos(A+B) + \cos(A-B)$

$$\therefore\ i = \frac{1}{2}\ (e_0^2 + e_1^2) + \frac{1}{2}\ e_0^2 \cos 2\omega t + \frac{1}{2}\ e_1^2 \cos 2\omega_1 t + e_0\, e_1 \cos(\omega + \omega_1)t + e_0\, e_1 \cos(\omega - \omega_1)t$$

The terms represent:

a d.c component $\frac{1}{2}\ (e_0^2 + e_1^2)$

two second-harmonic components $e_0^2 (\frac{1}{2} \cos 2\omega t)$ and $e_1^2 (\frac{1}{2} \cos 2\omega_1 t)$

the sum frequency $e_0\, e_1 \cos(\omega + \omega_1)t$

and the difference frequency $e_0\, e_1 \cos(\omega - \omega_1)t$

Usually all the terms except the last are ignored. One of the input frequencies to the mixer is always a signal of some kind; the other is usually generated in the equipment housing the mixer, and is therefore called the *'local oscillator'* signal.

In a Doppler radar the local oscillator is the same oscillator, which supplies the transmitted signal. Only a very small fraction of its output is used by the mixer, so that the mixer works correctly in its small-signal, square law range. In this case ω and ω_1 are the transmitted and reflected frequencies discussed earlier, and the last term has a frequency $\left(\frac{v}{\pi\lambda c}\right)$. It is therefore a measure of v, the velocity of the reflecting object.

In order to separate the transmitted and received signals sufficiently, this experiment will use a *'hybrid tee'*, as illustrated in fig 5.1.

This a combination of the series and shunt-type tees. It operates in a similar manner to a hybrid transformer at low frequency. That is, it has two principal ports which are not directly coupled to each other, though each is coupled to two symmetrical load ports. These can produce reflections, which can pass to both principal ports. If the loads are symmetrical, the reflections from them cancels one another at the other principal ports, so that the latter are still not coupled together. If there is unbalance in the loads however, the reflection will not cancel and there will be some coupling between the principal ports.

In the hybrid tee a straight waveguide run has both a series-tee arm and a shunt-tee arm. These latter arms are the principle ports. They are not mutually coupled because in effect one is twisted 90° relative to the other. Any field generated by one in the other must, from symmetry have equal strength in one direction and the other, so that the resultant field must be zero. Each is however coupled to the other arms in either series-tee or shunt-tee fashion.

EXPERIMENTAL PROCEDURE

1. Connect the apparatus in the way shown in fig 5.2.

WARNING:

Keep your eyes AWAY from the antennas, at a distance of at least 30cm.

2. On the Control Console set the METER READS switch to ‘ detector output’, switch on the supply to the oscillator and set its left-hand switch for internal keying.
3. Adjust the Detector amplifier for maximum sensitivity.
4. If the system were perfectly balanced, the Detector would receive no signal. In practice this is unlikely. Try the effect of moving objects close to one or other of the antennas. A signal should then appear at the Detector and be indicated by the meter. This signal shows that the Detector is now receiving a small amount of the microwave energy sent out by the Oscillator.
5. Place the system with one Horn Antenna pointing to the space in front of the bench. Adjust it and the surrounding objects to give a mid-scale reading one the meter. (It will probably be convenient to place one of the Antennas pointing at the Control Console, and approximately 300mm distant from it whose reflection will serve to unbalance the system suitably). Then use your body **(BUT NOT your face!)** as a reflecting object ‘seen’ by the outward-facing Antenna. Observe the effect of moving slowly toward the Antenna, and away from it.

RESULTS AND CONCLUSION

1. Explain how the signal reflected by you can increase or decrease the detector signal.
2. Considering the meter current as having a d.c and an a.c component, what characteristic of the a.c component is related to your speed of motion?
3. Can you imagine how a Doppler system might measure position? What limitation would it have?

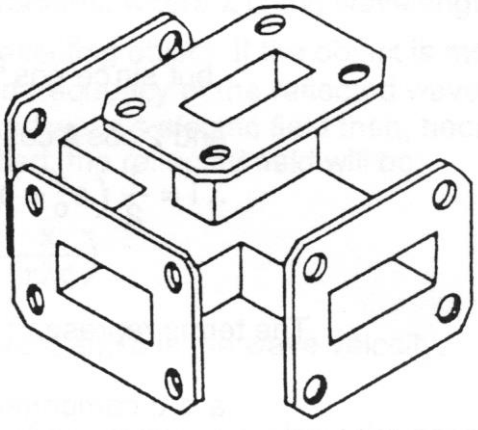

Fig 5.1

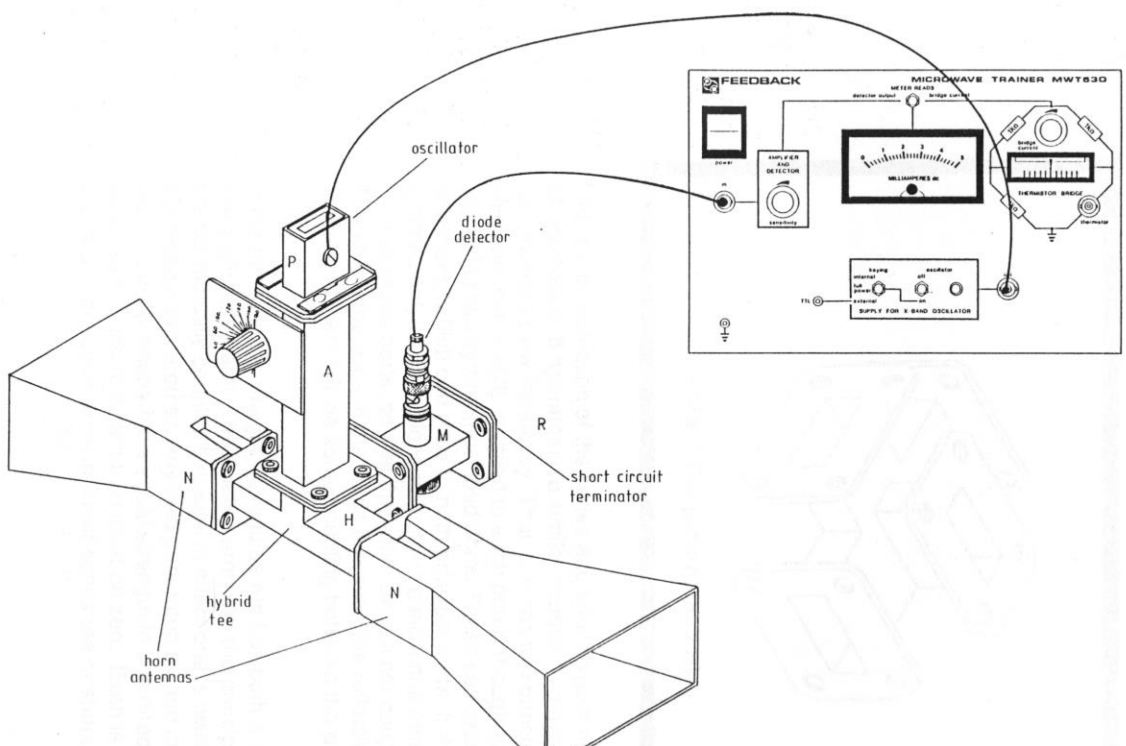
FEEDBACK
MICROWAVE TRAINER MWT630
oscillator
diode
detector
P
A
M
R
short circuit
terminator
N
H
hybrid
tee
N
horn
antennas

Fig 5.2