PRINTED CIRCUIT ANTENNAS

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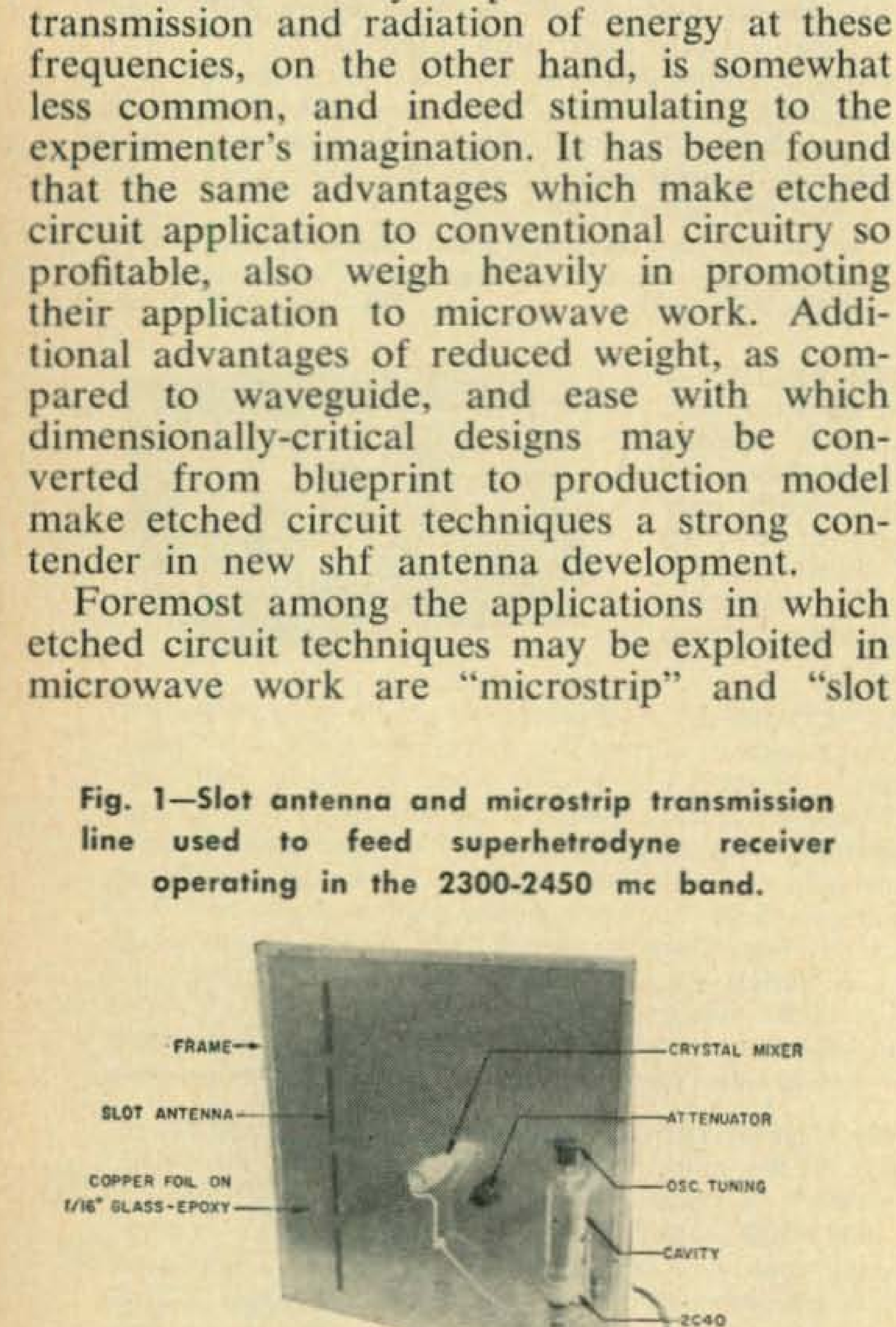
Antennas for the 2300-2450 mc frequency range suggest use of waveguide, horns, crystals and the other shf techniques which have come to be regarded as commonplace in radar and microwave-link work. Application of etched circuit board variety of printed circuits to the transmission and radiation of energy at these frequencies, on the other hand, is somewhat less common, and indeed stimulating to the experimenter's imagination. It has been found that the same advantages which make etched circuit application to conventional circuitry so profitable, also weigh heavily in promoting their application to microwave work. Additional advantages of reduced weight, as compared to waveguide, and ease with which dimensionally-critical designs may be converted from blueprint to production model make etched circuit techniques a strong contender in new shf antenna development.

Foremost among the applications in which etched circuit techniques may be exploited in microwave work are "microstrip" and "slot antennas". This article gives a straightforth introduction to etched circuit techniques in both applications by comparing them to other more familiar radio-frequency techniques and by describing their employment in a practical receiver front-end.

Fig. 1—Slot antenna and microstrip transmission line used to feed superhetrodyne receiver operating in the 2300-2450 mc band.



Microstrip

A cross-sectional view of a typical microstrip transmission line is shown in Fig 2. As may be seen, microstrip is simply a three-inch wide strip of dielectric material having copper foil on both sides. The 7/32 inch wide foil is frequently called the conductor, and the three-inch wide foil is called the ground. Only the highest grade dielectric material having a high dielectric constant, low loss-factor and low moisture absorption may be used.

Increasing the conductor width decreases the characteristic impedance of the microstrip as well as increases its dielectric losses. Approximate impedance for the dimensions given is 50 ohms. This value was chosen for compatibility with existing coaxial transmission lines and fittings. Theoretically, the ground foil should be several wavelengths wide. However, experiment has shown that a width of two to three inches results in minimum practical fringing effect and radiation losses.

A variation of this type of etched circuit transmission line is called "stripline". Essentially, stripline is two microstrips face-to-face with the 7/32″ conductors sandwiched between the two ground plates similar to a flattened coaxial line. Higher transmission efficiencies are thus obtained at some sacrifice of mechanical simplicity. *Tri-plate,* a tradename of Sanders Associates is another term applied to such a system.

Construction and operation of microstrip may be better understood by reference to Fig 3. Here is shown a pictorial transition from the familiar open-wire type transmission line to three other microwave transmission devices. Of these, waveguide and coaxial line need no particular explanation other than to recognize that waveguide, due to its enclosed sides, is sensitive to frequency. As such, waveguide undergoes changes in characteristics impedance with changes in frequency, as well as being subject to a cut-off frequency below which it ceases to act as a microwave conductor.

Transmission of radio frequency energy requires two conductors between which the electric field is confined and upon whose surfaces electric currents flow. Inasmuch as higher frequency currents travel at or near the surface of the conductor, each of the individual wires of an open-wire transmission line may be considered as a tube or cylinder. These, if opened up and flattened out, would continue to act in much the same way as the wire in providing two surfaces between which an electric field may exist. It therefor follows that two conductors, such as the parallel foil strips in microstrip, will confine an electric field and permit propagation of energy along its length. Actually, approximately 75% of the energy is confined within the dielectric between the foil, and 25% constitutes the fringing field shown emanating from the top surface of the upper foil in the microstrip illustration, Fig 3. It is this fringing field that contributes to radiation losses from the microstrip. If it is desirable to attenuate the radio frequency energy traveling down the microstrip, a lossy material such as printed circuit resistive paint[1] or a piece of paper well-covered with soft pencil graphite may be placed flat upon the surface of the conducting strip and dielectric. Care should be taken to taper the leading and trailing ends of such an attenuating device so as to minimize physical discontinuities which would reflect energy causing deleterious standing waves on the line.

Microstrip is somewhat more lossy than coaxial line and waveguide. At 5 kmc, for instance, microstrip has an attenuation of 0.33 db per foot while RG-8/U and waveguide have attenuations of 0.25 db per foot and 0.021 db per foot respectively. For this reason, microstrip is usually not used for long runs such as feeding a remote antenna in a sensitive receiving system due to the losses which would be encountered. On the other hand, microstrip is most useful for relatively short runs and systems having the antenna and receiver together as an integral unit.

Wavelength In Microstrip

Prior to designing applications using microstrip, it is necessary to know the ratio of the electrical wavelength to actual wavelength in the microstrip. This is obtained by calculating or measuring the velocity factor for the microstrip. As in the case of coaxial transmission lines, radio frequency currents travel slower in microstrip and thus traverse a shorter distance in each cycle than they do in air or free space. The ratio of these speeds and thus the ratio of actual wavelength to electrical wavelength is called the velocity factor of the microstrip line.

Fig 4 shows a test set-up for measuring the velocity factor in microstrip having discrete cross-sectional dimensions and dielectric constant. The slotted line may be replaced with an open-wire line such as a Lecher wire system,

[1] Resistive paint type R-21 or R-31

[2] ARRL Handbook, 1953 issue.

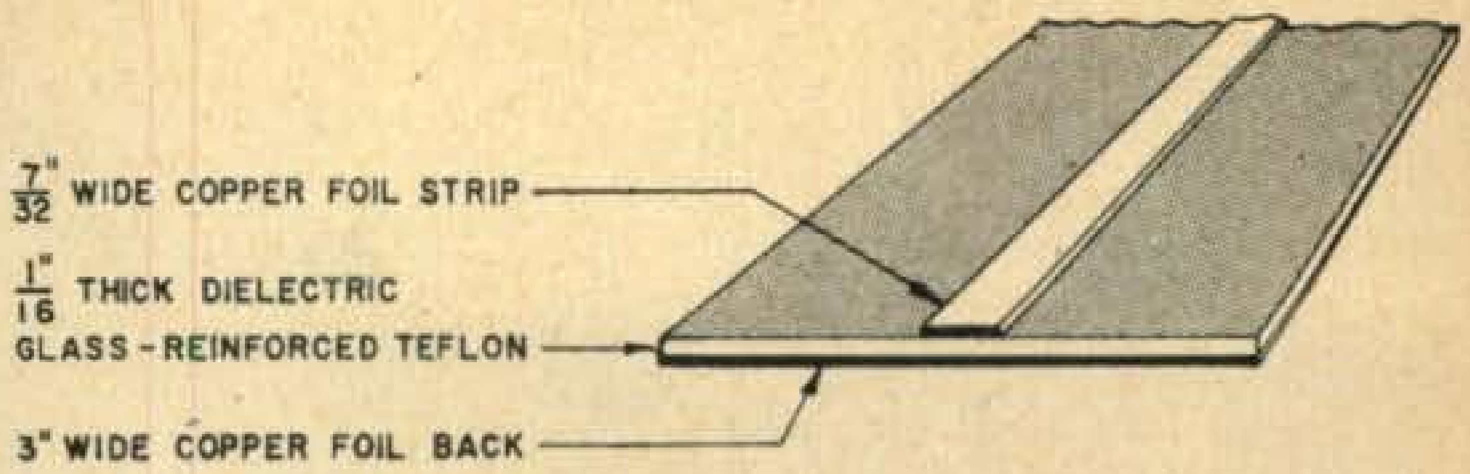


Fig. 2 — Basic construction of microstrip. Another variation, called stripline, has a second dielectric and 3" copper foil above the 7/32" strip in a sandwich arrangement. Sometimes an air dielectric is used.

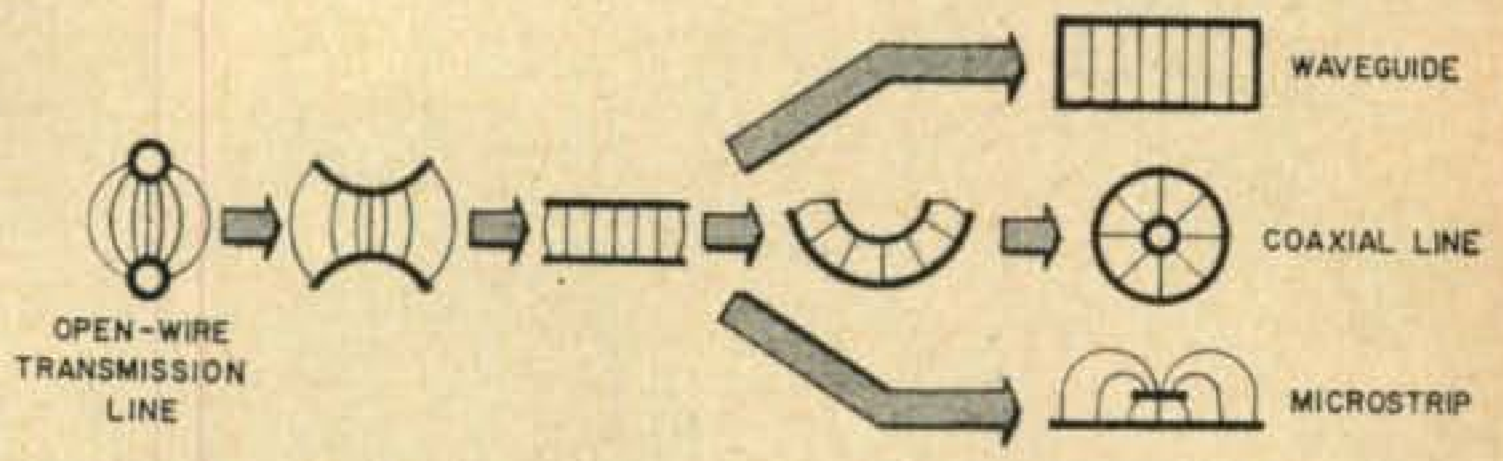
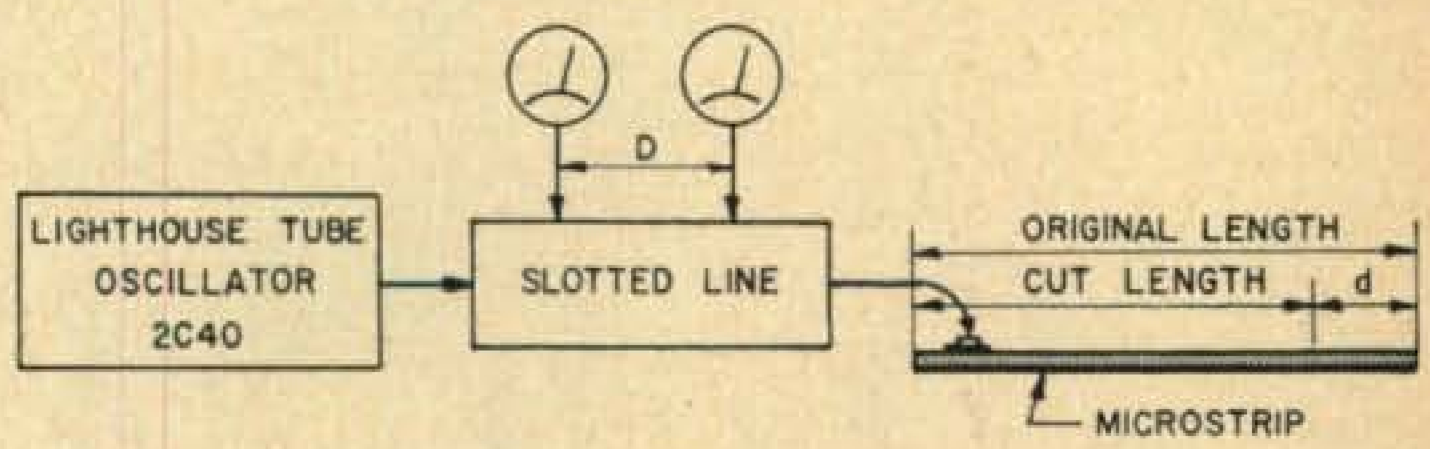


Fig. 3 — Geometric concept of evolution from "open-wire" transmission line to wageguide, coaxial line and microstrip. Light lines indicate the electric field between conductors.



$$\frac{d}{D} = V \quad (1)$$

$$\lambda_\ell = \lambda V \quad (2)$$

$$\frac{\lambda_\ell}{4} = \frac{7.5V}{f} \quad (3)$$

where: d = length cut from sample microstrip (cm)
D = distance indicator moves after cutting (cm)
V = velocity factor
λ_ℓ = wavelength in line (cm)
λ = wavelength in free space (cm)
f = frequency (kilo-megacycles)

Fig. 4 — Test set-up for wavelength measurements. The length of one-quarter wavelengths in Microstrip is calculated using formula (3).

MATERIAL				DIELECTRIC CONSTANT			WATER ABSORBTION % IN 24 HRS.
BASE	BINDER	GRADE	MFG'R	1 MC	100 MC	1 KMC	
PAPER	PHENOLIC	XXXP-26	A	3.8	3.6	3.5	.038
FIBERGLAS	POLYESTER	ESTOGLAS	B	3.88	--	--	---
		GM-PE	A	4.3	4.25	4.25	.40
FIBERGLAS	EPOXY	EPOGLAS	B	5.26	--	--	.016
		FF-91	C	4.75	--	--	---
FIBERGLAS	TEFLON	GB-112T	A	2.8	2.8	2.8	.02
FIBERGLAS	STYRENE CO-POLYMER	REXOLITE 2200	D	2.77	2.77	2.77	<.05

A - CONTINENTAL DIAMOND FIBER
B - PLASTILITE, INC.
C - FORMICA, INC.
D - REX CORPORATION

Fig. 5 — Characteristics of copper-clad laminates. Inasmuch as the dielectric constant is different for different frequencies, especially at the higher frequencies, the appropriate value should be chosen.

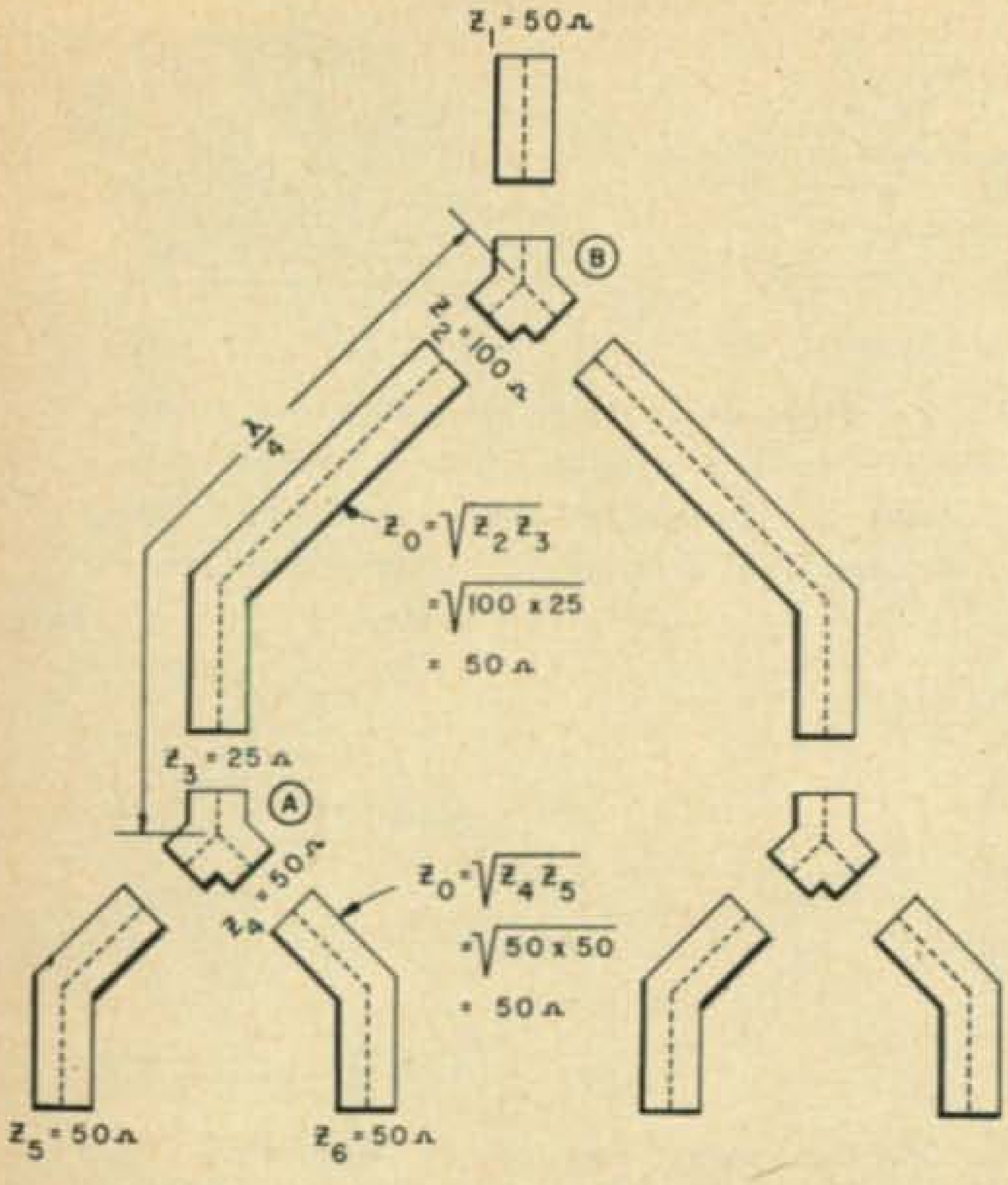


Fig. 6 — Four-way power splitter used to feed "beam" slot antenna. Minimum reflection of standing waves is maintained by use of quarter-wave transformer to match impedances at the several junctions.

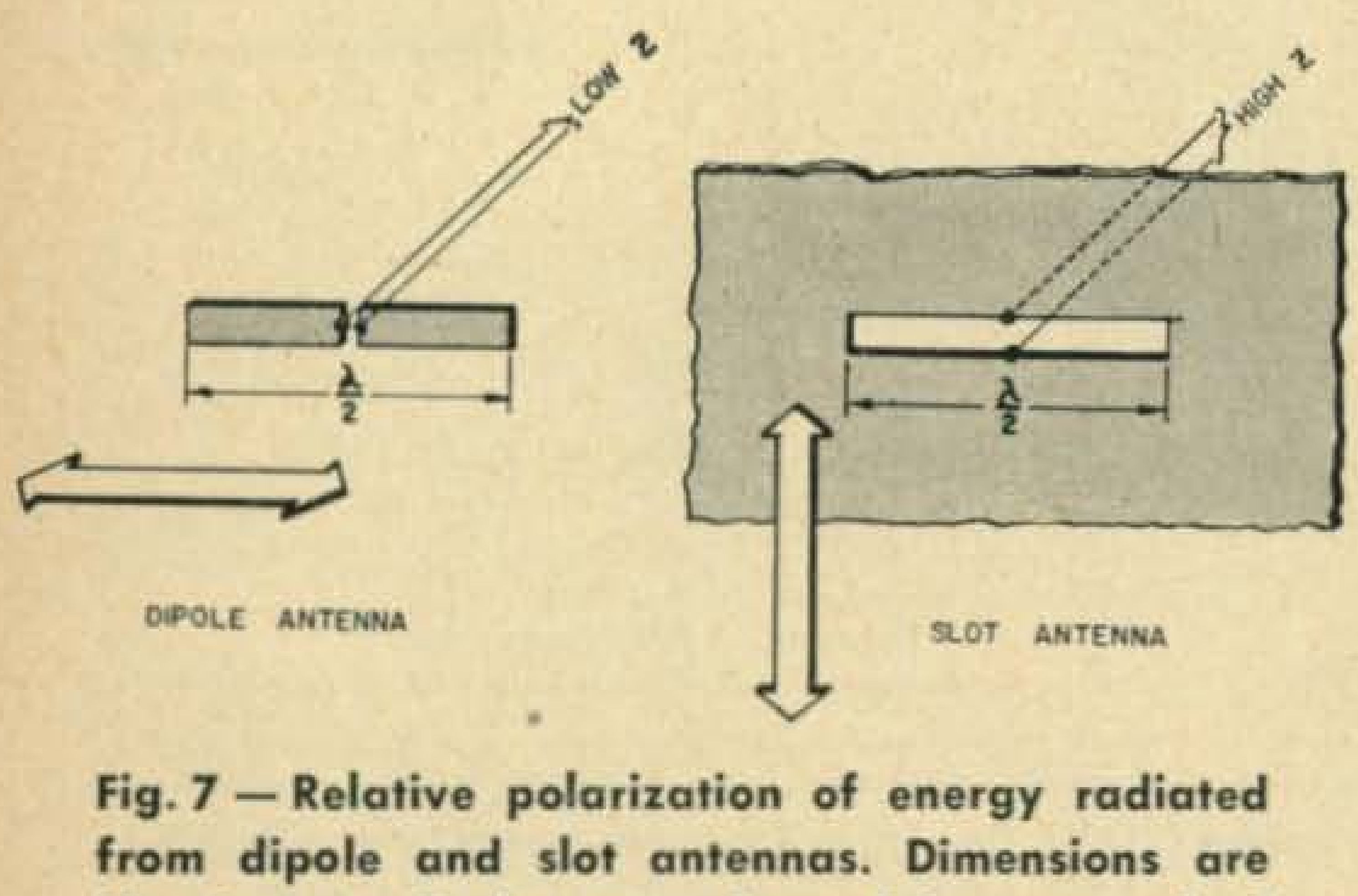


Fig. 7 — Relative polarization of energy radiated from dipole and slot antennas. Dimensions are identical, as if slot were formed by removal of dipole from an infinite plane.

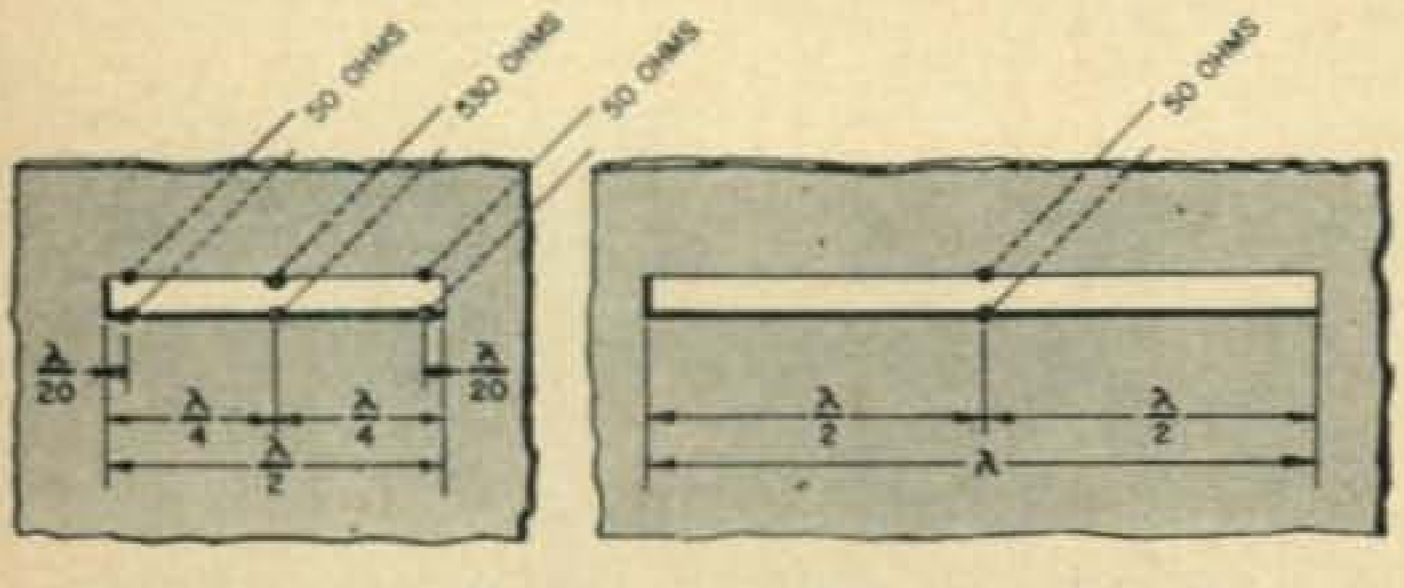


Fig. 8 — Impedances encountered at different possible feed-points on slot antennas. Slot width is a small fraction of wave-length.

using a voltage pick-up probe instead of the shorting bar normally employed. Source of 2450 mc energy may be from a 707B reflex-klystron or a type 2C40 lighthouse tube oscillator described by W2RMA.[2] The latter oscillator, incidentally, was used as the local oscillator in the superhetrodyne receiver designed to work in conjunction with the antenna system described here. Details of a suitable coaxial line-to-microstrip adapter are shown in Fig. 9.

Calculation of the velocity factor for microstrip can also be performed if the dielectric constant of the particular insulating material is accurately known at the particular frequency to be used. Fig 5 gives some values for more popular dielectric materials. An approximate figure for the velocity factor may be obtained from the following relationship:

$$\text{Velocity factor} = \frac{1}{\sqrt{\text{Dielectric constant}}}$$

Power Splitter

Having ascertained the velocity factor for the microstrip, it is then possible to lay out an actual quarter wavelength in the line. Such quarter-wave tranformers in the power splitter served to transform impedances to suitable values so that sections of microstrip may be paralleled or split, as the case may be, and still maintain proper impedance matching which is essential in minimizing standing waves.

Power splitters used in the microstrip line to a four element etched circuit antenna, are described in Fig 6. In this instance, the power is being combined instead of being split. If two 50 ohm lines from two of the antenna elements are joined together at point "A", the resultant parallel impedance will be 25 ohms. The quarter-wave transformer then transforms this impedance to 100 ohms at point "B" where the parallel impedance of the two 100 ohm ends is 50 ohms. Thus, power from four antenna elements is added in phase and the impedances of the microstrip line at the four sources and terminal end are the same.

Slot Antennas

Slot antennas are formed by cutting a narrow slot in a large metal surface. Such antennas are shown in Figs 7 and 8. Slot antennas may be compared to conventional half-wave dipoles consisting of two flat metal strips of size equal to the slot cut out of the large metal sheet. Radiation patterns produced by slot antennas cut into an infinitely large metal sheet and those of the complementary dipole antennas are the same.

An important difference between the slot antenna and its complementary antenna is of interest. Their electric and magnetic fields are interchanged. With the slot antenna, the magnetic lines are horizontal and the vertical electric lines are built up across the narrow dimension of the slot. This causes vertical polarization from the horizontal slot as shown in Fig 7.

The impedance at the center of a slot whose electrical length is a half wave is 530 ohms. This impedance is reduced to a lower value as the input connection is moved toward the end of the slot. At a point about one-twentieth of a wavelength from either end, the input impedance falls to about 50 ohms as indicated in Fig 8. The slot length may be increased to a full wave if it is desired to achieve a 50 ohm match at the center of the slot.

Receiving System

Microstrip transmission line and power splitters were used with a four-element slot antenna in the superhetrodyne receiver illustrated in Fig 1. Inasmuch as the center impedance of the half wave slot is relatively high (530 ohms), the four sections of line feeding the slots must each be an odd number of quarter wavelengths long to obtain the necessary transformation to a lower value of impedance at the first parallel junction. Likewise, the subsequent transformer sections feeding the last junction adjacent to the crystal mount must be odd multiples of a quarter wavelength long. Obviously, a one quarter wave section would be physically too short. Connection from the microstrip conductor to one edge of the slot antenna is made by drilling a small hole through the etched circuit board and soldering a short length of hook-up wire to the copper foil on both sides. This connection also serves as the dc return for the crystal.

Energy from the local oscillator is limited by a variable attenuator before being mixed with the incoming signal in the crystal mount. Fig 9 shows modifications which were made to a coaxial connector to accommodate a type 1N23 crystal. rf by-passing is accomplished through the thin-walled teflon sleeves.

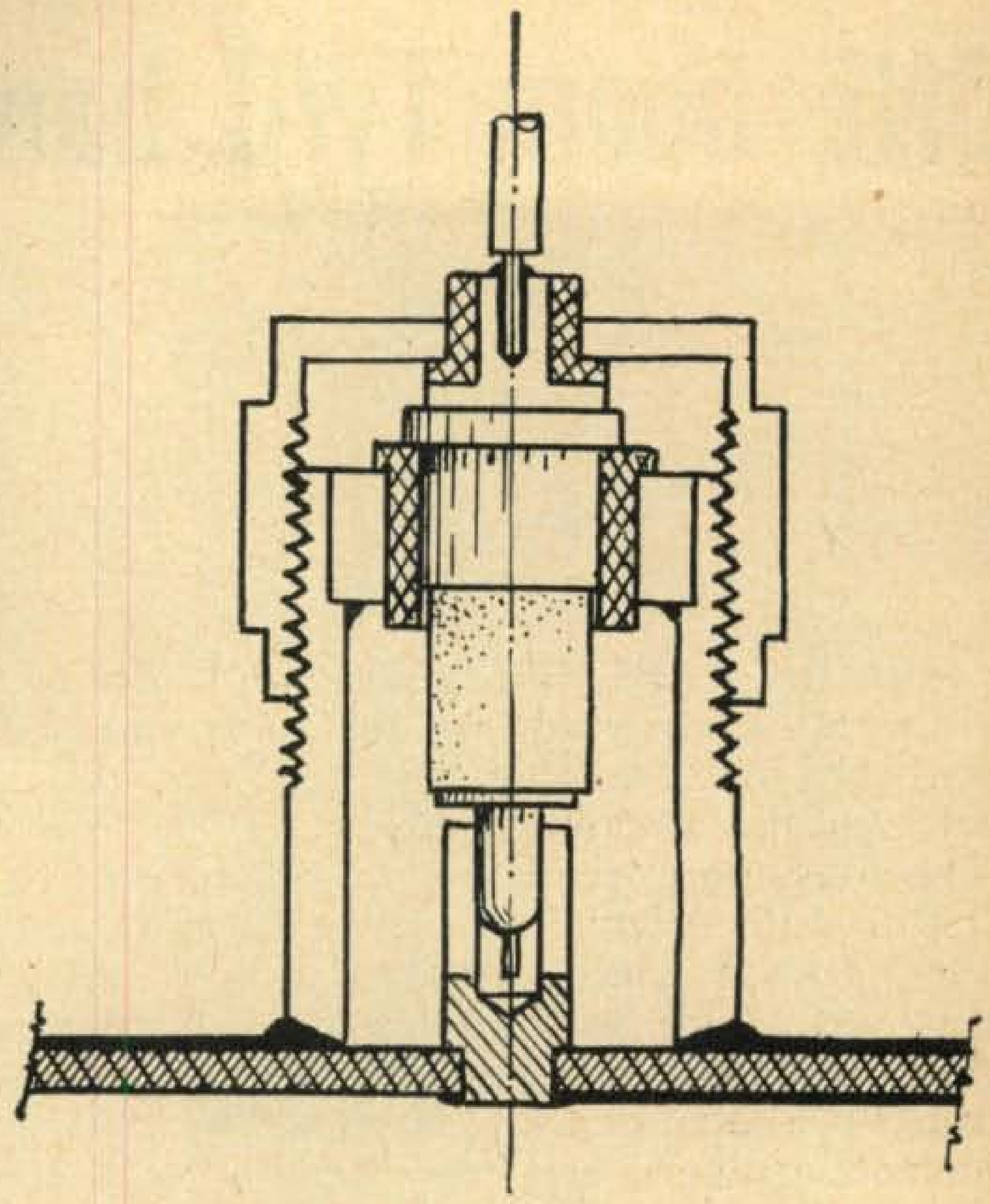
Experimentation with and proving of the various parts of this receiving system prior to final assembly are desirable due to appreciable variations encountered in electrical characteristics with small changes in size or type of material used.

Construction and Operation

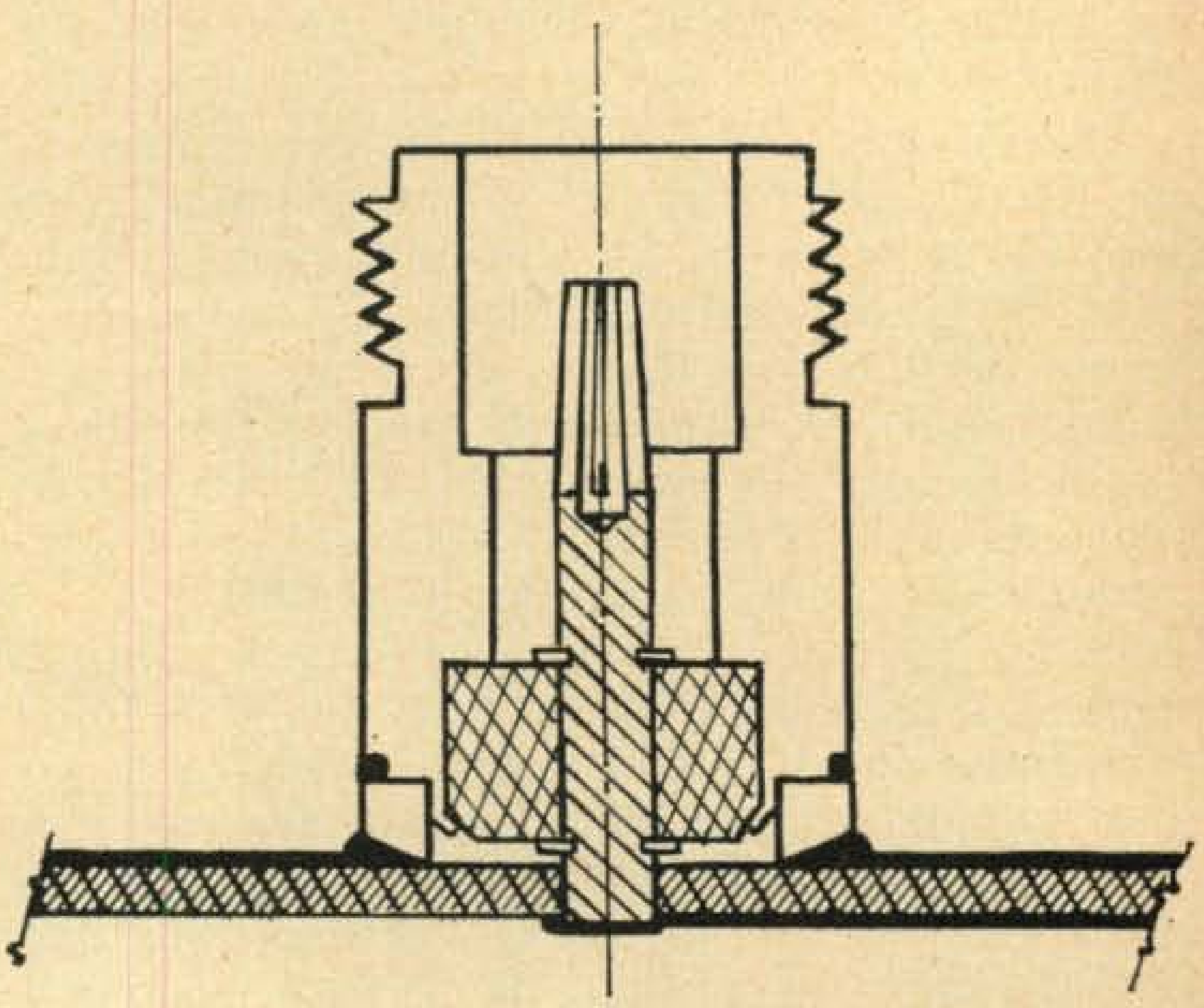
The complete receiving system including antenna is constructed on a 12 by 12 inch copper-clad glass-epoxy board. In lieu of making a master drawing and a photographic negative as is usually done when photo engraving etched circuit boards, strips of 7/32 inch wide draftsmans masking tape are applied directly to the copper surfaces of the board to resist the ferric chloride etchant. The half-wave slot antennas are formed by scoring the copper foil with a sharp knife and pealing it away from the four slot areas.

Care must be exercised when soldering the local oscillator fitting and crystal mount to the copper-clad board. Adequate caution and practice on sample pieces will insure good results. Make certain both pieces are well-tinned and that a minimum of solder remains. When sweating two pieces together, heat should be applied to the largest of the two masses of metal and then only long enough for the solder to flow.

A frequency check of the finished receiving system may be made by tuning slightly higher to the police radar band. By removing the attenuator and crystal mixer, this receiving system may be converted to a transmitter permitting two-way communication on the 2300-2450 mc amateur band. Who would guess it could be done with printed circuits? ■



CRYSTAL MOUNT



COAX ADAPTOR

Fig. 9 — Detail of fixtures used to mount crystal mixer in superhetrodyne receiver and to connect coaxial line to microstrip line by means of type N connector.