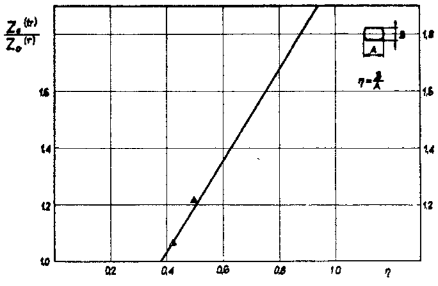

Fig. 3. Normalized characteristic impedance of a truncated circular waveguide vs. $\eta = B/A$. Theoretical curve shown continuously, triangles represent experimental results.

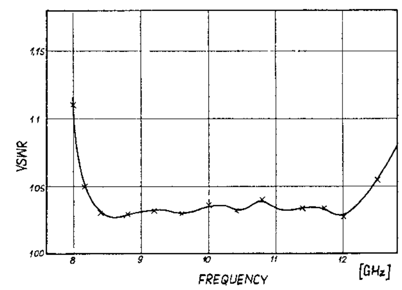

Fig. 4. Input VSWR of a four step Chebyshev's quarter-wave transformer connecting a standard rectangular waveguide WR-90 into circular waveguide with $\phi = 26.8$ mm.

systematic error seen in Fig. 2 is probably due to inadequate measurement accuracy of the truncated circular waveguide cutoff wavelength.

The determination of the truncated circular waveguide characteristic impedance is far more difficult. Also for this case an approximate method was applied by assuming that the truncated circular waveguide characteristic impedance, as normalized to the impedance of a corresponding rectangular waveguide, is a linear function of the ratio of $\eta = B/A$. The function is shown in Fig. 3.

The same assumption as previously used for wavelength calculation has been taken for the determination of the point $Z_0^{(tr)}/Z_0^{(r)} = 1$ while the point for $\eta = 1$ can be calculated theoretically. In the case in question [see (1)]:

for

$$\eta = 1$$

$$\frac{Z_0^{(tr)}}{Z_0^{(r)}} = 2$$

because

$$\lambda_c^{H_{11}} = \lambda_c^{H_{10}}.$$

An experimental verification of the above assumption is rather difficult due to deformations caused by the susceptance of the discontinuity at the junction of two sections, each having different η. However, the two measured points represented in Fig. 3 by triangles, which correspond to low values of η, seem to confirm the assumption at least for values of η close to 0.5.

In the transformer design, tables prepared by Young [7] were used and corrections were applied to the lengths of individual transformer steps as given by Cohn [1]. The transformer input was measured in rectangular waveguide, while the circular waveguide has been terminated by a matched sliding load. The transformer input VSWR as a function of frequency is given in Fig. 4.

In conclusion, an approximate theory was used for the determination of the truncated circular waveguide cutoff wavelength and its characteristic impedance. The obtained results were verified by experiment.

Basing on verified theoretical results a wideband mode-and-impedance transformer has been designed which provides reflectionless connection of a rectangular waveguide with H_{10} mode into a circular waveguide with H_{11} fundamental mode. The transformer consists of four quarter-wave truncated circular sections, each with its characteristic impedance being proportional to the Chebyshev coefficients. The unit connects a standard WR-90 waveguide to a ϕ-26.8 mm circular waveguide. The described transformer shows an input VSWR less than 1.05 over the frequency range of 8.2 to 12.4 Gc/s. The total transformer length is ca 35 mm ($1\frac{1}{2}$ inch).

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A Magnetic Loop, Diode Detector Compatible with Microwave and Beam Waveguides

Introduction

Improved detector performance is a common objective in any communication system. This is particularly true of the millimeter and submillimeter region [1] where the available signals are weak.

Point contact crystal detectors have almost a unique position in the microwave region. They also have been used at wavelengths as short as 0.5 mm. However, the conventional packaging configuration in a waveguide is difficult to realize and losses become excessive. Also, the typical electric probe arrangement cannot be adapted to the low loss, beam waveguide system [2], [3], more suitable for the submillimeter wave region.

In this letter a magnetic probe [4] crystal diode arrangement shown in Fig. 1 will be described. This detector configuration has the advantages of compatibility with both microwave and beam waveguides and, in measurements made to date, sensitivity somewhat better than a 1N53 cartridge in a conventional mount.[1]

As shown in Fig. 1, the semiconductor crystal chip is mounted on the end of the inner tungsten conductor of a coaxial line. The loop whisker wire is fastened to the outer conductor of the cartridge with the sharpened point making contact with the crystal in the normal fashion.

When used with a conventional waveguide, the loop detector is mounted at the end of the guide with the loop oriented parallel to the electric field. In this arrangement the maximum magnetic field will tend to remain at the loop and the coupling is nearly constant as the frequency changes.

In the case of a reflecting beam waveguide, the loop detector is placed in the center of one of the guide reflectors. Since the ratio of the loop to beam spot size is unfavorable, the coupling in general will be small. However, it can be greatly improved by making one section of the reflecting beam waveguide into a resonator as illustrated in Fig. 2. The resonator can be formed by placing a plane reflector and a grating coupler [5] (no. 1) in the positions shown in Fig. 2. In frequency mixing experiments, local oscillator power can be coupled into the system by forming a second resonator between the guide reflector and a second grating coupler (no. 2) placed as shown in Fig. 2. The resonator system is inherently narrow band (1–3 Mc) but is easily tunable by varying the spacing between the elements of the system.

Construction Procedure

The construction procedure for the prototype models of the cartridge shown in Fig. 1 is as follows:

A crystal chip is soldered to the end of a tungsten rod 0.030-inch in diameter and 0.750-inch long. Copper is then electroformed around the tungsten rod and crystal and the electroformed copper is then machined to a uniform diameter of 0.40-inch. The insulating layer can be made in either of two ways depending on the thickness of insulation desired. For operation at very short wavelengths (1–2 mm) a thin layer is desirable to prevent RF leakage into the coaxial system and is made by covering the post with a layer of glyptal. The outer conductor of the cartridge is then made by covering the glyptal with a layer of conducting silver paint and electroforming over the silver paint. It is desirable to have a hole in the outer conductor to house a 0.004-inch tungsten wire which serves as the coupling loop and whisker combined. This can be accomplished by electroforming to a diameter of approximately 0.080-inch, machining a

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[1] The mount used was a DE MORNAY-BONARDI type DBA-313.

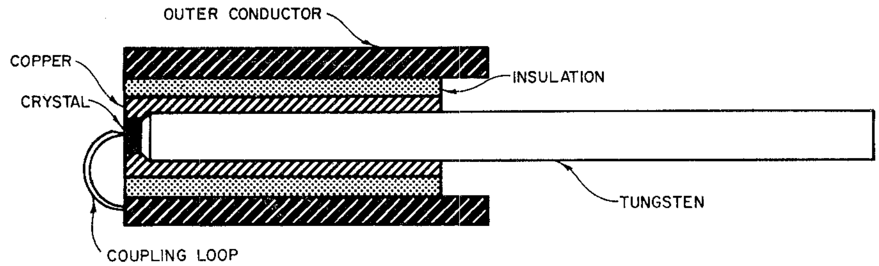

Fig. 1. Cross-sectional view of loop detector cartridge.

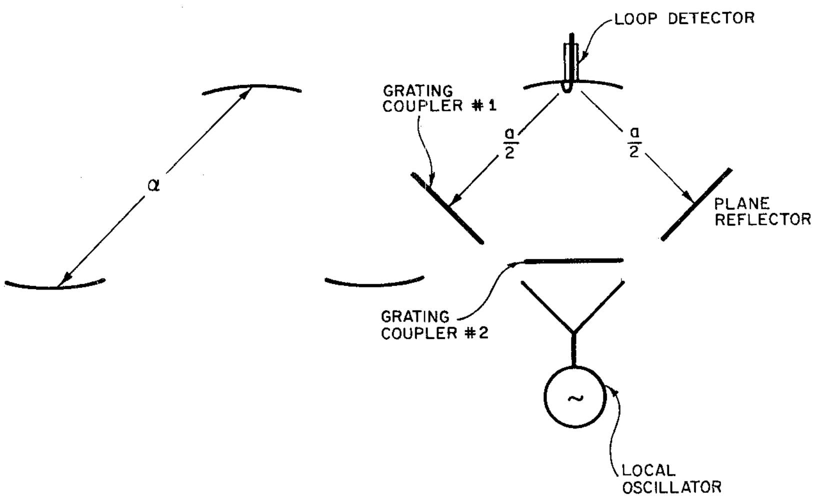

Fig. 2. Loop detector used with reflecting beam waveguide.

longitudinal slot 0.004-inch wide and 0.004-inch deep, filling the slot with paraffin, finishing the electroforming operation, and machining the assembly to a uniform diameter of 0.094-inch. The paraffin is then removed, leaving a 0.004-inch square hole to house the whisker wire. One disadvantage to this method of construction is that the two electroforming operations make the assembly time rather long. If a thicker layer of insulation is acceptable, or necessary (as in the case of a microwave IF frequency), the glyptal can be replaced by a teflon sleeve and the outer conductor of the cartridge need not be electroformed but simply constructed from appropriate size tubing. In this case a longitudinal slot 0.004-inch wide and 0.006-inch deep is machined in the outside of the tubing to house the whisker wire. This second method of construction eliminates one electroforming operation and thus shortens the assembly time considerably. Figure 3 shows two completed cartridges side by side for comparison. The one on the left was made using glyptal for insulation, and the one on the right was made using a teflon sleeve for insulation. The diameter of the coupling loop on these models is 0.040 inch which is approximately $\frac{1}{4}\lambda$ at the frequency (71 Gc) at which the cartridges were tested. An attempt is now being made to determine the optimum loop size both analytically and experimentally. For purposes of comparison, most of the loop detector cartridges have been made using *P*-type silicon ($\rho = 0.035$ Ω-cm) as the crystal material since this material is widely used in commercial cartridges. In the future, gallium arsenide will be tried since it is reported [6] to give improved performance at frequencies above 50 Gc.

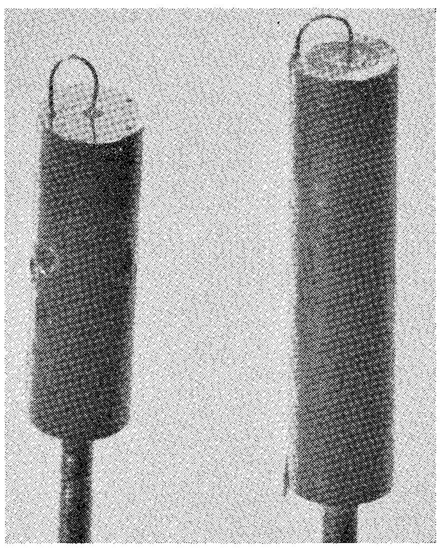

Fig. 3. Completed loop detector cartridges (Diameter of models = 0.094 inch).

It should be emphasized that the construction procedures outlined in the preceding paragraph have not proved to be entirely satisfactory. Twelve cartridges were constructed for testing and over a period of about one month, the static V-I characteristics of six of these were found to have deteriorated quite badly. The cause for this deterioration is now being investigated.

Electrical Measurements

Twelve cartridges were completed and tested in conventional 4 mm (RG99U) waveguide and in the reflecting beam waveguide. The video sensitivity measurements were performed with the cartridge mounted in 4 mm waveguide. For these tests, the klystron was amplitude modulated at a rate of 1,000 c/s and the output signal was fed into a Tektronix 531 oscilloscope fitted with a type "D" preamplifier (Type "E" for tangential sensitivity measurements).

The detector was also used as a mixer in conventional 4 mm waveguide and in a section of reflecting beam waveguide as shown in Fig. 2. For these measurements, the local oscillator, a Raytheon QK 369 klystron, was operated CW at a frequency of 70.8 Gc. The signal, which was produced by a DX151 klystron, was electronically tuned through a range of approximately 100 Mc by sawtooth modulating the repellor. The base frequency of the signal was then adjusted so that at some time during the sawtooth sweep, the difference frequency between the local oscillator and the signal was 60 Mc. The output of the crystal was fed into a 60 Mc IF amplifier with a band-pass of 6 Mc and the output of the IF amplifier was displayed on the oscilloscope mentioned previously. The sawtooth voltage applied to the repellor of the signal klystron was also used for the horizontal sweep of the oscilloscope. Thus, the oscilloscope trace represents the output of the IF amplifier vs. frequency.

When the experiment was performed in 4 mm waveguide, the local oscillator power and signal power were coupled to the detector using a hybrid tee configuration, and when the experiment was performed in a beam waveguide, the setup shown in Fig. 2 was used to couple the local oscillator power and signal power to the detector.

The result of the various tests described in the preceding paragraphs are shown in Table I. In addition to the test results summarized in the table which were performed at 70.8 Gc the video measurements were performed at several frequencies up to 75 Gc which was the frequency limit of the klystron used for these tests. The sensitivity was found to increase slightly with increasing frequency but the variation was smooth and exhibited none of the peaks and valleys usually associated with conventional in-guide crystal detectors. VSWR measurements were also made as a function of frequency and the VSWR was found to decrease from 2 at 70.8 Gc to 1.4 at 75 Gc. This indicates that the increasing sensitivity with increasing frequency can likely be attributed to the detector absorbing more of the incident power.

It was not possible to compare the loop detector to the Sharpless wafer detector mount at 4 mm because there were none available for testing.

Conclusions

The data of Table I show the sensitivity of the loop detector to be somewhat better than a 1N53 as well as demonstrate its compatibility with a reflecting beam waveguide. The fact that the loop couples to the magnetic field should make the detector in-

TABLE I

RESULTS OF SENSITIVITY MEASUREMENTS ($f = 70.8$ Gc).

Use	Measurement	Typical results	Best results	Selected 1N 53*
Video detector in conventional waveguide	Voltage sensitivity (mv./mw.)	300 to 500	640	230
	Tangential sensitivity (dbm.)	−48 to −51	−58	−44
Mixer in conventional waveguide	Tangential sensitivity (dbm.)	−78 to −80	−85	−77
Mixer in reflecting beam waveguide	Tangential sensitivity (dbm.)	−75 to −81	−85	—

* Selected from 12 available cartridges. Mounted in DE MORNAY BONARDI mount type DBA-313.

herently wide band although this has been demonstrated experimentally only for frequencies from 71 to 75 Gc. Only a few detectors were constructed and it is hoped with improved fabrication and/or other crystal materials, still further increases in sensitivity and performance could be expected.

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Some Experimental Results on the X-Band Junction Circulator

The general trend in the development of junction circulators is to provide a 20 dB isolation over the widest possible frequency band. However, in some special applications, ferrite circulators with higher isolation and low insertion loss are required for narrow bandwidth operation. An example of this is a circulator operating in connection with a parametric amplifier or maser, where the circulator insertion loss should be held small to decrease the inevitable noise. Also, in some systems diplexing signals of different frequency, high isolation of the neighboring channels in a relatively narrow frequency band is a ferrite circulator fundamental feature. These and other problems lead UNIPAN-Scientific Instruments Corp. towards some conceptions in junction circulator design.

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Following reports of other authors [1], [2] experiments with ferrite inserts in a symmetrical waveguide H-plane Y junction have been carried out. Prism inserts with a triangular base were tested. When studying the circulation effect the prism height h and the base side a were changed and various external magnetic fields were applied along the Y axis—see Fig. 1. No additional reactive matching elements were introduced into any one of the branches.

When testing the circulation for a fixed ferrite configuration, while altering the frequency and the magnetic field strength, curves similar to that given in Fig. 2 were obtained. It was found, that for inserts with different side length of triangle and height h equal to that of the standard WR 90 waveguide, maximum isolation values between port 1 and 3 in Fig. 1 exist at frequencies which can be predicted. It was further found, that points which correspond to maximum isolation constitute a straight line, with a slope of $a/\lambda = 0.287$, as in Fig. 3. The result is similar to that of Aitken and McLean [2] for cylindrical rods.

The confirmation of the curve in Fig. 3 allows circulator design for any desired frequency. The following characteristics could be obtained with such circulators: maximum isolation 50 dB at any frequency, isolation better than 20 dB over band ±150 Mc/s around center frequency, VSWR below 1.20, and insertion loss below 0.2 dB—without additional reactive elements.

Looking for broadbanding it was assumed that perfect matching of the Y comprising the magnetized ferrite insert is the only necessary condition which should be satisfied to obtain circulation. It is seen from Fig. 2, that the introduction of a ferrite into Y will produce narrow-band matching. Introduction of matching elements requires the ferrite prism to be lowered, and results in increase of demagnetization coefficients, in and the application of higher magnetic field strength which, in turn, will improve the circulator stability when operating in external stray magnetic fields.

Input admittance measurements have been carried out on Y's comprising longitudinally magnetized ferrite prisms of various dimensions. A reverse mode of cir-

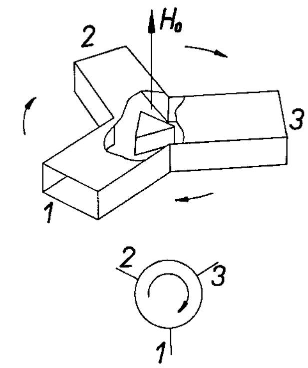

Fig. 1. Three-port junction ferrite circulator.

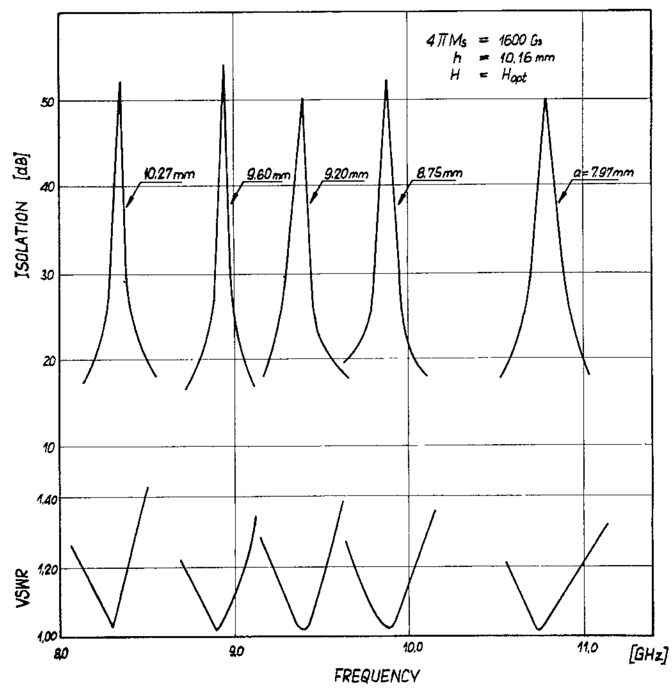

Fig. 2. Isolation and VSWR of some narrow-band circulators.