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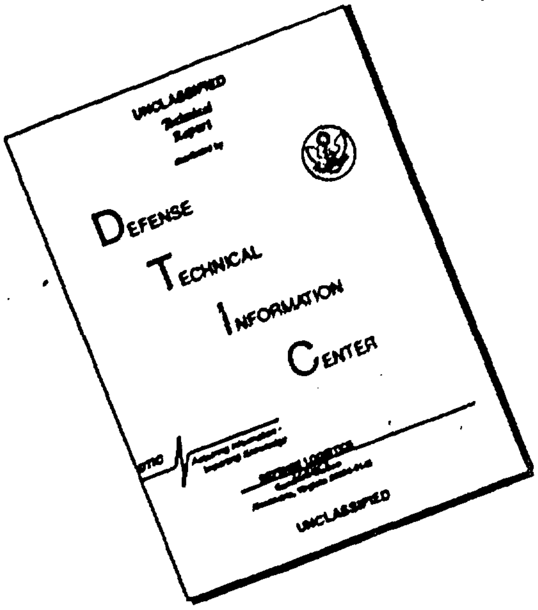

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TR-1151

A HIGH ISOLATION ABSORPTION MODULATOR-SWITCH FOR 1.2-CM WAVELENGTH

Frank Reggia

8 July 1963

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FOR THE COMMANDER:
APPROVED BY

H. Sommer
Chief, Laboratory 200

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ABSTRACT

This report describes the design and operation of a K-band absorption modulator for high-speed switching or amplitude modulation of microwave power. This reciprocal ferrite modulator, designed in standard rectangular waveguide and making use of a longitudinal magnetic control field, has electrical characteristics particularly desirable in a microwave switch. These include a zero-field insertion loss of less than 1 db, a switching action (isolation) of greater than 75 db—which is nearly independent of the magnetic control field in this state, and a matched input impedance for all values of applied field. These electrical characteristics are nearly constant over a 20-percent bandwidth. It is also possible to design this amplitude modulator for small phase shifts at the desired operating frequency.

Other characteristics of the modulator include small size (3 in. max. length), magnetic control fields of less than 50 oersteds, operating temperature exceeding 100°C, and a switching-time capability of less than 0.1-μsec.

1. INTRODUCTION

It has been shown (ref 1) that the relationship between the induced rf flux density $\vec{b}$ and the internal rf magnetic field $\vec{h}$ in a magnetized but unsaturated infinite ferrite medium at microwave frequencies is given by a permeability tensor of the form

$$\begin{vmatrix} \mu & -jK & 0 \\ jK & \mu & 0 \\ 0 & 0 & \mu_z \end{vmatrix}$$

where μ, K and μ_z are the components in the three mutually perpendicular directions, and the static magnetic field is taken along the Z-direction. Thus,

$$b_x = \mu h_x - jKh_y$$

$$b_y = jKh_x + \mu h_y$$

$$b_z = \mu_z h_z$$

As seen from the first two expressions, an rf magnetic field h_x applied in the X-direction induces a component of the rf flux density

b_x which is proportional to [illegible] to the electron spins precessing about the direction of the dc magnetic field, also induces a component b_y in the Y-direction proportional to K. For a linearly polarized wave propagating in the Z-direction, this latter component of the permeability tensor accounts for the transfer of the incident microwave field to a tightly coupled perpendicular wave in a magnetized ferrite medium.

If a very thin film of absorptive material is used to attenuate this perpendicular field, without appreciable loss to the vertically polarized microwave field which exists when the ferrite medium is unmagnetized, it is possible to obtain a broadband absorption modulator (ref 2) with electrical characteristics especially desirable in a high-speed microwave switch. This is the technique used to design, in standard rectangular waveguide, the K-band absorption modulator-switch.

2. DESIGN PROCEDURE

Beginning with the design data available (ref 3) at X-band, and choosing a standard rectangular waveguide (0.170 x 0.420 in.) for 21 to 25 Gc, it was first necessary to select a suitable ferrite material. A small dielectric and magnetic loss tangent at the operating frequency range was required in order to obtain a microwave switch with a low insertion loss in the ON state. Also, since the amount of attenuation obtained is known to be proportional to the magnitude of the saturation magnetization ($4\pi M_s$), a NiZn ferrite (ref 4) having a linewidth of 40 oersteds and a $4\pi M_s$ of 5000 gauss was selected (ref 5). This material has made possible an absorption modulator-switch with a figure of merit (ref 6) of 100.

The next problem was to determine the minimum height and width required to obtain sufficient concentration of the microwave energy in the ferrite (a necessary condition for obtaining large amplitude modulation), and the maximum cross-sectional dimensions to avoid generation of spurious modes in the ferrite-loaded waveguide. The cross-sectional dimensions of the ferrite rod, critically dependent on the narrow dimension (0.170 in.) of the rectangular waveguide, also determine the bandwidth for which the electrical characteristics remain nearly constant. With the particular Ni-Zn ferrite chosen, it was found that a height of 0.100 in. and a width of 0.110 in. was optimum over the 21 to 25-Gc frequency range.

Impedance matching was accomplished by making use of linear tapers at both ends of the rectangular ferrite rod and dielectric polyfoam or teflon support. An input VSWR of less than 1.20 for the absorption modulator-switch for all values of applied magnetic field was considered satisfactory.

3. ABSORPTION MODULATOR-SWITCH

Cross-sectional views of the absorption modulator (or microwave switch) for 21 to 25 Gc are shown in figure 1. It consists of a low-loss Ni-Zn ferrite rod (split along its length) centrally located inside a standard rectangular waveguide excited in its fundamental TE_{01} mode. Both the ferrite rod and the polyfoam dielectric support make use of linear tapers at both ends for impedance matching. A thin resistive film, placed between the sections of the split rod, and in a plane perpendicular to the input rf electric field, is used to attenuate the perpendicular component of this field generated in the magnetized ferrite rod.

The low-current solenoid, wound around the 1/4 by 1/2 in. rectangular waveguide section, is used to supply the longitudinal magnetic control field. It consists of 11,500 turns of No. 38 wire and its total length is 2 1/2 in. The normal operating currents of this solenoid are from 0 to 50 ma, corresponding to a magnetic field strength from 0 to 115 oersteds. A control power of approximately 1w is required to obtain a field strength of 30 oersteds. An epoxy resin is then used to pot the modulator winding.

4. ELECTRICAL CHARACTERISTICS OF MODULATOR-SWITCH

The attenuation (or isolation) characteristics from 21 to 25 Gc of the rectangular-waveguide absorption modulator versus the applied magnetic field are shown in figure 2. These results were obtained with a 3-in. long rectangular ferrite rod, including 9/16-in. tapers at both ends, having a height of 0.090 in. and a width of 0.100 in. A metalized-mica attenuator element (0.0005 in. thick) having a resistivity of 60 ohms per square was used between the split sections of the ferrite rod. The width and length of the attenuator element were approximately the same as those of the ferrite rod.

As seen in figure 2, when the modulator is operating in the OFF-state, an isolation of greater than 75 db is obtained over the frequency range from 23 to 25 Gc. This isolation is seen to be nearly independent of the magnitude of the magnetic control field in this state, a characteristic especially desirable in a high-speed microwave switch. Below this frequency range, due to the decrease of energy concentration in the ferrite rod, the isolation characteristics slowly deteriorate. Thus, it is expected that the optimum frequency range for the above ferrite rod dimensions would be from [illegible] to [illegible] Gc. These electrical characteristics are reciprocal--that is, they do not depend upon the direction of propagation or magnetic control field. The zero-field insertion loss for this modulator-switch varied from 0.6 to 0.8 db and the input VSWR remained less than 1.2 for all values of the applied field over the above frequency range.

Improved isolation characteristics of the absorption modulator-switch over the 21- to 25-Gc frequency range was obtained by increasing the cross-sectional area of the ferrite rod. Some of these

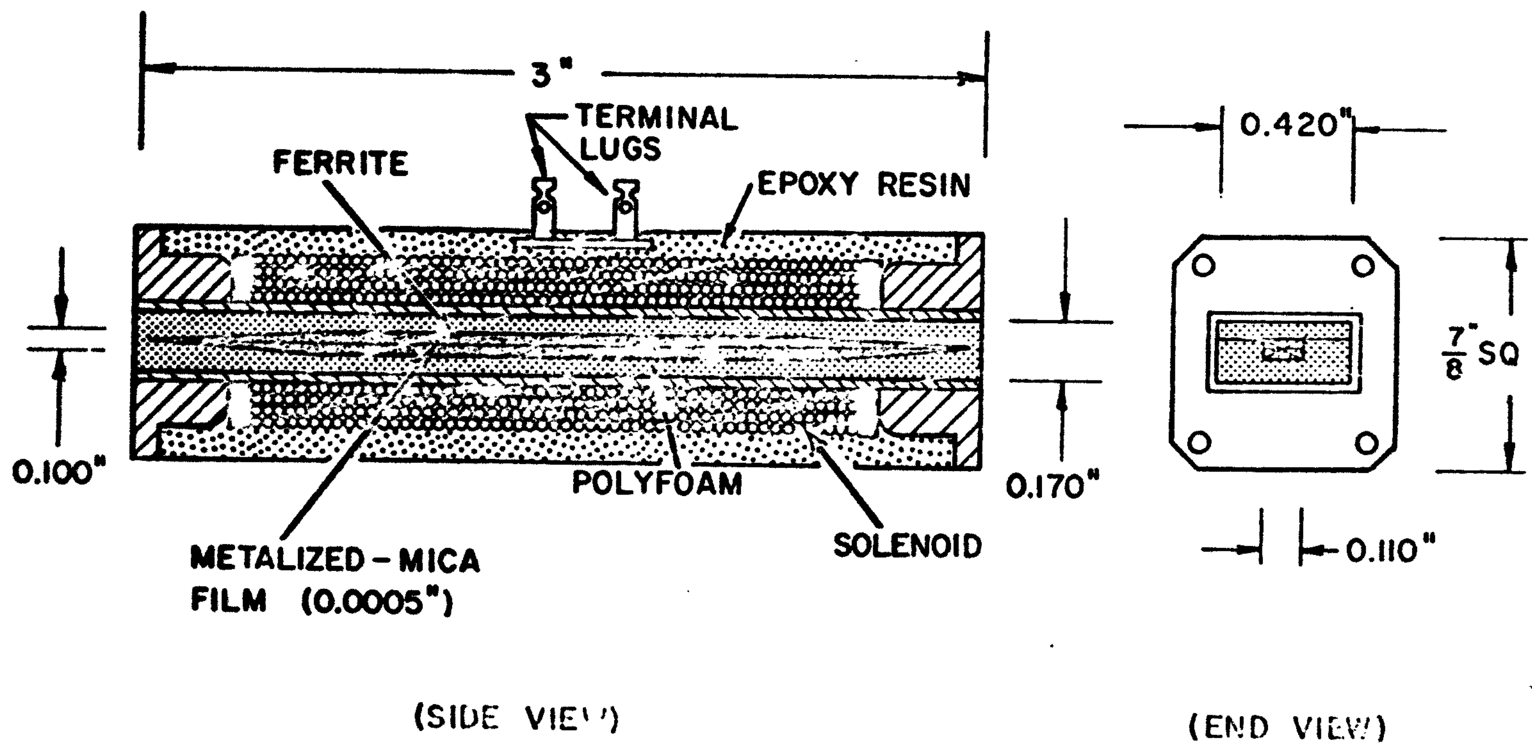

Figure 1. Cross-sectional views of ferrite absorption modulator-switch. The rectangular ferrite rod is centrally located inside a standard K-band waveguide.

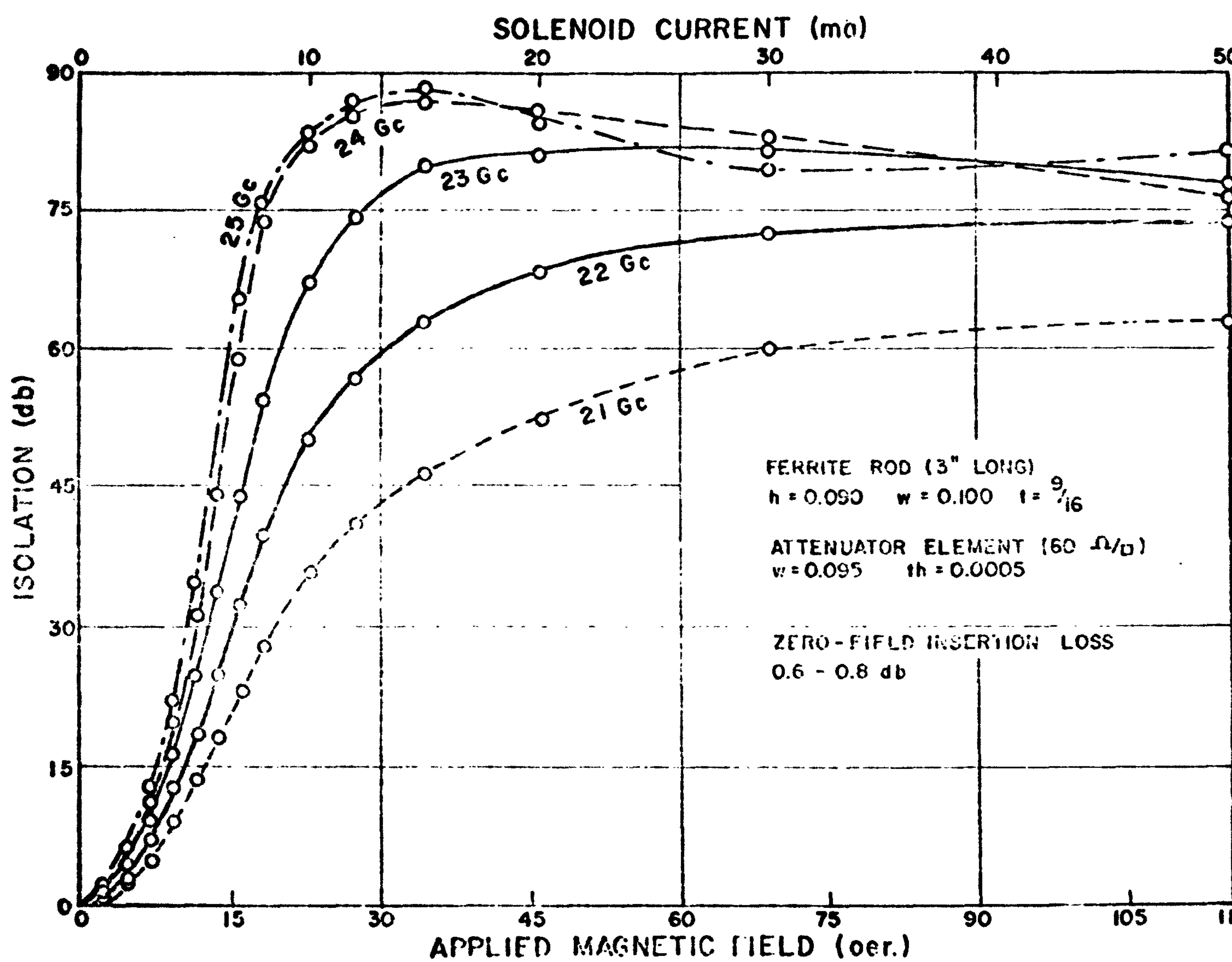

Figure 2. Isolation-bandwidth characteristics of absorption modulator using Ni-Zn ferrite rod 3 in. long, 0.090 in. high, 0.100 in. wide with 9/16-in. impedance matching tapers of both ends.

results, obtained for a rectangular ferrite rod having a height of 0.100 in. and a width of 0.110 in., are shown in figure 3. As seen in this figure, the isolation characteristics did not vary greatly over the 21- to 23-Gc bandwidth, reaching a maximum value in excess of 75 db. Similar results, not shown, were obtained at 24 and 25 Gc. The input VSWR of this modulator at 23 Gc (typical of that obtained at other frequencies over the operating bandwidth) is shown at the bottom of figure 3 and the solenoid current required to obtain the necessary magnetic field strength is shown at the top.

The zero-field insertion loss of the absorption modulator-switch depends largely upon the flatness of the ferrite surfaces in contact with the attenuator element. It is important that the air gap between these two parallel surfaces be as small as possible to minimize the distortion of the rf electric field across the attenuator element. A new resistive material (metalized film on mylar) is now available with a thickness of 0.0002 in. It is presently being used in the modulator-switch to obtain lower insertion loss without deterioration of the isolation characteristics.

Isolation characteristics of the absorption modulator at 24 Gc versus applied magnetic field as the resistivity (R) of the attenuator element was increased from 20 ohms to 100 ohms/square are shown in figure 4. This modulator made use of a ferrite rod and attenuator element having the same dimensions (given at the bottom of the figure) as those used to obtain the data shown in figure 2.

As seen in figure 4, the maximum isolation that can be obtained increases rapidly until the resistivity reaches approximately 60 ohms per square, and decreases again as the resistivity is increased above this value. Thus, it is important to select the correct value of resistivity if good isolation characteristics are to be obtained. The value of resistivity chosen for a particular operating frequency also determines the phase-shift characteristics (ref 3) of this ferrite modulator. Time did not permit further evaluation of this important characteristic.

A photograph of the broadband absorption modulator used for the above measurements is shown in figure 5. The tapered ferrite rod, polyfoam dielectric support, and metalized-mica attenuator element are shown in the foregound. Standard UG-159/U flanges were used at both ends of the absorption modulator. The length of the modulator and ferrite rod was 3 in. and the low-current solenoid consisted of 11,500 turns of #38 wire. Its total weight was 5 oz.

5. HIGH-SPEED ABSORPTION MODULATOR-SWITCH

It has been shown by LeCraw (ref 7) that the response time of the ferrite can be as low as 12 nsec. Therefore, in the design of ferrite switches with switching times of about 0.1 μsec the ferrite

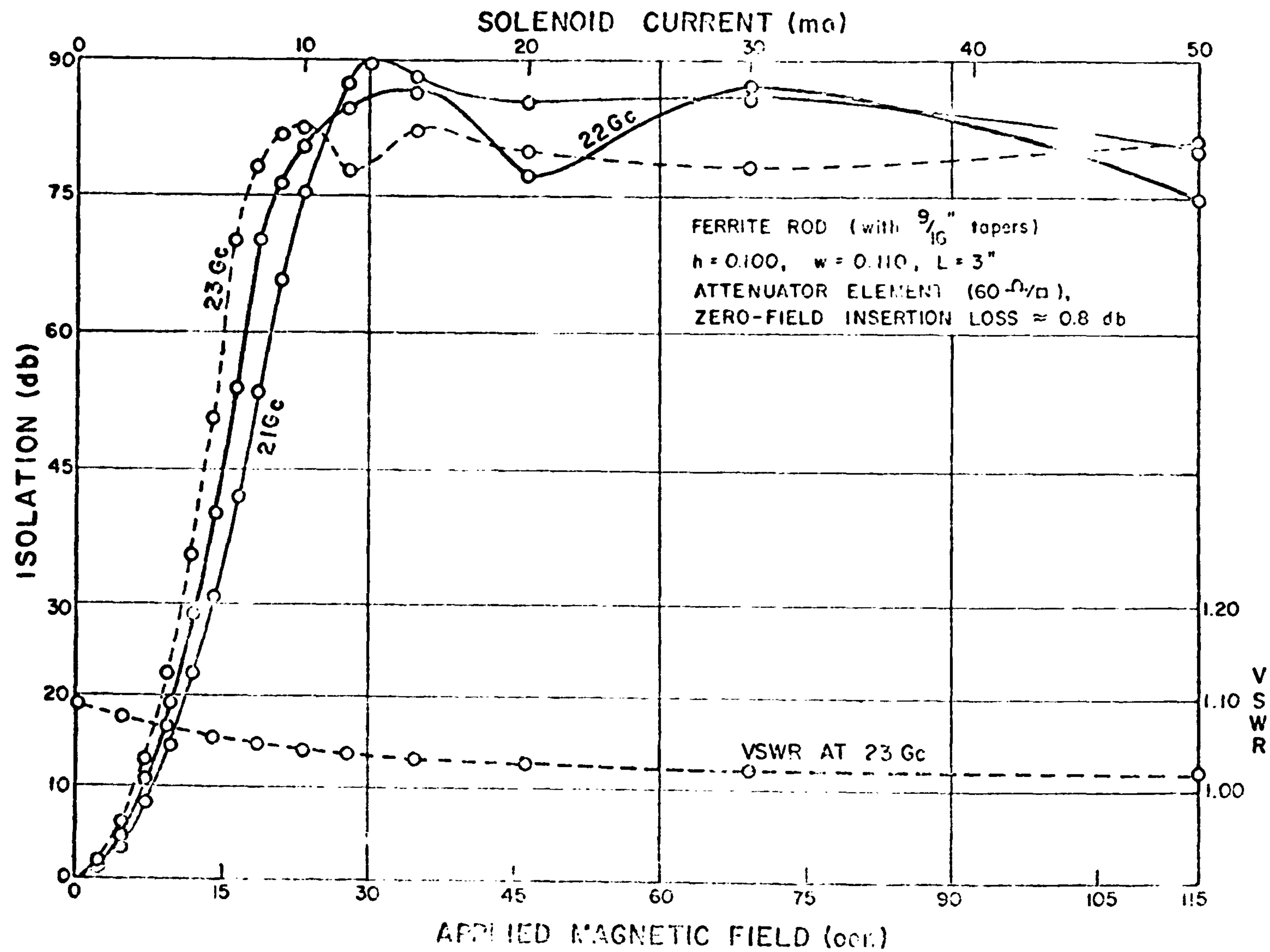

Figure 3. Isolation-bandwidth characteristics of modulator using ferrite rod (3 in. long) with height of 0.100 in. and width of 0.110 in. A d-c power of approximately 1w was required to obtain a field of 30 oersteds.

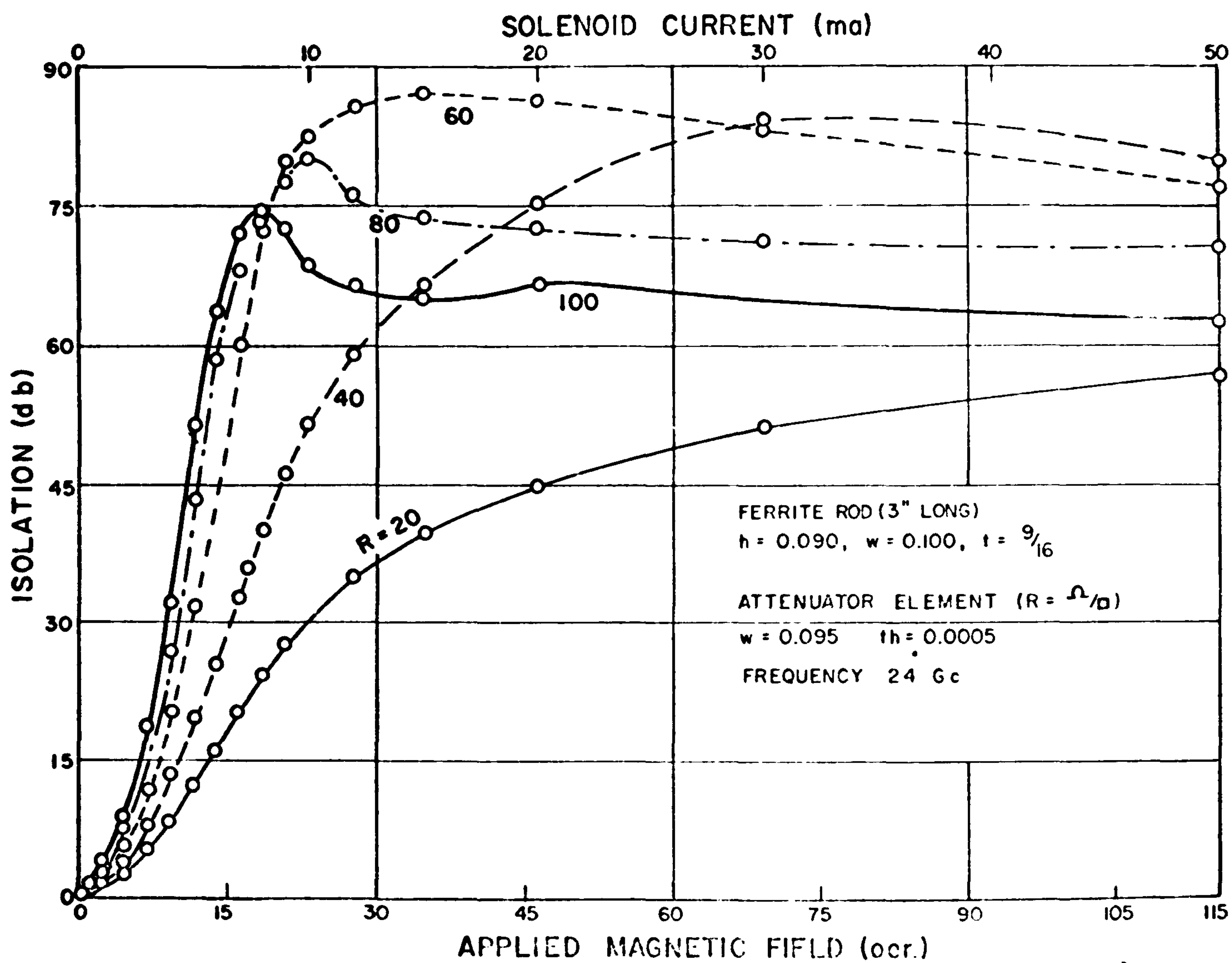

Figure 4. Isolation characteristics versus applied magnetic field for a 0.090- by 0.100-in. ferrite road for various attenuator element resistivities in ohms per square.

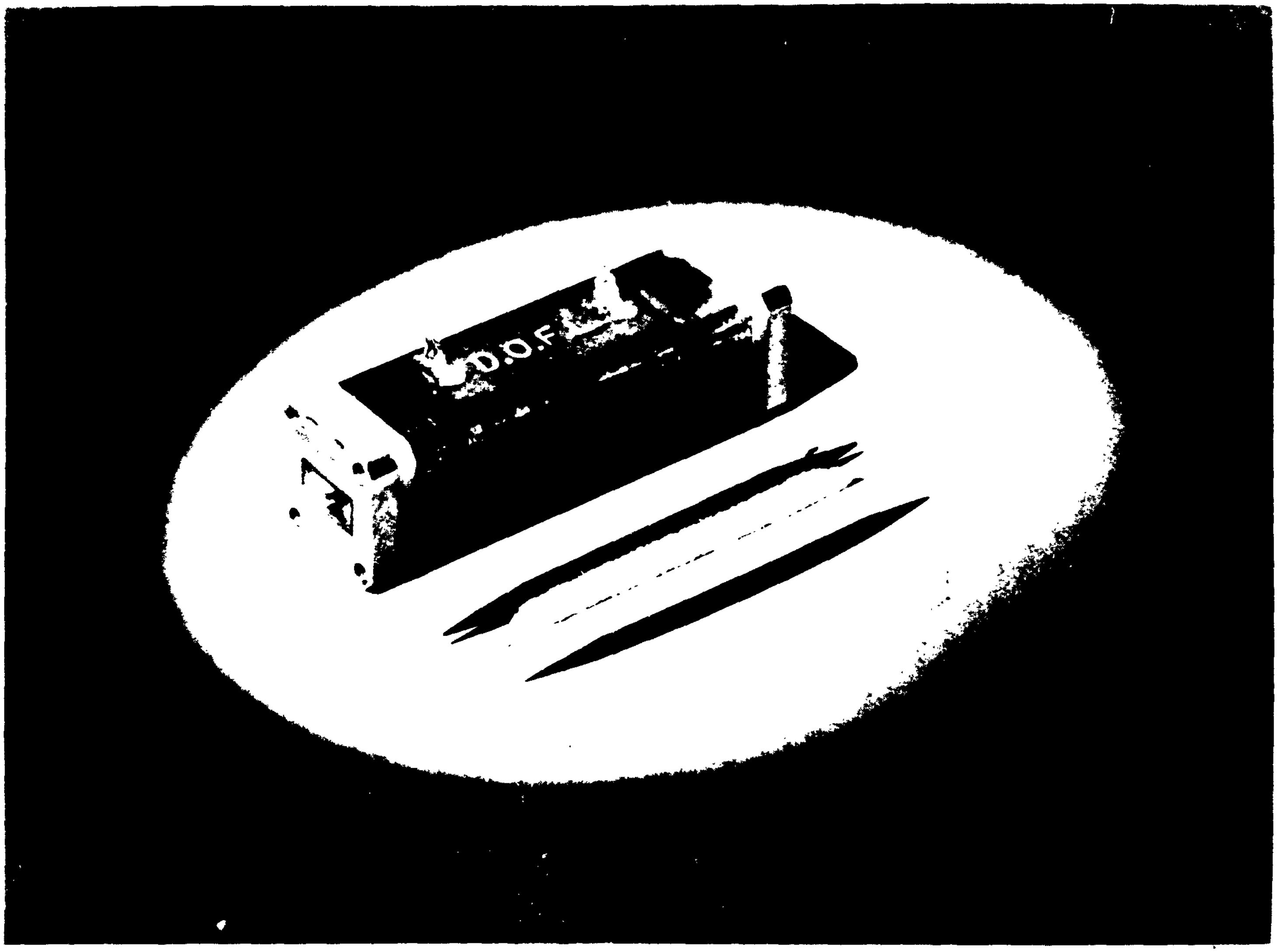

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Figure 5. Photograph of K-band absorption modulator-switch. (Total length of modulator is 3 in.)

is apparently not the limiting factor. The problem is to design a waveguide structure, driving solenoid, and solenoid power supply such that a pulsed magnetic field with sufficiently small rise time is impressed upon the ferrite.

To minimize the modulating power losses, due primarily to the eddy current losses in the waveguide walls, several techniques were used to interrupt the circumferentially circulating eddy currents. The most important of these was to cut away a large portion or all of the waveguide wall in the region of the ferrite. This is possible because of the large dielectric constant and cross section of the ferrite rod, which causes essentially all of the microwave energy to be concentrated in the region of the ferrite. Another technique used to minimize eddy current losses was to reduce the thickness of the waveguide wall to several skin current depths.

A photograph of several absorption modulator-switches making use of the design techniques described above is shown in figure 6. These high-speed plastic models made use of a 0.0005-in. silver plating (gold flashed) on the inside of the waveguide and on the face of the flanges. They were all 3 in. long and made use of standard K-band waveguide (0.170 x 0.420 in.).

The plastic waveguide model at the right has 30 turns of #14 wire wound around the 1/4 by 1/2-in. waveguide section. The tapered ferrite rod (0.100 x 0.110 in.) and polyfoam dielectric support, which were used in this high-speed modulator, are shown in the foreground at the right. A switching time of approximately 1 μsec with non-critical magnetic control fields was possible with this full-size waveguide ferrite modulator.

The plastic waveguide model shown at the left has a portion (1 3/4 in.) of the waveguide wall removed in the region of the ferrite rod to further minimize the eddy current losses and reduce the size of the modulating coil cross section (1/4 x 1/4 in.). This reduction in the coil cross section greatly increases the strength of the magnetic control field in the ferrite medium, thus increasing the efficiency of the modulating circuit. The solenoid wound in the region of reduced cross section consisted of 23 turns of #14 wire and was potted for increased mechanical strength. The tapered ferrite rod and teflon dielectric support which were used in this modulator is also shown at the left foreground. The reduced cross section of the teflon in the center region is clearly shown. A switching time of approximately 0.5 μsec was obtained with this microwave switch with the reduced waveguide cross section.

A relatively easy way to obtain a high-speed microwave switch with a standard metalic waveguide section is shown in figure 7. Here, either a portion of the metalic waveguide wall is removed (seen in background) or all of its center region is removed (in the foreground)

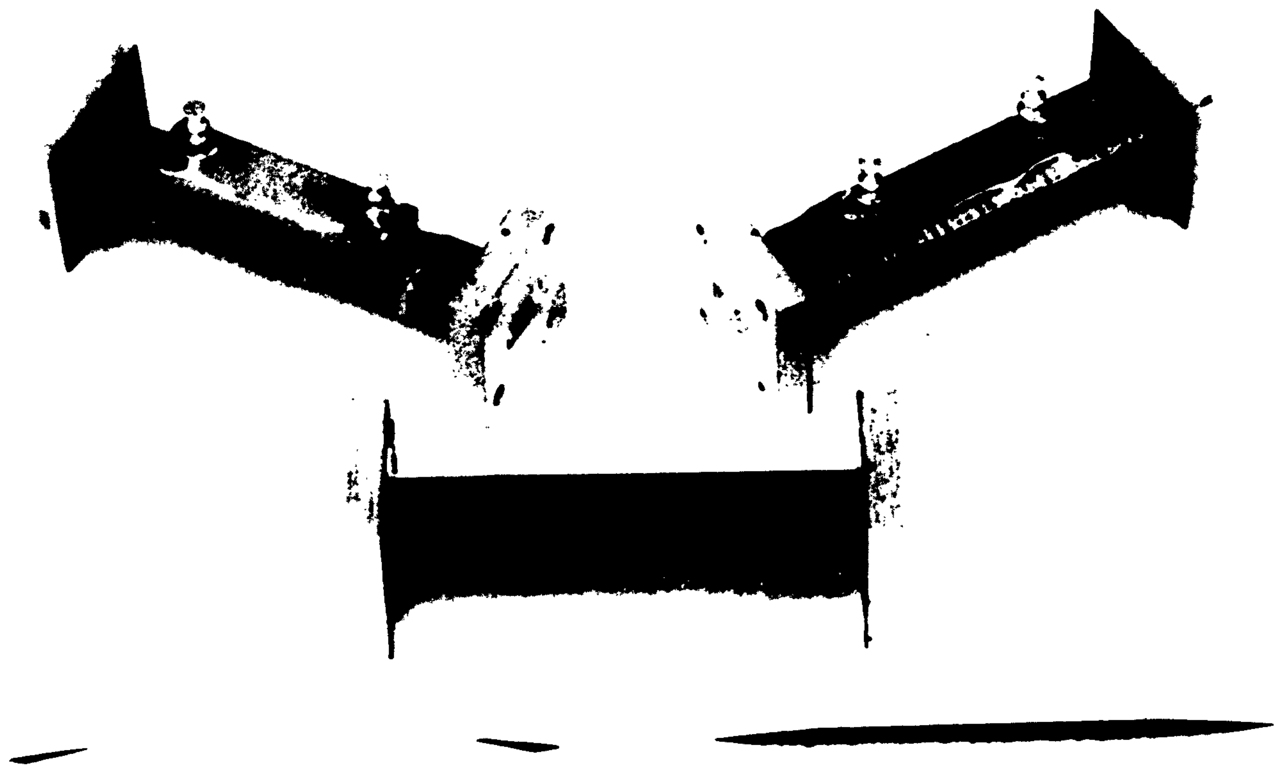

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Figure 6. Plastic waveguide models of the absorption modulator for high-speed switching of microwave energy.

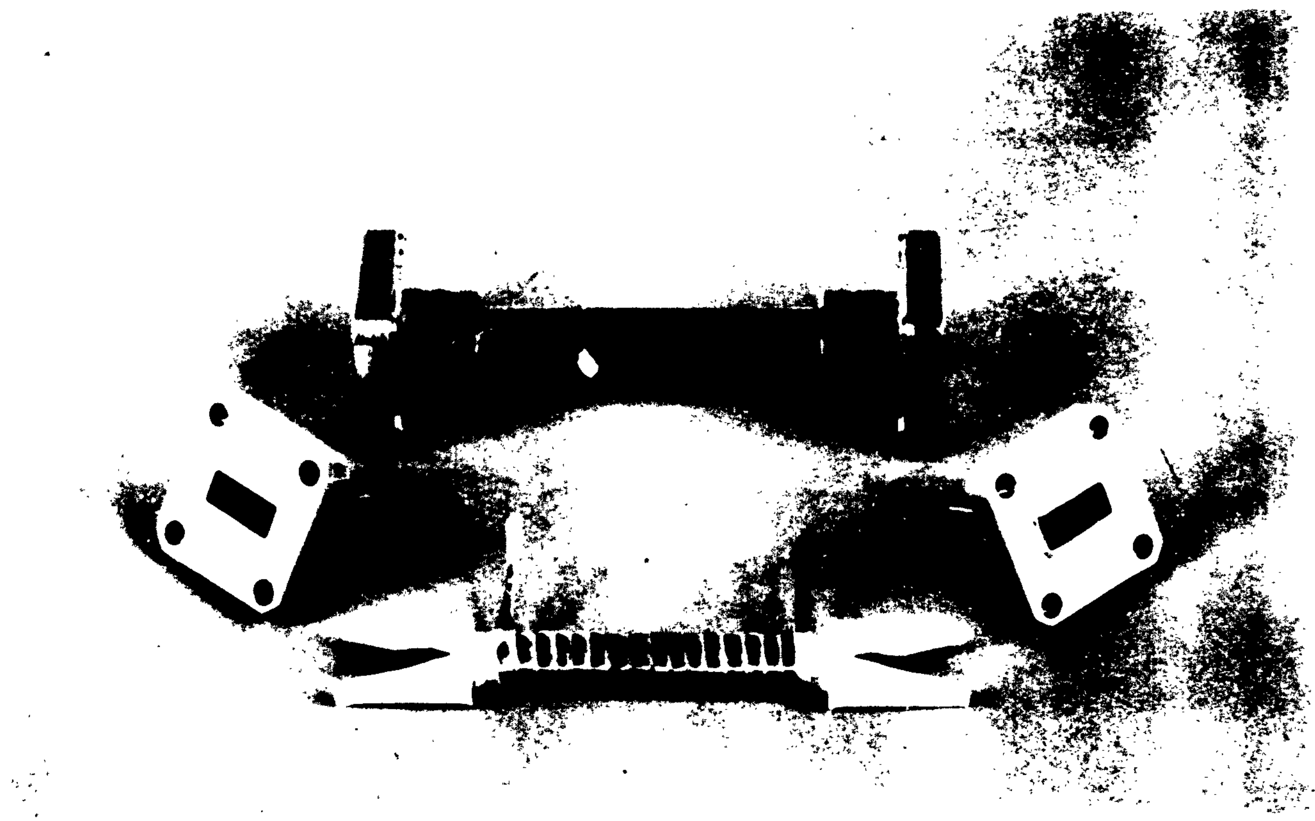

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Figure 7. Technique used to obtain high-speed microwave switch in standard K-band metallic waveguide.

to reduce the eddy current losses and cross section of the modulating coil. This latter technique, making use of 15 1/2 turns of ribbon wire wound around the cutaway portion of the teflon dielectric support (0.2-x 0.2-in. cross section), resulted in a switching time of approximately 0.1 μsec. This is the same technique used by Jones (ref 8) at X-band and later by Bendix (ref 9) to obtain a switching time of 40 nsec.

The detected microwave pulses at the output of two high-speed switches described above are shown in the oscillogram of figure 8. The oscillogram at the top (0.5 μsec/cm time base) was obtained at 24 Gc with the plastic waveguide model shown at the left in figure 6. A 0.001-μfd capacitor was shunted across its 23-turn solenoid to reduce the rise and fall time of the output pulse. The zero-field insertion loss for this microwave switch was about 1 db and a switching action of greater than 20 db was not difficult to obtain with a typical laboratory pulse generator.

The oscillogram at the bottom shows the microwave output pulse at 24 Gc obtained from the modulator-switch shown in the foreground of figure 7. The time base for this oscillogram was 0.1 μsec/cm. A 470-pf capacitor was used in shunt with the 15 1/2-turn modulating solenoid to obtain the 0.1-μsec rise and fall time of the pulse shown here. The ferrite rod used in this high-speed switch had a cross section of 0.100 by 0.110 in. and a total length of 3 in., including the 5/8-in. impedance-matching tapers at both ends.

6. CONCLUSION

A high isolation absorption modulator-switch for 1.2-cm wavelength has been designed that is capable of less than 0.1-μsec switching time. These small reciprocal modulator-switches have important applications in microwave systems which include magnetically tuned variable attenuators, radar duplexing, rf pulse-forming networks, receiver-blanking circuits and phased-array antenna systems.

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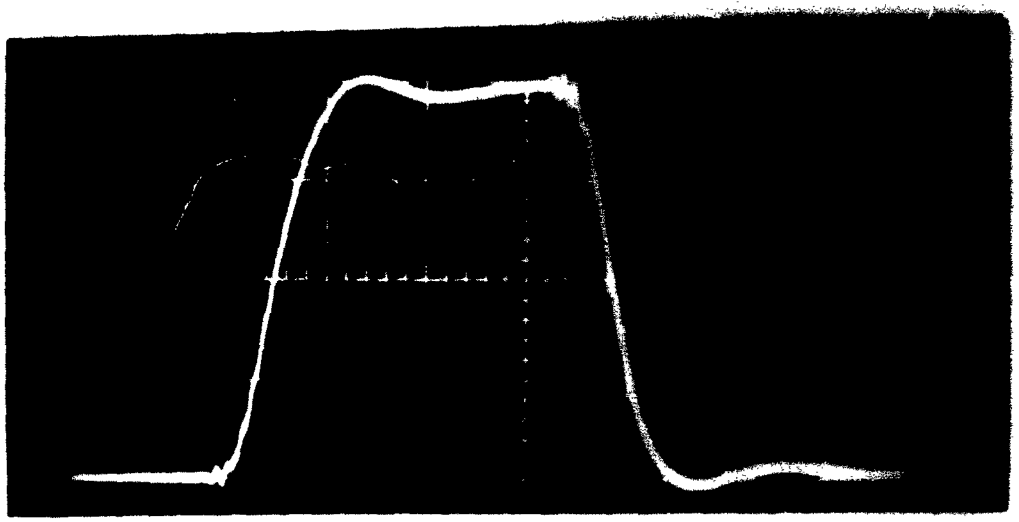
ACKNOWLEDGEMENT

The author wishes to thank Richard [illegible]. Norris for his contributions in the metalizing and gold-plating techniques used on the nonmetalic (phenolic) waveguide models of the absorption modulator-switch.



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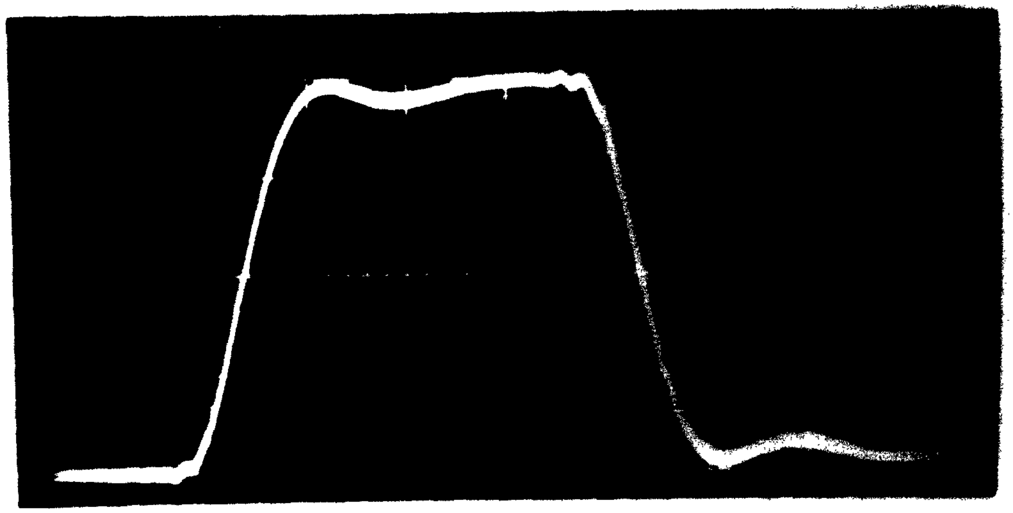

[b]

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Figure 8. Oscillogram showing detected output pulse of two high-speed microwave switches. (Time bases are [a] 0.5 μsec/cm and [b] 0.1 μsec/cm.)

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TR-1151, 8 July 1963, 14pp text, 8 illus. DA-1P523801A300, AMCMS-5523.11.62400, HDL Proj. 26300, UNCLASSIFIED Report

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Harry Diamond Laboratories, Washington 25, D. C.

A HIGH ISOLATION ABSORPTION MODULATOR-SWITCH FOR 1.2-CM WAVELENGTH
Frank Reggia

TR-1151, 8 July 1963, 14pp text, 8 illus. DA-1P523801A300, AMCMS-5523.11.62400, HDL Proj. 26300, UNCLASSIFIED Report

This report describes the design and operation of a K-band absorption modulator for high-speed switching or amplitude modulation of microwave power. This reciprocal ferrite modulator, designed in standard rectangular waveguide and making use of a longitudinal magnetic control field, has electrical characteristics particularly desirable in a microwave switch. These include a zero-field insertion loss of less than 1 db, a switching action (isolation) of greater than 75 db, which is nearly independent of the magnetic control field in this state, and a matched input impedance for all values of applied field. These electrical characteristics are nearly constant over a 20-percent bandwidth. It is also possible to design this amplitude modulator for small phase shifts at the desired operating frequency.

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