NRC·CNRC

NRC Publications Archive
Archives des publications du CNRC

A variable waveguide short circuit for high power microwave systems

Van Koughnett, A. L.; Dunn, J. G.; Wyslouzil, W.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21276329
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1971-08

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=852f64b4-7c0a-425b-ba5d-f7490bbfc039
https://publications-cnrc.canada.ca/fra/voir/objet/?id=852f64b4-7c0a-425b-ba5d-f7490bbfc039

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada　Conseil national de recherches Canada

Canada

Ser
QC1
N21
ERB-858

ERB-858

UNCLASSIFIED

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

NATIONAL RESEARCH COUNCIL
LIBRARY
SEP 23 1971
OTTAWA
CANADA
NATIONAL SCIENCE LIBRARY

ANALYZED

A VARIABLE WAVEGUIDE SHORT CIRCUIT FOR HIGH POWER MICROWAVE SYSTEMS

- A. L. VANKOUGHNETT, J. G. DUNN, AND W. WYSLOUZIL -

OTTAWA

AUGUST 1971

ANALYZED

ABSTRACT

A variable waveguide short circuit with high average power handling capabilities is described. The reactive element consists of a rotatable length of short-circuited circular waveguide which is bifurcated by a metallic vane. The short circuit is intended to form the variable reactive element of a tuning stub in an automated triple-stub tuner for microwave heating systems operating at power levels as high as 30 kilowatts.

CONTENTS

FIGURES

A VARIABLE WAVEGUIDE SHORT CIRCUIT FOR HIGH POWER MICROWAVE SYSTEMS

– A.L. VanKoughnett, J.G. Dunn, and W. Wyslouzil –

Introduction

Several microwave heating systems developed in the past and systems proposed for future development at the National Research Council of Canada are resonant in nature. Such microwave devices consist essentially of a microwave power source, a tuning mechanism, and a cavity. The material to be treated is introduced into and extracted from the cavity on a continuous basis. The resonant frequency and coupling to the cavity are both functions of the properties of the material, such as transport speed, etc., and consequently the tuner must be variable to compensate for detuning of the system which occurs when these quantities change. In relatively low Q systems with microwave power heads which deliver 5 kilowatts or less, conventional slide-screw tuners have been found adequate. However, for high Q systems delivering such quantities of power or for any system delivering larger quantities of power, slide-screw tuners are inadequate owing to breakdown and leakage problems. Most other types of tuner require the equivalent of a sliding short circuit in waveguide. For this reason, the variable short circuit described herein was developed.

Several forms of variable short circuit in waveguide are possible. The most elementary form of sliding short circuit consists of a metallic block edged in finger stock which is slideable in the waveguide. This approach is inappropriate for high Q systems because of heating of the fingers and waveguide, and breakdown due to the relatively high losses in the short circuit. A second possible form is the conventional noncontacting sliding short circuit. Noncontacting shorts of the alternating high-impedance – low-impedance line type are unsuitable owing to breakdown problems, but noncontacting sliding short circuits of the choked variety are probably suitable in circular waveguide. Although the latter form seems electrically appropriate, it is more desirable mechanically to vary the effective position of the short by rotary rather than linear motion. Consequently, the form shown in Fig. 1 was chosen.

Figure 1 depicts two sections of circular waveguide. The right hand section is electrically coupled to the left by a choke joint and is rotatable. The right hand section is bifurcated by a metallic vane and terminated by a short circuit. When the metallic vane is perpendicular to the electric field in the waveguide, reflection of incident energy takes place at the circular waveguide short circuit. When the metallic vane is aligned with the electric field, incident energy is reflected from near the leading edge of the vane and, consequently, the effective position of the short circuit can be varied continuously from near the edge of the vane to the circular waveguide short circuit by rotating the bifurcated section.

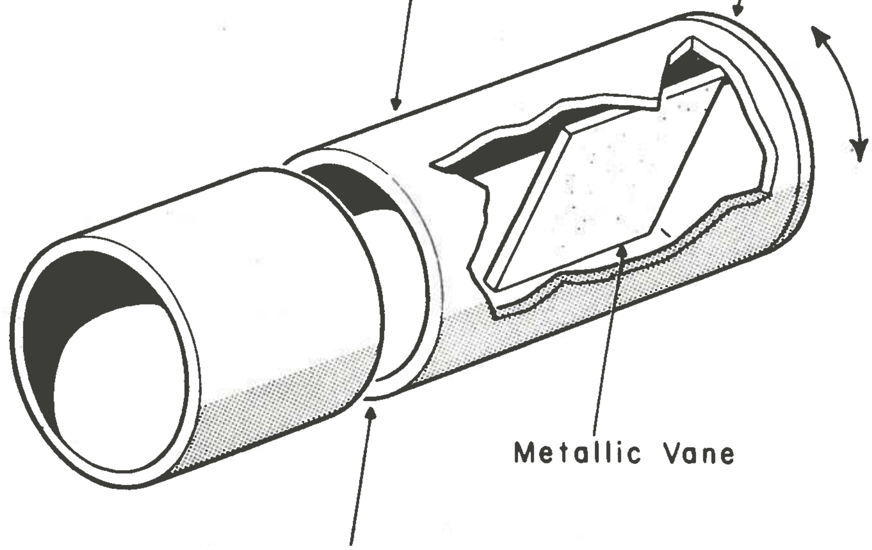

Figure 1 An illustration of the form of the variable short circuit

This configuration possesses two limitations. The structure clearly is frequency sensitive but this limitation is acceptable since microwave heating systems must operate within narrow allocated bands (2450 ± 25 MHz in the present case). Secondly, as shown later, the total movement of the effective position of the short circuit is restricted to less than one-half of a guide wavelength. This limitation is more severe, but is acceptable for some types of tuners, and in particular is acceptable for triple-stub tuners.

The following section analyzes the configuration shown in Fig. 1, the construction of the device is then described, and in the final section experimental results are given and comparisons of theory and experiment made.

Analysis

Consider the variable short circuit depicted in Fig. 2. A rectangular waveguide is coupled to a circular waveguide by either a matched or unmatched transition. The circular waveguide is terminated by the rotatable short-circuited circular waveguide with bifurcation shown in Fig. 1. We seek to determine the effective position of the short circuit as a function of angle of the rotatable section.

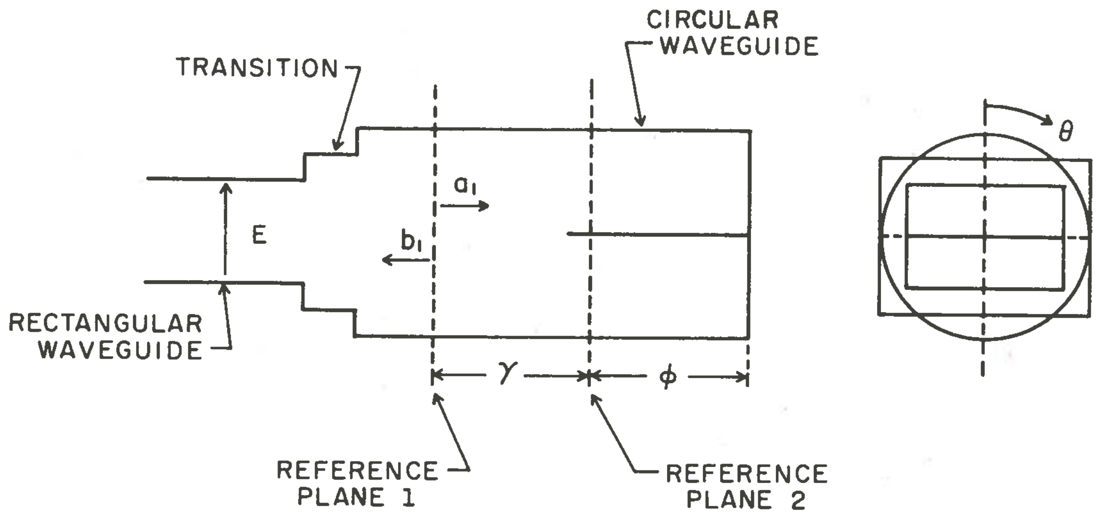

Figure 2 Geometry of the variable short circuit

In Fig. 2 the angular position of the vane is denoted θ and is measured with respect to the direction of the electric field vector ($\theta = 90°$ as shown). Two reference planes are defined in the circular waveguide. Reference plane 2 is slightly toward the short circuit from the leading edge of the fin and represents the apparent position of the short circuit for an incident wave which is polarized parallel to the fin. Inside the circular waveguide there are two propagating modes. For one mode the electric vector is parallel to that in the rectangular waveguide and, hence, this mode is coupled to the rectangular waveguide. The second mode is polarized perpendicular to the electric vector in the rectangular waveguide and, hence, is not coupled to it. For this cross-polarized mode the transition and rectangular waveguide appear as an open circuit at the reference plane denoted 1. The distances ϕ and γ are, respectively, the electrical distances between reference plane 2 and the short circuit and between reference planes 1 and 2. It is assumed that a wave a_1 polarized parallel to the electric vector of the rectangular waveguide is incident on reference plane 1 and we wish to find the phase of the reflected signal b_1 of like polarization.

The analysis consists of the following steps. The incident wave a_1 is resolved into components of polarization parallel and perpendicular to the fin. The reflection of these components by the fin and short circuit are treated separately and the reflected waves are then resolved into components parallel and perpendicular to the electric vector in the rectangular waveguide. Reflection of the cross-polarized component is accounted for and self consistency is required to obtain the following result—

$$b_1/a_1 = -\exp(-j2\gamma)R/R^* \qquad (1)$$

where * denotes complex conjugate and

$$R = \cos(\phi + \gamma) - j\sin\phi\sin^2\theta e^{j\gamma} \qquad (2)$$

Propagation of the form $\exp(-jkz + j\omega t)$ is assumed. In the extreme positions $\theta = 0$ and $\theta = 90°$, b_1 / a_1 varies from $-\exp(-j2\gamma)$ to $-\exp(-j2\gamma - j2\phi)$ as expected. At first glance it would appear that any desired degree of phase shift can be obtained simply by choosing ϕ properly. More careful examination of equations (1) and (2) reveals that this is not the case. In particular, it can be shown that the phase shift obtained by the short circuit cannot vary by more than $\lambda_g/2$. In addition, the apparent position of the short circuit can move either toward the generator or toward the load as θ is increased from 0° to 90° depending upon the choice of γ. For example, if $\phi = 60°$ and $\gamma = 60°$, b_1 / a_1 varies from $-\exp(-j120°)\exp(-j360°)$ through $-\exp(-j120°)\exp(-j180°)$ to $-\exp(-j120°)\exp(-j120°)$ as θ varies from 0° to 90°. In this case, the apparent position of the short circuit moves toward the generator as θ is increased and the total phase shift is 240°. If $\phi = 60°$ and $\gamma = 120°$, b_1 / a_1 varies from $-\exp(-j240°)\exp(-j360°)$ through $-\exp(-j240°)\exp(-j420°)$ to $-\exp(-j240°)\exp(-j480°)$ as θ varies from 0° to 90°. Here, the apparent position of the short circuit moves toward the load as θ is increased and the total phase shift is only 120°.

It is clear that the value of γ is somewhat arbitrary but an optimum value can be established on the basis of losses or frequency dependence for a given required phase shift. As indicated above, cross polarized fields exist in the structure. The strength of these fields and hence the losses and frequency dependence of the short circuit are functions of ϕ and γ. The magnitude of the cross-polarized fields is inversely proportional to R and thus we choose γ to make the minimum value of $|R|$ as large as possible. The minimum value of $|R|$ occurs when

$$\sin^2\theta = \frac{-\cos(\phi + \gamma)\sin\gamma}{\sin\phi} \tag{3}$$

and has the value

$$|R|_{min} = |\cos\gamma\cos(\phi + \gamma)| \tag{4}$$

Equation (4) is differentiated with respect to γ and the result set to zero to find the value of γ which yields the maximum value of $|R|_{min}$ This yields

$$\tan\gamma = \frac{\cos\phi \pm 1}{\sin\phi} \tag{5}$$

and the minimum value of R for this optimum value of γ is

$$|R|_{min} = \frac{\sin^2\phi}{2(1 \pm \cos\phi)} \quad (6)$$

Equations (1), (2), and (5), thus determine the values of ϕ and γ for a desired phase shift. In the design example cited below, a total phase shift of 240° is desired. This can be obtained by making $\phi = 120°$ and, from (5), $\gamma = 120°$ or $\gamma = 300°$.
$\phi = 60°$ and $\gamma = 60°$ or $\gamma = 240°$ achieves the same result. In the interest of compactness, $\phi = \gamma = 60°$ was chosen.

Construction

This section describes the construction of a variable short circuit designed on the basis of the preceding analysis to give a total phase variation of approximately 240° (apparent short circuit variation of $\lambda_g/3$). The device is required to operate at a center frequency of 2450 MHz and have a WR340 waveguide input.

In place of the transition depicted in Fig. 2 a butt joint between the rectangular and circular waveguides is used for mechanical simplification and the resulting discontinuity is partially matched by a symmetrical inductive iris. The construction details are shown in Fig. 3.

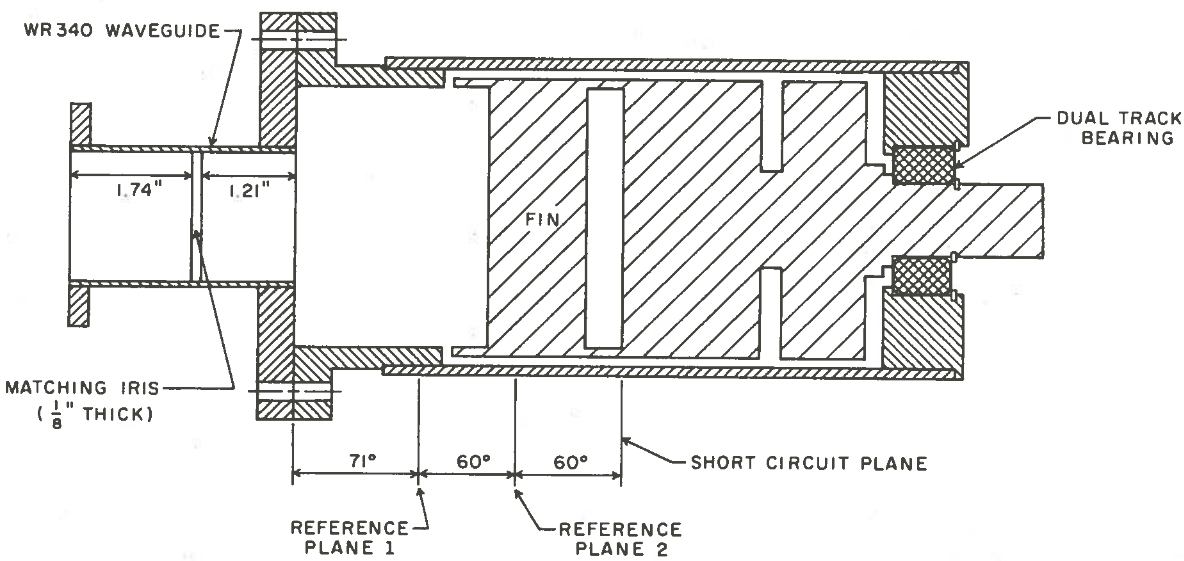

Figure 3 Details of the construction of a variable short circuit for operation at 2450 ± 25 MHz

The position of reference plane 1 was established by sliding a short circuit in a circular waveguide of the appropriate diameter which was butt joined to a rectangular WR340 waveguide. The resonance associated with the cross-polarized mode in the circular waveguide was monitored and the sliding short circuit position adjusted until the resonance appeared at the design frequency. It was then known that the length of the cavity formed for the cross-polarized mode was $n\lambda_g/2$, and hence the apparent position of the open circuit seen by a cross-polarized mode propagating toward the rectangular waveguide could be inferred. The apparent position of the short circuit seen by a wave polarized parallel to the fin was established by noting the phase of the wave reflected by a fin, replacing the fin with a sliding short circuit, and adjusting the position of the short circuit to realize the same phase. The position of the sliding short circuit then determines the position of reference plane 2 with respect to the leading edge of the fin. The trailing edge of the fin is terminated approximately 0.5 inch in front of the short circuit to avoid mechanical problems associated with welding the fin to the short circuit.

The choke joint is conventional in operation but somewhat different mechanically to facilitate mounting of the rotating member in a relatively small bearing. The groove shown forms a radial waveguide which reflects an open circuit in the coaxial waveguide which supports propagation in the gap between the rotating member and the outer tube. The position of the groove is chosen to reflect a short circuit at the gap between the rotating and fixed portions of the device. The electrical distance from the groove to the bearing is chosen to transform the short circuit at the bearing to a short circuit at the groove and thus provide a double choking action. The rotating member is constructed of silver plated aluminum and all other parts are brass.

To partially match the rectangular/circular waveguide transition, an iris is included in the location shown. The iris is of the symmetric inductive type and extends into the waveguide 0.5 inch from each side.

Performance

The theoretical performance of the variable short circuit differs from that predicted by equation (1) since the rectangular/circular waveguide transition is not matched. However, the performance of the device shown in Fig. 3 can be predicted if the properties of the iris and the transition are known. The measured characteristic admittance of the circular waveguide relative to that of the rectangular waveguide is $Y = 0.52$. The rectangular/circular waveguide transition also exhibits a measured shunt susceptance of 0.126 relative to the characteristic admittance of the rectangular waveguide. Given these data and equation (1) the performance of the variable short circuit without the matching iris can be predicted from transmission line theory. With the geometry of Fig. 3 but without the iris, the total theoretical phase shift between $\theta = 0°$ and $\theta = 90°$ is 240° at reference plane 1 and 192° in the rectangular waveguide. The total measured phase shift in the rectangular waveguide was 198°. Consequently, approximately 45° of phase shift is lost by not matching the transition. This loss can readily be regained by inserting the iris shown in Fig. 3. One approach is simply to choose the dimensions and position of the iris to match the transition, in which case a total phase shift of 240° would be expected. An alternate approach yields somewhat greater flexibility. At a point approximately 1.27 inches toward the generator from the transition, the input susceptance of the device varies approximately from $j0$ through $j1$ to $j\infty$ as θ varies from 0° to 90°. If an iris of susceptance B is inserted at this point, the susceptance variation becomes jB to $j\infty$ and thus the phase shift can be increased (decreased) by inclusion of an iris of negative (positive) susceptance. In the present case a symmetric inductive iris 1/8 inch thick extending 1/2 inch into the waveguide on each side was used. The measured relative susceptance of the iris is $-j0.60$.

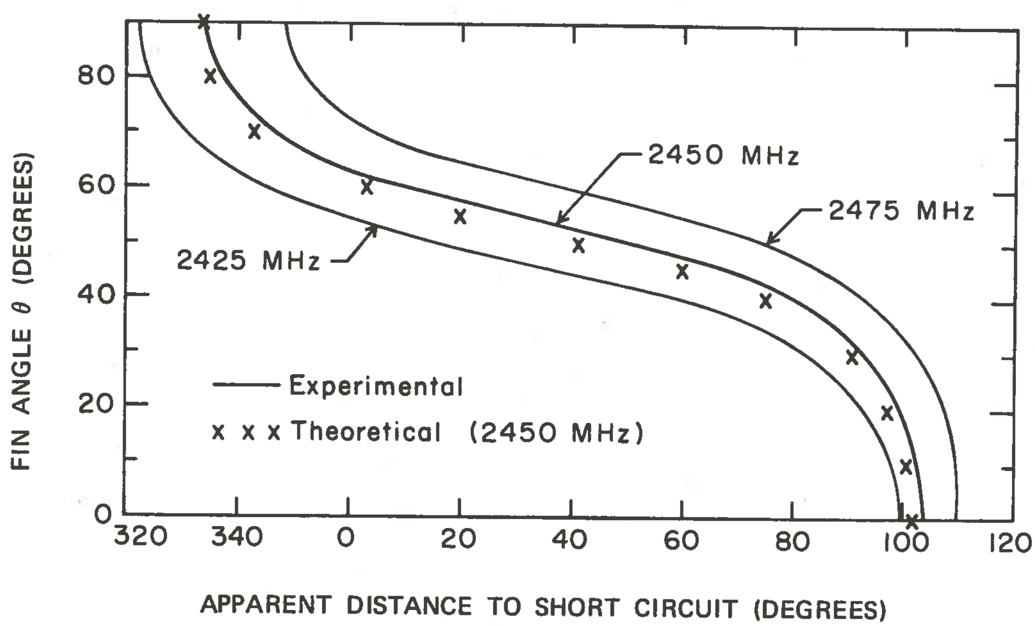

Figure 4 Apparent electrical length of the variable short circuit as a function of angle of the bifurcating fin

Figure 4 shows the measured and predicted apparent electrical length of the device of Fig. 3 referred to the plane of the rectangular waveguide flange. The total phase variation is approximately 260° at the center frequency and 274° and 242° at the low and high end of the 50-MHz band required. The agreement of theory and experiment at the center frequency is well within the limits of experimental error.

Several attempts were made to measure the return loss of the short circuit as a function of fin angle θ. Without precision equipment, the most promising approach appeared to consist of constructing a resonant cavity by short-circuiting the rectangular flange of Fig. 3 and coupling to the cavity with a probe. The variable short circuit was then adjusted until the cavity resonated at 2450 MHz and the cavity $Q = \omega L/R$ measured. From the data of Fig. 4 and knowledge of the length of waveguide added to the device of Fig. 3 the equivalent ωL can be inferred and hence the equivalent terminating resistance R found. To infer losses for other fin positions, waveguide spacers were inserted, the cavity retuned to resonance and the Q measured. Unfortunately, it was found that the largest component of loss in the cavity was loss at flange connections and thus only one meaningful point on the θ vs. loss curve could be found. This point corresponded to the fin position $\theta = 63°$ which yields a cavity which resonates at 2450 MHz when the device of Fig. 3 is terminated by a short circuit at the rectangular waveguide flange. For this value of θ the cavity Q was 10,600 and the total circuit resistance was 0.0021 ohm . If the resistance of the short circuit applied to the flange is neglected, this corresponds to a return loss of 0.036db from the variable short circuit when $\theta = 63°$. All available evidence indicates that the return loss is of this order of magnitude for all θ.

Plate I shows a photograph of a prototype of the device.

Conclusions

The device described herein appears suitable as a variable waveguide short circuit for high power microwave systems. The prototype displays sufficient phase shift over the 2450 ± 25 MHz band to be useful in microwave heating systems as the variable reactive element of an automated triple stub tuner.

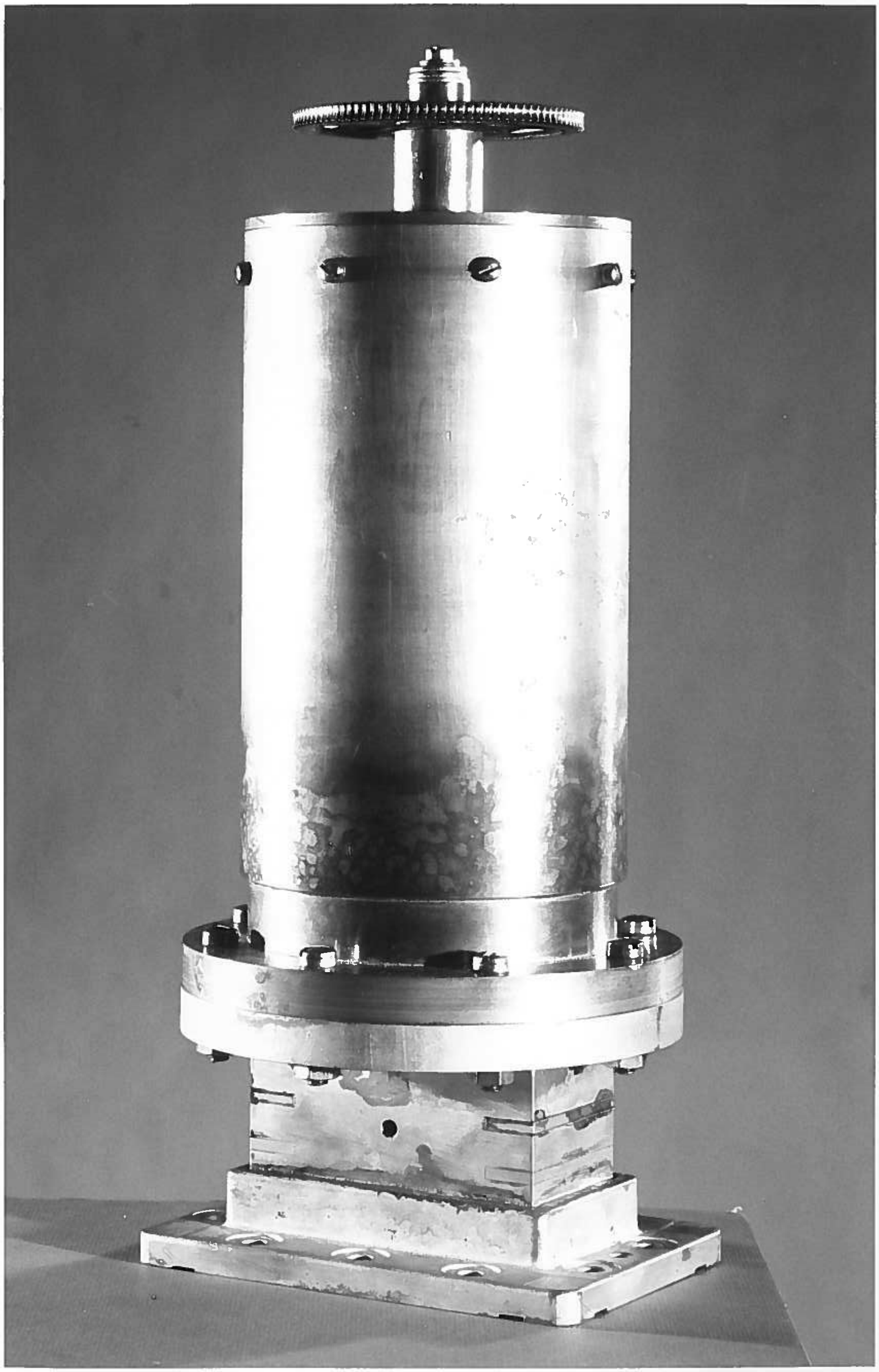

Plate I Prototype variable short circuit