ductor (which is assumed to be homogeneous and isotropic), as a replacement for the actual slow-wave circuit, implies the presence of both axial and azimuthal slowing, although only the latter is of importance in E-type devices. A limitation inherent in the use of the dielectric cylinder arises from the fact that the dielectric is perfectly smooth, so that analyses based on this model indicate the presence of only one of the infinite number of possible space harmonics produced in the actual structure. However, the constraint is not serious so long as the conditions are such that the electron beam effectively interacts with only one space-harmonic component of the RF field.

A Further Examination of the Field Relations

A study of the field equations leads to some interesting conclusions concerning the characteristics of the transmission system described above. It is convenient in this study to regard the entire cross-sectional area of the system as being divided into the "slow-wave region," containing the periodic RF structure, and the "interaction space" which surrounds the slow-wave region. Thus, in the slow-wave region the radial propagation constant k_{2n} is given by

$$k_{2n}{}^2 = \left[\omega^2\mu_0\epsilon_2 - \left(\frac{n\pi}{L}\right)^2\right], \tag{7}$$

where ϵ_2 is the permittivity associated with the dielectric cylinder in farads per meter. It is apparent that $k_{2n}{}^2$ must be greater than zero, for otherwise wave propagation would be cut off in the slow-wave region, and therefore in the entire system. It follows that the radial variation of all field components in the slow-wave region must exhibit the real argument (rather than the imaginary argument) Bessel function behavior. The cutoff condition for axial propagation in the slow-wave region, $k_{2n}{}^2 \equiv 0$, leads to

$$|\,n\,| \leqq \frac{\omega L}{\pi}\sqrt{\mu_0\epsilon_2}, \tag{8}$$

as shown in Fig. 1. It may be noted that the allowed range of axial eigenvalues, corresponding to the integer n values, increases with frequency, with the height of the waveguide parallel to the cylindrical axis, and with the dielectric constant.

Since only the cutoff modes were assumed to be present in deriving the field relations given above, then the radial propagation constant appropriate to the interaction space k_n yields, for the condition $k_n{}^2 = 0$,

$$\left|\frac{\omega L}{\pi}\sqrt{\mu_0\epsilon_0}\right| < |\,n\,| < \infty,$$

as shown in Fig. 2. Thus, a finite and bounded set of axial eigenvalues associated with wave propagation in the slow-wave region leads to a pair of sets of infinite eigenvalues associated with the cutoff modes permeating the interaction region. It is apparent, however, that if the guide height L or the operating frequency is sufficiently increased to permit E- or H-wave *propagating* modes to exist in this space, then the elements of the periodic structure act as sources of radiation that excite strong fields in the region surrounding the RF circuit. The *propagating-wave* axial eigenvalues then

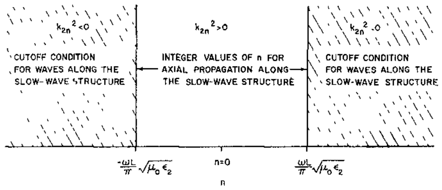


Fig. 1—Graphical representation of the range of n in the slow-wave region.

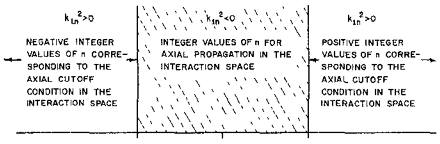


Fig. 2—Graphical representation of the range of n in the interaction space.

lie in the shaded area of Fig. 2, and the radial variation of all field components now take on the real-argument Bessel function variation.

Since the Hankel functions of the first and second kinds are linearly related to the two types of Bessel functions of real argument, it may be shown that radially propagating waves accompany axially propagating waves, and that radially attenuating functions accompany axially cutoff modes. The fields on the slow-wave structure must always be associated with radially and axially propagating modes, since operation below the cutoff frequency of the RF circuit suppresses electromagnetic radiation in the entire system. The fields in the interaction space may be associated either with radially and axially propagating or attenuating waves, depending on the relation of the operating frequency to the cutoff frequency of the interaction space.

The lowest E-mode field occurs for $n = 0$, because E_z has the axial variation

$$\cos\left(\frac{n\pi}{L}z\right),$$

while the lowest H-mode field occurs for $n = 1$, because H_z has the axial variation

$$\sin\left(\frac{n\pi}{L}z\right).$$

However, since E_θ possesses the same axial variation as H_z, it follows that the lowest mode, for which effective electron-wave interaction in E-type devices is possible, occurs when $n = 1$.

In contrast to the "permitted sets" of axial eigenvalues, all field components possess an azimuthal variation of the form $e-j\beta_0\theta$. A study of this function leads to the interesting physical intepretation that, as far as azimuthal variations are concerned, the waves may be regarded as propagating in a Riemann space.[9] Each *spatial* excursion of θ corresponding to 2π electrical radians of $\beta_0\theta$ causes the waves to encounter a "new leaf" of this surface, so that the total number of leaves required to provide a closed domain of electrical angular values of the fields is equal to the circular propagation constant. Thus, β_0 is a measure of the number of leaves encompassed in completing a spatial excursion of 2π radians. The order of the real and hyperbolic Bessel functions which specify the radial behavior of all fields are therefore determined by the number of Riemann leaves involved.

W. M. Nunn, Jr.
Electron Physics Lab.
Elec. Engrg. Dept.
The University of Michigan
Ann Arbor, Mich.

[9] S. A. Schelkunoff, "Electromagnetic Waves," D. Van Nostrand Co., Inc., New York, N. Y.; 1953.

Ring Network Filter*

A filter circuit comprising two ring networks which are connected by two quarter-wavelength lines is described. This circuit has one output with a relatively wide pass band and a second output with a sharp rejection band. A printed microstrip version designed for 1-Gc operation is shown in Fig. 1. Input is at terminal 1, band-pass output at terminal 3, and rejection band output at terminal 2.

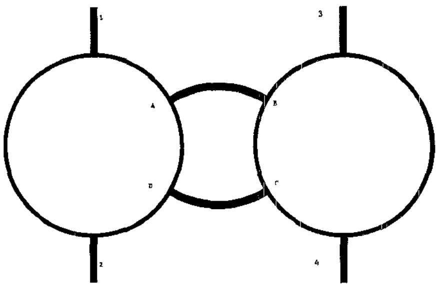


Fig. 1—1-Gc filter on $\frac{1}{16}$- inch teflon fiberglass.

A heuristic explanation of circuit action at the center frequency is as follows: Current entering arm 1 tends to divide equally between terminals A and 2 of the first ring network. A portion of the current entering terminal A travels around the loop $ABCD$, arriving at terminal D. Here one-half of the current goes to terminal 2 and one-half to terminal A. The part going to terminal A arrives in-phase while the part going to terminal 2 arrives antiphase with the currents flowing directly from terminal 1. The resultant partial cancellation at terminal 2 forces more current to enter arm AB, which in turn reduces the output from terminal 2 even more. Equilibrium is reached when the net current at terminal 2 is zero and all current into terminal 1 leaves by terminal 3. For zero circuit losses, cancellation of currents at terminal 2 would be complete, and there would be zero insertion loss between terminal 1 and terminal 3. Rejection occurs for a narrow band of frequencies at or near which the loop $ABCDA$ is one-wavelength long.

* Received by the PGMTT, March 10, 1961.

Ideally, all current entering the second ring network at terminal B flows out at terminals 3 and C. Terminal 4 is inherently isolated from terminal B and therefore from terminal 1 because no current enters the second ring network at terminal C. The isolation between terminals 1 and 4 can be no better than the intrinsic isolation between alternate terminals of either ring network.

The circuit of Fig. 1 is printed on $\frac{1}{16}$-inch teflon fiberglass with a copper backing. No effort is made to conserve space. The characteristic impedance of the printed lines used for the terminals 1-2-3-4 and coupling arms is 50 ohms, while the characteristic impedance of printed lines in the rings is approximately 70 ohms.

Characteristics for a single filter section designed for 1 Gc are shown in Fig. 2. These include VSWR of the input to arm 1 and isolation (or insertion loss) of the filter between terminal 1 and each of the other three terminals with unused terminals terminated in 50 ohms. Fig. 3(a) shows the isolation for two units cascaded into a band-pass filter, while Fig. 3(b) shows isolation for the same two units cascaded into a rejection filter. The two peaks in the rejection curve of Fig. 3(b) are due to a 10-Mc separation of the peak rejection frequencies of the individual sections.

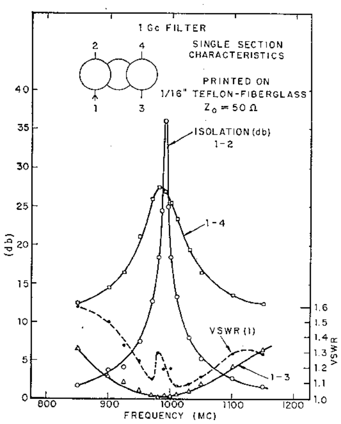
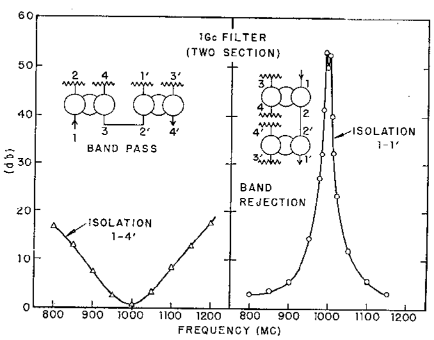


Fig. 2.



(a) (b)

Fig. 3.

J. A. Kaiser
Microwave Branch
Ordnance Corps.
Diamond Ordnance Fuze Labs.
Washington, D. C.

A Technique for Obtaining DC Isolation in Coaxial Cable RF Transmission Lines*

Introduction

In many applications involving microwave tubes it is desirable to monitor the voltages and currents of the various tube elements. This is particularly true of experimental tubes. The situation may be illustrated by a high voltage pulsed traveling-wave tube in which the collector and body are operated at or near ground level with the cathode at a negative potential. In order to observe current pulses at collector and body it is necessary to ground these points through a series resistor. Since the RF terminals of the device are generally fixed to the body, some form of dc isolation is required on the input and output transmission lines. If the ports are of waveguide construction, one method commonly employed is to place a thin teflon or polyethylene window between two cover flanges which are held together with nylon insulating screws. Tubes with coaxial connectors are usually adapted to waveguide and the above procedure is followed. The technique described below has been developed for obtaining dc isolation quite simply in coaxial cable.

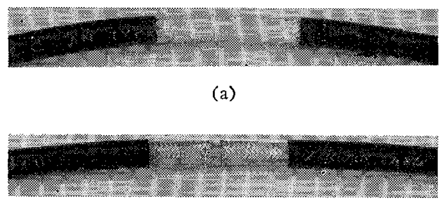
The basic idea is to sever the outer conductor or shielding braid of the coaxial line, in this case a cable of the RG-9B/U type. A sever presents an open circuit to the DC path but permits transmission of the RF. It is noted that a capacitive coupling on the center conductor would not be satisfactory for this application. Most attempts to cut the braid with a sharp knife or other instrument will result in some damage to the dielectric underneath. An alternate approach might be to lift each strand individually and snip with electricians scissors, but this is a rather lengthy procedure. However, a very satisfactory method is described in the section below.

Description of Technique

The cable is first cut to the desired length and the outer protective covering removed for a distance of two or three inches near the middle. A strip of electrical tape about one-sixteenth of an inch wide is then wrapped circumferentially about the exposed braid at the position selected for the sever. It is necessary to keep the sever small with respect to cable wavelength in order to prevent excessive radiation. A narrow opening also minimizes the effect of the discontinuity presented to the TEM traveling-wave. The remaining braid is then completely covered with a layer of melted paraffin. After the wax has hardened a wedge-shaped cut is made at the severing point and the wax removed until the band of tape is uncovered. The tape is then peeled off leaving a narrow strip of exposed braid [Fig. 1(a)]. The careful application of concentrated nitric acid by means of a cotton swab rapidly etches away the silvered-copper braid. This operation should be performed under a hood. The paraffin protects the remaining braid [Fig. 1(b)] and the polyethylene dielectric does not react with nitric acid. The acid residue can be rinsed away with water and the paraffin removed by gentle heating or scraping. A very thin coating of paraffin left on the braid will prevent the loose strands from fraying throughout the rest of the procedure. It is important that all the frayed ends lie flat so that they do not puncture the insulating sleeve that follows.

The braid is then wrapped with thin teflon, polyethylene or electrical tape. An outer sleeve of braid is placed over this wrapping in contact with just one end of the outer conductor. The open end should overlap the sever by about a quarter wavelength in order to reduce radiation losses. A final covering with electrical tape keeps the outer sleeve snugly in place and presents a neat finished appearance. The desired cable connectors are then placed on the ends.

* Received by the PGMTT, March 16, 1961.



(a)

(b)

Fig. 1—(a) Before etching. (b) After etching.

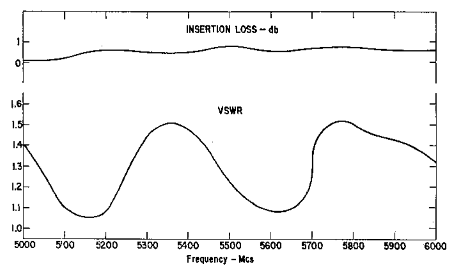


Fig. 2.

Results

An experimental cable was obtained and the technique described above was carried out. A continuity check of the assembled cable indicated an open circuit between the ends of the outer conductor. A further confirmation was obtained by applying a potential of five hundred volts with no arcing or current reading. To prevent possible contact at the sever, the gap may be wrapped with electrical tape during the procedure. Measurement of the RF characteristics showed that a VSWR of 1.5 or less and an insertion loss of about 0.5 db could be expected over the band from 5000 to 6000 Mc (Fig. 2). Considering the load and connector characteristics, these results are comparable to an unsevered cable.

The experimental data indicate that this technique provides the dc isolation and RF transmission required for this type of application.

R. A. Sparks
Appl. Phys. Lab.
The Johns Hopkins University
Silver Spring, Md.