V-12. A 7 Gc Narrow-Band Waveguide Switch Using PIN Junction Diodes

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A narrow-band waveguide switch has been designed in WR-137 waveguide which will handle a power level in excess of 8 watts. When passing a signal, this switch has an insertion loss of less than 0.5 db, but when it is "turned off" it has an insertion loss of greater than 80 db over a minimum bandwidth of 10 Mc. The switch is designed using PIN junction diodes in band elimination filter sections.

Design of Band Elimination Filters in Waveguide. Waveguide band elimination filters may be synthesized and realized from the measurable quantities of loaded Q, frequency, bandwidth, and insertion loss. The theory may be developed beginning with the conventional low-pass prototype filter. Element values are:

$$y_p = j\omega C_p = j\omega g_p \quad (p \text{ odd}); \qquad z_p = j\omega L_p = j\omega g_p \quad (p \text{ even}).$$

Tables are available giving values of g_p for Butterworth and Tchebycheff filters with various ripple characteristics.

A transformation will give a derived band elimination filter:

$$\omega \longrightarrow \frac{\omega_B}{\omega_o \Omega},$$

where

$$\Omega = \frac{\omega}{\omega_o} - \frac{\omega_o}{\omega},$$

$$\omega_B = \omega_2 - \omega_1, \quad \omega_o = \omega_1 \omega_2,$$

$$y_p \longrightarrow y_p'', \quad z_p \longrightarrow z_p'';$$

where

$$y_p'' = -j\, Y_o\, g_p \frac{\omega_B}{\omega_o \Omega} \; (p \text{ odd}), \qquad z_p'' = -j\, Z_o\, g_p \frac{\omega_B}{\omega_o \Omega} \; (p \text{ even})$$

Beginning with an expression for the insertion loss of a shunt admittance, y_p'', it may be shown by matrix analysis that the loaded "Q_p" of the corresponding p-th tuned circuit is

$$Q_p = \frac{2\, Q_T}{g_p} \; (p \text{ odd}), \quad \text{where } Q_T = \frac{\omega_o}{\omega_B}. \tag{1}$$

The same result applies in the case of the series impedance z_p'' (p even).

It may be shown that if shunt admittances y_p''' are spaced along a transmission line at distances of $\lambda/4$ or $((2n-1)\,\lambda/4)$, they may be related to the y_p'' and z_p'' elements of the low-pass prototype-derived band elimination filter as follows:

$$y_p''' = y_n'' \quad (p \text{ odd}), \qquad y_p''' = Y_o^2 z_p'' \quad (p \text{ even}).$$

In terms of the unloaded Q_u of each section of a n-section band elimination filter, the dissipation reflection loss at reject band center in terms of the reflection coefficient ρ is

$$\text{R.L.} = \left|\rho(\omega_o)\right|^2 \approx \left|\frac{g_1 \dfrac{Q_u}{Q_T} - 1}{g_1 \dfrac{Q_u}{Q_T} + 1}\right|^2 \tag{2}$$

where $\rho = V_{\text{reflected}}/V_{\text{incident}}$.

The transmission insertion loss at reject band center through the n-section band reject filter is

$$\text{I.L.}\ (\omega_o) \simeq \left(\frac{Q_u}{Q_T}\right)^{2n} \left(\frac{g_1 g_2 \ldots g_n}{2}\right)^2 \tag{3}$$

A single-section band elimination filter can be a shorted section of waveguide whose electrical length is approximately $\lambda g/2$ at resonant frequency when the cavity is loaded with the input coupling.[1] The coupling slot susceptance B_a is negative for both capacitive and inductive slots. The slot susceptance B_b is negative for inductive coupling and positive for the capacitive case. Values of B_a and B_b can be determined as indicated by Marcuvitz.[2]

For resonance at ω_o, the length ℓ_s of the stub transmission line is

$$\ell_s = \frac{1}{\beta g_o} \tan^{-1} \frac{1}{B_b},$$

where

$$\beta g_o = \frac{\omega_o^2 - \omega_c^2}{c};$$

ω_c is the cutoff frequency of the waveguide, and c is the velocity of light. The parallel combination of B_b and the transmission line is an admittance, y:

$$y = jB_b - j \cot\left(\frac{1}{c} \tan^{-1} \frac{1}{B_b}\right)$$

where

$$c = \frac{\omega_o^2 - \omega_c^2}{\omega^2 - \omega_c^2}.$$

A multiple section band-stop filter can therefore be assembled as indicated in Fig. 1. It is made up of single-section resonators coupled by line lengths ℓ which are approximately $3\lambda g/4$ long, i.e.,

$$\ell = \frac{1}{\beta g_o} \tan^{-1} \frac{1}{B_a}.$$

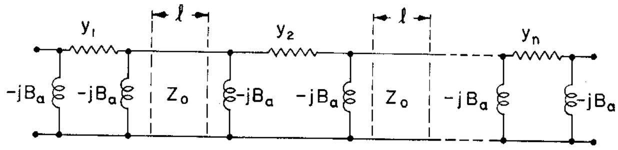

Fig. 1 Multiple-section band elimination filter.

Normal filter synthesis thus requires only knowledge of the type of filter desired, the center frequency, and the specified bandwidth. Requisite values of Q_p can be determined from the value of Q_T and the g_p's. Also readily found are the line lengths ℓ_s and ℓ. Filter specifications may be chosen by taking into consideration acceptable values of reflection loss and insertion loss.

Switch Design. A switch can be realized by using a band stop filter with a semiconductor junction diode placed in each resonator to provide means of changing its resonant frequency with diode bias. Figure 2 shows such a filter (4-section) with its diodes. If a filter section is tuned with the diode forward biased, the resonant frequency shifts to a higher frequency when the bias is reversed. Such a diode must have two impedance states: one approaching an open circuit (reverse bias), and the other a short circuit (forward bias). The series resistance in the forward bias state must be small so that diode temperature rise and insertion loss will be small. The capacitance of the diode must be sufficiently small in the reverse bias state that adequate filter detuning (and thus switching) is achieved with bias change. The PIN type diode satisfies these requirements. Also, it has a rather high Q, which offers advantages of lower insertion loss and narrow band design as desired.

A plot of Q_p (loaded Q) vs capacitive coupling slot size is given in Fig. 3. This represents measured data taken on single-section filters using PIN diodes.

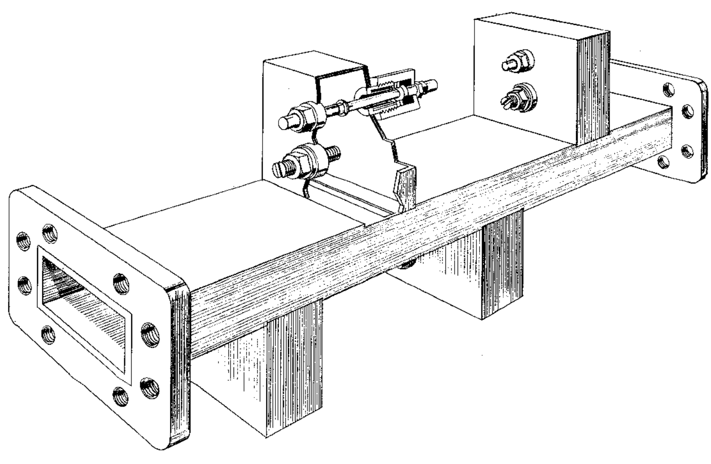

Fig. 2 Waveguide switch using PIN junction diodes.

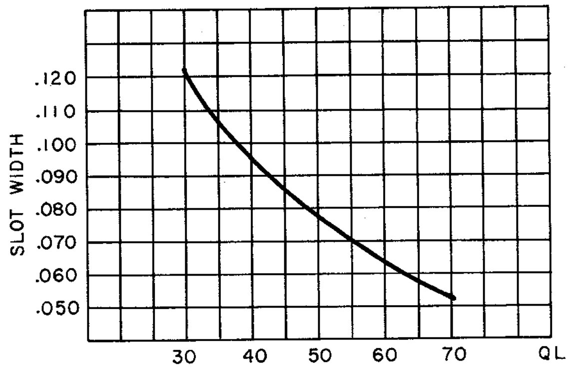

Fig. 3 Filter Switch: Q_p vs capacitive slot size for single cavity with PIN diode.

Figure 4 shows the measured insertion loss of a single-section filter vs frequency for both states of the switch. From the measured insertion loss at band center and Eq. (3), the unloaded Q_u can be estimated. These measurements should be made for both the forward and the reverse bias conditions. With this data, it is possible to design and meet many different switching specifications.

Figure 5 shows the attenuation characteristics of a 4-section equal-Q filter-switch for both conditions of switching, while Fig. 6 shows the reflection loss. It is to be noted that the attenuation is in excess of 80 db for a bandwidth of 10 Mc in the reject band, and that the insertion loss in the passband at a frequency displacement of 120 Mc is less than 0.5 db.

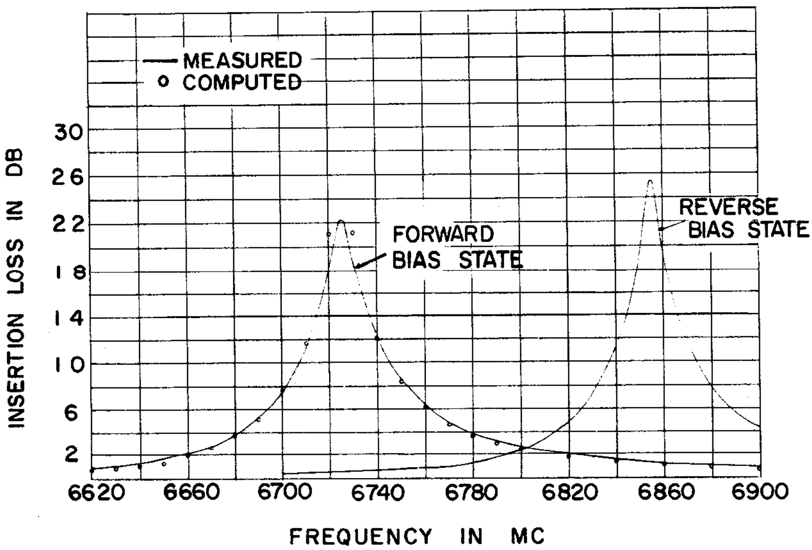

Fig. 4 Single-element filter switch.

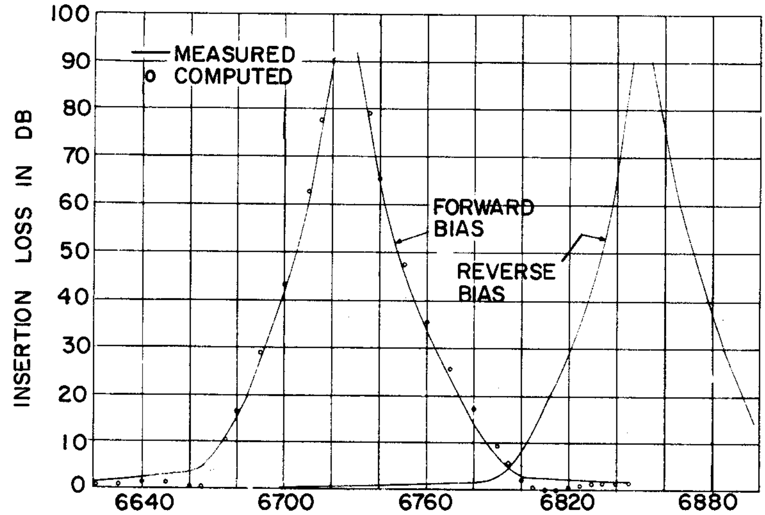

Fig. 5 Four-cavity switch response (equal-Q elements).

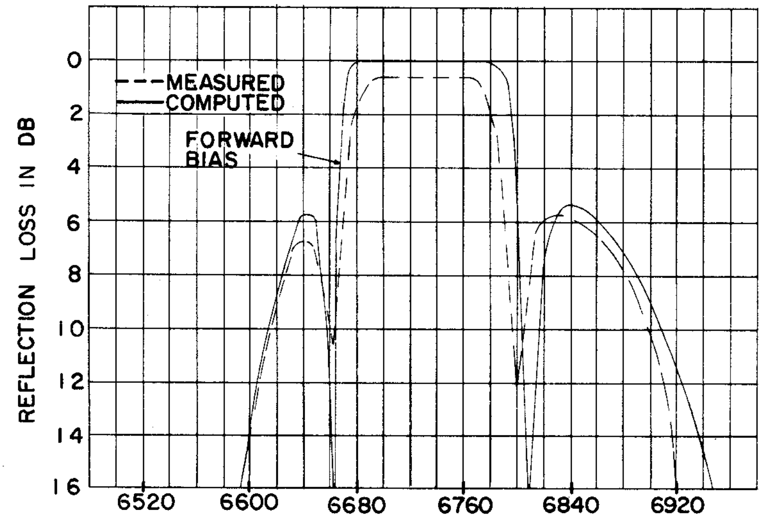

Fig. 6 Four-cavity filter switch (equal-Q elements).

The characteristics of this switch operating at 8 watts of rf power were checked over a temperature range of +65 °C to −10 °C, and no change in response or loss attributable to the diodes was measured. The only effect of the replacement of all four diodes with others of "limit" characteristics, without retuning the filter sections, was to detune the filter by 3 Mc.

One application for such a switch is a telecommunications radio system in which a transmitter consists of two klystron oscillators operating simultaneously on the same frequency, one radiating and the other in a "hot standby" condition. For this case, two such switches operating out of phase would be required, one "on" and the other "off." Connection to a common waveguide could be achieved through known diplexing methods.[3]

ACKNOWLEDGMENT

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3. G. C. Southworth, *loc. cit.*, pp. 313–317.