# Bandstop Filter in Nonradiative Dielectric Waveguide Using Rectangular Resonators

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*Abstract* —**A bandstop filter realized by means of rectangular resonators coupled to the center dielectric strip of a nonradiative dielectric (NRD) waveguide is described. This filter has the advantage that it is simple to manufacture, making use of a center dielectric of standard cross section. The design procedure is similar to the conventional strip line design procedure, with the stubs replaced by "stubs" of dielectric, or resonators. The design equations for the stub coupling are derived; the properties of the stubs are obtained through measurement.**

## I. Introduction

A NEW BANDSTOP filter realized by means of rectangular resonators coupled to the center dielectric strip of a nonradiative dielectric (NRD) waveguide is described in this paper. Other bandstop filters in this medium have made use of coupled lines [1] or circular cylindrical resonators [2]. This filter has the advantage that it is simple to manufacture, as the dielectric resonators used are of the same cross section as the main dielectric line. The resonators are spaced only $3\lambda_g/4$ apart, on alternating sides of the main line.

The design procedure is based on conventional synthesis [3], and because of the extreme analytical complexity, the stub coupling properties are determined through measurement. A fabricated filter gave excellent performance, and is very easy to tune.

In order to combat the high cost involved in millimeter-wave component manufacture, this trial filter was scaled to work at $X$-band, and use was made of a plastic with low dielectric constant, giving a maximum frequency band stretching from about 8.5 to 10 GHz. If a dielectric with $\epsilon_r = 9$ is used, with dimensions of $12.5 \times 10$ mm, this bandwidth would span the range 6.05 to 12 GHz, which is nominally the same as that of normal $X$-band guide.

## II. Stub Characterization

The reflection coefficient versus frequency of a number of dielectric resonators of the same cross section as the center dielectric strip of an NRD guide was measured, with dimensions defined as shown in Fig. 1 The guide was terminated in a matched load, and resonant frequencies and bandwidths were obtained from the measurements. It was found that the resonant frequency of the stubs is almost entirely determined by the length of the stub, with only a secondary dependence on the tightness of coupling to the center strip. At the same time, the relative stub bandwidth is only a function of the coupling to the guide for a given stub length. Fig. 2 shows the measured resonant frequency versus stub length for different coupling values. The 3-dB bandwidth of a stub versus gap for a number of stub lengths is shown in Fig. 3.

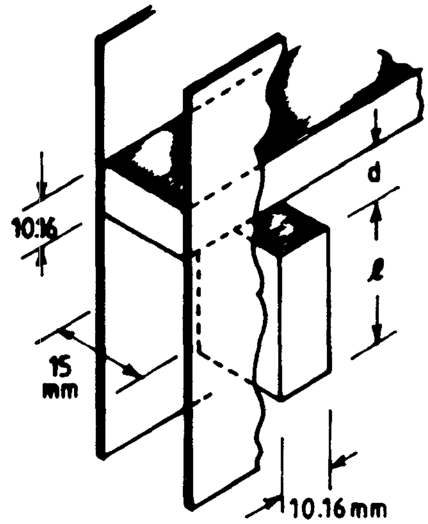


Fig. 1. Dimensions of dielectric stubs.

Fig. 4 shows the equivalent circuit of the stub connected to the terminated main dielectric line. The input admittance as seen from A-A′ is given by

$$y_{\text{in}} = 1 + jn^{-2} \tan k_z l_0 \tag{1}$$

where $k_z$ is the guide wavenumber, $f_0$ the stub and filter center resonant frequency, and $l_0$ the stub length. Under Richard's transform [3], the input admittance for a capacitor is given by

$$y_C = jC \tan k_z l_0 \tag{2}$$

and comparison with (1) shows that

$$C = 1/n^2. \tag{3}$$

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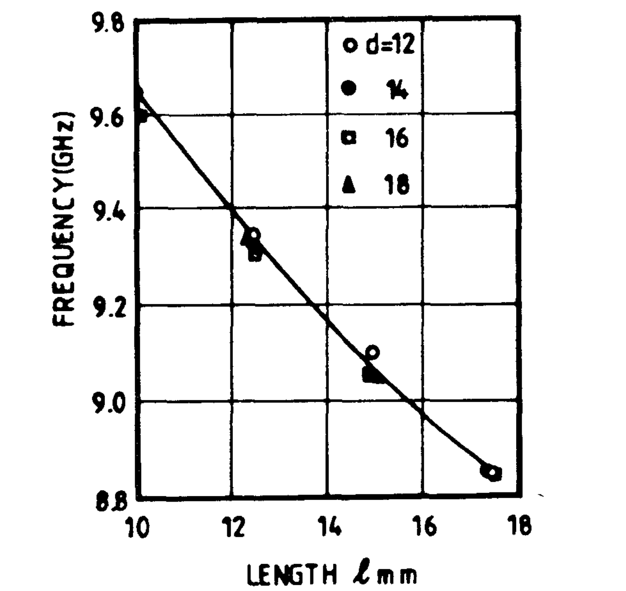


Fig. 2 Measured resonant frequency versus stub length for various coupling values.

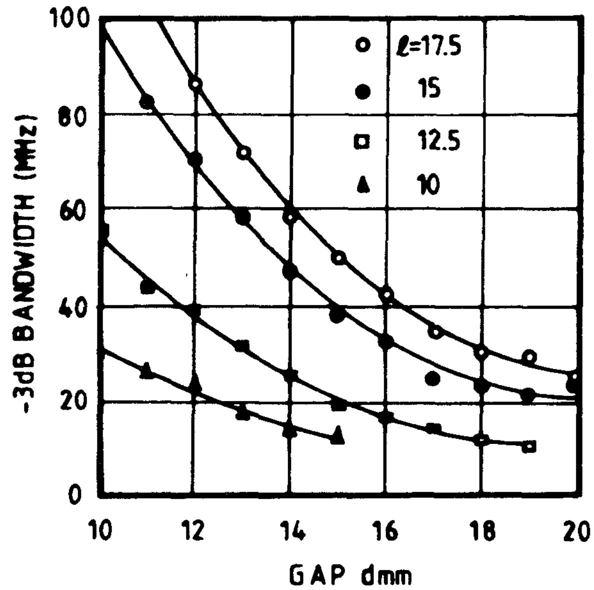


Fig 3. Bandwidth of stubs for different coupling values.

The modulus of the reflection coefficient is given by

$$|\Gamma| = \left(4n^4 \cot^2 k_z l_0 + 1\right)^{-1/2}. \tag{4}$$

At the half-power frequency $f_c$, the wavenumber is $k_z'$; therefore,

$$4n^4 \cot^2 k_z' l_0 = 1. \tag{5}$$

Substituting, we find that

$$k_z' = \left(\cot^{-1} C/2\right) l_0 \tag{6}$$

where $C$ will be known from the synthesis procedure. The half-power frequency for each stub is obtained by solving for $k_c$ simultaneously, from [4],

$$k_z' = \sqrt{k_c^2 \epsilon_r - (\pi/a)^2 - \beta^2} \tag{7}$$

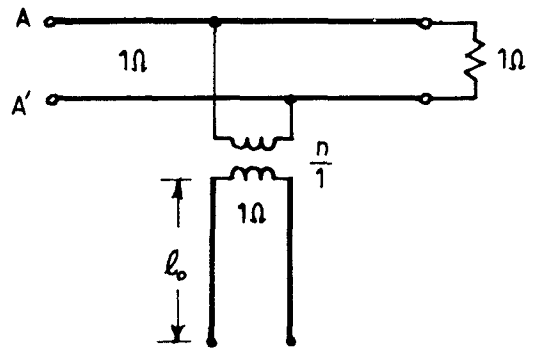


Fig. 4. Equivalent transmission line circuit for NRD stub.

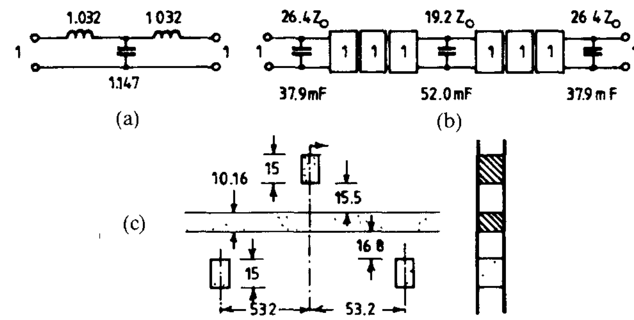


Fig. 5. Development of a microwave filter prototype. (a) Lumped element filter. (b) Microwave realization. (c) Physical construction.

with

$$\beta \tan \beta b/2 = \epsilon_r \alpha \tag{8}$$

$$\alpha^2 + \beta^2 = k_c^2(\epsilon_r - 1) \tag{9}$$

$$f_c = \frac{k_c}{2\pi\sqrt{\mu_0 \epsilon_0}}. \tag{10}$$

The $-3$-dB bandwidth of the stub is then related to the half-power frequency by

$$B = 2(f_0 - f_c). \tag{11}$$

The propagation velocity in the stub is known, and consequently the stub length can be calculated if the stub terminating impedances are known. In [5], the open end of such a stub is evaluated by the author, and an expression derived by which the resonant length of the stub can be calculated. Using the (7)–(9), and setting $k_c = k_0$, $k_z' = k_z$, we obtain $l_0$ from

$$\frac{\omega\mu}{k_z}\left[1 - \frac{\beta^2}{k_0^2 \epsilon_r}\right] = \frac{\omega\mu}{\alpha} \tan \tfrac{1}{2} k_z l_0. \tag{12}$$

However, while the calculated value of stub resonant frequency agrees with the measured value to within about 1.3 percent, this is not accurate enough for the narrow bandwidth filters under consideration; under such circumstances, the designer must in any case resort to prior measurement or tuning. The former method is used here.

## III. Filter Design

The design of a bandstop filter using rectangular stubs is illustrated by means of an example. Fig. 5(a) shows a third-order Chebyshev low-pass filter prototype with 0.1-dB

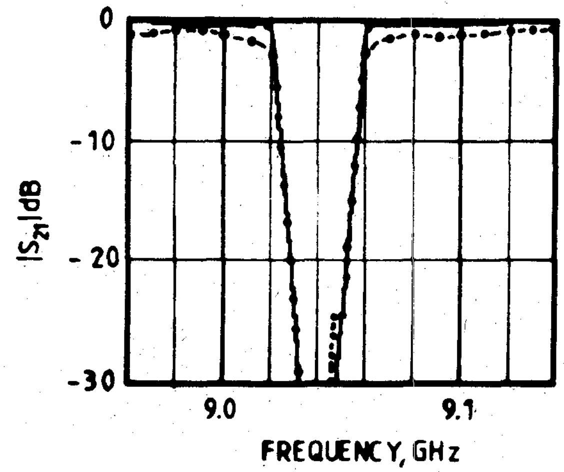


Fig. 6. Frequency response of the realized filter. Measured values are shown dashed.

passband ripple, a design bandwidth of 60 MHz, and a center frequency of 9.04 GHz. (These values were chosen because dielectric resonators of the correct length were already available.) No impedance scaling is performed, because the design is normalized to the waveguide impedance. At the center frequency of 9.04 GHz, $k_{z_0}$ is calculated from (7)–(9) with $k_c = k_0$ as 88.52. The frequency at bandedge is 9.01 GHz, and the corresponding wavenumber $k_{z_c}$ is calculated to be 85.97.

The expression for the Richards' variable is modified:

$$\Omega_c = \tan\left(\frac{\pi}{2} \cdot \frac{k_{z_c}}{k_{z_c}}\right) = 22.06.$$

Bandwidth scaling is performed by dividing all the reactive elements by the value of the transformed frequency variable at the band-edge.

Three unit elements are introduced to each end of the filter, and transformed across the inductors at the extremities as shown in Fig. 5(b). After each Kuroda transform, the impedance level of the transformed unit element increases, but because of the very low reactance values caused by the narrow bandwidth, the unit element values remain at unity to good approximation. They can consequently be realized directly.

The stub lengths are determined by the center frequency, and are obtained from Fig. 2. The capacitance values for each of the shunt capacitors are inserted in (6) and the −3-dB bandwidths determined from (7)–(11). Fig. 3 then yields the coupling gaps. The stubs are fitted to alternating sides of the main dielectric strip.

## IV. Measurements

The filter constructed in this way did not perform satisfactorily, because of coupling between the resonators. Consequently, first two and then four additional unit elements were transformed into the circuit from each end, in order to reduce this coupling. Fig. 6 compares the theoretical frequency response to the measured values for the case where two additional unit elements are introduced at each end. It was found that the stubs were sufficiently decoupled in this case.

## V. Conclusions

The design procedure described in this paper is fast and simple, and gives filters with properties that agree well with the design values. It is extremely easy to tune the filter or make adjustments in the design, as this can be achieved by shifting the resonators. The filter has only three unit elements between each pair of stubs.

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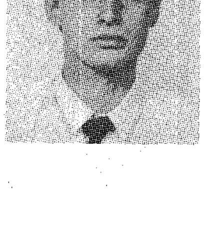

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