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60 GHz Bandpass Filter Using NRD Guide E-Plane Resonators

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SUMMARY A novel structure of bandpass filter using NRD guide E-plane resonators is proposed. The NRD guide E-plane resonator is constructed by inserting metal foils in the E-plane of NRD guide. Simulation, fabrication and handling of the filter are very easy because each resonator is separated by simple metal foils. Chebyshev response bandpass filters are designed based on the theory of direct-coupled resonator filters and fabricated at 60 GHz. Simulated and measured filter performances agreed well with the design specifications. Insertion losses of the fabricated filters were found to be around 0.3 dB for 3-pole filter and 0.5 dB for 5-pole bandpass filter, respectively.

key words: *millimeter wave bandpass filter, NRD-guide, NRD guide E-plane resonator, millimeter wave integrated circuits*

1. Introduction

With the rapid advance of information technology, millimeter wave applications have attracted much attention to realize high-speed and wide-band communication systems. Actually, several millimeter wave wireless systems have been developed using Non-Radiative Dielectric (NRD) waveguide [1]–[3] as well as other transmission media [4].

For the construction of such wireless systems, millimeter wave filters play an important role [5]–[7]. Several bandpass filters suitable for NRD guide circuit applications have been also reported so far [8]–[10]. However, they are by no means convenient to put to practical use. In the case of bandpass filters using ceramic or dielectric resonators [8], [9], it is difficult to hold resonators at position. A bandpass filter which has metal foils inserted in the H-plane of NRD guide requires very accurate simulation and fabrication technique, because small gap between metal foils and conductor plates of NRD guide makes the electromagnetic field concentrate there tightly [10].

In this paper, the NRD guide E-plane resonator which is constructed by inserting metal foils in the E-plane of NRD guide is proposed. Simulation and fabrication of this filter is very simple because any discrete ceramic or dielectric resonators are not needed and any concentrations of the electromagnetic field are not observed. Based on this technique, Chebyshev response 3-pole and 5-pole bandpass filters are designed, and fabricated at 60 GHz. Measured frequency responses of the fabricated filters agree satisfactorily with the simulated prediction, and insertion losses of them are found to be quite small.

2. NRD Guide E-Plane Resonator

The structure of the NRD guide E-plane resonator is shown in Fig. 1, where the part of the upper conductor and dielectric strip of NRD guide are not drawn for the explanation. NRD guide consists of PTFE strips with height a of 2.25 mm, width b of 2.50 mm, and relative permittivity ε_r of 2.04 at 60 GHz, inserted in a below cutoff parallel metal plate waveguide [1]. NRD guide with this dimensions have the single-mode operation over the frequency range from 54.9 GHz to 66.4 GHz. The NRD guide E-plane resonator is composed of two metal foils with a length M which are placed at position $a/2$ of PTFE strips in parallel with the E-plane, since the LSM_{01} mode of NRD guide has a cut-off condition in the metal foil part when the space between the metal foil and the conductor plate is below 2.02 mm. The distance between two metal foils is equal to the resonator length L. It is assumed that the metal foils use copper foils and that the conductor plates of NRD guide use aluminum plates.

The values of resonant frequency f_0, and unloaded Q-factor Q_u are computed by using a 3-dimensional electromagnetic simulator Ansoft HFSS Ver.8.5 at 60 GHz band. The variation of the resonant frequency f_0 versus the length L is shown in Fig. 2 by black circle, where the length M of the metal foils between the resonator and input/output NRD guide are equal to 3.00 mm so as to be a weak coupling. Fitting curve (f_0=0.702L^2 − 8.03L + 80.99) deduced from the calculated results is also shown in Fig. 2 by black line. The resonant frequency f_0 can be calculated from this curve and the length L as f_0=60.5 GHz is equal to 3.84 mm. More-

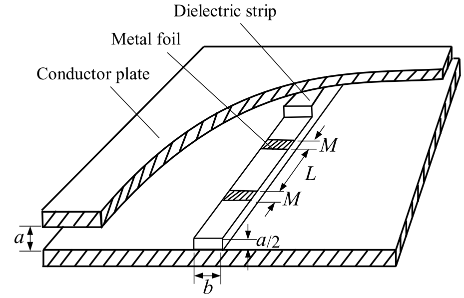

Fig. 1 The NRD guide E-plane resonator.

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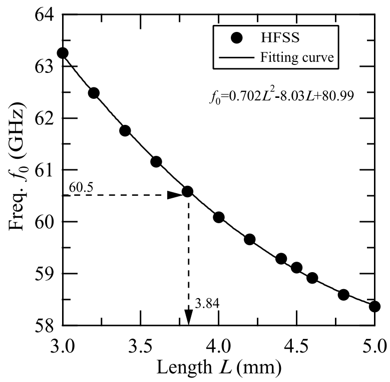


Fig. 2 The variation of the resonant frequency f_0 vs. the length L.

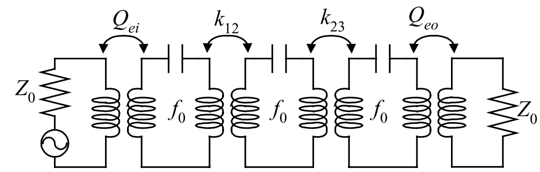


Fig. 3 Equivalent circuit for the 3-pole bandpass filter.

over, the value of unloaded Q_u is computed using values of the ideal loss shown in the following; the conductivity of the copper foil: $\sigma_{cu} = 58 \times 10^6$ S/m, aluminum plate: $\sigma_{al} = 36.5 \times 10^6$ S/m and the loss tangent of PTFE: tan $\delta = 2 \times 10^{-4}$. As a result, we can get the values of the Q-factor in the following; Q_c=6400, Q_m=14000, Q_d=4100 and Q_u=2100, respectively, where Q_c is due to the loss of the aluminum conductor plate of NRD guide, Q_m is due to the loss of the copper metal foil inserted in the E-plane, and Q_d is due to the dielectric loss. It is found that the unloaded Q_u is mainly determined by the dielectric loss, since the electric field is concentrated in the dielectric part.

3. 3-Pole Chebyshev Bandpass Filter

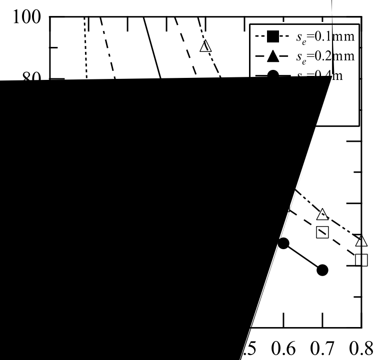
The 3-pole Chebyshev bandpass filter is designed using the proposed resonators. The filter has a center frequency f_0 of 60.5 GHz, 3 dB passband width of 2 GHz, and a passband ripple of 0.1 dB. This filter is designed based on the theory of direct-coupled resonator filters. The equivalent circuit of the 3-pole bandpass filter is shown in Fig. 3. The values of external Q-factor Q_e and coupling coefficient k_{ij} can be calculated easily by using the well-known formulas [11]. From the specifications of the filter, we get the element values of Q_e=Q_{ei}=Q_{eo}=36.67 and k=k_{12}=k_{23}=0.02586.

3.1 External Q-Factor

The required external coupling between the first/last resonators and the input/output lines is too large to be adjusted by changing only the metal foil length s_e. In order to overcome such a difficulty, a gap of width w_e is introduced at the center of the metal foil as shown in Fig. 4. The gap makes the external coupling stronger due to the field propagated in the gap. The S-parameters with different values of s_e and w_e are computed by using HFSS. The value of the external Q_e is obtained from the computed S-parameters using the following formulas [11].

$$Q_e = Q_L \tag{1}$$

$$\because \ \frac{1}{Q_L} = \frac{1}{Q_u} + \frac{1}{Q_{ei}} + \frac{1}{Q_{eo}}, \quad Q_u = Q_{eo} = \infty \tag{2}$$


100
80
s_e=0.1mm
s_e=0.2mm
0.6
0.7
0.8

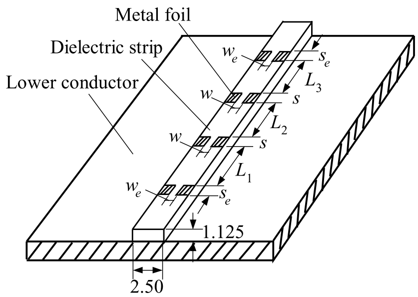
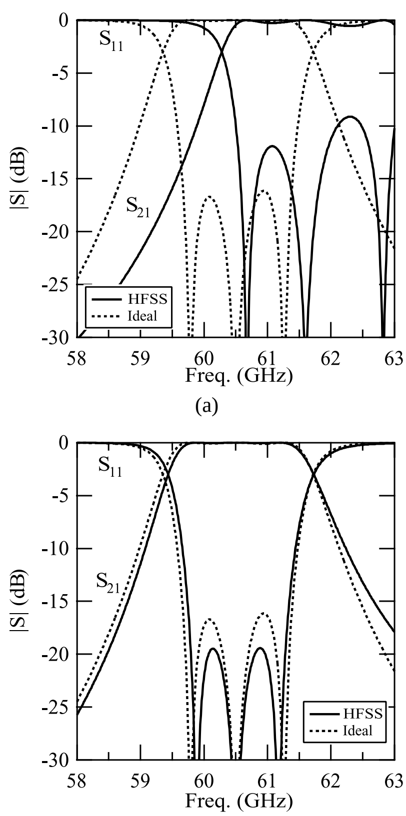


Fig. 8 The cross sectional view of the 3-pole bandpass filter structure.



(a)

(b)

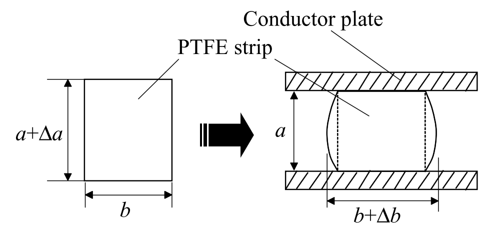
Fig. 9 The simulated results of the frequency responses for the 3-pole bandpass filter. (a) Before adjustment, and (b) After adjustment.

about 61.5 GHz and its value is 1 GHz higher than the specification value. The reason for the discrepancy may be due to the presence of resonators at both sides, one of which is ignored at the initial stage of design.

In order to improve the frequency response designed so far, diagnosis is performed to estimate the values of the each filter elements using the circuit simulator Agilent ADS2004A provided with optimization function [12], [13]. The adjusted values are determined from the difference between the estimated and design values, and the calculated results with the fitting curve by HFSS shown in Figs. 2, 5, and 7. The simulated frequency response of the adjusted filter and the ideal response are shown in Fig. 9(b) by solid line and dashed line, respectively. The frequency response by

(a) (b) (c)

Fig. 10 Photograph of the 3-pole bandpass filter. (a) The actual structure, (b) The metal foil pattern part, and (c) The base part.



(a) (b)

Fig. 11 The deformation of the PTFE strips. (a) PTFE strips, and (b) PTFE strips with conductor plates.

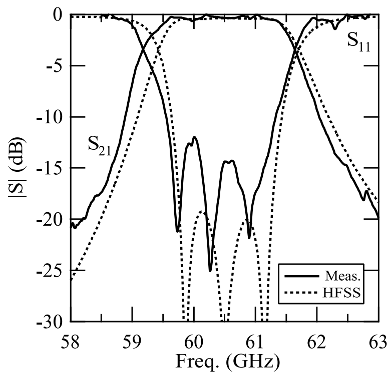
HFSS agrees considerably with the ideal one. The final dimensions are L_1=L_3=4.94 mm, L_2=4.68 mm, s_e=0.60 mm, w_e=0.70 mm, s=0.50 mm, and w=0.20 mm.

3.4 Fabrication and Measurement

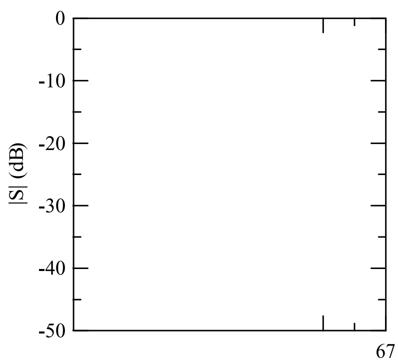
The 3-pole bandpass filter designed above is fabricated by using a numerical controlled processing machine, a photo-lithograph, and a wet etching process. The numerical controlled processing machine is used to make the dielectric strip part. The photo-lithograph and the wet etching processed are used to make the metal foil pattern. The photograph of the fabricated 3-pole bandpass filter is shown in Fig. 10.

The filter is measured by using a vector network analyzer through COAX-WG transitions and WG-NRD transition horns [14]. A calibration is taken by using a standard waveguide calibration kit and the through line of NRD guide, because there are not any standard NRD guide calibration kits.

The frequency response of the fabricated filter is measured at 25°C. However, the measured center frequency is lower than the designed one about 0.5 GHz because of the change of the guide wavelength due to a slight deformation of the PTFE strips as shown in Fig. 11. In the present fabrication, the height of PTFE strip $a + \Delta a$ is slightly higher than the height a between two conductor plates to avoid an air gap between the strip and the conductor plate, which causes parasitic LSE_{01} mode, since the high precise fabrication equipment is not possessed. In order to compensate the change of the center frequency, the lengths L of each


0
-5
-10
-15
-20
-25
-30
|S| (dB)
58
59
60
61
62
63
Freq. (GHz)
S_{11}
S_{21}
Meas.
HFSS

(a)


0
-10
-20
-30
-40
-50
|S| (dB)
67

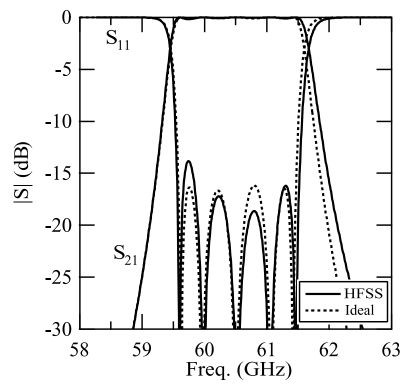
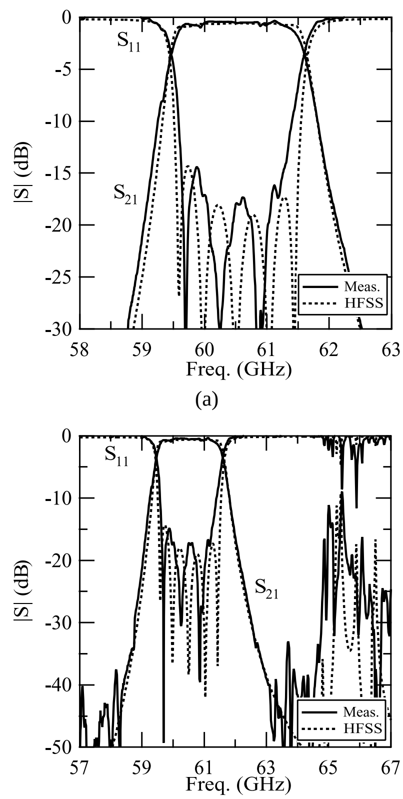


Fig. 15 The simulated results of the frequency reposes for the 5-pole bandpass filter after adjustment.



(a)

(b)

Fig. 16 The measured results of the frequency responses for the 5-pole bandpass filter. (a) Narrow band response, and (b) Wide band response.

wide band response is also measured from 57 to 67 GHz. As can be seen from Fig. 16(b), the sharper skirt characteristic is realized compared with the 3-pole bandpass filter and the first spurious resonance appears at around 65 GHz, which agrees with the simulated one.

5. Conclusions

By using the novel NRD guide E-plane resonator, the 3-pole and 5-pole bandpass filters have been designed and fabricated at 60 GHz band. The fabricated filters satisfied well the design specification, and validated the proposed resonator. Moreover, the insertion losses of them are found to be sufficiently small. We expect that the filters can be applied readily for high-speed and broadband wireless systems using millimeter wave.

Acknowledgments

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