

An X-band bandpass WR-90 filtering antenna with offset resonators

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Abstract: A novel structure of filtering antenna working at a center frequency of 10 GHz with a fractional bandwidth of 10% is presented in this letter. It consists a third-order Chebyshev filter with resonators coupled by shifted layers and an array of two aperture antenna elements in the end. This new structure without any iris is very suitable for machining layer by layer. Therefore, it would be a solution in some special conditions in which traditional ways of manufacture could not be realized. In the end, the antenna array is fabricated by computer numeral control (CNC) milling technology. Conclusion and analysis to the measurement are presented, as well as the methods for improvement.

Keywords: Chebyshev filter, filtering antenna, offset resonators, X-band antenna array, aperture waveguide antenna

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

Antennas are important components in communication system. As [1], [2] and [3] mention, many waveguide antenna arrays are designed with many small slots arranged on the wall for radiation. However, the return loss would be large, which lead to a low radiation efficiency of the antenna arrays.

The concept of filtering antenna is already raised in [4] in 2002. The topology in conventional way is shown in Fig. 1(a), where a matched antenna is connected to the filter. However, it is a waste of space and time to make them matched. [4] mentioned a novel configuration (Fig. 1(b)) in which the filter integrated with the open-ended waveguide antenna directly. And this new structure of antenna has been tested by the author in [5] to prove the realization. Besides, some work also could be found in [6], [7] and [8] which did much research about this theory. Therefore, more space is available to arrange several antenna elements to make them a larger array if needed.

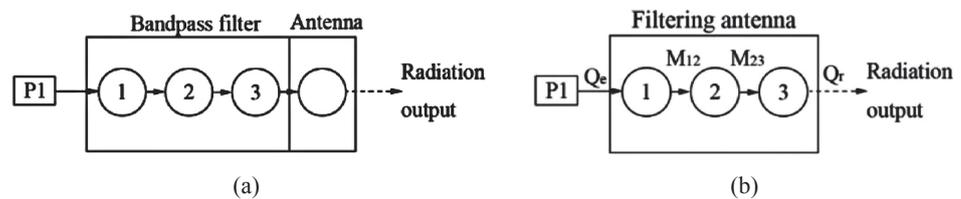


Fig. 1. (a) Topology of conventional antenna. (b) Topology of the design of filtering antenna.

A novel coupling method is mentioned in [9]. By shift layers to different directions, they are coupled perfectly the same as with iris. However, this method could save more space than that in the way of coupling by iris. In every resonator, the tune direction is not along the transmission in conventional way. This method is adopted in this design to reduce the whole configuration to a minimum space. Especially, it is very helpful for the components machined layer by layer or these working in a very high frequency, because the size of components would be very restrictive in high frequencies.

For saving space mostly, this paper presents a novel way to synthesize two antennas into a 1×2 array in detail which also consists of a third-order Chebyshev filter designed with the theory introduced in [10]. Simulation and measurement both agree with the theory well.

2 Theory

2.1 Coupling matrix

[7] introduces a way to figure out the external quality factor and coupling coefficients which are needed for a certain filter. These values in a filtering antenna is presented in Fig. 2. After making a Chebyshev filter, the external quality factor Q_e in the output port will be replaced by a radiation quality factor, which is equal to the original factor ($Q_r = Q_e$). So firstly, the parameters of the filter are calculated as follows.

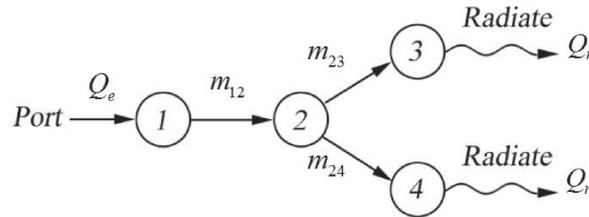


Fig. 2. Topology of the filtering antenna mentioned in this paper. Q_e is the external quality factor at the input port. m_{12} , m_{23} and m_{24} are the coupling coefficients between the resonators. Q_r is the radiation factor which equals to Q_e .

According to [7], the Chebyshev coupling matrix M is given as

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix} = \begin{bmatrix} 0 & 0.1032 & 0 & 0 \\ 0.1032 & 0 & 0.0730 & 0.0730 \\ 0 & 0.0730 & 0 & 0 \\ 0 & 0.0730 & 0 & 0 \end{bmatrix} \quad (1)$$

And the external quality factor Q_e and radiation quality factor Q_r ,

$$Q_e = Q_r = 8.5158 \quad (2)$$

$$Q = \begin{bmatrix} \frac{1}{Q_e} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{Q_r} & 0 \\ 0 & 0 & 0 & \frac{1}{Q_r} \end{bmatrix} \quad (3)$$

$$A = Q + pU - i \times M \quad (4)$$

Here, $p = \omega/\omega_c - \omega_c/\omega$. ω_c is the central frequency of the passband. U is a 4-by-4 identity matrix. Substituting (1) and (3) into (4), S_{11} could be obtained,

$$S_{11} = \left| \frac{1 - 2A_{11}^{-1}}{Q_e} \right| \quad (5)$$

The calculated response is plotted in Fig. 3.

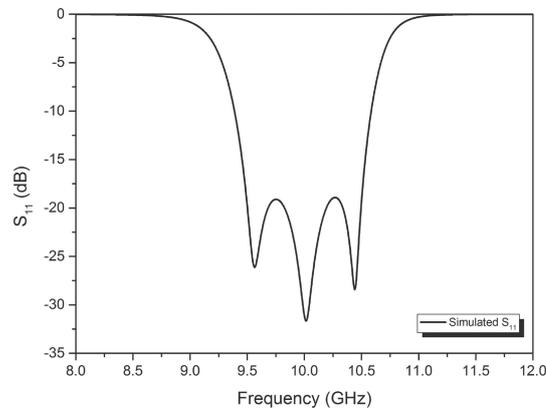


Fig. 3. Theoretical reflection coefficient calculated with the coupling matrix by Matlab.

What is shown in Fig. 3 performs the same as a third-order Chebyshev filter in return loss graph, in spite of two output ports in the composition.

2.2 Extraction of Q and M values

After calculation of the Q and M values, the next is to extract these values from realized configuration. It is very important to decide the initial dimension of the structure before optimization. Here are some distances which are for extracting the certain Q and M values showed in Fig. 4.

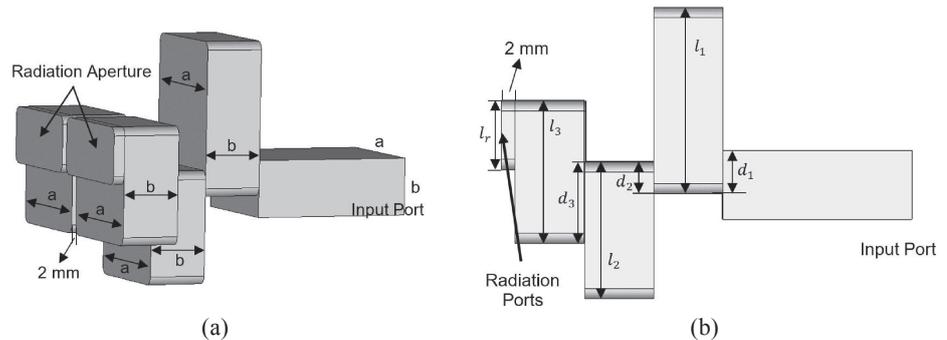


Fig. 4. The whole structure of the filtering antenna array. (a) 3D view. (b) Side view. a and b are the size of WR-90 waveguide which are 0.864 mm and 0.432 mm separately. l_1 , l_2 , l_3 , l_r , d_1 , d_2 and d_3 are dimensions to extract.

According to the methods mentioned in [5], initial values of l_1 , l_2 , l_3 , l_r , d_1 , d_2 and d_3 could be extracted for optimization. The variation of the parameters is presented in Table I.

After optimization, the simulated result is shown in Fig. 5.

Fig. 6 presents the realization of the array for processing layer by layer. Because of the radiation apertures on Layer 4, it should be 2 mm thicker than other three.

Table I. The variation of the dimensions before and after optimization.

Parameters	Initial Values (mm)	Optimized Values (mm)
l_1	27.28	27.51
l_2	20.43	20.17
l_3	21.33	20.93
l_r	9.85	10.14
d_1	6.13	6.36
d_2	4.42	4.67
d_3	12.32	11.90

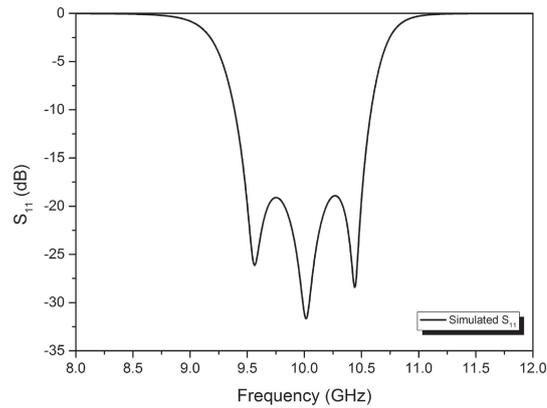


Fig. 5. Simulated reflection coefficient by CST.

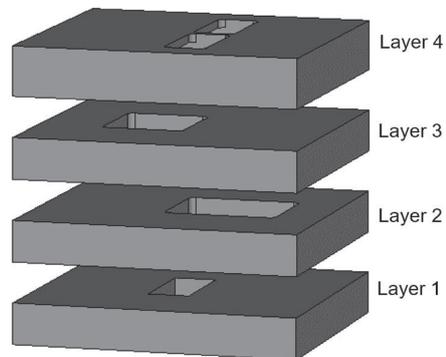


Fig. 6. Realization of the design in Fig. 4 after optimization.

3 Fabrication and measurement

Fig. 7(a) shows the machined antenna array processed by CNC milling technology.

The measured S_{11} does not perform very well (Fig. 8). However, it agrees with the simulated response in which there is an air gap between every two layer.

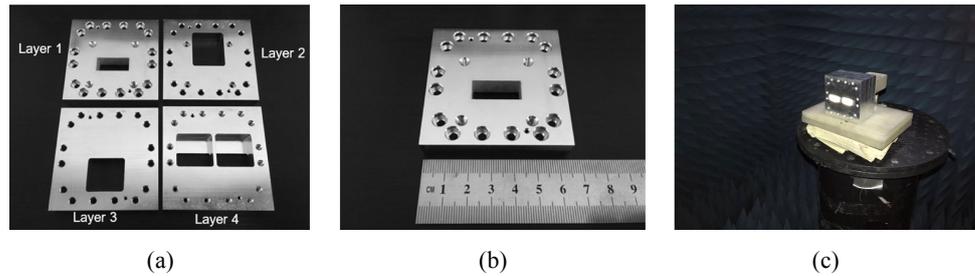


Fig. 7. Machined components of the antenna array with CNC technology. (a) Machined four layer. (b) The size of one layer. (c) Photograph of measurement.

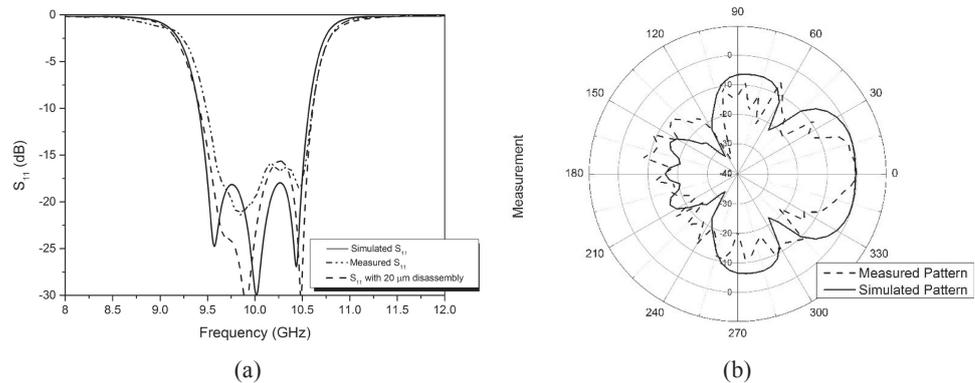


Fig. 8. (a) Measured reflection coefficient compared with simulation of disassembly of 20 μm air gap between every two layers and optimized result. (b) Measured beam pattern compared with simulated one.

4 Conclusion

As Fig. 8(a) shows, the measurement is almost the same as the simulated result with disassembled layers of 20 μm between every two layers. The air gap between every two layers leads to the leakage of power, which results in the response about 4 dB lower than the designed one. Moreover, the beam pattern in Fig. 8(b) is also affected by the leakage. On the other side, it can be seen that in Fig. 7(c), during the measurement, the panel does not perfectly match the component, so that it need some paper below the bottom plate to keep it constant, which lead to the axis of the array is not absolutely along horizon and not at the same height with the source antenna.

Some methods could be adopted to improve the result of this design. For example, 3D printing technology is very suitable for this array, because with this technology, the structure would be made as an integral whole, which has no any air gap between layers.