Design and Fabrication of Square Shaped Ceramic Resonator Filter for NRD Guide Integrated Circuit at 60GHz

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Abstract **— Cylindrical ceramic resonators with $TE_{0n\delta}$ resonant modes are usually used at centimeter frequencies due to their low loss natures. However they have a difficulty in making wide-band band-pass filters in the millimeter-wave region because of the poor coupling factors between the resonators and input/output waveguides. Having this fact in mind, we propose the use of square shaped ceramic resonators. From the theoretical and experimental investigations, it is confirmed that the coupling factor of the square shaped ceramic resonator with $EH_{12\delta}$ resonant mode is larger than that of the cylindrical one.**

I. INTRODUCTION

Millimeter-waves have attracted much attention for the construction of novel wireless systems. Actually, several kinds of millimeter-wave applications such as multiple TV signal distribution [1] and wireless LAN [2] have been proposed in many institutes, laboratories, and companies. In such systems, it is strictly necessary to develop low-loss and wide-band band-pass filters with the bandwidths of more than 2GHz. Indeed a band-widening technique has been reported by using printed transmission lines [3]. In order to improve the excess insertion loss of the band-pass filters, low-loss ceramic resonators are preferable to the printed resonators, because the printed resonators suffer from a lot of transmission losses at millimeter-wave frequencies. The $TE_{0n\delta}$ mode ceramic resonators have a low-loss nature and are usually used at centimeter frequencies [4], however, they have a difficulty in making the wide-band band-pass filters in the millimeter-wave region due to the weak coupling between the resonators and input/output waveguides. From view point of band-widening, the use of $EH_{nm\delta}$ modes, dealt with spurious modes, has been proposed [5].

With this in mind, we newly propose the use of square shaped ceramic resonators to obtain more tight coupling performance in this paper. From the theoretical investigations based on the high frequency structure simulator (HFSS), it is cleared that the $EH_{12\delta}$ resonant mode of the square shaped resonator is suitable for wide-band applications compared with the $EH_{11\delta}$ resonant mode of the cylindrical resonator. Moreover it has a great advantage such as sharp skirt cut off performance as well.

II. DESIGN DIAGRAM OF SQUARE SHAPED CERAMIC RESONATORS

Figure 1 shows the structure of a square shaped ceramic resonator for NRD guide integrated circuits, where the thin square ceramic piece is located at the horizontal mid-plane in a below cut off parallel metal plate waveguide. In order to keep the symmetrical shape, the ceramic piece is supported by thin Teflon piece which acts as a cutoff guide. Since the resonator is fed by NRD guide, we assumed an electric wall on the y-z plane and a magnetic wall on the x-y plane, respectively. Figure 2 shows the calculated

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resonant frequencies for each resonant mode versus the side length of the square ceramic piece, where the relative permittivity and thickness of the ceramic piece was set to be 25 and 0.4mm, respectively, and the metal plate separation is selected to be 2.25mm so as to be less than half a free space wavelength. It seems that several types of resonant modes appear in the 60GHz frequency band. The rough sketches of the electric field distributions for some modes are shown in Fig.3, where the nomenclature of these modes is referred to [6]. From among these modes, an $EH_{12\delta}$ mode is chosen as an operating mode because the resonant frequencies of neighboring $HE_{10\delta}$ and $HE_{11\delta}$ modes are away from that of the $EH_{12\delta}$ mode.

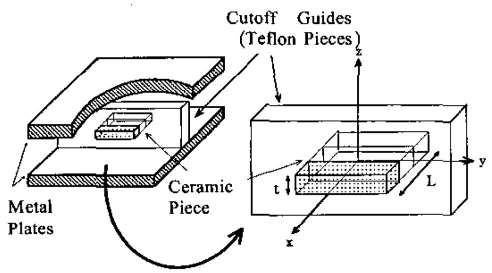

Fig. 1. Structure of square shaped ceramic resonator inserted in an NRD guide housing

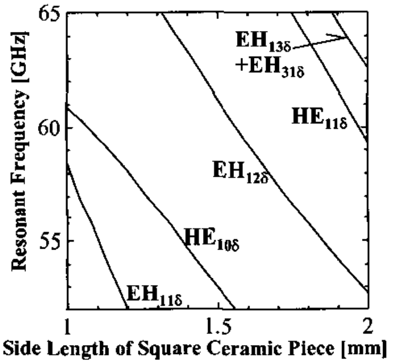

Fig.2 Calculated resonant frequency versus the side length of the square ceramic piece

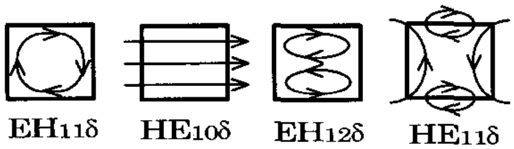

Fig.3 Rough sketches of the electrical fields of the resonant modes in the square ceramic resonators

III. Coupling Characteristics of Square Ceramic Resonators

The coupling coefficient of the $EH_{12\delta}$ mode was calculated as shown in Fig. 4, where the side length of the ceramic piece is chosen to be 1.67mm so as to tune at 57.5 GHz from Fig. 2. For comparison, the calculated coupling coefficient of an $EH_{11\delta}$ mode cylindrical ceramic resonator is shown in this figure [5]. From this result, it is confirmed that the coupling factor of the square shaped ceramic resonator is larger than that of the cylindrical one as predicted. The measured coupling coefficient is also plotted in this figure. Agreement between theory and measurement is quite satisfactory.

Figure 5 shows a comparison between singly loaded Q factors of $EH_{12\delta}$ square shaped resonator and $EH_{11\delta}$ cylindrical resonator. In this case, the coupling factor between the square shaped resonator and input/output ports is also higher than that of cylindrical resonator, and validity of prediction was confirmed because the measured loaded Q factors agreed with the calculated values.

By using these results, we have investigated a relative bandwidth of the $EH_{12\delta}$ mode band-pass filter. Assuming the 3-pole, 1dB Chebyshev ripple band-pass filter as shown in Fig. 6(a), the relative bandwidth against the coupling spacing are derived as shown in (b). For comparison, the calculated relative bandwidth of the same type filter using $EH_{11\delta}$ mode cylindrical resonator is shown in Fig. 7. From these results, it is clear that the relative bandwidth of more than 10% can be kept by using the square ceramic resonator filter, while that of the cylindrical ceramic resonator filter is no more than 3%.

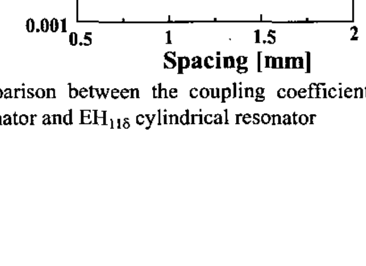

Fig.4 Comparison between the coupling coefficients of $EH_{12\delta}$ square resonator and $EH_{11\delta}$ cylindrical resonator

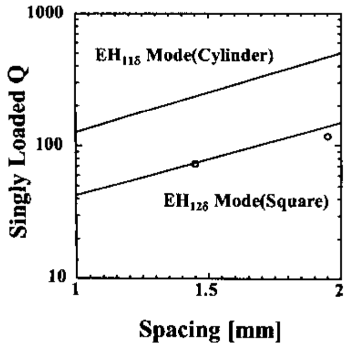

Fig.5 Comparison between the loaded Q factors of $EH_{12\delta}$ square resonator and $EH_{11\delta}$ cylindrical resonator

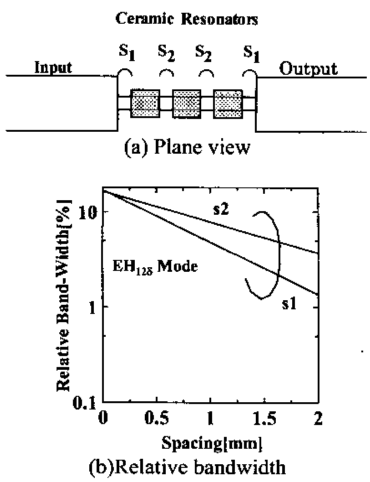

Fig.6 Calculated relative bandwidth versus coupling spacing in 1dB Chebyshev ripple type 3-pole $EH_{12\delta}$ square resonator filter

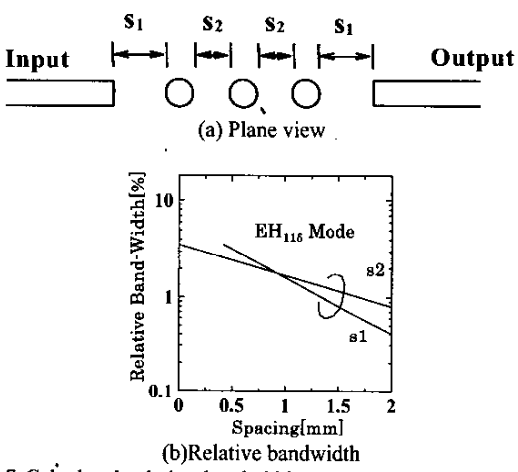

Fig.7 Calculated relative bandwidth versus coupling spacing in 1dB Chebyshev ripple type 3-pole $EH_{11\delta}$ cylindrical resonator filter

IV. DESIGN AND FABRICATION OF SQUARE CERAMIC RESONATOR LOADED NRD GUIDE BAND-PASS FILTER

Assuming that the filter response is 5-pole, 1dB Chebyshev ripple band-pass filter with the bandwith of 2.3GHz at the center frequency of 57.5GHz, the coupling coefficients and singly loaded Q factor as shown in Fig.8 are decided to be

$$Q_{01} = Q_{56} = 56.123$$
$$k_{12} = k_{45} = 0.024924$$
$$k_{23} = k_{34} = 0.021022$$

and then, each spacing is derived from Fig.4 and 5 as follows.

$$s_1 = s_6 = 1.48[mm]$$
$$s_2 = s_5 = 2.00[mm]$$
$$s_3 = s_4 = 2.34[mm]$$

The calculated and measured transmission losses are shown in Fig. 9 as solid and dotted curves, respectively. Agreement between the simulation and measurement is quite satisfactory. The excess insertion loss was found to be 0.4dB, which is close to the theoretical value of 0.3dB. For comparison, the measured transmission loss of the 5-pole, 1dB Chebyshev ripple band-pass filter using the $EH_{11\delta}$ mode cylindrical ceramic resonators, which is designed at 60.5 GHz, is also shown in this figure as a dotted curve [5]. It is obvious that the skirt cutoff performance of the square shaped resonator loaded filter can be improved in the higher frequency region because the resonant frequency of the neighboring $HE_{11\delta}$ modes is away from that of the $EH_{12\delta}$ mode.

VI. CONCLUSION

Band-widening technique of the ceramic resonator loaded NRD guide band-pass filter has been developed. It was found that the $EH_{12\delta}$ mode in the square ceramic resonator has a tight coupling factors between resonators and input/output ports compared with those of the cylindrical ceramic resonators The $EH_{12\delta}$ mode band-pass filter has great advantages such as wide pass-band beyond 1GHz as well as sharp skirt cutoff performance in the rejection band. It is confirmed that the $EH_{12\delta}$ mode is suitable for construction of the wide-band band-pass filters in millimeter-wave region. The issue to be considered next is to build the EH12δ mode filters in the NRD guide transmitter and receiver for applications to the multi-TV signal distribution system and multiple access wireless LAN.

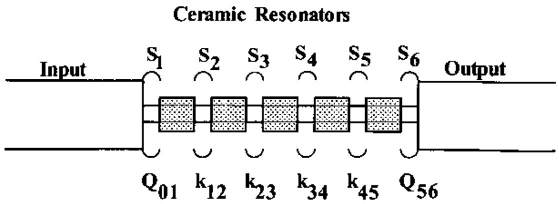

Fig.8 Plane view of the 5-pole square ceramic resonator loaded bandpass filter

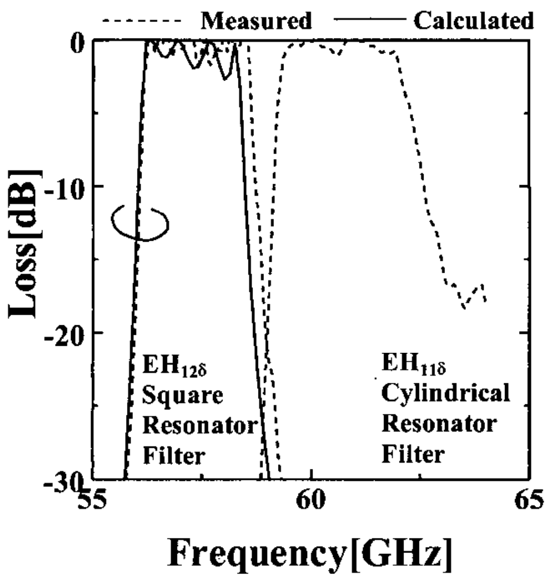

Fig.9 Performance of the 5-pole square ceramic resonator loaded NRD guide band-pass filter

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