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Band-pass filters with $(Zr_{0.8}, Sn_{0.2})TiO_4$ dielectric resonators

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Band-pass filters with dielectric resonators of $(Zr_{0.8}, Sn_{0.2})TiO_4$ ceramic materials (ZST) were developed for X-band applications. The ZST materials exhibit a dielectric constant of about 36.8 and low loss in microwave range. A *Qxf* product higher than 50,000 was achieved for the ZST samples with 0.2 % wt NiO sintering addition. The external coupling was performed using microstrip lines on a substrate of 9.22 dielectric constant and 0.635 mm height. Filters with a minimum insertion loss between 0.46 dB and 1.74 dB, the bandwidth between 40 MHz and 170 MHz and with the central frequency around 10 GHz were manufactured.

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1. Introduction

Recent investigations showed that ceramic based $(Zr_{0.8}, Sn_{0.2})TiO_4$ ternary compounds (ZST) are very attractive for microwave and millimeter-wave applications [1-3]. The evolution of wireless communications requires devices suitable for microwave integrated circuits (MIC). The advantages of a filter with ZST dielectric resonators (DR) are: reduction in volume due to the ZST high dielectric constant, low in-band insertion loss due to the high intrinsic quality factor Q_u and good temperature stability due to the DR's frequency temperature compensation.

2. ZST material

The ZST ceramic materials were prepared by standard solid-state reaction technique. The structural and morphological investigations showed that the compound $(Zr_{0.8},Sn_{0.2})TiO_4$ was the majority phase [2]. The ZST material was pressed and sintered into cylindrical samples of different dimensions.

Table 1. The dielectric parameters in microwave range for ZST samples.

NiO (% wt)	Sintering time t_p (h)	Dielectric constant ε_r	tan δ (x10^4)	Product $Q \cdot f$ (GHz)
0	2.0	36.8	2.14	31,080
0	2.25	36.6	2.91	22,760
0	2.50	36.2	2.62	25,530
0.2	2.0	36.3	1.45	46,480
0.2	2.25	36.8	1.32	50,830
0.2	2.50	36.1	2.12	32,160

The cylindrical samples were placed into a Courtney holder and the dielectric parameters were measured in the microwave range by using the Hakki-Coleman method [4]. The measurements revealed values of the dielectric constant between 36.1 and 36.8 as shown in Table 1. A product $Q \times f$, between the quality factor Q and the measurement frequency f, of more than 50,000 was achieved for samples doped with 0.2 wt % NiO. Furthermore, the measured resonance frequency temperature coefficient τ_f takes values between –4 and +4 ppm/^{o}C.

3. Filter design

The electromagnetic energy is coupled to the dielectric resonators by using microstrip lines as shown in Fig. 1. Each resonator is positioned between two microstrip lines. This configuration was preferred to the direct coupling between the dielectric resonators, due to its simple design procedure.

While the signal frequency is outside the filter pass-band, the input signal is reflected at the input port. For the signals with the frequency in the filter pass-band, first dielectric resonator couples the energy from the input microstrip line to the intermediate microstrip line. The second resonator couples the energy from the intermediate line to the output line. The device is reciprocal and the input and output ports can be interchanged.

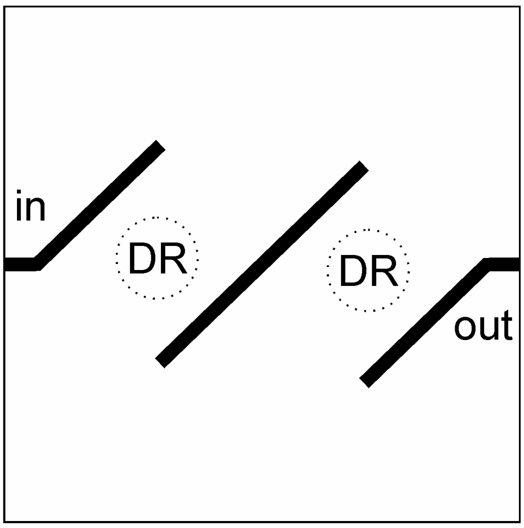

Fig. 1. Position of the dielectric resonators (DR) relative to the microstrip lines (ground plane not shown).

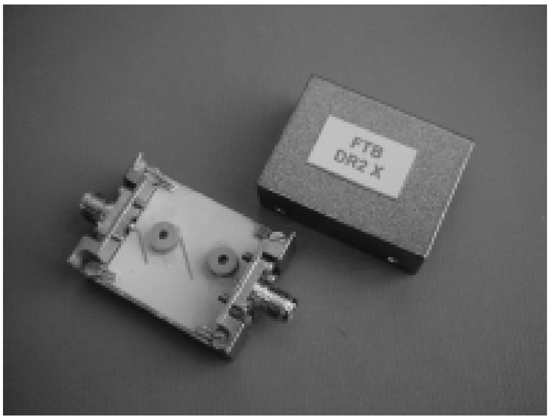

Fig. 2. Two-pole band-pass X-band filter.

The picture of a two-pole band-pass filter with ZST dielectric resonators manufactured on a 9.22 dielectric constant and 0.635 mm height substrate is given in Fig. 2. The effect of the axial holes in the cylindrical resonators consists in a better separation between the resonance modes and an improved filter rejection.

4. Band-pass filter

The filters were designed with resonators operating in the $TE_{01\delta}$ mode because this mode has the highest intrinsic quality factor Q_u among all resonant modes and because its electromagnetic energy is mostly confined near the resonators. The magnetic lines of the DR mode have the same direction with the magnetic lines of the wave, which propagates along the microstrip line. Therefore, a dielectric resonator in a $TE_{01\delta}$ mode operates like a magnetic dipole with an efficient magnetic coupling to a microstrip line. A two-port equivalent to the dielectric resonator simultaneously coupled with two microstrip lines was considered for the filter design. The S matrix of the equivalent two-port is

$$S = \begin{bmatrix} \dfrac{\kappa_1 - \kappa_2 - 1 - j2Q_u\delta}{1 + \kappa_1 + \kappa_2 + j2Q_u\delta} & \dfrac{2\kappa_1\kappa_2}{1 + \kappa_1 + \kappa_2 + j2Q_u\delta} \\ \dfrac{2\kappa_1\kappa_2}{1 + \kappa_1 + \kappa_2 + j2Q_u\delta} & \dfrac{\kappa_2 - \kappa_1 - 1 - j2Q_u\delta}{1 + \kappa_1 + \kappa_2 + j2Q_u\delta} \end{bmatrix} \quad (1)$$

where κ_1 and κ_2 are the coupling constant with the external circuit, which depend on the distances to the microstip lines, δ is the frequency shift relative to the central frequency and Q_u is the intrinsic quality factor of the resonator. The influence of the conductive walls on filter characteristics was investigated. The resonance mode operates below the waveguide cutoff frequency of the metallic enclosure. The resonance frequency of the $TE_{01\delta}$ mode decreases with the distance to the upper metallic wall. This effect was used for resonance frequency adjustments. In the general case, the coupled resonators are asymmetrical, due to the slightly different resonance frequencies.

The experimental investigations on ZST filters were performed using a computer aided measurement system in microwaves. The system combines a HP 8757C network analyzer and a HP 8350B sweep oscillator. The same measurement system was also employed for measurement of the ZST dielectric parameters in microwave range.

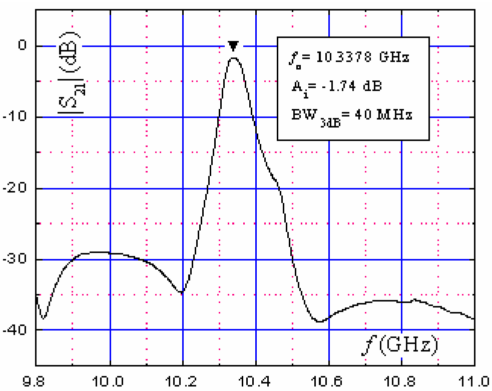

Fig. 3. Measurement characteristics of the first type filter.

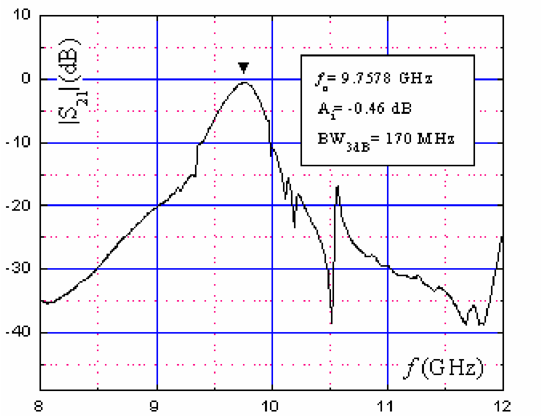

Fig. 4. Measurement characteristics of the second type filter.

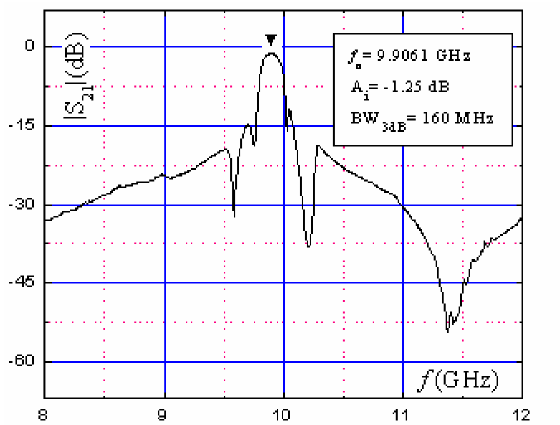

Fig. 5. Measurement characteristics of the third type filter.

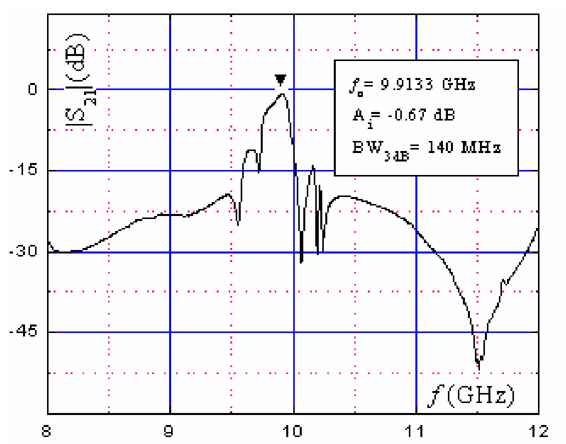

Fig. 6. Measurement characteristics of the fourth type filter.

Four types of filters with different fractional bandwidths were manufactured. All filters have two ZST resonators tuned for several central frequencies in the X-band. The measurement characteristics, i.e. the magnitude of S_{21} versus frequency, are presented in Figs. 3-6. The developed filters exhibit an insertion loss between 0.46 dB and 1.74 dB, a pass-band between 40 MHz and 170 MHz and a central frequency around 10 GHz.

5. Conclusions

The feasibility of X-band filters with cylindrical resonators of ZST material was demonstrated. The high $Q \times f$ product of more than 50,000 allowed a low insertion loss down to 0.46 dB. The filters are low volume due to the ZST dielectric constant of 36.8. Moreover, the resonance frequency temperature coefficient τ_f, which takes values in the range –4 to +4ppm/°C offers a very good thermal stability of the filter characteristics.

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