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STW Resonators with the High Quality Factor and Reduced Sizes

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Abstract—**This paper presents the STW resonators with high Q-factor and reduced sizes on 36°YX90° cut quartz. The resonators are realized as 1-port scheme when an IDT is placed between 2 reflectors. The Q-factor of these resonators is determined by the reflectivity of the reflectors, propagation attenuation, conductive loss in Al electrodes of the IDT, frequency agreement of the center of stopband and maximal reflectivity of the reflectors with maximal admittance of the IDT. The constructional and topological optimization of the STW resonators with computer simulation using equivalent circuit model allows to obtain the high Q-factor and reduced sizes. The 500-1000 MHz STW resonators have shown Q-factors of 8600-9500 and were housed in the miniature 3x3x1.2 and 5x5x1.8 mm SMD package.**

Keywords— surface transverse wave, resonator, quality factor.

I. INTRODUCTION

The surface transverse waves (STW) on quartz have a high propagation velocity V_0=5000 m/s, low temperature coefficient of frequency of $-0.05\cdot10^{-6}$ 1/°C^2 and handle high power up to do several watts. All of these things allow successfully to use the STW for creating high frequency resonators [1-3]. However a large number of electrodes 400 in the reflectors is required to ensure the high quality (Q) factor of the resonators. This leads to increase the resonator sizes especially on the frequencies < 1000 MHz.

This paper presents the STW resonators with high Q-factor and reduced sizes on 36°YX90° cut quartz. The resonators are realized as 1-port scheme when a IDT is placed between 2 reflectors (Fig.1). The Q-factor of these resonators is determined by the reflectivity of the reflectors, propagation attenuation, conductive loss in Al electrodes of the IDT, frequency agreement of the center of stopband and maximal reflectivity of the reflectors with the maximal admittance of the IDT.The reflectivity of the reflectors depends on a number of the electrodes in the reflectors, electrode thickness and metallization ratio. The reflectivity of the reflectors for STW is slightly higher than the reflectivity for Rayleigh wave for the same thickness and metallization ratio of the electrodes [4]. Consequently, the reduced number electrodes in the reflectors can be used for decrease of resonator sizes. The propagation attenuation due to material itself in substrate is determined by the resonant cavity length and depends on the number of the electrodes in the IDT (N) and reflectors (N_{REF}). The conductive loss in Al electrodes of the IDT depends on the electrode thickness, metallization ratio and aperture W (Fig.1). The frequency agreement of the center reflectors stopband with the maximal input IDT admittance depends on relationships between the electrode periods of the IDT (d) and reflectors (d_{REF}) (Fig.1). In this case the STW resonator becomes «non-synchronous» resonator [3].

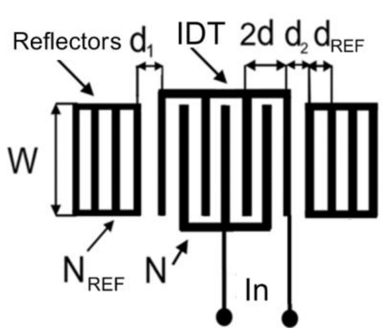

Fig. 1. Topology of the 1-port STW resonator

II. SIMULATED AND EXPERIMENTAL RESULTS

The constructional and topological optimization of the STW resonators was provided with a computer simulation using an equivalent circuit model [5]. The equivalent circuit of the STW resonator is similar to equivalent circuit of the conventional SAW resonator and is shown on Fig.2. The STW features – the propagation attenuation due to material itself in substrate are entered in simulation by the special coefficients [2]. Here P is a mixed matrix of IDT, Z_0 is characteristic impedance of the medium between IDT and reflectors, V_0 is a STW velocity, $R = Z_0(1+\Gamma)/(1-\Gamma)$ is an equivalent impedance for the reflector, Γ – reflection coefficient of reflector. The theoretical analysis of 1-port STW resonator is provided with regard to that Γ is optimal for the reflector.

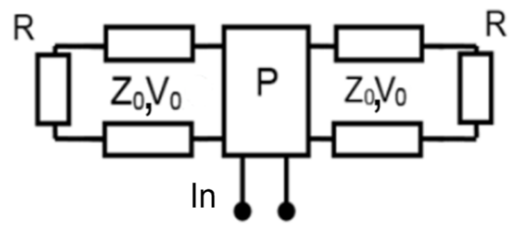

Fig. 2. Equvalient circuit of the 1-port STW resonator

Γ is defined experimentally with the maximal STW reflection from reflectors with the specified number of the electrodes in the reflectors for the selected electrode thickness and metallization ratio from data of the test structures. The optimization of the mentioned parameters of the resonator topology (Fig.1) allows to obtain a high Q-factor of the STW resonators in a frequency range of 500-1000 MHz. In this case the IDT and reflectors become the lesser long and sizes of the resonators are reduced in comparison with the known methods [1-3]. The optimal parameters of the resonator topologies are shown in Table I.

Here λ is STW length on frequency of maximum for the real part of the resonator admittance. The distance between IDT and reflectors $d_1 = d_2$ is distance between centers of the adjacent electrodes of the IDT and reflectors.

TABLE I. PARAMETERS OF THE RESONATOR TOPOLOGIES

Parameters	**500 MHz**	**765 MHz**	**1000 MHz**
Number of the electrodes in reflectors	230	285	350
Number of the electrode pairs in IDT	80	100	100
Relation between the electrode periods of the IDT and reflectors , d/d_{REF}	0.997	0.997	0.997
Distance between IDT and reflectors	d_{REF}	d_{REF}	d_{REF}
Overlapped aperture, W	80λ	80λ	80λ
Relative electrode thickness, h/λ	2.5%	2.5%	2.5%

The simulated (Fig.3) and measured (Fig.4) frequency responses of the real and imaginary parts of the 500 MHz resonator admittance show good agreement.

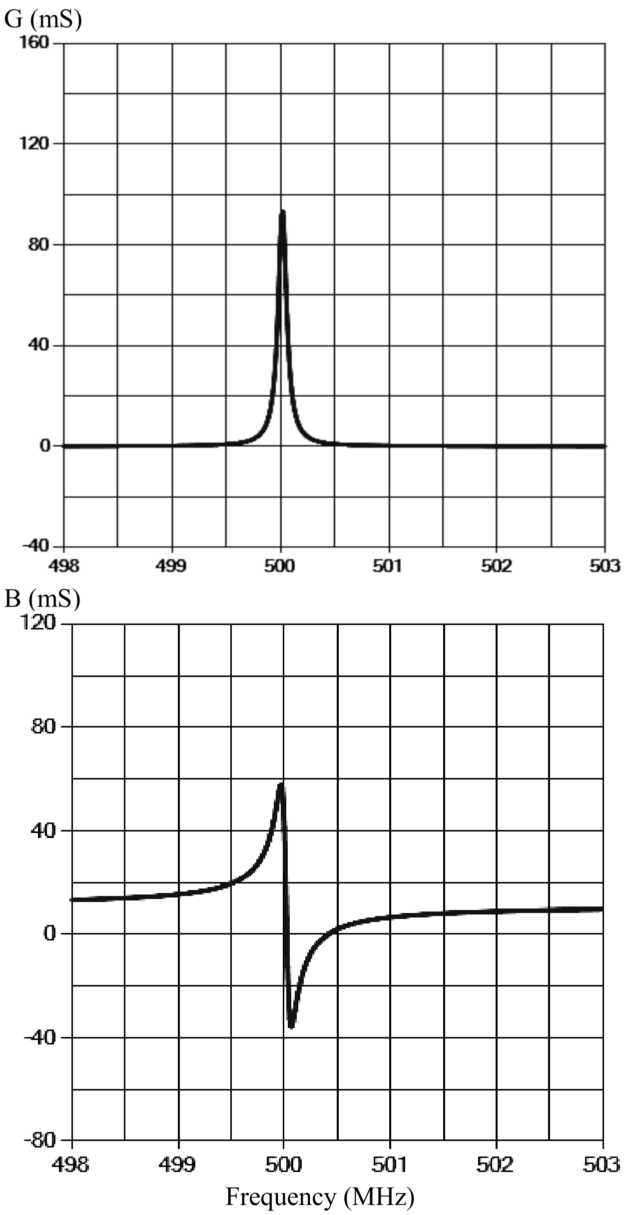

Fig. 3. Simulated frequency responses of the real and imaginary parts of 500 MHz resonator admittance

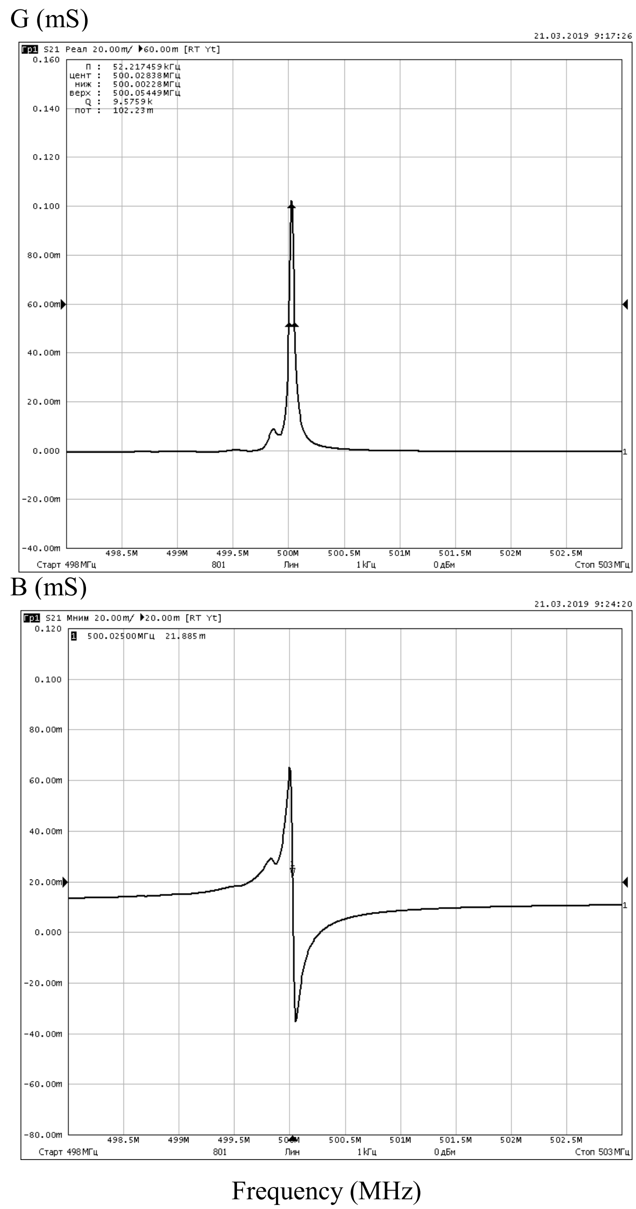

Fig. 4. Measured frequency responses of the real and imaginary parts of 500 MHz resonator admittance

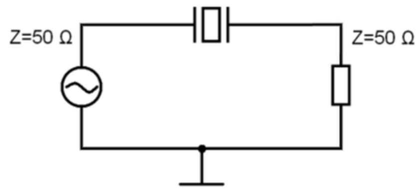

Fig. 5. Series measured curcuit of STW resonator

The STW resonators were housed in the SMD packages and measured in series test systems with R_0=50 Ohm (Fig.5). The frequency responses of the admittance Y (the real and imaginary parts) were calculated from the measured real and imaginary parts of transfer function S_{21} by formula [3]:

$$Y = \frac{S_{21}}{2R_0(1 - S_{21})} \quad (1)$$

This conversion (1) was realized in network analyzer and mapped by associated frequency responses of the real and imaginary parts of the resonator admittance.

An equivalent circuit with lumped elements R, L, C is convent to use for analysis of the STW resonator. The equivalent circuit of 1-port STW resonator (Fig.6) is similar to equivalent circuit of the conventional SAW resonator and consists from the dynamic inductance L_D, dynamic capacitance C_D, static capacitance C_0, dynamic resistance R_D characterizing the interior losses in the resonator. For an evaluation of the equivalent parameters of the STW resonator in SMD package the formulas are used from equivalent circuit for 1-port SAW resonators [6]:

$$Q = \frac{f_0}{\Delta f},\ R_D = \frac{1}{G_m},\ L_D = \frac{QR_D}{2\pi f_0},\ C_D = \frac{1}{(2\pi f_0)^2 L_D}, \quad (2)$$

where Q is quality factor; Gm is maximal value of the real part resonator admittance on frequency f_0; Δf is bandwidth at level of $G_m/2$. The static capacitance C_0 is measured on the low frequency with regard to SMD package capacitance.

The STW resonator on frequency f_0=500 MHz was provided Q-factor=9500, G_m=102 mS (Fig.4). Resonator with chip size of 3.17x1x0.5 mm was mounted in 5x5x1.8 mm SMD package. The static capacitance with regard to SMD package C_0=3.6 pF, capacitance ratio C_0/C_D=1058.

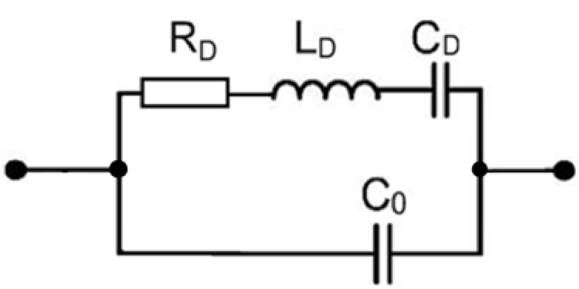

Fig. 6. Equivalent curcuit of the 1-port STW resonator with the lumped elements R, L, C

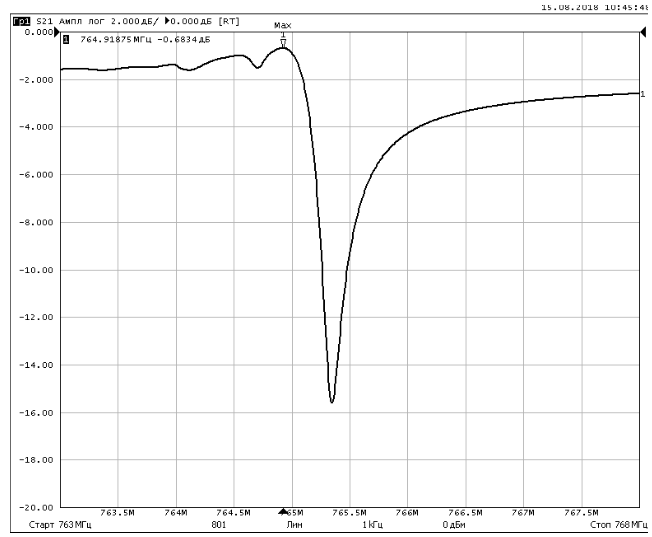

Fig. 7. Measured frequency response S_{21} of 765 MHz STW resonator

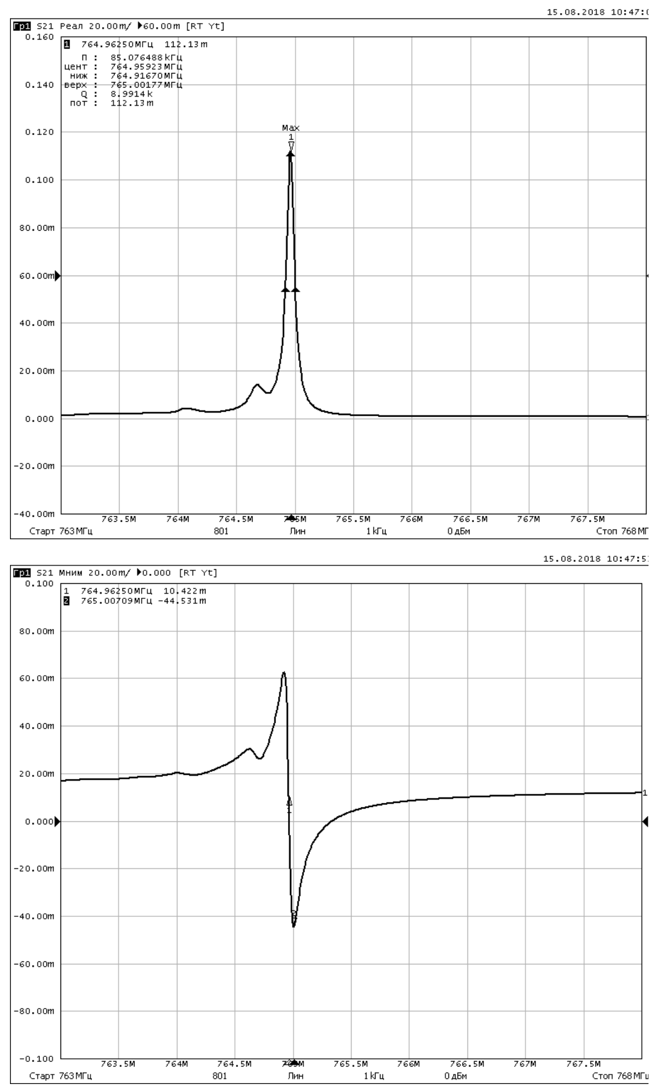

Fig. 8. Measured frequency responses of the real and imaginary parts of 765 MHz resonator admittance

Fig.7 shows the measured frequency response of transfer function S_{21} for the 765 MHz resonator with series circuit (Fig.5). On the series resonance frequency of 764.92 MHz the very low insertion loss of 0.68 dB was obtained. It is indicates that STW resonator have the low R_D and high Q-factor. The measured frequency responses of the real and imaginary parts of the 765 MHz resonator admittance are displayed in Fig.8. The STW resonator was shown Q-factor=9000, G_m=112 mS. Resonator had chip size of 2.8x1x0.5 mm and was housed in 5x5x1.8 mm SMD package. In so doing the static capacitance C_0=3.8 pF, capacitance ratio C_0/C_D=1467.

In Fig.9 the measured frequency responses of the real and imaginary parts of the 999.87 MHz resonator admittance are presented. The STW resonator was provided Q-factor=8600, G_m=90.5 mS. The resonator had chip size of 2.2x0.85x0.5 mm. This was allowed to house it in 3x3x1.2 mm SMD package. In this case C_0=1.86 pF, capacitance ratio C_0/C_D =1120.

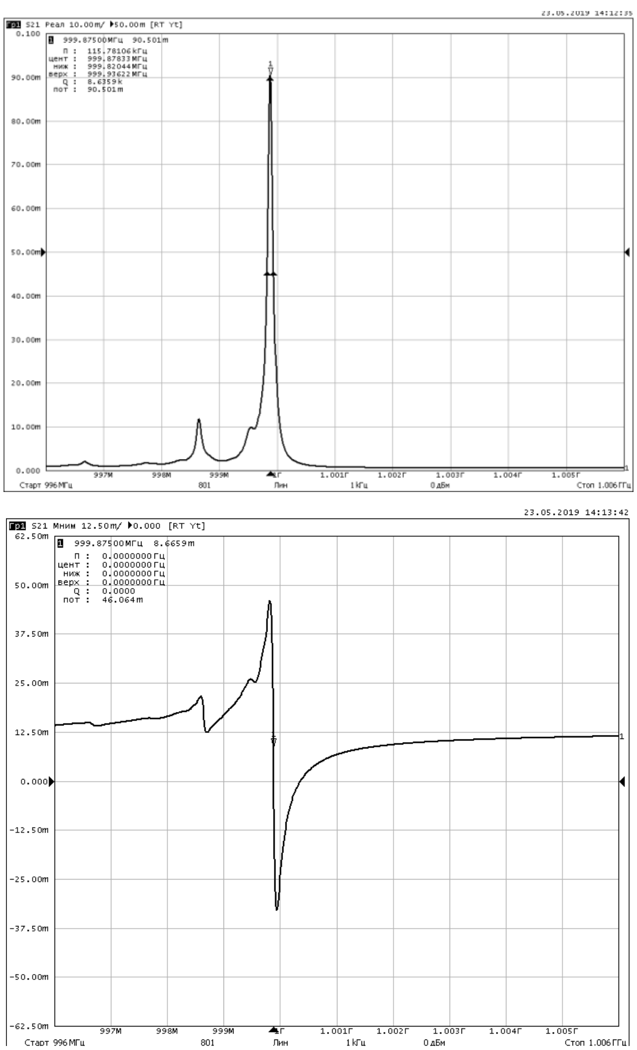

Fig. 9. Measured frequency responses of the real and imaginary parts of 765 MHz resonator admittance

The parameters of the equivalent circuits of the 1-port STW resonators calculated from the measured frequency responses by the formulas (2) are presented in Table II. These parameters can be used for the simulation and development of the low noise oscillators.

TABLE II. THE EQUIVALENT PARAMETERS OF STW RESONATORS

Parameters	500 MHz	765 MHz	1000 MHz
R_D, Ohm	9.7	8.9	11
L_D, μH	29.6	16.7	15.2
C_D, pF	0.0034	0.00259	0.00166
C_0, pF	3.6	3.8	1.86

III. CONCLUSION

The STW resonators in the frequency range of 500-1000 MHz were provided the high quality factors of 8600-9500, reduced electrodes number in IDT and reflectors as compared with the known prototypes [1-3] and were housed in 3x3x1.2 and 5x5x1.8 mm SMD packages. The developed STW resonators with high quality factor and reduced sizes will be widely used in the miniature low noise oscillators.

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