Indonesian Journal of Electrical Engineering and Computer Science
Vol. 1, No. 1, January 2016, pp. 78 ~ 87
DOI: 10.11591/ijeecs.v1.i1.pp78-87

Scattering Parameters prediction for 433MHz SAWR with Minimum Insertion loss

M.M. Elsherbini[1]*, M.F. Elkordy[2], A.M. Gomaa[1]
[1]Dept. of Electrical Engineering, Shoubra Faculty of Engineering, Benha University, Cairo, Egypt
[2]Dept. of Communications, Faculty of Electronic Engineering, Menoufia University, Menouf, Egypt
e-mail: motaz.ali@feng.bu.edu.eg

Abstract

A proposed schematic design for surface acoustic wave resonator (SAWR) is introduced in this paper. A simplified equivalent model for both one and two port 433MHz SAWR is built. Scattering parameters of the proposed design is extracted and compared with a commercial one of the same resonant frequency. Advanced system design tool is nominated to give the main parameters like Impedance and Admittance with their real and imaginary response. The insertion loss predicted mathematically and recorded from simulation then compared with the measured value. The proposed design tool introduced adequate results with minimum hardware procedure specifications.

Keywords: *SAWR, Resonator, ADS*

1. Introduction

The Acoustic Wave propagates upon the surface of piezoelectric material in which its amplitude decays with depth into the substrate material. These waves are generated by the piezoelectric material (Quartz-LiNbO3-LiTaO3 –etc.). In the piezoelectric material, when the potential is applied it deforms the generated waves and when a force is applied, then charge accumulates. Inter-digital transducers are electrodes where the applied electric signal is applied and then converted to electromechanical waves. The dimensions of IDTs determine the wavelength (frequency control) and the material properties determine the propagation velocity.

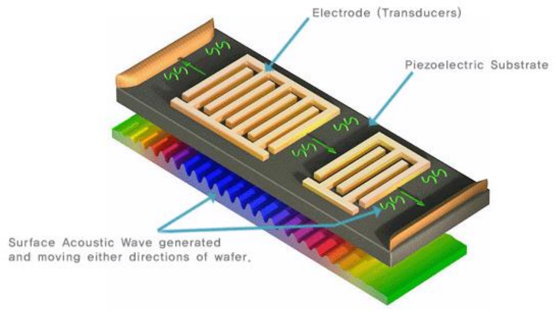

Figure 1. Surface acoustic wave device structure [1]

Figure 1 indicates the basic structure of SAW device. Delay lines, filters, sensors, resonators and oscillators are most famous products of SAW devices. Some previous studies in SAW delay line modeling and simulation through different tools were presented [2-3].

In SAW resonators, SAW are generated from both sides of IDT and reflected by reflection gratings at the resonant center frequency. SAWR have wide applications in radio transmitters, remote control (OOK), radio links and alarms. The main advantages of using SAW resonator compared with LC circuits and quartz crystals are due to have better performance, cost and size. This paper presents simple analytical modeling for 1-port SAW resonator (Figure 2) at 433MHz which main part in wireless remote control and OOK. The analytical method used

Received September 10, 2015; Revised November 15, 2015; Accepted December 2, 2015

in this study is built and modified to determine the resonant frequency with semi-accurate way. SAWR occupies narrow bandwidth and very low insertion loss. It can be used as a passive network in colpitts oscillator. The equivalent circuit of SAWR (Figure 3) is optimized as Lumped RLC circuit that is series – parallel resonance circuit. Other modeling and simulation studies using FEM analysis rather than equivalent circuit modeling are previously introduced [4]. This study determine the optimum parameters required to design 1-port SAWR working at 433MHz resonant frequency and the simulation extracts S-parameters of the model. The contribution of this study is to provide a low insertion loss (less than 5dB) that is required in BPF of new generation of mobile phones. SAWR applied to high frequency circuit and oscillates over a center frequency up to GHz. A future work will apply one and two port SAWR in low cost oscillators as colpitts or in voltage controlled oscillator.

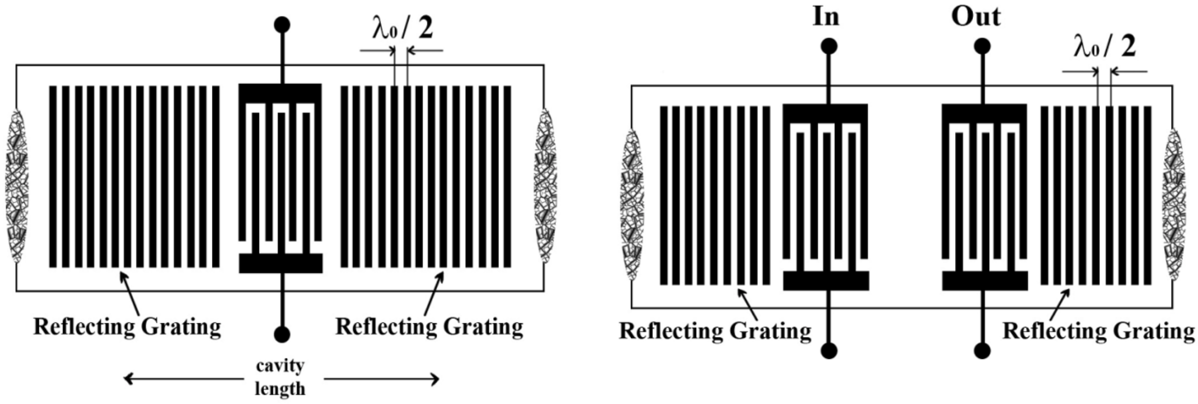

Figure 2. One and two-port SAWR [5-6]

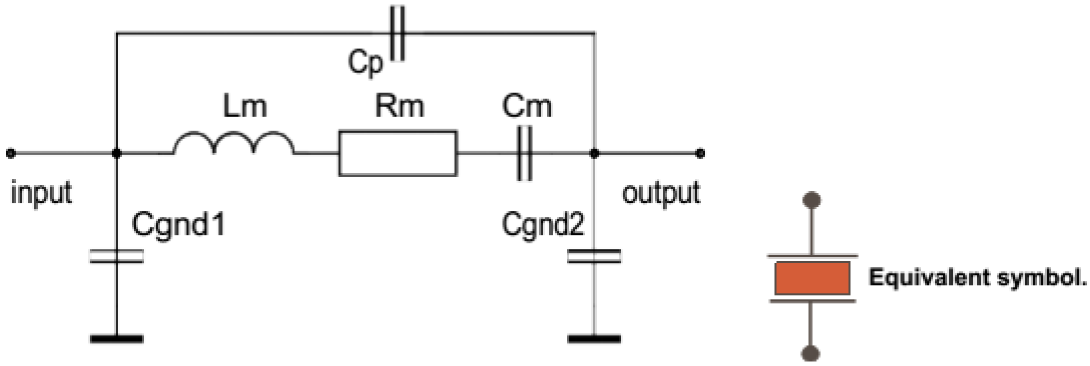

Figure 3. Equivalent circuit of SAWR and equivalent symbol

2. SAWR Mathematical Modeling

The model selected for 1-port SAW resonator is equivalent circuit model shown in figure (3) which based on series resonance circuit with Lm, Rm and Cm shunted by a capacitor Cp. The series and parallel resonant frequencies obtained from basics of simple resonance electrical circuit. Lm (motional inductance), Rm (motional resistance), Cm (motional capacitance), Cp (internal IDT capacitance) due to electric field between electrodes, Cgnd1 and Cgnd2 refers to housing capacitances and can be neglected [7]. Resonation occurs by reflections through the electrodes of IDTs spaced λ/2.

$$f_s = \frac{1}{2\pi\sqrt{L_m.C_m}} \quad (1)$$

$$f_p = f_s \sqrt{1 + \frac{C_m}{C_p}} \tag{2}$$

The ratio C_m/C_p determines the separation between resonant and anti-resonant frequencies. Resonance is done when the input impedance is minimum value and anti-resonance is done when impedance is maximum value. One port resonator has large C_m/C_p and small frequency deviation between series resonance-parallel resonance. With ignoring the effect of finger reflections, so R_m, L_m, C_m and Quality factor can be selected from the following formulas

$$R_m = \frac{1}{G_a(f_o)} \frac{(1-|\rho|)}{(1+|\rho|)} \tag{3}$$

$$G_a(f_o) = 8K^2 f_o C_s N_P^2 \tag{4}$$

$$L_m = \frac{d_e}{\lambda_o} \frac{1}{(4f_o G_a(f_o))} \tag{5}$$

$$C_m = \frac{1}{(4\pi^2 f_o^2 L_m)} \tag{6}$$

$$C_p = C_s N_p W_a \tag{7}$$

$$W_{a=} \frac{1}{R_{in}} \left(\frac{1}{2f_o C_s N_p} \right) \left\{ \frac{4K^2 N_p}{\left(4K^2 N_p\right)^2 + \pi^2} \right\} \tag{8}$$

$$f_p - f_s = \frac{f_o}{2} \frac{C_m}{C_p} \tag{9}$$

$$Q = \frac{d_e}{\lambda_o} \frac{2\pi}{(1-|\rho|^2)} \tag{10}$$

Where $|\rho|<1$, ρ is the reflection coefficient. Ga (fo) is the radiation conductance at center frequency fo = 433MHz. $K^2$is electromechanical coupling coefficient, d_e is the effective resonant cavity length and it is multiple of half wavelength and Q is the quality factor. N_p is the total number of electrode fingers, Cs is the capacitance per unit length for a pair of fingers and W_a is the finger overlap. Maximum Q at grating reflection coefficient where $|\rho|$ close to 1. The previous parameters determined by the type of piezoelectric substrate material used in the design. For Quartz material as an example, K^2 = 0.0016, W_a = λ/4 and Cs = 0.503385 pf/cm. The total admittance, impedance and insertion loss of SAWR are given by

$$Y = j\omega C_p + \frac{1}{R_m + j\omega L_m + \frac{1}{j\omega C_m}} \tag{11}$$

$$Z = \frac{1}{Y} \quad (12)$$

$$IL = -20Log_{10}\left(\frac{4}{4+3\pi^2/k^2Q}\right) = 20Log\left(\frac{R_{in}+R_{load}}{R_m+R_{in}+R_{load}}\right) \quad (13)$$

Typical calculated Values for L_m, R_m, C_m and C_p that satisfies 433MHz resonant frequency are given in table 1. R_{in} and R_{load} are obtained as 50Ω for each.

Table 1. Calculated Values for L_m, R_m, C_m and C_p of 1-port SAWR

Component	Calculated Value
L_m	0.1675mH
R_m	36.25Ω
C_m	0.8 fF
C_p	3.6pF

3. 1-Port Simulation and Results

The previous equations were used to build the equivalent model parameters of SAW resonator. The calculated values for resistance, inductance and capacitances shown in the above table are used in ADS schematic design shown in figure (4) to ensure the required simulation results.

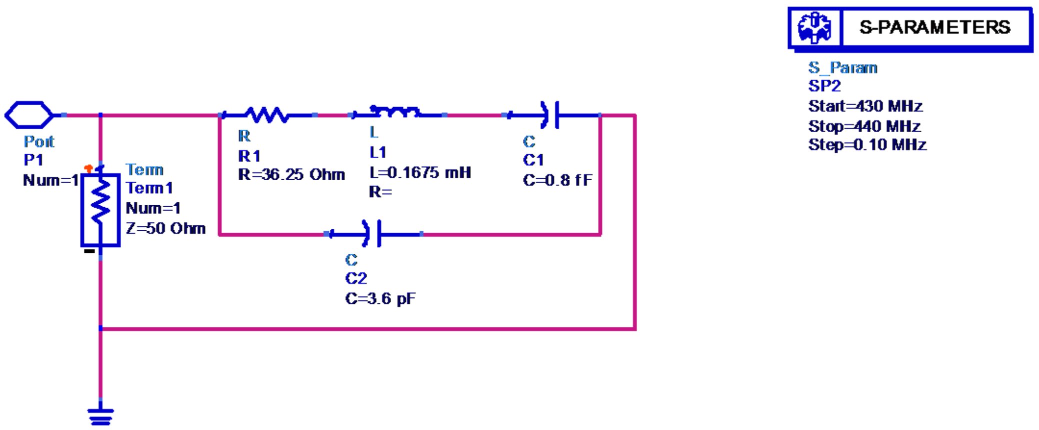

Figure 4. Proposed Schematic design for 1-port SAWR

We selected one term with input impedance 50 Ω to be a terminal for prediction S-parameters. S_{11} is expected for the reflected signals from the electrodes. The frequency range of simulation is selected between 430MHz and 440 MHz with step 0.1MHz to obtain most clearly results. A Linear Frequency Sweep simulation has been performed and took 0.47 seconds for simulation. S_{11} parameter can be estimated mathematically using the following relation [8]

$$S_{11} = 20Log\left(\frac{Y_o - Y}{Y_o + Y}\right) = 20Log\left(\frac{Z - Z_o}{Z + Z_o}\right) \quad (14)$$

Where $$Z_o = \frac{1}{Y_o} = 50\Omega$$

By using ADS software we reached the results for 1-port configuration. Figure 5 describe S_{11} parameter (reflection signal) which the minimum insertion loss can be obtained as 9.7dB. By comparing the IL value with the measured for commercial device B39431-R2632-B110 fabricated by Siemens Matsushita Components, it shows IL between 7.8 dB and 9.5 dB in data sheet. The difference between simulated value and measured value gives an adequate difference [9]. Figure 6 indicates the real and imaginary parts of calculated S_{11}. Figures 7 and 8 recorded smith-chart and polar plot of the 1-port resonator in case of using 50Ω as input (terminal) impedance. Figure 10 shows the phase response of the equivalent circuit design, while figure 11 describes the time domain signal of SAW resonator.

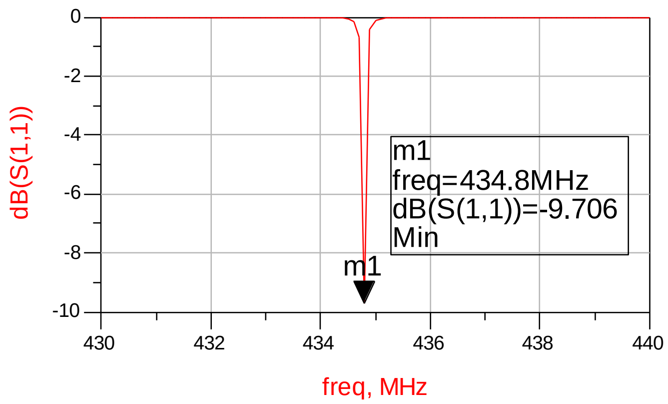

Figure 5. S_{11} parameter for 1-port SAWR

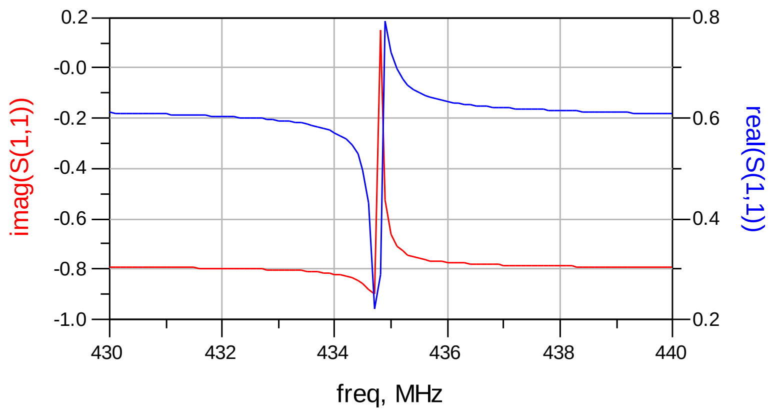

Figure 6. Real and imaginary S_{11} parameter for 1-port SAWR

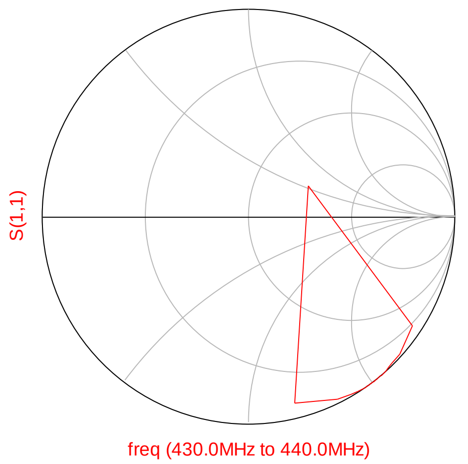

Figure 7. Smith chart for 1-port SAWR

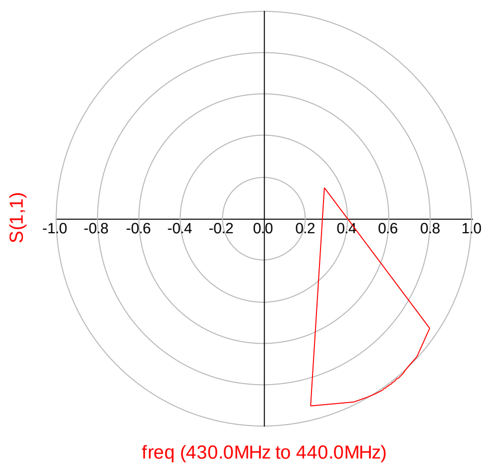

Figure 8. Polar Plot 1-port SAWR

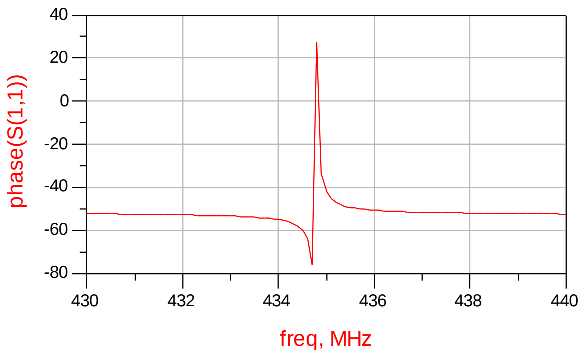

Figure 9. Phase response for 1-port SAWR

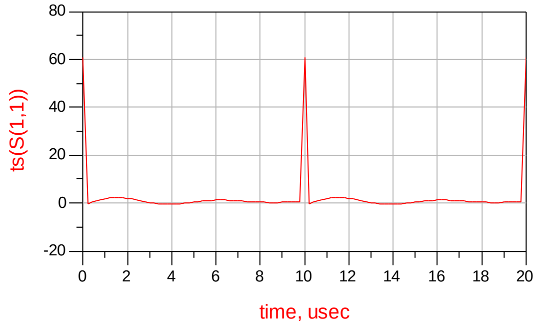

Figure 10. Time domain signal of 1-port SAWR

4. 2-port Simulation and Results

The same equivalent circuit of 1-port SAW model can be used for 2-port configuration but with 2 groups of IDTs and two terminals instead of one [10]. Figure 11 is built using ADS and shows the equivalent circuit model of 2-port SAWR with components of table 2. For the previous design of 1-port resonator, small modifications have been performed in the component values to operate the same device as 2-port resonator. L_m and R_m are multiplied by 4 while C_m is be halved. In this proposed schematic $C_p$is divided into two branches, one with input terminal and the other is with output terminal with series equivalent of the C_p in one port mode, this means that $C_p$is also be halved. Figures 12 and 13 indicate S_{21} (transmission) and S_{11} (reflection) respectively. The insertion loss is noticed also here as 9.703dB. It is still an acceptable value compared with that measured in R641 commercial device. Figures 14, 15 and 13 designate real and imaginary S_{11} parameter, Phase response and smith chart for 2-port SAWR.

Table 2. Calculated Values for L_m, R_m, C_m and C_p of 2-port SAWR

Component	Calculated Value
L_m	4*0.1675mH
R_m	4*36.25Ω
C_m	0.8/4 fF
C_p	3.6/2pF Or two series cap. Of 3.6pF

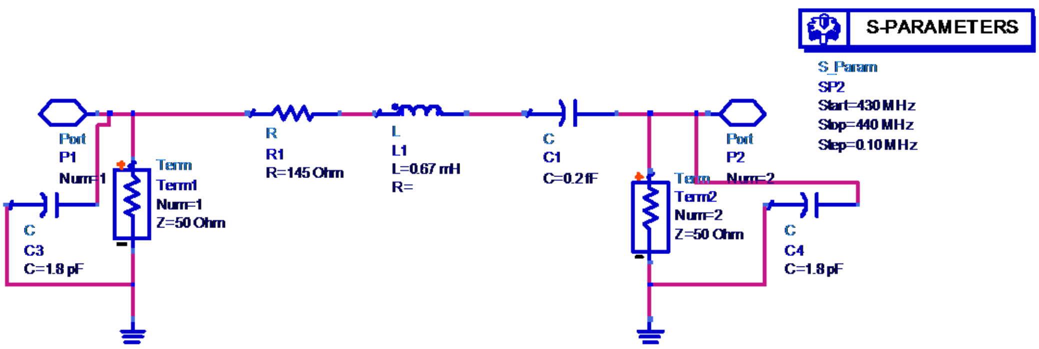

Figure 11. Equivalent circuit for 2-port SAW device

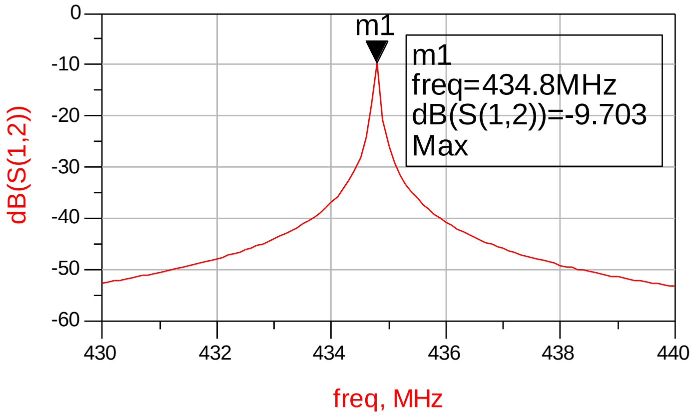

Figure 12. S_{12} parameter (transmission signal)

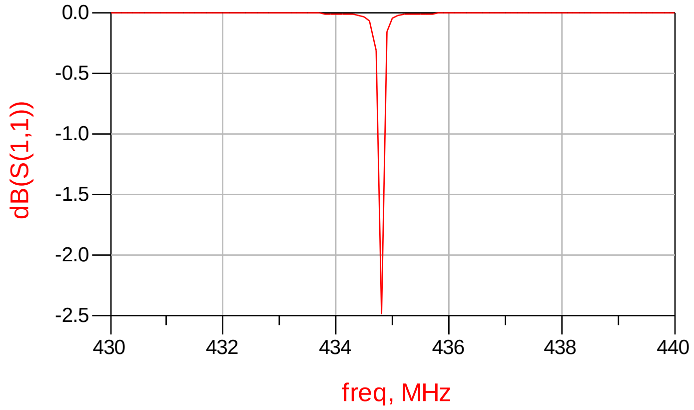

Figure 13. S_{11} parameter (Reflection signal)

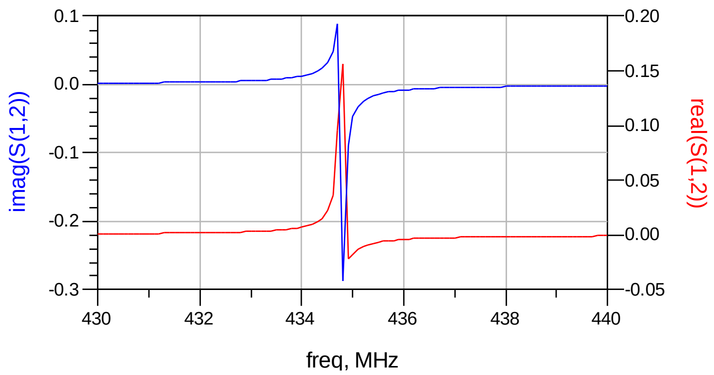

Figure 14. Real and imaginary S_{11} parameter for 2-port SAWR

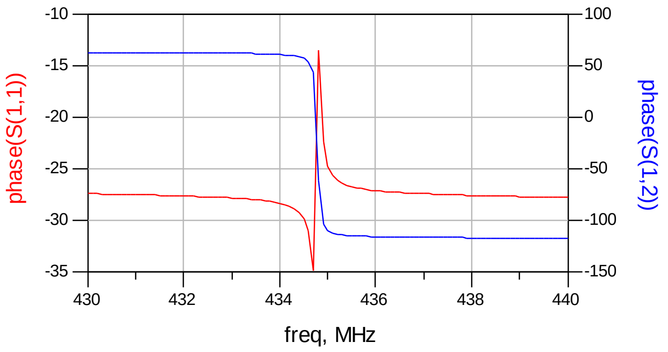

Figure 15. Phase response for 2-port SAWR

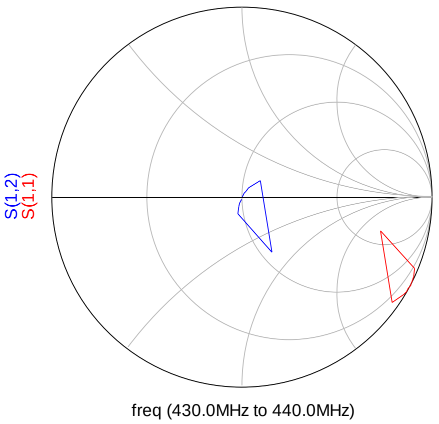

Figure 16. Smith chart for 2-port SAWR

5. Conclusion

A simple equivalent circuit for one port and two port SAW resonator was introduced in this paper. Mathematical analysis was performed to manually calculate the schematic components. ADS tool was used to perform the simulation. Scattering parameters S_{11} and S_{12} were monitored. The insertion loss of SAWR was recorded with minimum value and the simulation gives an adequate record comparing with a measured value. The proposed design model is suggested to be used in oscillators design rather than using crystals. The future work is to design Colpitts oscillator using SAWR discussed through this paper.

References

[1] Athanasios Margiolakis. "FEM analysis of surface acoustic wave resonators of piezoelectric Gallium Nitride on Sillicon substrates for frequencies above 5 GHz". Msc Thesis, University of Crete. 2013.

[2] MM Elsherbini, MF Elkordy and AM Gomaa. "Towards a Simple Model for SAW Delayline Using CAD". *American Journal of Circuits, Systems and Signal processing*. 2015; 1(3): 86-92.

[3] MM Elsherbini, MF Elkordy and AM Gomaa. "Insertion Loss Prediction and Monitoring for SAW Delay-line". *International journal for research in emerging science and technology*. 2015; 2(9): 16-18.

[4] Stefanescu A, V Buiculescu, Adrian Dinescu, A Cismaru, A Muller, G Konstantinidis, A Stavrinidis, and G Stavrinidis. "Modeling of SAW resonators fabricated on GaN/Si". In *Microwaves, Communications, Antennas and Electronics Systems (COMCAS), 2013 IEEE International Conference on*, IEEE, 2013: 1-4.

[5] Kannan, Thirumalai. Finite element analysis of surface acoustic wave resonators. PhD Thesis. University of Saskatchewan Saskatoon. 2006.

[6] K Sreenivas and RP Tandon. "Development of thin film based surface acoustic wave saw sensor". PhD Thesis, University of Delhi. 2014.

[7] SAW-components: Design-guide for the SAW oscillator, optimization for best frequency stability, fast start up time and ghost-less working: Application note 25. Munich: EPCOS. 2008.
[8] Riccardo Manenti. "Surface Acoustic Wave Resonators for Quantum Information". M.Sc. thesis, University of Oxford, UK. 2014.
[9] Siemens Matsushita Components, SAW Resonator, R 641 433, 92 MHz, http://www.datasheets.pl/quartz_crystal_resonators/D11080.pdf
[10] Ignacio Moreno. "Design of a tunable one-port Surface Acoustic Wave resonator using BST". M.Sc. thesis, University of Colorado at Colorado Spring. 2014.