ARBITRARY Q-FACTOR DIELECTRIC RESONATOR

Karel HOFFMANN, Vratislav SOKOL, Zbyněk ŠKVOR
Dept. of Electromagnetic Field
Czech Technical University in Prague
Technická 2, 166 27 Praha 6
Czech Republic

Abstract

New circuit component, active resonator, is proposed for use in microwave and millimetrewave circuits. It consists of a common resonator and an amplifier, compensating for losses in the resonator. Properly designed, such an arrangement behaves as a (passive) resonator with dramatically increased quality factor. High quality factors can be achieved even at millimetrewave frequencies, where common resonators suffer from losses due to small skin depths.

Viability of the component is experimentally verified at microwave region using a $TE_{01\delta}$ dielectric resonator and an oscillator.

Keywords

Resonator, loss compensation, feedback

1. Introduction – Motivation

Revolution in information technology and mobile communication requires in more and more channel bandwidth. Requirement causes rapid expansion towards higher microwave and millimeterwave frequencies. Resonator is a basic part of communication circuits, with application overlapping to dielectric and pollution measurements.

Increase in frequency generally causes a decrease of resonator quality factor. Where high quality factor is necessary, resonators with metallic walls are often used. As rule of thumb, for given resonator mode quality factor follows

$$Q\sqrt{f} = const. \tag{1}$$

as a result of decreasing skin depth. Fabry–Perrot arrangement, can increase quality factor limit. Unfortunately, integration of open resonators into monolithic circuits gets difficult. Resonator quality factor is given by

$$Q_u = \omega_0 W / P = 2\pi f_0 C / G \tag{2}$$

where ω_0 stands for angular frequency, W represents the energy contained in resonator and P energy lost in one oscillation period, C and G correspond to parallel equivalent circuit of the resonator. Lost energy consists of two parts - energy dissipated in the resonator and energy moved out of the resonator. Therefore coupling common resonators to external circuits results in additional energy loss and quality factor decrease.

As the bandwidth of single filter is inversely proportional to resonator quality factor, it is impossible to design ultra-narrow-band filters composed of resonators with low quality factors. Even with reasonable quality factors, narrow-band filters require in loosely coupled resonators, and that results in high pass-band attenuation.

In order to increase resonator quality factors, some works have suggested coupling negative resistances to the resonator. Such an arrangement really increases the quality factor, however a more general approach can be found.

2. Theory

Due to the fact that the resonator itself is lossy, the unloaded Q_u factor is finite. Moreover, each use of a resonator results in coupling to external circuit, which results in loosing more energy. Hence, even an ideal resonator with zero inner losses and $Q_u \rightarrow \infty$ exhibits finite loaded Q_l.

We propose a solution for increasing Q_u and Q_l of the resonator. The losses in the resonator can be decreased, compensated or overcompensated by the means of an extra active circuit coupled to the resonator. It may be e.g. an amplifier with the resonator in a feedback, see Fig. 1 or a reflective amplifier [4], where the resonator is in both cases coupled to a line. Both active circuits create some effective negative conductance $-|G_n|$ which adds to the positive conductance of the resonator G. A new active resonator is created this way with corresponding conductivity G_a given by

$$G_a = -|G_n| + G < G \tag{3}$$

Q_u of this resonator is increased with respect to (2). Fig. 2 shows its equivalent circuit, which is the same as for common passive resonator.

In the active resonator the common passive resonator is coupled to the active circuit so that in principle a circuit very similar to an oscillator is created. A common oscillator needs the amplitude and the phase condition to be satisfied for oscillations build up at f_o, [1]. In the case of the active resonator, the only phase condition for oscillation build up at f_o is satisfied, the amplitude condition is not satisfied. The oscillations will not build up and the active element can work in the small signal linear regime. Its gain and power added to the circuit will reduce the inner losses of the active resonator. When

$$-|G_n| + G = 0 \tag{4}$$

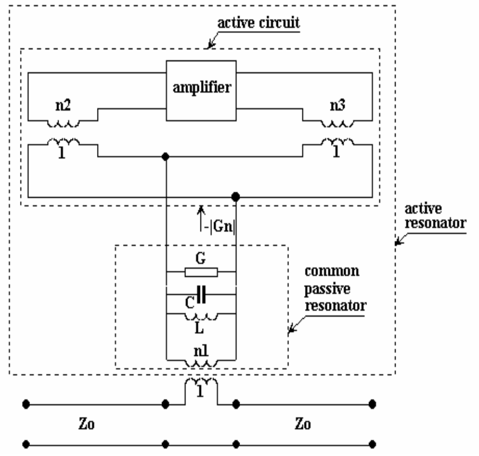

Fig. 1 An active resonator with feedback arrangement.

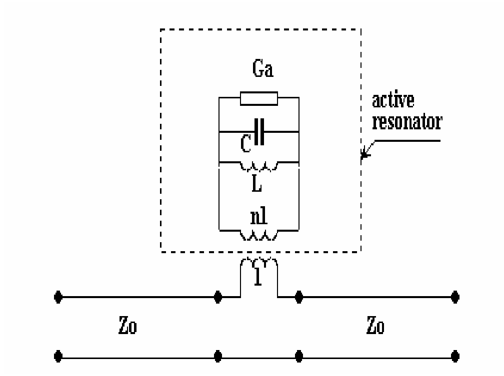

Fig. 2 Equivalent circuit of the active resonator.

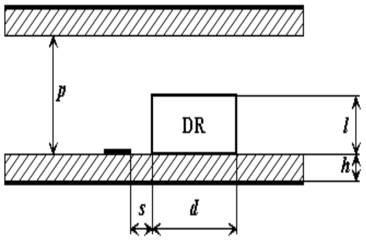

Fig. 3 Experimental setup

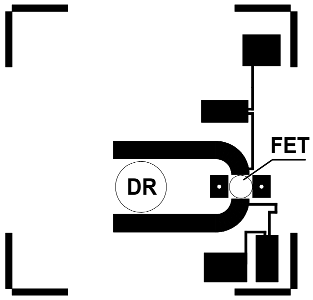

Fig. 4 Active circuit layout.

full compensation of P results in $Q_u \to \infty$ with finite and increased Q_l when coupled to a line or a circuit. In practical applications

$$0 < G_a \tag{5}$$

should be satisfied to prevent oscillations, still keeping increased Q_l.

3. Experiments

In order to verify the idea an ordinary DR was measured first for a reference. The same DR was measured also included in the structure of the active resonator. Then the Q factors were derived in both cases using the below mentioned technique and results were compared. A dielectric resonator (DR) with diameter d=5 mm and length l=2.2 mm was used for experiments. Fig. 3 shows a corresponding mechanical arrangement. DR was placed on CuClad 233 substrate (ε_r =2.33) with thickness h=0.5 mm. It was coupled to a 50 Ω microstrip line used for Q factor measurements. Another parallel CuClad substrate with a metallic layer on the top was placed above the DR. The distance between substrates was p=4.5 mm.

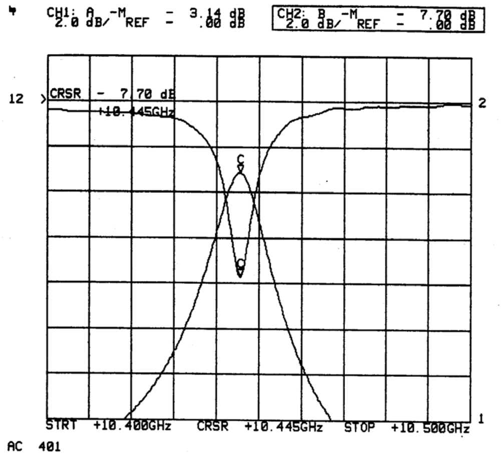

Fig. 5 Measured S_{11o} (1) and S_{21o} (2) of standard passive DR, d=5mm, l=2.2 mm, h=0.5 mm, p=4.5 mm, s=1 mm.

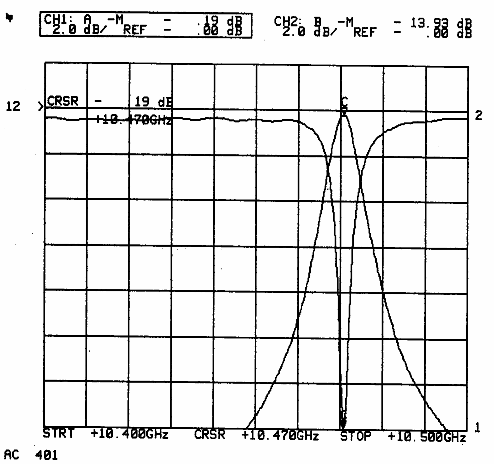

Fig. 6 Measured S_{11o} (1) and S_{21o} (2) of the active DR, in the same arrangement as in Fig. 5., s=1 mm.

HP 8757 scalar network analyzer was used for reflection and transmission measurements using technique designed by Khanna and Garault [2] for Q_l and Q_u determination.

In the first reference measurement the upper substrate was empty with lower metallic layer etched off. Fig. 5 shows measured S_{11o} and S_{21o} giving corresponding Q_l =969 and Q_u=3191.

For the active resonator measurements the extra active circuit on CuClad 223, h=0.5mm, in the form of the shunt feedback oscillator configuration suggested by Fiedziuszko [3] corresponding to Fig.1 was realized, see Fig. 4. The small signal approach for oscillator design was applied, [1]. Agilent general purpose Gallium Arsenide FET ATF 26884 was used as an active device. The substrate with the active circuit on the bottom side was placed in the height of p=4.5 mm above the lower substrate, that means in the same location as the empty one in the reference measurement. Structure was measured with different s and different coupling factor between the active circuit and the DR. Fig. 6 shows measurements of the active DR in the arrangement corresponding to the reference measurement. Corresponding Ql =1189 and Qu =54 729. Even greater Q factors for lower coupling factor between DR and microstrip line when s =1.5 mm were achieved, for example Ql = 3395 and Qu =149 040. $|S_{11o}|=1$ with corresponding $Qu\to\infty$ or even $|S_{11o}|>1$ were also observed. In these cases the whole structure tended to oscillate when it was weakly coupled to the microstrip line degrading the linear matter of the active resonator.

Varying feedback gain, eg. FET bias, not only resonator quality factor, but too coupling factors is affected

To complete these experiments, a reflection type oscillator with the same DR was realized. Corresponding spectrum is shown at Fig. 7. In a second step, the coupling of the DR to the oscillator was decreased so that the oscillations did not build up when the resonator was passive. Once above mentioned amplifier has been added to form the active resonator, oscillation build up occurred. This demonstrated that the idea of the active resonator works. No improvement of the phase noise has been observed in this experiment, see Fig. 7. and Fig. 8.

4. Conclusion

A new component, active resonator, has been proposed and experimentally verified at microwave frequencies. The arrangement has been found capable of improving the quality factor of a resonator by several orders of magnitude. Such an active resonator may be used in any frequency range. Viability in the microwave range has been experimentally verified.

Acknowledgement

This work has been conducted at the Dept. of EM Field of CTU in Prague and supported by research program *Investigation of new methods for measurement of physical quantities and their application in instrumentation* (J04/98:210000015, Czech Ministry of Education) and *New methods for broadband vector network measurements* (102/01/0573, GACR).

References

[1] VENDELIN, G. D., PAVIO, A. M., ROHDE, U. L. Microwave Circuits Designs Using Linear and Nonlinear Techniques. John Wiley & Sons, 1990.

[2] KHANNA, A., GARAULT, Y. Determination of Loaded, Unloaded, and External Quality Factors of a Dielectric Resonator Coupled to a Microstrip Line. IEEE Trans. Microwave Theory Tech. vol. MTT-31, no. 3, March 1983. p. 261-264.

[3] FIEDZIUSZKO, S. J. Microwave Dielectric Resonators. Microwave Journal. 1986, vol. 29, p. 189-200.

[4] HOFFMANN, K., SKVOR, Z. Active microwave and millimetrewave resonator. In EMC proceedings. London 2001, vol. 3, p. 17-20.

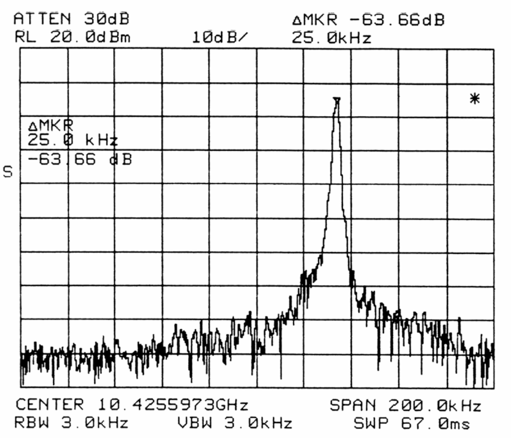

Fig. 7 Spectrum of the oscillator under test, passive DR.

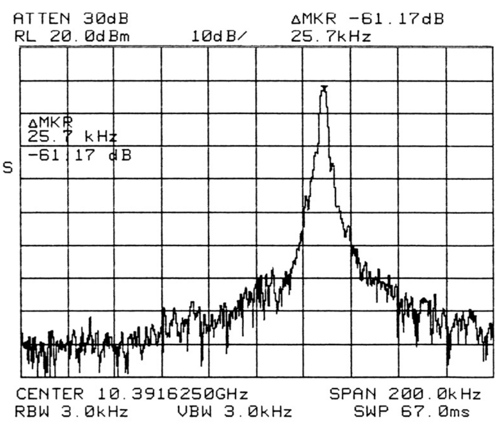

Fig. 8 Spectrum of the oscillator under test, active DR.