ACTIVE MICROWAVE AND MILLIMETERWAVE RESONATOR

K. Hoffmann and Z. Skvor

Czech Technical University in Prague, dpt. Electromagnetic Field
Technicka 2, 166 27 Praha 6, Czech Republic
Internet: hoffmann@fel.cvut.cz, voice: (+420-2) 24352276, fax: (+420-2) 3119958

Abstract

New circuit component – active resonator – is proposed for use in microwave and millimeterwave 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 millimeterwave 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.

Introduction – Motivation

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

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 a rule of thumb, for given resonator mode the quality factor follows

$$Q\sqrt{f} = const. \qquad (1)$$

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

$$Q_u = \omega_0 W / P \quad = 2\pi f_0 C / G \qquad (2)$$

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 a single filter is inversely proportional to resonator quality factor, it is impossible to design ultra-narrowband filters composed of resonators with low quality factors. Even with reasonable quality factors, narrowband filters require in loosely coupled resonators, and that results in high passband attenuation.

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 an external circuit, which results in loosing some more energy. Therefore, even an ideal resonator with zero inner losses and $Q_u \rightarrow \infty$ will exhibit 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 for example 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 in 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 a common passive resonator.

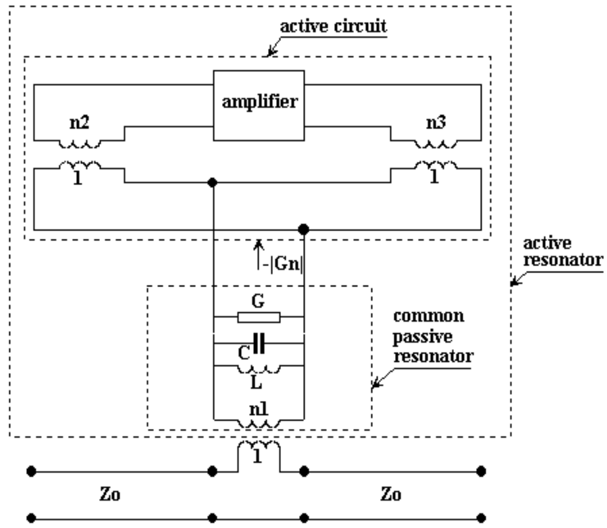


Fig. 1. An active resonator with feedback arrangement.

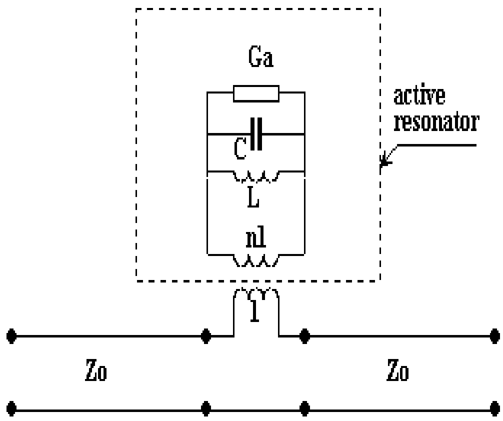


Fig. 2. Equivalent circuit of the active resonator.

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

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

full compensation of P will result in $Q_u \rightarrow \infty$ 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.

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 the results were compared.

A dielectric resonator (DR) with the diameter d=5 mm and the 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 50Ω 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. 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 the oscillator design was applied, [1]. Agilent general purpose Galium Arsenite 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. The 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 the DR and the 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 the feedback gain, eg. FET bias, not only resonator quality factor, but also coupling factors were 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 the above mentioned amplifier has been added to form the active resonator, oscillation build up occured. 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.

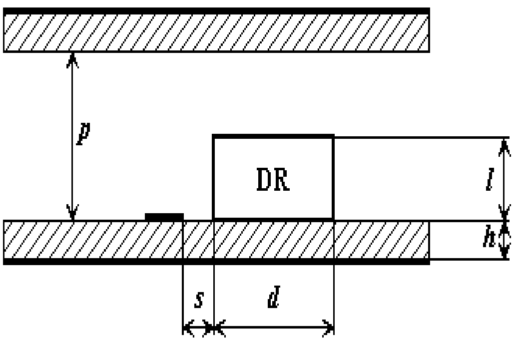


Fig. 3. Experimental setup.

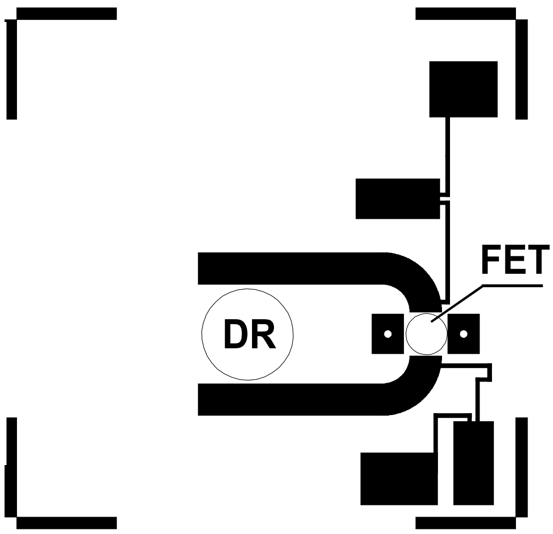
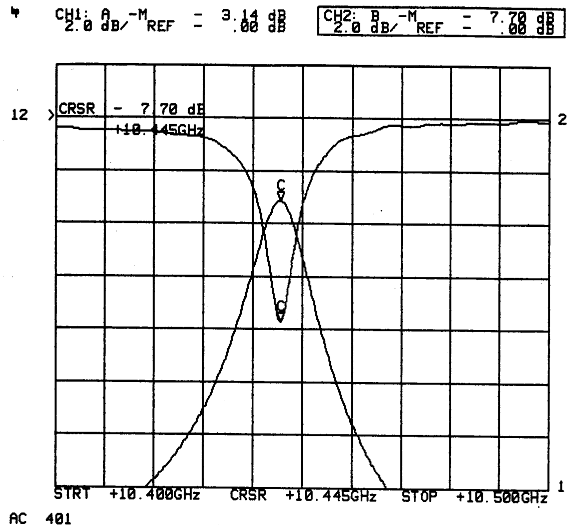


Fig. 4. Active circuit layout.

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.



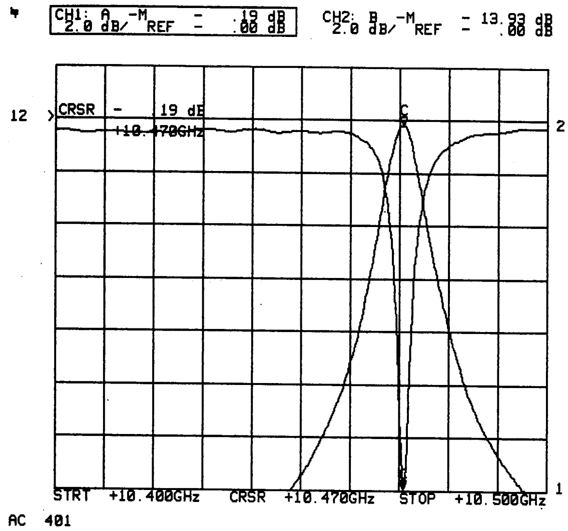
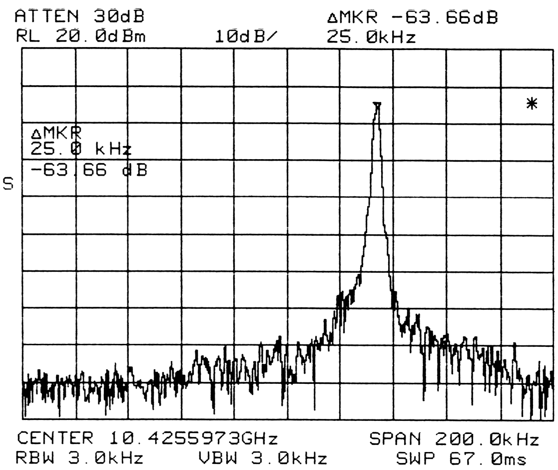


Fig. 5. Measured S_{11o} (1) and S_{21o} (2) of standard passive DR, d=5 mm, l=2.2 mm, h=0.5 mm, p=4.5 mm, s=1 mm.

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.



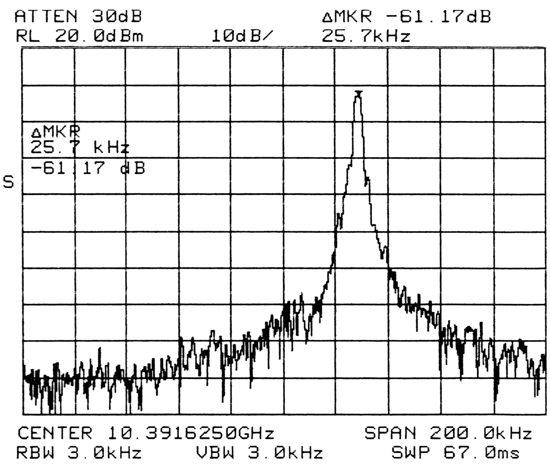


Fig. 7. Spectrum of the oscillator under test, passive DR.

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

Acknowledgement

This work has been conducted at the Department of Electromagnetic Field of Czech Technical University in Prague and supported by research program “Investigation of new methods for measurement of physical quantities and their application in instrumentation” No.: J04/98:210000015 of the Czech Ministry of Education and “New methods for broadband vector network measurements”, No GACR 102/01/0573.

References

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

[2] A. Khanna and Y. Garault, ’’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, pp. 261-264, March 1983

[3] S. J. Fiedziuszko, “Microwave Dielectric Resonators’’, *Microwave Journal*, vol. 29, September 1986, pp. 189-200

[4] K. Hoffmann and Z. Skvor: Active resonator. In: EUROCON 2001 proceedings, IEEE, Vol. 1., pp. 164-166, Bratislava 2001,