Active Resonator

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Abstract

A new electrical component -active resonator- is designed. The component consists of common passive resonant circuit whose losses are compensated by an extra active circuit. Experimental verification was done with TE01δ mode dielectric resonator with resonant frequency 10.4 GHz. Unloaded Q factor approaching infinity was achieved.

1. Introduction

Resonators are used in a number of applications in frequency bands covering audio, rf., microwave and optical frequencies. They are basic elements in filters, oscillators, antennas, etc. Finite quality factor of a resonator/resonant circuit is a limit for properties of many circuit where high selectivity is a must. Special arrangements could compensate for losses. A kind of such an arrangement is a laser, where the losses in a resonator are (over)compensated by a material with negative loss factor. Such an arrangement is used at optical frequencies only and there is no known cost-effective application of this method at RF and microwave frequencies. A way of compensation of inner losses of a resonator proper for the band from audio frequencies up to mm waves is proposed and experimentally verified on microwaves in this paper.

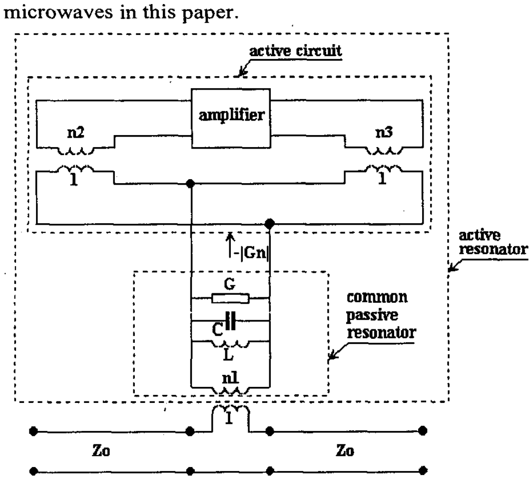

Fig. 1. Reduction of the resonator losses by a feedback amplifier.

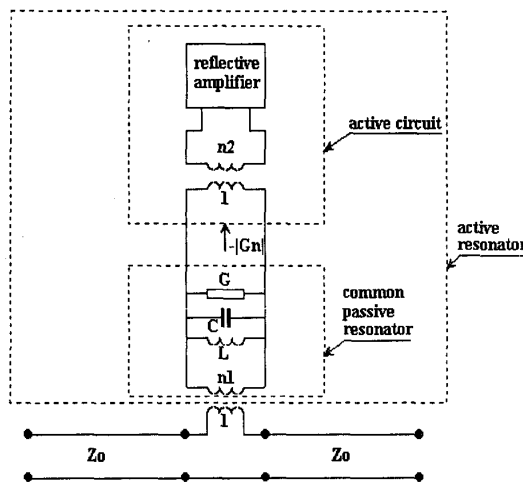

Fig. 2. Reduction of the resonator losses by a reflective amplifier.

2. Theory

The unloaded quality factor Qu of a resonator is limited by the energy lost in one oscillation period. This is expressed as

$$Qu = \omega_0 W/P \quad \text{or} \quad Qu = 2\pi f_0 C/G \qquad (1)$$

Where P is the average power loss in the resonator, and W is the total energy stored in the resonator, C and G correspond to the parallel equivalent circuit of the resonator. Due to the fact that the resonator itself is loss, the unloaded Qu 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 $Qu \to \infty$ would have finite loaded Ql.

We propose a solution for increasing Qu and Ql 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, see Fig. 2, where the resonator is in both cases coupled to a line.

Both active circuits create some effective negative conductance $-|Gn|$ which adds to the positive conductance of the resonator G. A new active resonator is created in this way with corresponding conductivity Ga given by

$$Ga = -|Gn| + G < G \quad (2)$$

Qu of this resonator is increased with respect to (1). Fig. 3 shows its equivalent circuit which is the same as for a common passive resonator.

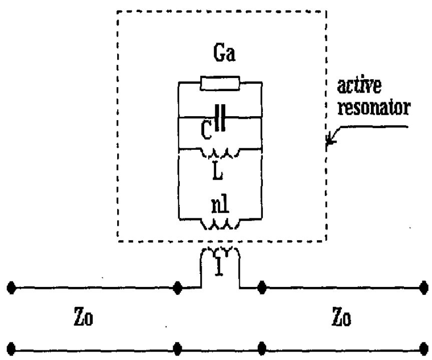

Fig. 3. Equivalent circuit of the active resonator.

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 fo, [1]. In the case of the active resonator, the only phase condition for oscillation build up at fo is satisfied, the amplitude condition is not satisfied. The oscillations will not build up and the active element will work in the small signal linear regime, which is advantageous with respect to noise. Its gain and power added to the circuit will reduce the inner losses of the active resonator. When

$$-|Gn| + G = 0 \quad (3)$$

full compensation of P will result in $Qu \rightarrow \infty$ with finite and increased Ql when coupled to a line or a circuit. In practical applications

$$0 < Ga \quad (4)$$

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

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 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. 4 shows a corresponding mechanical arrangement. DR was placed on CuClad 233 substrate (εr =2.33) with thickness h= 0.5 mm. It was coupled to 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 p=4.5 mm. HP 8757 scalar network analyzer was used for reflection and transmission measurements with technique designed by Khanna and Garault [2] for Ql and Qu determination.

In the first reference measurement the upper substrate was empty with lower metallic layer etched off. Fig. 5 shows measured S11o and S21o giving corresponding Ql =969 and Qu=3191.

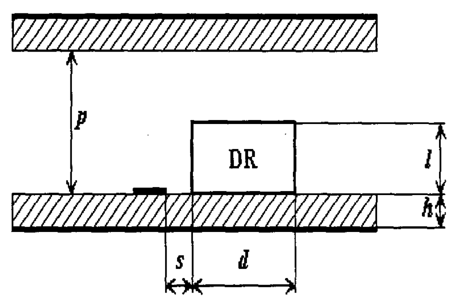

Fig. 4. Experimental set up.

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. 6. 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, it is in the same place 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. 7 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, see Fig. 8. Corresponding Ql = 3395 and Qu =149 040. |S11o|=1 with corresponding $Qu \rightarrow \infty$ or even |S11o|>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.

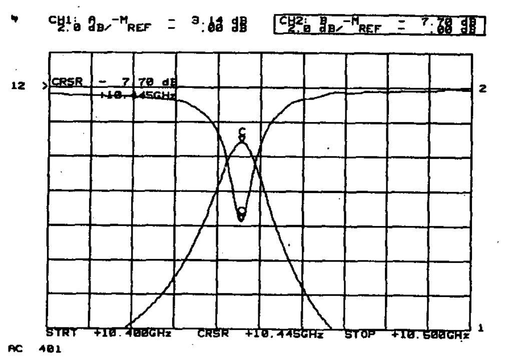

Fig. 5. Measured S_{11o} (1) and S_{21o} (2) of standard passive DR, d=5mm, l=2.2mm, h=0.5mm, p=4.5mm, s=1mm

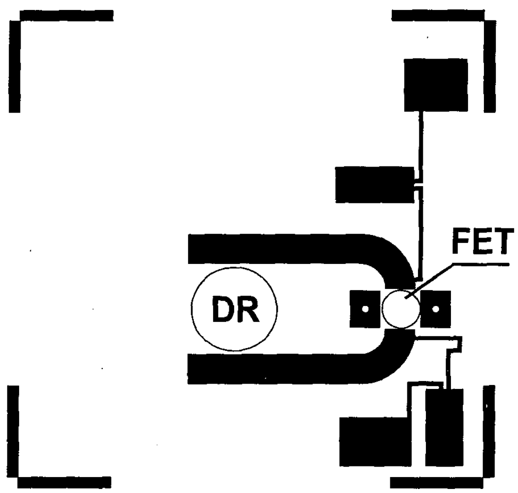

Fig. 6. Active circuit layout.

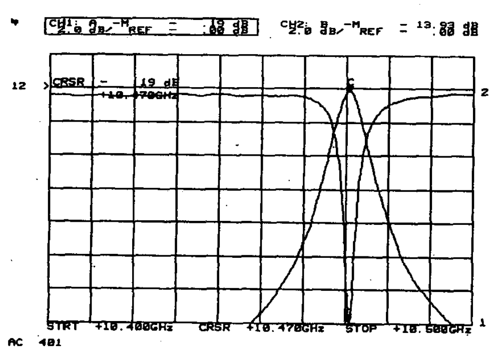

Fig. 7. Measured S_{11o} (1) and S_{21o} (2) of the active DR, in the same arrangement as in Fig. 5., s=1mm

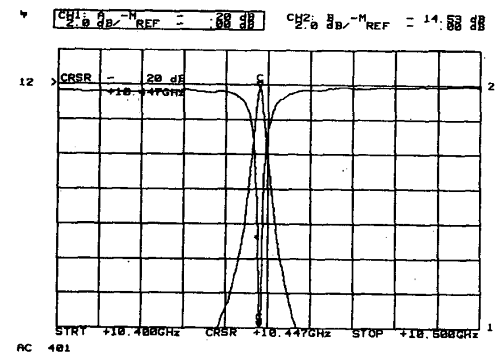

Fig. 8. Measured S_{11o} (1) and S_{21o} (2) of the active DR, in the same arrangement as in Fig. 5., s=1.5mm

4. Conclusion

A new circuit element -active resonator- was designed and experimentally verified on the structure with the dielectric resonator included. It makes possible practical realizations of resonant circuits with *Ql* significantly greater when compared to common passive resonant circuits and to achieve *Qu* approaching infinity. The active resonator has a linear nature promising small up-conversion of 1/f noise to the vicinity of the resonant frequency. Applications in high selective filters and low phase noise oscillators are supposed.

Acknowledgement

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