LUMPED MODE MICROWAVE RESONANT STRUCTURES

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Abstract

A new class of electrically small microwave resonators working in lumped mode is described for filter and oscillator applications. These resonators are tunable over a wide range and have a Q of about 2000. Tuning, coupling, and applications of these resonant structures are discussed.

Introduction

At the low frequency microwave bands of L and S, resonant elements present a problem because of the large size of resonant cavities and the high loss of lumped element resonators. Caulton in [1] describes miniature lumped element LC resonant circuits which are composed of an interdigital capacitor and a loop inductor on a MIC substrate. Here we describe a resonator with a lumped mode field configuration where the transmission line between the inductive and capacitive elements is eliminated and therefore these elements are in juxtaposition which results in a low loss. The other advantages of these resonators are ease and low cost of construction, compact size and easy access to electromagnetic fields for coupling and tuning.

The Resonator

The loop-gap (or split-ring) resonator is shown in figure 1. It consists of a conductive cylindrical loop cut by one or more longitudal slots (or gaps). In this paper only the one gap resonators are discussed. The electric fields, as shown in figure 1., are supported by the gap and the magnetic fields surrounding the loop. A cylindrical shield is needed to prevent radiation. The structure is typically one tenth of a wavelength in size. Table 1 shows physical dimensions in milimeters and resonant frequency and Q factor for four silver plated brass resonators.

Res. No.	r0	w	t	R	Z	f0(MHz)	Q0
1	6.3	2.5	.23	15.0	17.8	1413.0	2050
2	3.2	2.4	.33	10.2	10.2	3050.8	1800
3	6.3	6.3	.25	19.0	30.5	998.5	1600
4	1.5	.8	.33	4.0	5.1	8877.0	1100

Table 1.

A structure based on the same principle was used [2] for acceleration of charged particles utilizing the high electric field intensity of the gap area. The loop-gap resonator is now being used in magnetic resonance spectroscopy because of its better filling factor compared with cavity resonators [3],[4].

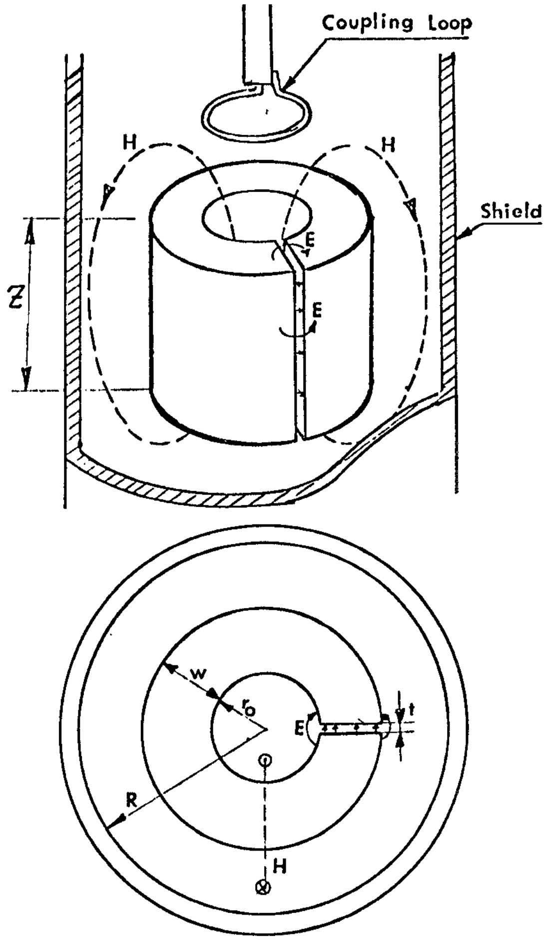

Fig. 1. A loop-gap resonator and its cross sectional view.

Tunability

The resonant frequency of the loop-gap resonator can be tuned by electric and magnetic means. Utilizing the high intensity of electric fields in the gap, an effective means of electric coupling is insertion of a dielectric slab in the gap. Figure 2 shows the variations of the resonant frequency of the resonator No. 2 in table 1. versus the penetration of three different dielectric slabs of different thicknesses and dielectric constants. Magnetic (inductive) tuning can be carried out by moving a conductive shorted loop at one end of the resonator as described in [3]. The tuning range of about 5 percent can be achieved by this method. The loop-gap resonator can be tuned by a varactor by placing the device in close proximity of the gap. For the resonator No. 2 in table 1, a resonant frequency variation of 200 MHz was obtained by a GaAs varactor model 46600H (MW Associates) with a bias voltage variation from 0 to 50 volts.

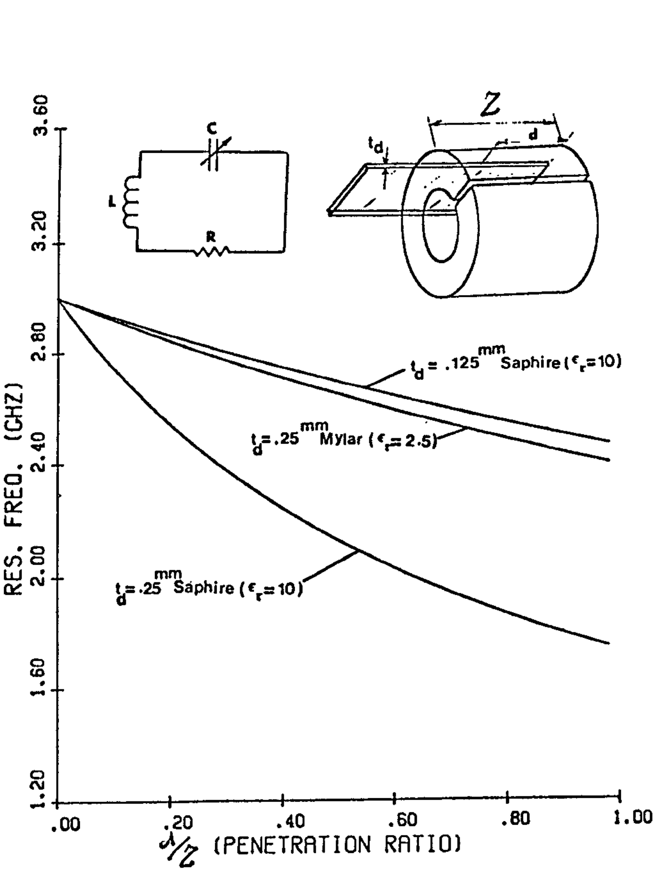

Fig. 2. Tuning of a loop-gap resonator by insertion of a dielectric slab in the gap. a) equivalent circuit, b) Schematic configuration, and c) Tuning curves.

Coupling

An important feature of a loop-gap resonator is the possibility of coupling to external circuits using the fields at the two end of of the resonator. Since the diameter of the shield is much smaller that the resonant wavelength, the shield acts as a waveguide below cutoff. This means that the shield can be open at two ends without any radiation loss, which provides easy access to fields for coupling. One example is coupling to a coaxial transmission line by means of a coupling loop as shown in figure 1. For resonator No. 2 in table 1 and a loop with radius of 3 mm connected to a 50 Ohm line, a coupling coeficient of unity is obtained when the resonator and the loop are 4 mm apart. The resonator can be directly coupled to other loop-gap resonators for filter applictions as shown in figure 5. The evanescent mode in the shield between the two resonators is mainly a cylindrical TE01 mode and calculation of the coupling factor between the two resonators was carried out on this basis. The loop-gap resonator can be magnetically coupled to a microstrip line as shown in figure 3, which makes these resonators compatible with microwave integrated circuits. Electric coupling of a probe to the fringe fields of the gap is also possible. Figure 4 shows this coupling configuration.

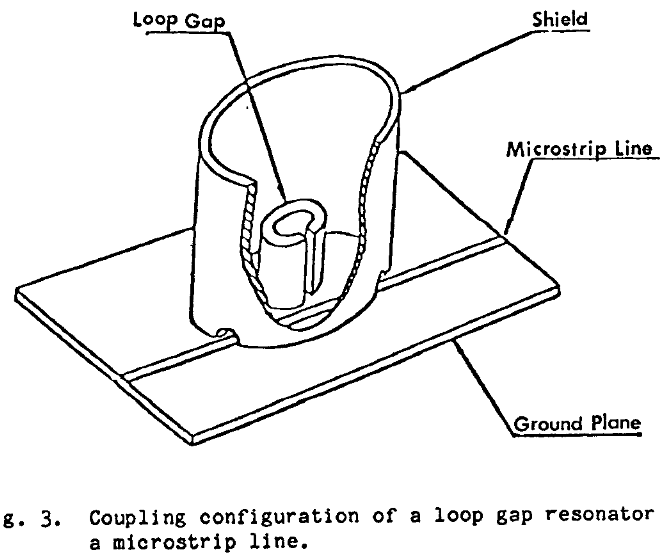

Fig. 3. Coupling configuration of a loop gap resonator to a microstrip line.

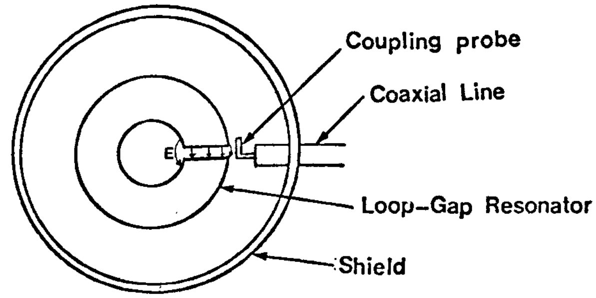

Fig. 4. Electric coupling configuration to a loop-gap resonator.

Calculation of the resonant frequency

A rough estimation of resonant frequency of a loop-gap resonator can be carried out by considering the gap as a parallel plate capacitor and the loop as a solenoid [4]. This method ignores the magnetic and electric fringe fields and the magnetic fields in the annular region between the resonator and the shield. The following expression was found considering those effects for a resonator with the inner loop radius of r_0, length Z, gap width W, gap distance t and shield radius R :

$$f_0 = \frac{c}{2\pi r_0}\sqrt{\frac{t}{\pi W}}\sqrt{\frac{r_0^2}{R^2-(r_0+W)^2}}\;\frac{\sqrt{1+\frac{\Delta Z}{Z}}}{\sqrt{1+\frac{\Delta W}{W}}}$$

Here c is the velocity of light. The parameter ΔZ is the equivalent extension of the resonator length due to the magnetic fringe fields at the two ends of the resonator. Similarly, ΔW is the equivalent extension of the gap width due to the gap electric fringe fields. The values of ΔZ and ΔW can be found by analysis of fringe fields. The following approximations for the equivalent length extensions give the resonant frequency within few percent error:

$$\Delta Z \cong 0.18 R$$

$$\Delta W \cong 3t$$

Filter Structures With Loop-Gap Resonators

Because of coupling flexibility and high Q of loop-gap resonators, they can be used as resonant elements in compact filter structures. Figure 5 shows a typical multisection filter configuration with loop-gap resonator elements. The equivalent circuit of this filter configuration is shown in figure 6. The design equations for such filter with inductive coupling is given by Cohn in [7]. Figure 7 shows the response of two element band pass filter direct coupled loop-gap filter. This filter is 20 mm in cross sectional diameter and 80 mm in length. The resonant elements are the same size as the resonator No. 2 in Table 1. As long as the sizes are kept much smaller than pass band, the effect of sporious resonances is minimum.

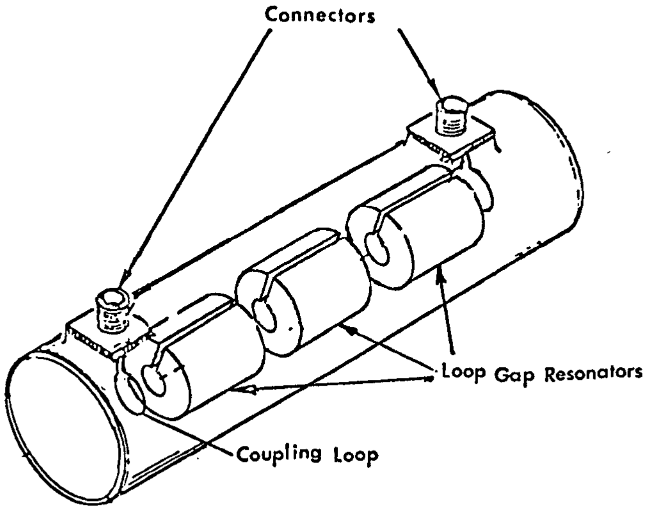

Fig. 5. A direct coupled multisection filter congiguration with loop gap resonator elements.

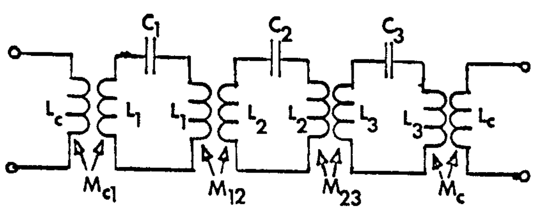

Fig. 6. The equivalent circuit of a direct coupled loop gap resonator filter.

Oscillators With Loop-Gap Resonators

A loop-gap resonator can be used as a stabilizing element for a microwave oscillator. An oscillator for 3 GHz was tested using ther coupling configuration to microstrip line of figure 3 with a bipolar HP transistor model #HXTR-3101 as the active element. An external quality factor of 600 was obtained.

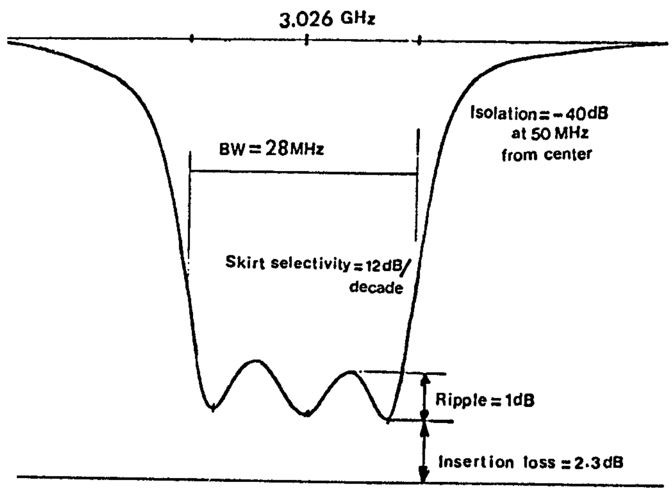

Fig. 7. A typical frequency response for a multisection loop gap resonator filter.

Conclusion

It has been demonstrated in this research that a loop-gap resonator which is a lumped element microwave resonant structure, has a wide range tunability and flexibility of strong colpling to external circuis. It was also shown that because of these characteristics they can be used in microwave communication systems as filter elements and stabilizing circuits for microwave oscillators.

Acknowledgement

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