Dielectric Ring-Gap Resonator for Application in MMIC's

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Abstract

A new dielectric resonator — the dielectric ring-gap resonator — is introduced and analysed. The resonant frequency and unloaded Q factor of the fundamental quasi-TE_{O11} mode have been calculated by a numerical field analysis and an appropriate equivalent circuit. The calculated resonant frequencies show an accuracy of <1% compared with the experimental results.

Introduction

It is well known that dielectric resonators have not only the advantages of a small size and a small weight, but also those of a high unloaded Q factor and a high temperature stability of resonant frequencies. Often used structures of the dielectric resonators are dielectric disc and ring resonators [1], [2]. In this article a new dielectric resonator — the dielectric ring-gap resonator — is introduced and analysed. The dielectric ring-gap resonator is obtained by sawing a very narrow gap (or slit) into a dielectric ring resonator. Its configuration and the field pattern of the fundamental quasi-TE_{O11} mode are shown in Fig. 1.

The desired, technically applicable resonant mode in the dielectric ring-gap resonator has a similar field distributions to the TE_{O11} mode in the corresponding dielectric ring resonator except the electric fringing field in the vicinity of the gap edges and the electric field in the air gap, as shown in Fig. 1. This mode will be named quasi-TE_{O11} mode. When the gap is narrow enough, the magnetic fringing field near the gap is very weak and it can be neglected. The electric fringing field near the gap edges can be much stronger than the electric field anywhere else outside the ring. The electric field in the air gap is ε_r times (ε_r is the relative permittivity of the ring material) stronger than that in the dielectric ring.

Besides the advantages of dielectric disc and ring resonators, the dielectric ring-gap resonator has four following important properties:

1. The gap in the dielectric ring resonator raises the resonant frequencies of the TE_{Opq} modes. Furthermore the fundametal quasi-TE_{O11} mode can be excited effectively suppressing other undesired higher order modes at the same time. The best experimental result shows that the desired fundamental mode can be excited dominantly over a measured frequency range from 45 MHz to 40 GHz in a proper designed ring-gap resonator.
2. The dielectric ring-gap resonator may be coupled directly to a microstrip line, to a slotline or to a coplanar waveguide on a MMIC chip by the electric fringing field in the vicinity of the gap.
3. The resonant frequency of the dielectric ring-gap resonator can be tuned by a dielectric slice in the gap besides the tuning techniques used in the dielectric ring resonator.
4. The dielectric ring-gap resonator has a higher dielectric Q factor due to some of the electric energy stored in the lossless air gap, but a lower conductor Q factor than the dielectric ring resonator. The total Q factor may be higher or lower compared to the dielectric ring resonator dependent on the geometrical structure.

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Theoretical Analysis

A dielectric ring-gap resonator used in practice is usually placed in a parallel-plate waveguide or in a cylindrical cavity together with other dielectric materials, for example with a substrate and a dielectric spacer as shown in Fig. 2. Fig. 3 shows an appropriate equivalent circuit for the quasi-TE_{Opq} mode in this resonant system. The equivalent circuit is composed of an inductance L_r and two parallel RC circuits. One of the RC circuits ($C_{rg,r}$, $R_{d,rg,r}$ and $R_{c,rg,r}$) is used to characterize the stored electric energy and dissipated power, due to dielectric and conductor losses respectively, in the volume V_r of the resonator outside the slot region (Fig. 2). Another ($C_{rg,g}$, C_f, $R_{d,rg,g}$ and $R_{c,rg,g}$) characterizes those in the small slot volume V_g. C_f is an equivalent capacitance due to exitance of the electric fringing field near the gap. Except C_f all

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elements can be approximately determined from the resonant frequency and the field distribution of the TE_{Opq} mode in a dielectric ring resonator (Fig. 4), which has the same geometrical structure as the dielectric ring-gap resonator except for the gap. The resonant frequency and the unloaded Q factor due to dielectric and conductor losses of the dielectric ring-gap resonator can be evaluated by neglecting C_f in the equivalent circuit shown in Fig. 3, because C_f is much smaller than $C_{rg,g}$.

A numerical procedure ("radial mode matching method" [1], [2]) is extended in order to determine the resonant frequencies and the field distributions for the TE_{Opq} modes in a dielectric disc or ring resonator placed in a parallel-plate waveguide or in a cylindrical cavity together with other cylindrically shaped dielectric materials. The resonator is divided into some complementary annular regions filled with different dielectric layers. For example the dielectric ring resonator shown in Fig. 4 is divided into 5 complementary annular regions. It is assumed that all dielectric materials are lossless and the metal shield is perfectly conducting. Dielectric losses and conductor losses are calculated from the derived electromagnetic field using a perturbation theory.

Numerical and Experimental Results

Computer programs have been developed to analyse and design dielectric disc, ring and ring-gap resonators in different environments. Some dielectric ring-gap resonators have been theoretically and experimentally investigated. They are placed on a dielectric spacer (D_s=4.14 mm, d_s=1.3 mm, L_s=0.50 mm, ε_r=4.45) over a substrate (h=0.635 mm, ε_r=10) and in a parallel-plate waveguide (H=10 mm), as shown in Fig. 2. It is assumed that all dielectric materials have the same dielectric loss tangent of $\tan\delta_d$=0.0001 and the metal enclosure has a conductivity of $\sigma=2\cdot10^5$ $(\Omega cm)^{-1}$.

In Table 1 the calculated values of resonant frequencies and unloaded Q factors of four dielectric ring-gap resonators are compared with the experimental results. Fig. 5 shows the comparison of the calculated and measured resonant frequencies and unloaded Q factors of the dielectric resonators with diffenrent gap sizes (s). The calculated resonant frequencies show an accuracy of <1% compared with the experimental results. Because the dielectric spacer below the ring-gap resonator has a small height, the conductor losses of the ground plane, excited by the gap fringing field, are high. Therefore the total Q factor of the ring-gap resonator in this case is lower than that of the ring resonator and increases with the gap width s. In cases where L_s (Fig. 2) is large, the total Q factor of the ring-gap resonator may be higher than that of the ring resonator and may increase with s. Fig. 6 shows the electromagnetic field pattern of the TE_{O11} mode in the cross section of the dielectric ring resonator as shown in Fig. 4.

The gap in the dielectric ring resonator raises the resonant frequencies of the TE_{Opq} modes. Furthermore the ring-gap resonator has the advantage that the fundamental quasi-TE_{O11} mode can be excited dominantly suppressing the higher order modes at the same time. This is due to following facts: the undesired higher order modes in the ring-gap resonator are axially unsymmetrical and their field distributions are changed azimuthally with different positions of the gap; The electric field of the quasi-TE_{O11} mode is very strong near the gap and the magnetic field is strong around the ring opposite to the gap. If for example the resonator is excited by a nearby microstrip, this can effectively be done by a magnetic coupling as shown in Fig. 7a. In the best case, no undesired modes can clearly be observed over a measured frequency range from 45 MHz to 40 GHz (Fig. 7a). If the same experiment is performed with a dielectric ring resonator, the higher order modes cannot be suppressed so effectively. If the position of the ring-gap resonator is changed by 90° (Fig. 7b), some undesired higher order modes cannot be suppressed, and in the case of a electric coupling (Fig. 7c) the higher order modes can be excited more effectively than the fundamental mode.

Other coupling techniques of the dielectric ring-gap resonator to e.g. a microstrip line on a thin substrate (Fig. 8), using the electric fringing field in the vicinity of the gap edges, have been experimentally investigated and show promising properties. The dielectric ring-gap resonator may also be coupled directly to a slotline or to a coplanar waveguide on the thin substrate by the electric fringing field. Using this coupling in MMIC´s, for example in a MMIC oscillator, the circuits are more compact and the bonding of the MMIC chip onto a substrate can be avoided.

Conclusion

Computer programs have been developed to analyse and design dielectric disc, ring and ring-gap resonators in different environments. The characteristics of the fundamental quasi-TE_{O11} mode in the dielectric ring-gap resonator have been theoretically and experimentally investigated. New coupling techniques to couple the dielectric ring-gap resonator to e.g. a microstrip line on a thin subtrate, using the electric fringing field near the gap edges, have been experimentally investigated.

References

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[2] Y. Kobayashi, N. Fukuoka and S. Yoshida, "Resonant modes for a shielded dielectric rod resonator", Electronics and Communications in Japan, vol. 64-B, no. 11, pp. 46-51, 1981.

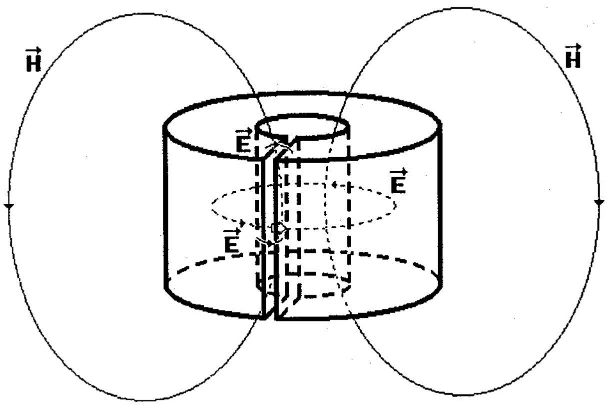

Fig. 1. Dielectric ring-gap resonator and its field pattern

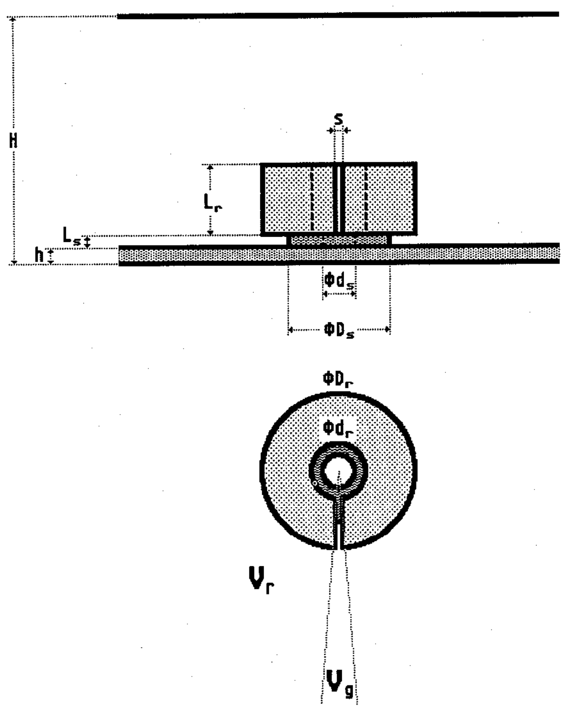

Fig. 2 Configuration of the dielectric ring-gap resonator

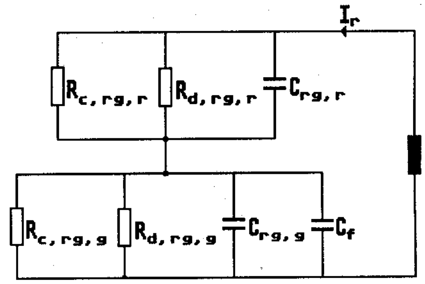

Fig. 3 Equivalent circuit for the quasi-TE_{0pq} mode in the dielectric ring-gap resonator

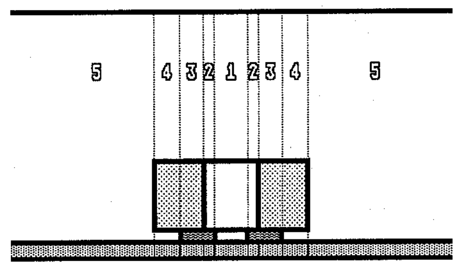

Fig. 4 Cross section of the dielectric ring resonator

Table 1 Comparison of calculated and experimental results of the resonant frequencies (f_r) and the unloaded Q factors (Q_r)

No.	D_r mm	d_r mm	L_r mm	ε_r	s μm	f_r GHz theo.	f_r GHz exp.	Q_r theo.	Q_r exp.
1	6.23	2.18	2.80	29.57	190	10.757	10.861	4030	3130
2	6.23	2.18	2.80	29.57	270	11.087	10.980	3600	2780
3	6.23	2.18	2.80	29.57	280	11.128	11.011	3550	2550
4	6.74	2.11	2.51	28.07	270	11.017	10.914	3330	2850

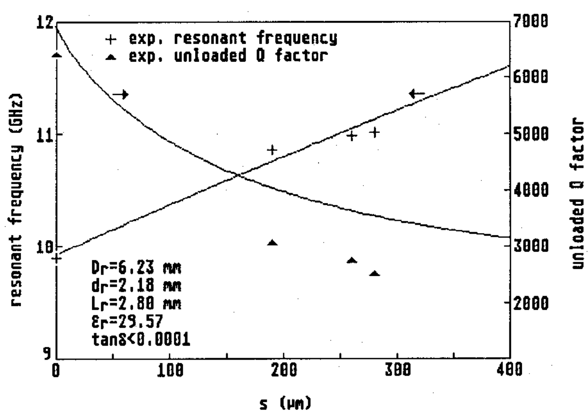

Fig. 5 Resonant frequencies and unloaded Q factors versus the gap size (s)

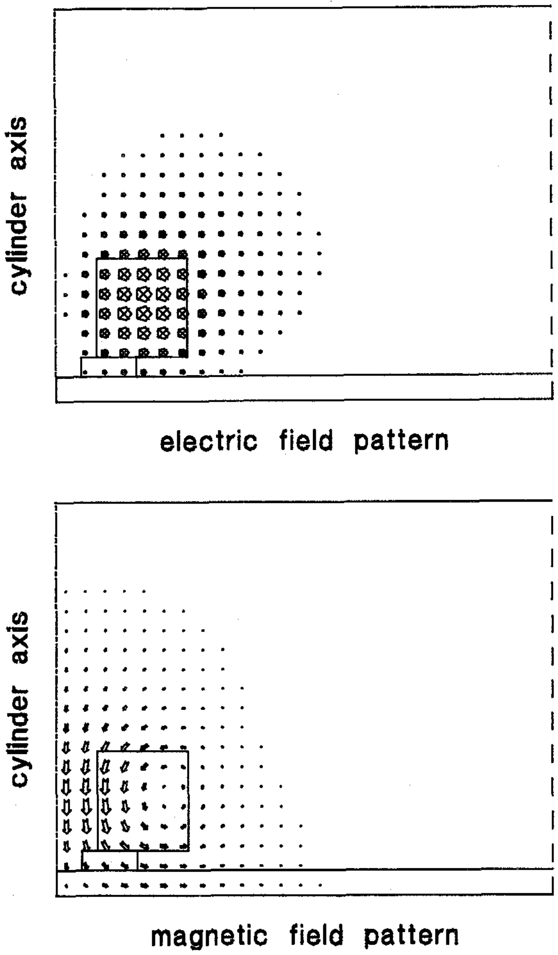

Fig. 6 Field patterns of the TE_{O11} mode in the cross section of the dielectric ring resonator

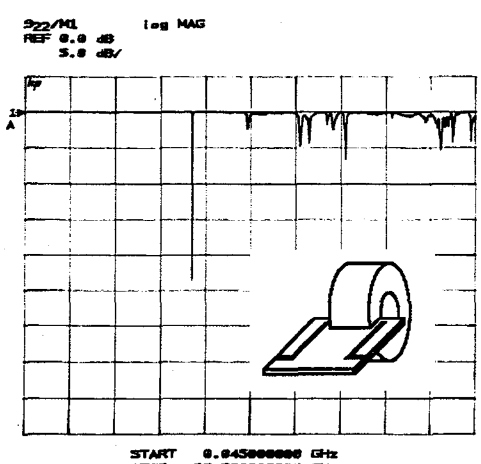

Fig. 8 Frequency response of the dielectric ring-gap resonator coupled to a microstrip line

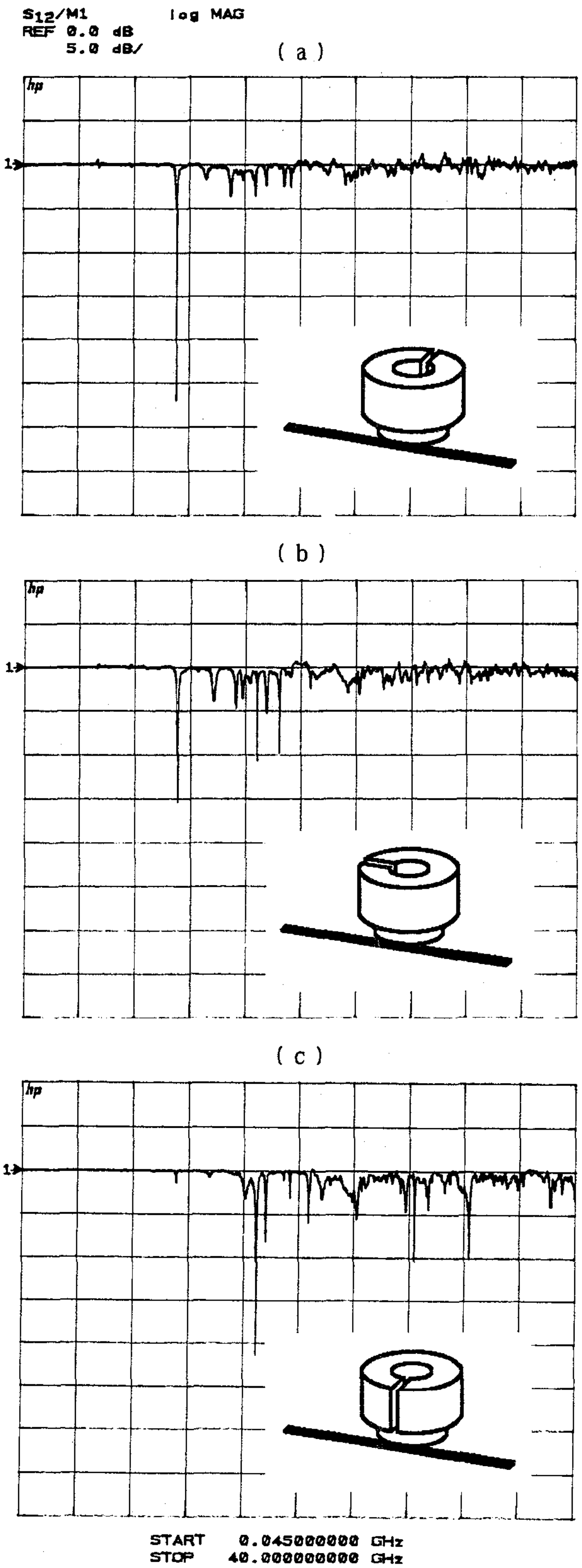

Fig. 7 Frequency responses of the dielectric ring-gap resonator excited by a nearby microstrip