Novel Invasive Electronic Tuning of Dielectric Resonators

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Abstract — **Electronically tuned dielectric resonator (DR) structures have, in the main, in the past employed external tuning techniques. This paper presents the investigation results on a novel tuning technique termed "invasive tuning". Invasive tuning involves the machining of rectangular shaped slot in the dielectric resonator and embedding the tuning mechanism inside this slot, which is within the boundary of the resonator. This results in a very compact tuning arrangement, which provides substantial tuning bandwidth of 7.1% using electronic means. The effect of slot perturbations on the DR resonant frequency and quality-factor are reported in this paper. Variations in the performance of the slotted resonator are characterized and the results from a number of tuning experiments are discussed. The incorporation of the new tuning technique into practical circuits such as filters have shown good performance for a compact design. This technique may also be used for the electronic tuning of oscillators.**

Key words: **Dielectric resonators, Microwave devices and components**

I. Introduction

Dielectric resonators are commonly used in oscillator and filter applications. Their low cost, compact size and performance make them eminently useful in microwave applications. As the demand for communications grows worldwide, and with the advent of third generation mobile personal communication devices which will operate at microwave frequency band, there is a growing demand for suitable high specification microwave components and subsystems for such communication systems. In particular, there exists a need for fast (in excess of GHz/μs) tunable DRs providing a relatively large tuning bandwidth, for application in next generation re-configurable systems. A number of different techniques have been devised in the past to bring this about [1]-[2]. In the main tuning has been carried out via devices and/or a mechanism external to the DR. Existing electronic tuning techniques provide tuning bandwidth limited to about 0.75% [1]-[2]. A new and recent tuning technique using piezoelectric transducer (PET) has shown to provide a tuning bandwidth of 3.7% at 11.78 GHz [3].

This paper explores and evaluates the proposed novel invasive tuning technique. The invasive tuning technique differs from the conventional known techniques in that there is direct coupling between the electronic tuning element such as varactor diode, and the electric field of the slotted DR. The degree of this coupling is governed by the DR slot size and/or the type of varactor diode employed in order for the tuning technique to be viable. The slot size that is machined into the DR is dependent on the varactor type used and must be large enough to accommodate the varactor diode. It is shown that the choice of a suitable varactor diode plays an important role in the circuit performance. Varactor diodes of the LID and pill-type are used in the circuitry evaluated here. The invasive tuning technique is demonstrated to provide the largest tuning range to date using electronic means. The invasive technique can achieve a tuning bandwidth of 7.1% centered at 4.47 GHz.

II. Tuning Mechanism

Two types of varactor diodes were used in the investigation; the Marconi DC4373B LID and the Microwave Associates pill-type series M1-4500. The latter are manufactured from GaAs and are from a family of abrupt junction devices featuring quality factors in excess of 4000. This series is specifically designed for broadband high-Q tuning performance from VHF to 40 GHz. Typical applications are solid-state tuning of VCOs using transistors, Gunn diodes or IMPATT diodes, as well as voltage tunable filter and amplifier circuits. The varactor diodes depletion layer capacitance is given by

$$C_j = \frac{C_o}{\left(1 - \frac{V}{V_o}\right)^{\gamma}}$$

Where C_o, is the junction capacitance without bias, V the tuning voltage, V_o the contact potential and γ a function of the doping profile. For varactor diodes with abrupt doping profiles γ is equal to 0.5. The varactor packages used are shown in Figure 1 together with the design of the varactor diode holder.

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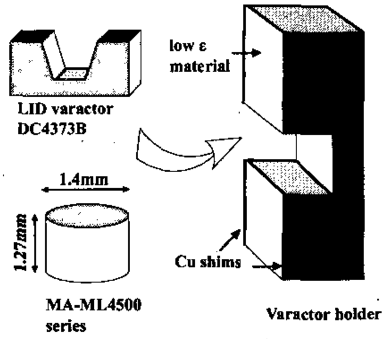

Figure 1. Varactor packages and holder layout

III. Measurement of a DR With a Slot

The following outlines the procedure for assessing a slotted DR, shown in Figure 2 and diagrammatically in Figure 3. The slotted DRs are assessed against an unslotted DR of the same type in terms of resonant frequency, insertion loss and 3 dB bandwidth.

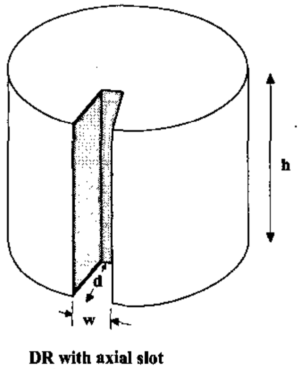

Figure 2. Perspective view of slotted DR

Slot dimensions

Slot width w (mm)	Slot depth d (mm)
1.5	2.5
2.0	2.0
2.5	1.5
3.0	2.5
4.0	3.0

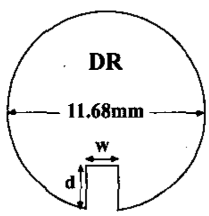

Figure 3. Slot dimensions

The slot dimensions are shown in the table in Figure 3 and the measured results in Table 1. The DR was manufactured by MURATA (DRD117MC056, h = 5.16 mm, r = 5.84 mm).

Table 1 Measured Results

Width of slot w (mm)	Depth of slot d (mm)	Resonant frequency (GHz)	Bandwidth (MHz)	Insertion loss (dB)	Unloaded Q-factor
0	0	6.299940	2.151	27.50	2810
1.5	2.5	6.405930	2.113	32.10	2958
2.0	2.0	6.386800	2.020	29.60	3060
2.5	1.5	6.353700	2.116	30.40	2915
3.0	2.5	6.444476	2.180	30.71	2873
4.0	3.0	6.531100	2.204	30.70	2879

IV. Analytical Analysis of The DR Structure

The analytical techniques developed by Cohn [4] and Itoh [5] were used in the analysis of the coupling between the DR and a microstrip. A computer program was developed in order to calculate the resonant frequency of a DR in a cavity. The accuracy of the theoretical results was then correlated with measured.

A dielectric substrate with ε_r = 2.33 and h = 0.7874 mm was used inside the cavity. The cavity height was adjustable by a metal plunger. Microstrip arc patterns were used to couple the electromagnetic energy into and out of the resonator structure. The resonant frequency in the $TE_{01\delta}$ mode is selected in a similar way to that with the parallel plate method. Figures 4 and 5 show the change of resonant frequency for varying gap width g between the top of the DR and the plunger in the cavity (see Figure 6), the plunger representing the top of the cavity. The tuning range measured with the DR placed directly on the substrate is ≈ 12.0%. When the DR is supported on a dielectric spacer (ε_r=6.4) the tuning range is also ≈ 11.0%.

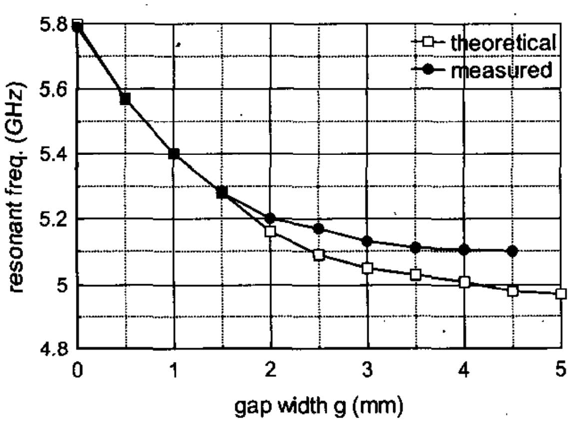

Figure 4. Resonant frequency variation without spacer

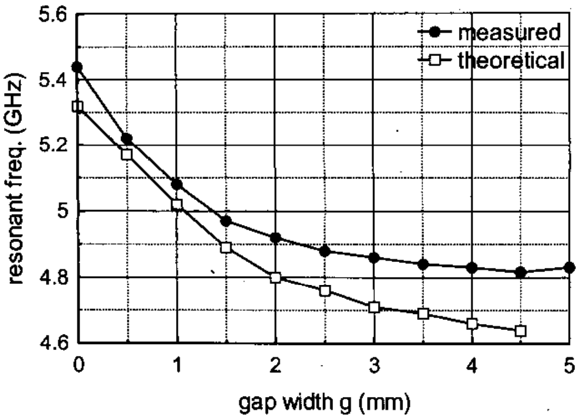

Figure 5. Resonant frequency variation with 2.5mm spacer (ε_r = 6.4)

V. Practical Design

The tuning experiments were carried out on slotted DRs within the test cavity. Access to the slotted DR structure and hence filter is achieved via the base of the cavity as shown in Figure 6. Thin wires of length $\lambda/4$ at the nominal resonance frequency of the structure are passed through 1 mm diameter holes to the varactor carrier. The anode of the varactor is connected to the filter base and is therefore grounded. The cathode is connected via a 1nF feed-through capacitor to prevent any microwave signal reaching the varactor dc control voltage supply. The varactor carrier sides are metallized to ensure that the perturbed field appears uniformly at the sides of the slot. This field is then displaced in synchronism by varying the varactor control voltage, and hence varactor capacitance.

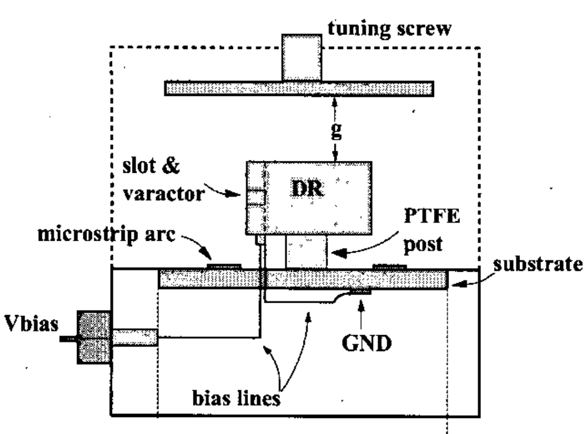

Figure 6. Slotted DR tuning arrangement in cavity

VI. Measured Results

The slotted DRs referred to above were embedded inside the test cavity and the variations of resonant frequency, 3 dB bandwidth and insertion loss measured. The varactor control voltage was kept below the minimum breakdown voltage of 30V. Figures 7(a) to 8(c) are samples of the results obtained and are self explanatory. In general these results indicate an increase in resonant frequency, a decline in 3dB bandwidth, and decline in change in associated insertion loss with an increase of varactor reverse bias voltage. Frequency tuning of 317.5 MHz with a slot width of 2 mm and depth of 2 mm has been obtained for an MA-ML4514 varactor, which is tuned from 0 to 25V. At a center frequency of 4.47 GHz this amounts to 7.1%.

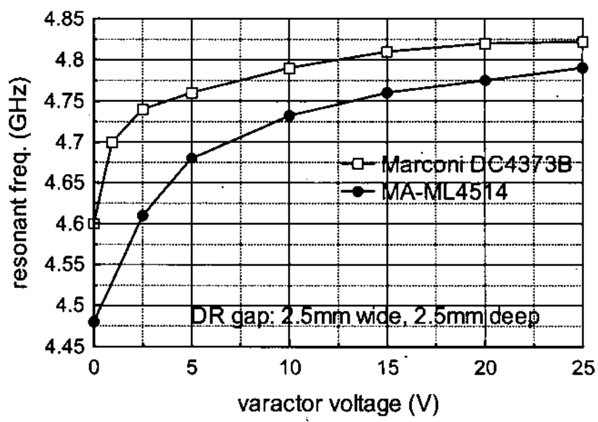

Figure 7(a). Change in resonant frequency for two different varactor types as a function of varactor reverse bias voltage

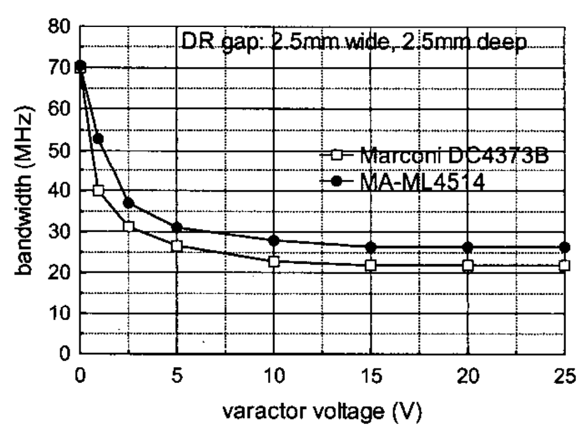

Figure 7(b). Change in associated bandwidth as a function of varactor reverse bias voltage

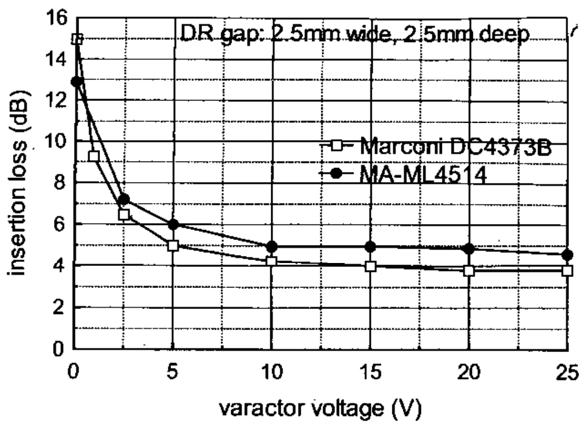

Figure 7(c). Change in associated insertion loss as a function of varactor reverse bias voltage

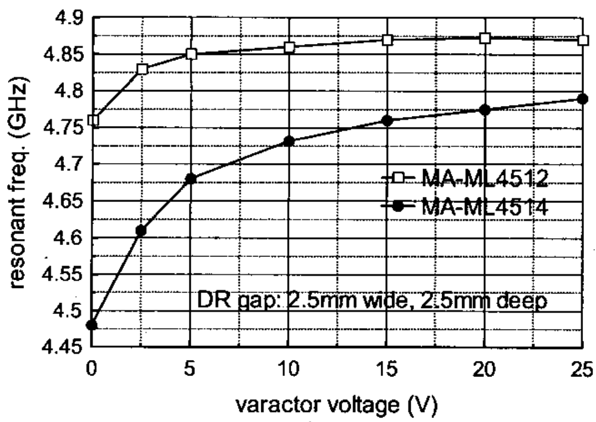

Figure 8(a). Change in resonant frequency of two MA-ML4500 series varactor diodes types as a function of varactor reverse bias voltage

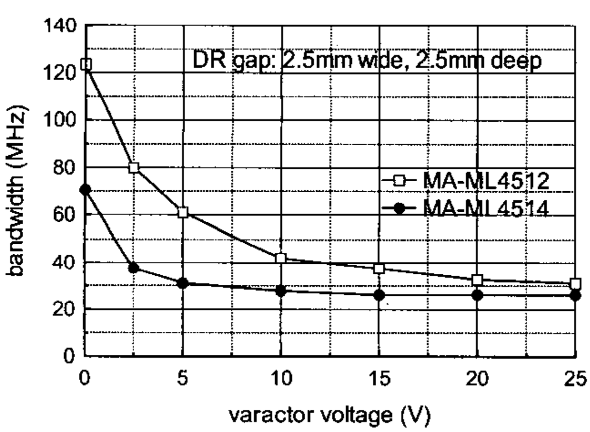

Figure 8(b). Change in associated bandwidth types as a function of varactor reverse bias voltage

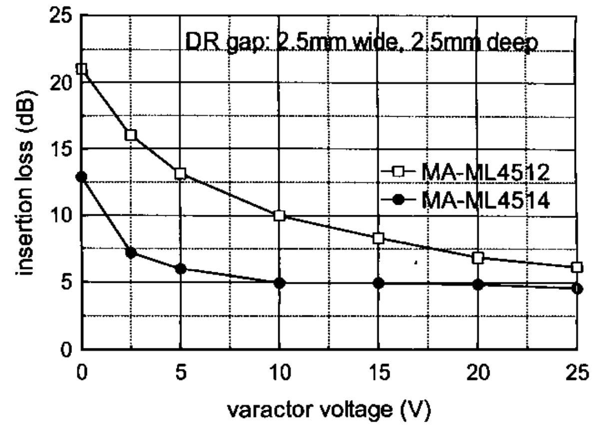

Figure 8(c). Change in associated insertion loss types as a function of varactor reverse bias voltage

VII. Conclusions

It has been demonstrated that a relatively small rectangular shaped slot cut in a dielectric resonator does not adversely affect its performance in terms of resonant frequency and quality factor. The DRs resonant frequency can be perturbed by inserting a tuning mechanism in the form of a varactor diode within the slot. This invasive electronic tuning technique produces a substantial tuning range of 7.1% centered at 4.47 GHz. The varactor diode placed into the slot degrades the DRs quality-factor, which depends on slot size, varactor junction capacitance and quality factor of the varactor carrier. Performance can be improved at the expense of the tuning range by connecting a capacitor in series with the varactor. This has also a beneficial effect when designing filters based on invasive tuning.

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