Improving the Quality Factor of the Coplanar Waveguide Resonator

Mohamed Ismaeel Maricar[1], Ata Khalid[2], D S R Cumming[2] and C H Oxley[3]
[1]: School of Engineering and Computing Science, University of Durham, Durham, UK, DH1 3LE
[2]: Microsystems Technology Research Group, University of Glasgow, Glasgow, UK, G12 8LT
[3]: Department of Electronics Engineering, De Montfort University, Leicester, UK, LE1 9BH
Email: choxley@dmu.ac.uk

Abstract:

A novel method of introducing a notch at a point of high magnetic field in a coplanar waveguide (cpw) radial and diamond stub resonator to increase the quality factor (Q) was analysed. For comparison both radial and diamond shaped cpw resonators with and without notches were fabricated on gallium arsenide (GaAs) semi-insulating substrate at the James Watt Nanofabrication Centre and tested in the milli-metric laboratory at University of Glasgow. The notch increased the loaded Q factor of the diamond resonator by approximately 28% and good agreement was obtained between the measured and simulated loaded Q for both cpw radial and diamond resonators.

Keywords: Diamond stub resonators, radial stub resonator, Q-factor, milli-metric wave, GaAs material.

Introduction:

Microwave integrated resonators are widely used in microwave and milli-metric components, which include filters [1]–[3], oscillators [4]–[6] and antennas [7], [8]. One form of the integrated resonator is the coplanar waveguide (cpw) radial resonator [9] and more recently the diamond resonator which has been shown to occupy 55% less chip area than a comparable radial stub resonator [10]. An important parameter of any resonator is its 'quality factor' Q, which determines its frequency response [11]. To improve the frequency response the quality factor has to be increased and is a key factor in the design of planar integrated resonators. In this paper, a novel method to increase the quality factor of cpw diamond and radial stub resonator by introducing a notch at the high magnetic field regions of the resonator is presented. The design and physical size of the notch was analysed using Advanced Design System (ADS-2009) software package. Experimental cpw resonators with notches were fabricated on semi-insulating gallium arsenide (GaAs) material and RF characterised by using an Agilent high frequency network analyser. Both analytical and experimental results show higher loaded Q factors for cpw resonators which include a notch.

Design, fabrication and simulation of the CPW resonators:

Notches were introduced in the ground metallisation plane at regions of maximum magnetic field (Figure-1), for both the cpw radial and diamond stub resonator; where 't' represents the resonator metallisation thickness, 'R' the inner radius of the radial stub resonator and 'L' the inner length of the diamond stub resonator. The angle θ was used to describe the sectorial angle and set to 60^0 for both radial and diamond resonators. Both types of stub resonator were fed from a 50 Ohm cpw line Figure-1. It was assumed that both resonators were supported on a gallium arsenide semi-insulating substrate with a relative permittivity of 12.9 and a thickness of 620 μm. The cpw 50 Ω transmission line had a width 'W' of 60 μm and a gap 'G' of 40 μm, the dimensions were calculated using the ADS 'line calculator'. The structures contained no air bridging to equalise the potential between the earth planes. The resonator structures were analysed using the ADS momentum finite element package. Particular care was taken when choosing the mesh size to obtain realistic results; this is very important particularly for high frequency analysis where the dimensions can be very small. In practise the used mesh size is determined by the available desk top computer. The computer specification used for this work was 8 gigabyte RAM and i7 processors with the windows 7 operating system.

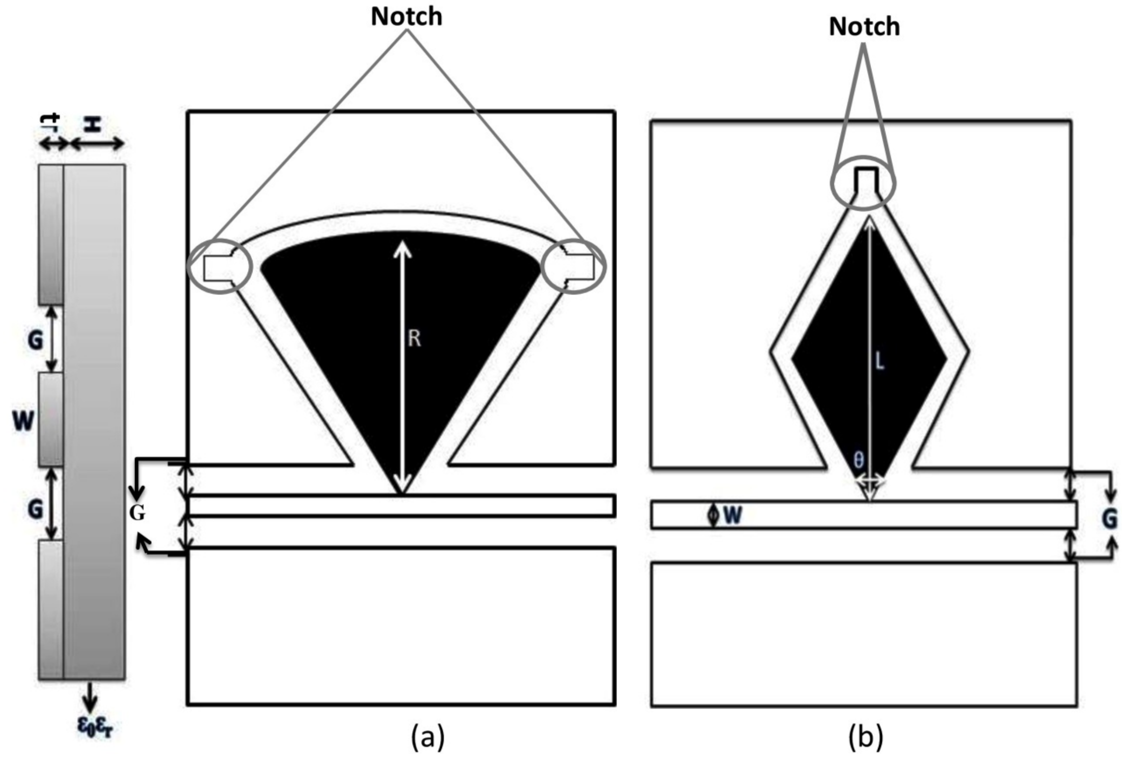


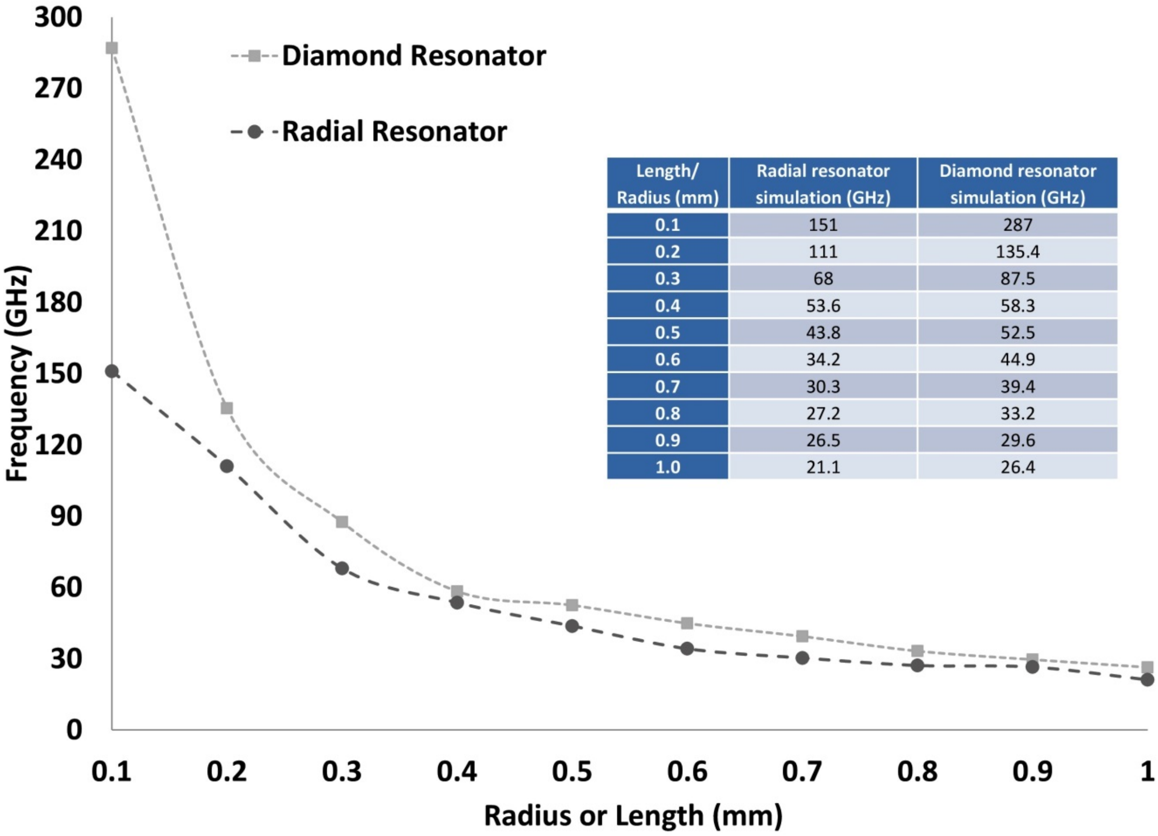
Figure-1 Schematic view of the cpw a) radial and b) diamond stub resonators

The ADS momentum software enabled the resonant frequency for both the radial and diamond stub resonators to be obtained as a function of R and L respectively. The resonant frequency of the resonator was defined as the frequency when S_{21} approached a low loss and the S_{11} approached a high return loss. Figure-2 shows that the computed resonant frequency as a function of R and L of the radial and diamond resonators respectively. Both resonators had a sectorial angle of 60^0. The simulated plots enabled polynomial equations to be derived allowing the extrapolation of the physical dimensions of the resonators into milli-metric wave frequencies. The polynomial equations are given by equations (1) and (2) respectively [10], [12].

$$f_0(Radial\ stub\ resonator) = 1060.1R^4 - 2768R^3 + 2713.1R^2 - 1231.5R + 253.7 \quad (1)$$

$$f_0(Diamond\ stub\ resonator) = 3221L^4 - 8368\ L^3 + 7827\ L^2 - 3180\ L + 530.9 \quad (2)$$

'R' represents the inner radius of the radial stub resonator and 'L' represents the inner length of the diamond stub resonator. Note the coefficients of the polynomial equations will change for different sectorial angles.



Length/ Radius (mm)	Radial resonator simulation (GHz)	Diamond resonator simulation (GHz)
0.1	151	287
0.2	111	135.4
0.3	68	87.5
0.4	53.6	58.3
0.5	43.8	52.5
0.6	34.2	44.9
0.7	30.3	39.4
0.8	27.2	33.2
0.9	26.5	29.6
1.0	21.1	26.4

Figure-2 Comparison of simulated resonant frequency of cpw radial and diamond stub resonators as a function of R (radial) and L (diamond) on a GaAs substrate.

The loaded Q of the resonators was calculated using $Q = \frac{\Delta f_{-3dB}}{f_0}$ where Δf_{-3dB} was -3dB bandwidth computed from S_{21} at the resonant frequency f_0. Notches were introduced into the ground plane of the both the radial and diamond stub resonators as shown in Figures-1. The geometrical dimension of the notch was varied to optimise the magnitude of Q for a particular resonant frequency. It was found that the notch only slightly perturbed the resonant frequency. By including a notch with dimensions of 25x50µm in the ground plane of a diamond resonator the loaded Q was increased by approximately 28%. Further optimisation may be possible by increasing the notch dimensions by 1µm rather than 25µm steps. Table 1 shows the computed Q for radial (R=500µm) and diamond (L=500µm) stub resonators on semi-insulating GaAs substrate, the dimensions of the notch was increased from 25x25 to 50x25µm. The results were also directly compared with the same dimensioned resonators without notches.

Table-1. The variation of the Q-factor for cpw radial and diamond resonators as a function of increasing notch geometrical dimensions from no-notch to 50x25 microns.

CPW resonators (L=R= 500 μm)	Dimension of the Notch (μm)	Resonant Frequency (GHz)	Loaded Q-factor
Radial	No Notch	41.73	61.29
Diamond		51.03	63.32
Radial	25x25	42.57	65.71
Diamond		51.68	69.81
Radial	25x50	43.76	81.31
Diamond		52.49	77.64
Radial	50x25	42.89	73.87
Diamond		51.87	71.21

Experimental results of CPW resonators:

A number of cpw radial and diamond stub resonators with an inner radius (R) and inner length (L) respectively, varying between 0.1 to 1.0 mm were fabricated with a notch of 25x50μm on 620 μm thick semi insulating GaAs wafer. The metallization thickness (t) of the resonators was 0.4 μm and these structures were directly fed with 50 Ohm cpw lines as shown in Figure-1. The cpw resonators were fabricated in James Watt Nanofabrication Centre and RF characterised at the milli-metric laboratory, University of Glasgow. The RF characterisation was carried out using a two port S-parameter measurements in the frequency range of 100 MHz to 110 GHz (Agilent E8364b network analyser) coupled to calibrated RF probes (Cascade MicroTech ACP11-100).

An identical definition of the resonant frequency (f_0) was used as for the computed resonant frequency i.e. the frequency at which S_{21} approached a low loss and S_{11} a high return loss. Table 2 shows good agreement between the simulated and experimental resonant frequencies of both notched cpw radial and diamond stub resonators with increasing R and L respectively. Both R and L were increased from 0.3 to 1.0 mm. The experimental resonant frequency departed from the simulated resonant frequency as R and L approached 0.3 mm and was thought to due to the mesh size not capturing the parasitic effects presented at the higher frequencies.

Table-2 Comparison between the measured and simulated resonant frequency of a cpw radial and diamond stub resonator with a 25x50 μm notch, **as a function of radius (R) and length (L) respectively. The resonators had a constant sectorial angle of 60^0 and were fabricated on GaAs semi-insulating substrate.**

Length/ Radius (mm)	Radial resonator simulation (GHz)	Radial resonator experiment (GHz)	Diamond resonator simulation (GHz)	Diamond resonator experiment(GHz)
0.1	151	*	287	*
0.2	111	88.13	135.4	96.36
0.3	68	-	87.5	-
0.4	53.58	50.58	58.34	58.14
0.5	43.76	-	52.43	51.86

0.6	34.18	33.67	44.87	-
0.7	30.3	-	39.38	38.56
0.8	27.14	26.96	33.2	-
0.9	26.5	-	29.61	29.01
1.0	21.13	20.98	26.36	26.13

** Outside the measurement range of the VNA and - not been fabricated*

The experimental Q factor was estimated from the measured S_{21} in the same way as the Q factor was obtained from the simulated results. Table-3 shows the simulated and experimental Q-factor of the notched radial and diamond stub resonator as a function of radius (R) and length (L) respectively. It was interesting to note that the notched diamond stub resonator gave a consistent increase in loaded Q with decreasing L.

Table-3 Comparison between simulated and measured Q-factor (at the resonant frequency) of a cpw radial and diamond stub resonators as a function of R and L respectively. The sectorial angle was 60^0 and fabricated on GaAs semi-insulating substrate.

Length/ Radius (mm)	Radial resonator simulated Q-factor (GHz)	Radial resonator experimental Q-factor (GHz)	Diamond resonator simulated Q-factor (GHz)	Diamond resonator experimental Q-factor (GHz)
0.2	26.9	29.8	101.0	109.5
0.3	31.0	30.3	85.1	-
0.4	7.85	10.3	77.8	83.6
0.5	74.1	81.3	70.0	75.6
0.6	9.1	10.6	54.7	-
0.7	21.2	26.7	42.8	45.3
0.8	18.9	21.0	37.3	-
0.9	9.685	13.5	32.1	37.5

Conclusion:

A novel method of including notches in the ground plane of cpw radial and diamond stub resonators to increase the loaded Q factor has been described. The radial and diamond resonators had a constant sectorial angle of 60^0 and were fabricated on semi-insulating GaAs. Good agreement between simulation and experiment was obtained. It was found by increasing the notch dimensions the loaded Q factor could be optimised for both the radial and diamond stub resonators. Both simulated and experimental results indicate that the loaded Q of the diamond resonator increased as L was reduced. The diamond stub resonator structure will be of interest to circuit designers as it occupies 55% less circuit area when compared to a comparable radial resonator.

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