

# CAD implementation of DR-based oscillator using non-linear analysis

The concept of modeling along with the simple design equations, characterization and implementation of the dielectric resonator (DR) puck model in oscillator simulation, are presented. It shows that the equivalent bandstop resonator model and the transformer ratio matches closely with the theoretical results. To make the oscillator response more predictable, the model is incorporated in a CAD tool.

By Kamaljeet Singh and Surendra Pal

A modern communication system requires low phase noise and low-cost local oscillator. The most popular method to reduce the phase noise is to employ a high Q resonator to improve the loaded quality factor. Dielectric resonators (DR) are high Q ceramic resonators conveniently sized for MIC applications<sup>[1]</sup>. The DR offers integration capability with MICs as well as quality factor and frequency stability approaching cavity resonators. The advantage of DR resonators over the metallic cavity is the reduction of the size by the amount  $1/\sqrt{\epsilon_r}$ . DR sustains same electromagnetic field modes of metal cavity resonators. Due to the dielectric walls of DR compared to the metal walls of a metal cavity, the two behave as dual to each other<sup>[2]</sup>. Consequently, due to its small size, low price and excellent integration capability in microwave integrated circuits (MICs), its application in active and passive circuits has been rapidly increasing. While DR resonators can be used in a variety of applications, this article describes its use as a low-noise, frequency-stable oscillator.

Using the harmonic balance technique, the simulation setup determines the accuracy of the prediction of the power and harmonics. Temperature stability of the DR puck, which is the main constraint for space application, was overcome using temperature-stable pucks. There are two ways of implementing the DR puck<sup>[3]</sup> in the circuit: as a passive stabilization element (stabilized DR oscillator or DRO) or as a circuit element in a frequency determining networks (stable DRO).

## Modes in DR

Both H and E resonant modes can be excited in a DR resonator. The H mode has a large normal magnetic field component at the boundary surfaces, while the E mode contains no predominant normal magnetic field component at the surfaces. The commonly used mode in cylindrical resonator is  $TE_{10\delta}$ . The  $TE_{10\delta}$  mode of cylindrical DR has the highest Q among all resonant modes because its electromagnetic energy is mostly confined in and near the resonator. Also, the required size of a DR to resonate is very small relative to free space wavelength. Also, the electromagnetic field outside the resonator is quasi-static and little radiation takes place. The  $TE_{10\delta}$  mode also operates like a magnetic dipole mode with an efficient magnetic coupling to a microstrip line (Figure 1).

## Selection of DR puck

The size of the DR puck defines the resonant frequency of the total circuit. A DR resonator's resonant frequencies are usually computed by assuming that the dielectric resonator is placed in unbounded space. In real conditions, however, DR resonators are placed in microwave structures that disturb the resonator's external fields, and alter their resonant frequency. The tuning screws permit geometric adjustment, which translates into a change of the resonance frequency. The first step in determining the size of a DR for a given resonant frequency in the  $TE_{01\delta}$  mode is to select the diameter ( $D = 2a$ ) of a cylindrical

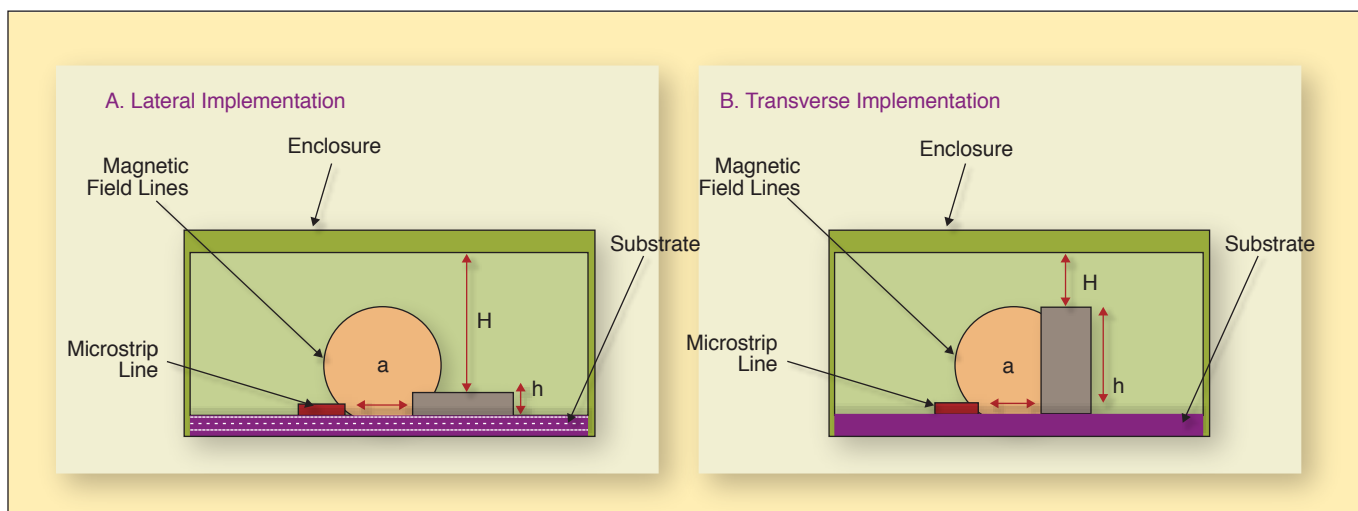


Figure 1. Coupling mechanism of a dielectric puck with microstrip line (both lateral and transverse implementations).

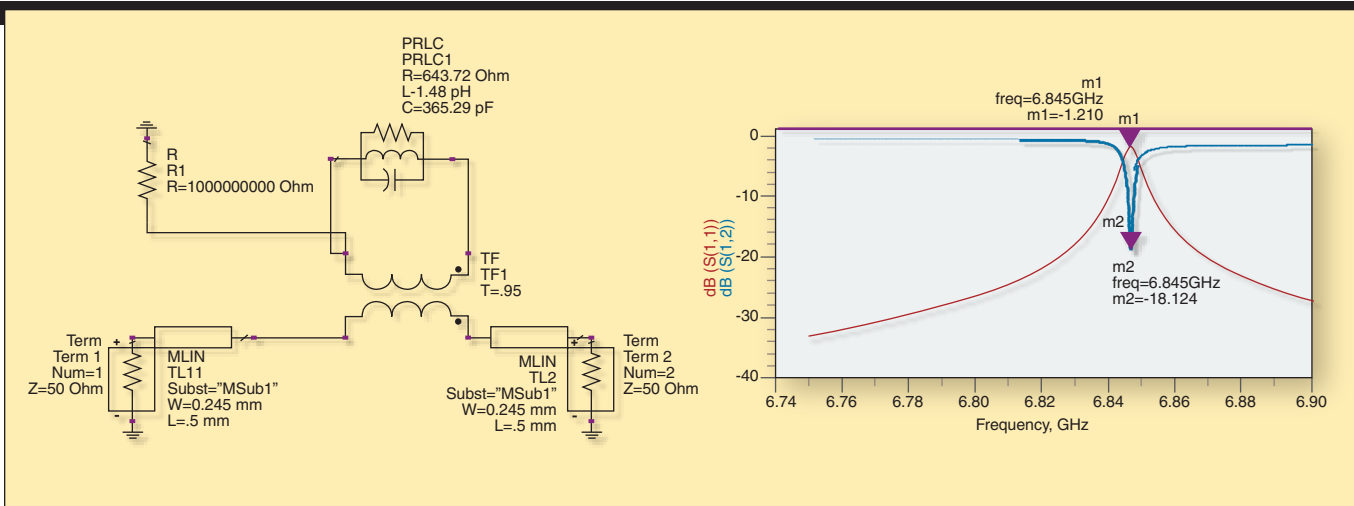


Figure 2. The simulated plot of the equivalent circuit.

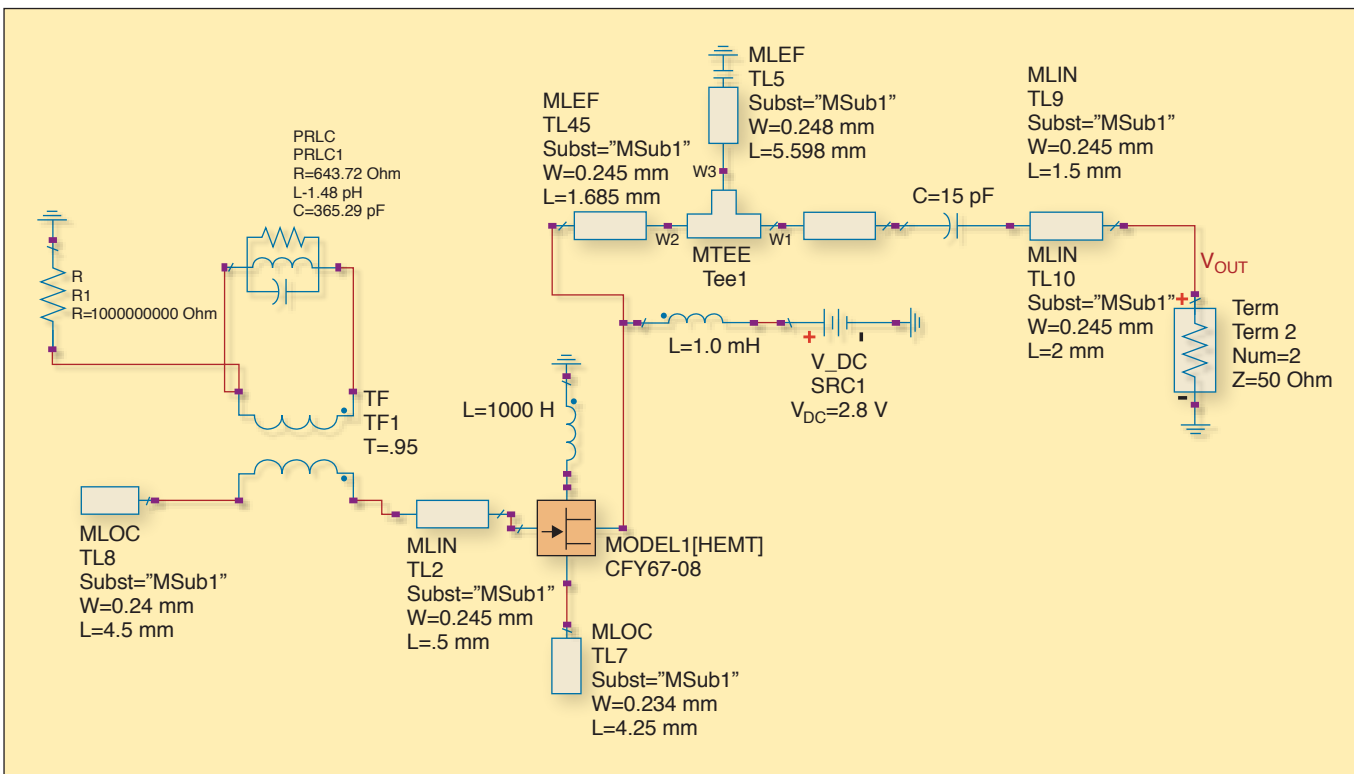


Figure 3. Schematic of the DR oscillator.

DR such that

$$5.4/(\beta \cdot \sqrt{\epsilon_s}) > 2a > 5.4/(\beta \cdot \sqrt{\epsilon_r}) \dots \dots \dots (I)$$

where,

$\epsilon_s$  = relative permittivity of the substrate

$\epsilon_r$  = relative permittivity of a DR

$\beta$  = free space propagation constant

The radius can be determined<sup>2</sup> using the formula

$$a = 1.2025 \cdot c/\omega_0 [1/\sqrt{\epsilon_r} + 1/\sqrt{\epsilon_s}] \dots \dots \dots (II)$$

The ratio of diameter with the height  $D/H = 2.53$ , upper cover height should be  $0.8H$ , where  $H$  is the height of the substrate. To increase loaded  $Q$ , the dielectric spacer must be added beneath the puck. With the spacer, the  $\epsilon_{eq} = (\epsilon_{spacer} \times L2 + \epsilon_{substrate} \times L1) / (L1+L2)$ , where  $L1 =$

the thickness of the dielectric,  $L2$  is the thickness of the spacer. The puck is chosen from the Teklec (Temex) for C-band application having the permittivity of 30.

### Design equations

The dielectric puck interacting with a microstrip line acts as a resonator in which  $TE_{016}$  mode couples magnetically to form a bandstop filter. The coupling can be adjusted by moving the resonator away from the microstrip line or by lifting the resonator on a special support above the microstrip line<sup>[4]</sup>. The distance between the DR puck and microstrip line determines the coupling coefficient. The equivalent circuit consists of the parallel combination of the  $R, L$  and  $C$  along with the transformer with the coupling coefficient changes with the puck distance. The precise values of the parameters result in close prediction of the oscillation frequency. The different techniques are reported in the literature and the easiest and more nearer to the practical values

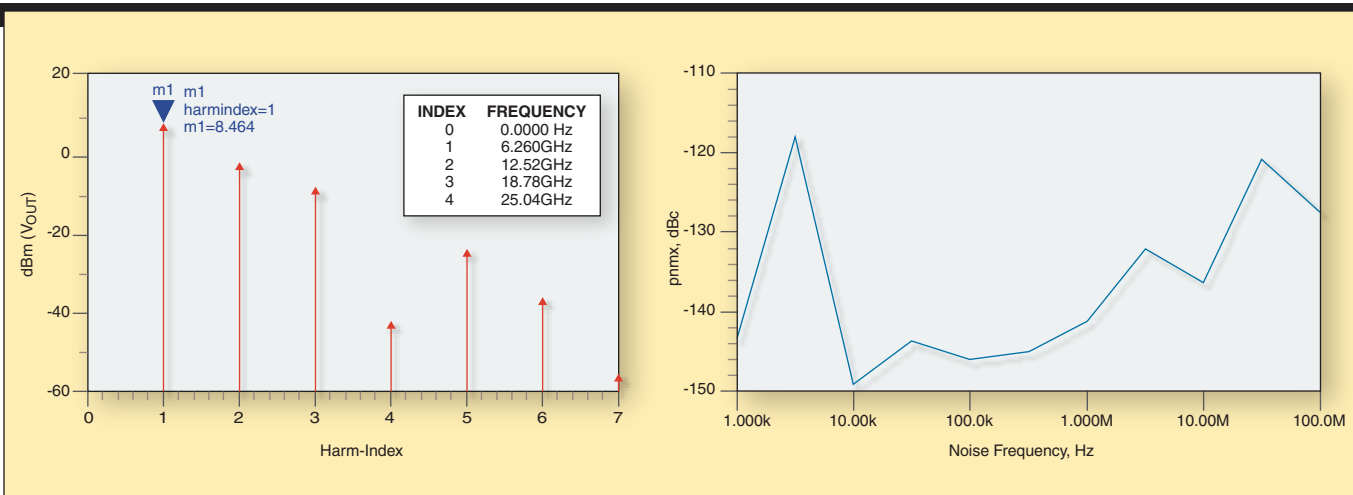


Figure 4. Simulated characteristics of the series feedback oscillator topology incorporating a DR resonator.

are detailed in this article. The model of DR, from the given equation can be directly incorporated in the CAD tool. The measured result shows the return loss of 20 dB, insertion loss of 2 dB, and bandwidth of 150 MHz. From the measured results, the coefficients found out are:

$$\beta \text{ (coupling coefficient)} \approx \frac{S_{11,C}}{S_{21,C}} = 6.4 \text{ , (here, C stands for center frequency)}$$

$$\Gamma \text{ (reflection coefficient)} = \beta / (\beta + 1) = 0.86$$

and equivalent values can be found out as

$$R = 2 \beta Z_0 \approx 645 \text{ } C = 1 / (\omega^2 L) \approx 365 \text{ pF } L = R / (\omega_0 Q_U) \approx 1.36 \text{ pH}$$

$$Q_U = fc / B.W \approx 154.3 \text{ where } Q_U = Q_L (1 + \beta) \text{ } \Gamma = N^2 R / (2Z_0 + N^2 R)$$

so  $N = 0.95$

These values are incorporated in a CAD tool and Figure 2 shows the plot more nearer to the practical results. This method of getting equivalent parameters is found to be suitable and simpler for CAD implementation rather than the Q approach, which can also be used.

The non-linear simulation has been carried out using ADS 2003 C. The HEMT (CFY67-08) transistor (for better phase noise) from Infineon Technologies was chosen in a common source topology for the ease of implementation. The non-linear model, which was developed in house has been used<sup>[7]</sup>.

(The Materka model of HEMT (CFY67-08) has been generated from the measured dc and RF parameters using active device modeler MDLGRED from Linmic<sup>[7]</sup>. The non-linear parameters are implemented in the ADS. The Materka model is chosen because it gives a more accurate representation of saturation of the output power along with the breakdown effects.)

The circuit is made unstable with the series feedback network. The first-cut oscillation frequency is determined by small signal analysis. Real part of admittance (Y) at the oscprobeport is as negative as possible at the desired frequency, imaginary part of admittance at oscprobe port is zero at the desired frequency. The oscprobe element is connected to the feedback path and imaginary Y (oscprobe) is plotted with the frequency. The crossover gives the first cut of the oscillation frequency. The DR model has been incorporated as the frequency-determining resonator circuit. The full circuit, (Figure 3), is subjected to harmonic balance analysis. The Vds is kept at 2.6 V, corresponding to Ids of 15 mA and can be slightly varied to make convergence easy. The convergence of the circuit has been attained using appropriate Samanskii constant as well as setting simulation in Kyrlov mode. The results are plotted, as shown in Figure 4.

### Conclusion

The integrated DRO shows the oscillation frequency of around 6.25 GHz. The slight shift in the DR resonance and the oscillator

frequency as radiation loss is not taken into account, which in turn affects the Q of the circuit. This article reports a simple way of implementing DR-based highly non-linear circuits in the CAD tools as convergence fails to come. So the accuracy of the resonant model in planar CAD tools is a must to predict the behavior. This way, the effect of circuit parameters, model parasitics can be easily seen to have close agreement with the measured values.

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