Design of Rectangular DRA for UWB Applications

A thesis submitted in partial fulfillment of the requirements for the
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in
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By

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Certificate

This is to certify that the thesis entitled, "**Design of Rectangular DRA for UWB Applications**" submitted by **Mr. Akshat Shah** and **Mr. Kaveesh Sharma** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in **ELECTRONICS AND COMMUNICATION ENGINEERING** at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

DATE: **(Dr. S. K. BEHERA)**

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(Mr. Akshat Shah) (Mr. Kaveesh Sharma)

Abstract

The world has seen difficulty in handling of huge size antennas with high maintenance cost. Dielectric Resonator Antenna (DRA) has some interesting characteristics that provide a solution from its characteristics like small size, high radiation efficiency, low losses, high power handling capacity, increased bandwidth and ease to integrate with existing technologies.

Here, a slotted rectangular type of DRA of Ultra-Wide band (UWB) applications is presented. The design combines advantage of small size DRA and thin planar monopole antenna. Antenna size is 15X33 mm^2 with 5.08 mm thickness. The Dielectric Resonator is shaped to house excitation feed using microstrip line feed. Air gaps are introduced / enhanced between the line feed and ground to improve the bandwidth. Two slots of (1×1) mm^2 dimensions are also introduced in the DR.

Proposed antenna results in a better return loss and is below -10 dB within range (3.3296 – 12.536) GHz and resonance frequency 4.811 GHz.The antenna is thin and compact which makes it easily portable. A maximum gain of 3.66 dB achieved at 4.811 GHz frequency. The VSWR parameter was found to be less than 2 within the operating frequency range. It can be used for WLAN, WiMax applications in the frequency range 5.2 to 5.8 GHz.

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Chapter 1

Introduction

Communication between humans was first by sound through voice. As always, with the desire for improvement in slightly more distance communication, devices such as drums, various visual methods such as signal flags and smoke signals came into existence or were used. These devices in optical communication, obviously utilized the light portion of the EM spectrum. Electromagnetic waves, very recently has been employed in the history outside the visible region for communication using radio. Antenna's been instrumental in harnessing the electromagnetic spectrum which is humankind's one of the greatest natural resource.

1.1 Objective of Project :

Dielectric resonator oscillator (DRO) is an electronic component that exhibits resonance for a narrow range of frequencies, generally in the microwave band. The aim of the thesis is to design rectangular Microstrip Patch Antenna with enhanced gain and bandwidth and study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant (εr), substrate thickness (t) on the Radiation parameters of Bandwidth.

1.2 What is an Antenna?

Antennas are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device like waveguide, transmission line etc. and the free space. Antennas are frequency dependent devices. Each antenna is designed for a certain frequency band beyond which it rejects the signal. So we can look at them as band pass filter and transducer. Antennas are therefore very essential components of all or mostly any equipment that uses radio.

1.3 How an Antenna Radiates?

Antennas basically consists of arrangement of metallic conductors, electrically connected (mostly through a transmission line) to the receiver or the transmitter. One oscillating current of electrons will create an oscillating magnetic field around the antenna elements while the charge of the electrons (e^{-s}) also creates an oscillating electric field along the elements. The entire time-varying field radiates away from the antenna into space as a moving EM field wave. During the reception, conversely, the oscillating electric (E-field) and magnetic fields (H-Fields) of an incoming radio-wave exert force onto the electrons (e^{-s}) in antenna elements, causing them to move, creating oscillating currents in the antenna.

1.4 Parameters affecting Antenna:

Some basic parameters are there which affect an antenna's performance. The designer must consider these while designing and should be able to adjust, as needed. Some critical parameters are as follows:

- Antenna radiation patterns
- Power Gain
- Directivity
- Polarization
- Impedance
- Radiation efficiency

1.5 What are its applications?

The most common uses of antennas are in systems such as radio broadcasting, broadcast television, communications receivers, etc. They are also very regularly used for radar, cell phones, and satellite communications.Apart from these areas, they are required in other devices such as garage door opening controllers, microphones (wireless), Bluetooth devices, wireless computer networks, baby monitors,Duplex (two-way) radio and RFID tags on merchandises. Certainly, the past decade has seen an extensive use of antennas by the public for cellular, GPS, satellite, Wireless LAN for computers (Wi-Fi), Bluetooth technology, Radio Frequency ID (RFID) devices, WiMAX, and so on.

1.6 What is UWB?

- UWB (Ultra Wide-Band) is a radio technology that uses very low energy pulses & it is intended for short-range-cum-high-bandwidth communications by using a large portion of the radio spectrum (in GHz Range).

- UWB has traditional applications in non-cooperative radar imaging. Most recent applications target sensor data collection, precision locating and tracking applications.

- UWB communications transmit in a way that doesn't interfere largely with other more traditional narrowband and continuous carrier wave uses in the same frequency band.

- UWB is a Very High-speed alternative to existing wireless technologies such as WLAN, HiperLAN.

• A February 14, 2002 Report and Order by the FCC (Federal Communication Commission) authorized the unlicensed use of UWB in the range of 3.1 to 10.6 GHz for commercial applications.

• The FCC power spectral density emission limit for UWB emitters operating in the UWB band is -41.3dBm/MHz. This is the same limit that applies to unintentional emitters in the UWB band, the so called Part 15 limit. However, the emission limit for UWB emitters can be significantly lower (as low as -75dBm/MHz) in other segments of the spectrum.

• UWB RF technology transmits Binary data (0/1) over a very wide spectrum of frequencies using low energy and extremely short duration pulses (in the order of Pico-seconds).In a Multi-user environment to minimize interference each device is given a unique PN code (Pseudo-random Noise).And a receiver operating with the desired PN code can decode the transmission.

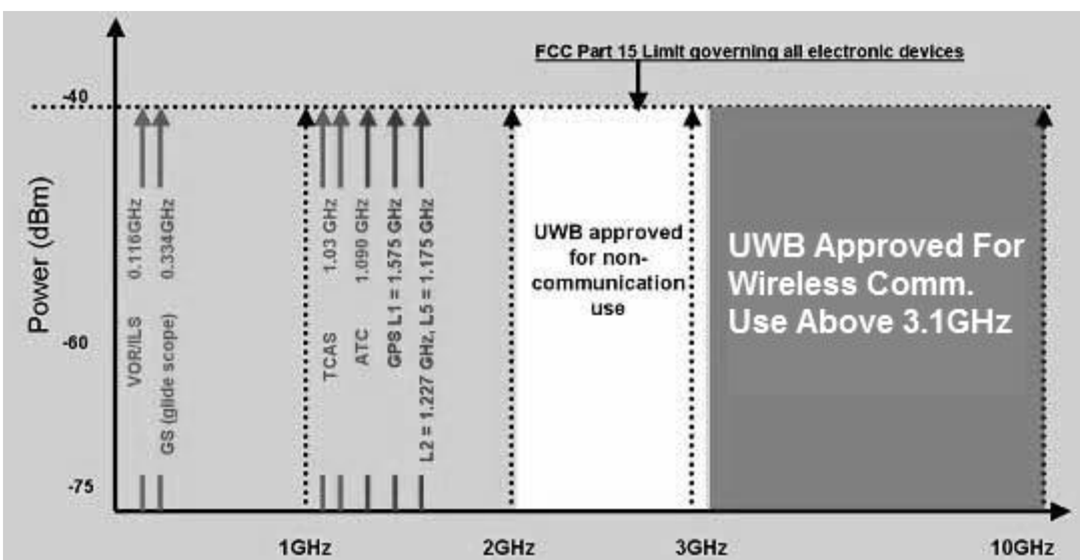

FIGURE 1.1 Spectrum of UWB

1.7 Why is UWB interesting?

- In the U.S., 7.5 Hz of 'free spectrum'
    - UWB was legalized by FCC for commercial use
    - Spectrum allocation overlays existing the users, but the allowed power level for it is very low mainly for minimizing interference
- Very High Data rates are possible
    - 500 Mbps can be achieved at distances of 10 feet under current regulations
- 'Moore's LAW RADIO'
    - With faster than ever CMOS circuits, data rate scales that have shorter pulse widths were made possible.
- Simple CMOS transmitters at very low power
    - Suitable for battery-operated devices
    - Low power is CMOS friendly

1.8 Characteristics of UWB

- Transmission energy is extremely low (less than 1mW)
- Bandwidth is very high within short range (200Mbps within 10m)
- Extremely difficult to intercept

– Wideband spectra is generated usingShort pulse excitations – low energy densities

– Interference to other services is also minimized by Low energy density.

- Multipath immunity
- Commonality of signal generation and processing architectures
- In Radar

– Has Inherent high precision and sub-centimeter ranging

– Wideband excitation is done for detection of complex, low RCS targets

- Geo location/Positioning

– Sub-centimeter resolution is achieved using pulse leading edge detection

– Easily passes through the building blocks, through walls, etc. (LOS not required)

- Low Cost

– Almost “all-digital” architecture

– It is Ideal for microminiaturization into a chipset

- Frequency diversity with minimal hardware modifications

1.9 Advantages of UWB Technology:-

Capacity

It can achieve very high data rate (can reach up to 500 Mbps).

$$C=B.Log_2 (1+SNR)$$

Where C=Channel Capacity.

B=Bandwidth of Channel.

Its bandwidth is from 3.1 GHz to 10.6 GHz and each channel is of more than 500 MHz BW.

Low power& low cost

No need of modulation. Un-modulated baseband pulses of very short duration are sent in this communication technology, that’s why it is known as a “Carrier free Impulse Baseband Radio”. It is an all-Digital System not requiring any kind of analog components such Mixers/Balanced Modulators for signal modulation.

It needs very small Transmitter power for its transmission. And Power is in microwatt range.

Fading Robustness

Wideband nature of the signal helps it avoiding the problem of time varying amplitude fluctuations.

It is also immune to Multipath Delays (introduced due to non-LOS(line of sight) communication where various version of same signal appear at the receiver which have undergone a variety of diffraction, reflection, scattering effects) as time delay introduced is generally more than the signal duration.

Short Range

Its normal range of operation is within 10 m, so its power requirement is low and interference with other short range devices is less. It comes under WPAN (Wireless Personal Area Network) protocol.

Security Aspects

It behaves as a wideband noise source for other NB (Narrow Band) systems operating in that frequency range; but it doesn't affect them because of its low signal power. It only increases the SNR requirement of those systems.By using PN (Pseudo Random) codes UWB system can be made undetectable for hostile receivers and can be protected from Jamming.

Chapter 2

Dielectric Resonator Antenna

2.1 What is dielectric resonator and dielectric resonator antenna (DRA)?

A **dielectric resonator** or **dielectric resonator oscillator (DRO)** is an electronic component that exhibits resonance for a narrow range of frequencies, generally in the microwave band. The resonance is similar to that of a circular hollow metallic waveguide, except that the boundary is defined by large change in permittivity rather than by a conductor. Dielectric resonators generally consist of a "puck" i.e. a circular disk of ceramic that has a large dielectric constant and a low dissipation factor. The resonance frequency is determined by the overall physical dimensions of the puck and the dielectric constant of the material. Hence **dielectric resonator antennas** are basically low-loss dielectrics, resonators with high Q elements for circuit applications such as filters and oscillators.

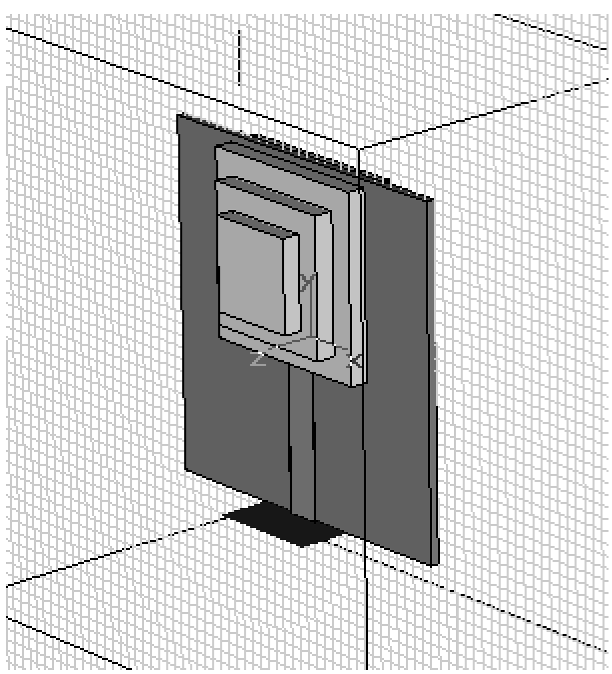

FIGURE 2.1 Geometry of a Rectangular DRA with Microstrip line feed

2.2 History:

The first most popular DRA developed was temperature-stable and low-loss designed from barium tetratitanate ceramics. For these circuits, resonators, which are typically cylindrical in shape, are made out of high dielectric constant materials (**ε_r> 35**) and are usually shielded to maintain the high quality factor needed for applications in oscillators, filters, etc. DRs of different shapes have various modes of oscillation. With the proper excitation of certain modes and with no shielding, these resonators can actually become efficient radiators instead of energy storage devices.

2.3 Types of DRA:

Different types of DRA are cylindrical, hemispherical and rectangular DRA. Mostly in recent times, Dielectric resonator Antennas (DRA) have attracted the designers in the field of antenna designing mostly in microwave and millimeter bands because of features like high radiation efficiency, low temp.co-efficient of frequency, '0'(zero) conductor losses and suitable scale in microwave band. Dielectric Resonators with **30 <ε_r< 60** is ideally suitable in the field of antenna applications, that's why a compromise can be or ismade between size, operating frequency and many other antenna radiation characteristics. Because of uniplanar nature of CPW line feed, it offers many advantages from P.O.V. (Point Of View) of integration with the active and the passive devices. And even more, due to the low loss nature and less dispersive nature of the CPW line feed, the CPW line feed has emerged as a very attractive alternative to traditional Microstrip feed and probe feed.

2.4 Advantages of DRAs:

As has been recently demonstrated, DRAs offer a high degree of flexibility and versatility over a wide frequency range, allowing for designers to suit many requirements. DRAs offer the following advantages:

● The DRA size is proportional to l_0 / $(\varepsilon_r)^{1/2}$, where l_0 is the wavelength at resonant frequency and ε_r is the dielectric constant of the DR .Thus for the same frequency there is a natural **reduction in size**, compared with their conventional counterparts like micro strip antennas. Also, **different values of ε_r(ranging from 4 to 100)** can be used, thus allowing the designer the **flexibility in controlling the size and bandwidth.**

● Depending on the resonator shape, **various modes can be excited** within the DRA element which **can produce different radiation patterns for various coverage requirements**. Also, the **Q-factor** of some of these modes will depend on the aspect ratio of the DRA, thus allowing one more degree of flexibility in the design.

● Many of the existing feeding schemes can be used (slots, probes, micro strip, coplanar waveguides, dielectric image guide, etc.). This makes them **easy to integrate with existing technologies**.

● **Compared with the micro strip antenna**, DRA has a **much wider impedance bandwidth**. This is because the micro strip antenna radiates only through two narrow radiation slots, whereas the DRA radiates through the whole antenna surface except the grounded part. Moreover the operating **bandwidth of a DRA can be varied** by suitably choosing the dielectric constant of the resonator material and its dimensions.

● DRAs have been designed to operate over a **wide frequency range** (**1 GHz to 44 GHz**) compared with other antennas existing in the literature.

● DRAs have a **high dielectric strength** and hence **higher power handling capacity**. Moreover the temperature-stable ceramics enable the antenna to **operate in a wide temperature range**.

●The antenna offers **good radiation** and **reflection properties** as well.

2.5 Fundamental Modes and Their Radiation Mechanisms:

A microwave resonator has an infinite number of resonant modes, each corresponding to a particular resonant frequency at which the stored electric energy is equal to the magnetic energy. The excited modes for **circular DRA can be classified into three distinct types: TE, TM, and hybrid.** The fields for TE and TM modes are axisymmetric, whereas hybrid modes are azimuthally dependent. **The *TE, TM,* and hybrid modes are classified as TEmnp+d, TM_{mnp+d} and HE_{mnp+d} respectively**.

The **index m** denotes the number of full-period field variations in azimuthal direction.

The **index n** (n = 1, 2, 3…) denotes the order of variation of the field along the radial direction.

The **index p + d** (p = 0, 1, 2…) denotes the order of variation of the fields along the Z-direction. The third index denotes the fact that the dielectric resonator is shorter than integer multiples of half the dielectric wavelength.

The actual value of d depends on the relative dielectric constant of the resonator and the substrate and on the proximity to the top and bottom conductor planes. An interesting feature of DR is the variation in field distribution of different modes, because the modes behave like electric and magnetic multipoles such as dipole, quadrupole, octupole, etc. The mode nomenclature makes possible the accurate prediction of far-field radiation of dielectric resonators in their application as antennas.

2.6 Excitation Techniques of DRAs:

The operational mode of a DRA depends on the method of excitation employed. Moreover, the coupling mechanisms significantly affect the resonant frequency and radiation Q-factor of a DRA. A number of excitation techniques have been adopted. These include coaxial probe, aperture coupling with a microstrip feed line, aperture coupling with a coaxial feed line, waveguide coupled aperture, direct microstrip feed line, coplanar feed, soldered through probe, slot line, conformal strip and direct image guide.

Aperture coupling methods:

The aperture can be of any shape, such as narrow slot, loop, cross, or C-shape cut in the ground plane and can be fed by a microstrip line/coaxial fee line beneath the ground plane or aperture cut on the surface of a waveguide. Here the aperture behaves like a magnetic current running parallel to the length of the slot, which excites the magnetic fields in DRA. This method has the advantage of feeding networks kept below the ground plane and hence avoids the spurious modes.

Coplanar waveguide lines:

The excitation of DRs using coplanar waveguide lines appears to be highly promising because they enable easy coupling with MMICs. In this case, coupling level can be adjusted by positioning the DRA over the coplanar structure. Impedance tuning can be done by adding stubs, slots, or loops at the end of the coplanar line. Though coaxial probes and coplanar loops work alike, the latter has the advantage of unobtrusive and planar structure to benefit integration. By moving the position of DR over the loop, the operational mode can be selected.

Dielectric image guide excitation:

It offers advantages over microstrip line methods in that they do not suffer from conductor losses, especially at millimeter wave frequencies. Here the coupling between the guide and the DR is usually small, but can be increased by operating the guide closer to the cut off frequency. This method is similar to the waveguide slot method, but with the image line replacing the waveguide.

Coaxial probe feed excitation:

Here the center pin of a coaxial transmission line is extended through the ground plane. It can also be soldered to a flat metal strip. This can be considered as an electric current running vertical to the DRA height. The probe can either be located adjacent to the DRA or can be embedded within the body. The strength of coupling depends on the length and location of the probe. Various modes can also be excited based on the probe location. The extent of coupling can be adjusted by modifying the probe height. In this method, various modes are excited depending on the position of the probe. Another advantage of this method is that the antenna system can be directly connected to a 50 Ω circuit without the aid of any matching network.

Direct microstrip line mechanism:

It is the simplest method to energize DRAs. In this method, a microstrip line printed on the same substrate excites a DR that could be placed directly over the microstrip line or nearby over the dielectric substrate. The level of coupling can be adjusted by the lateral position of the DR with respect to the microstrip line and by using substrate with different permittivity. For wider bandwidth, ε_r of the substrate should be kept low, but requires a reasonable value for better coupling. To have acceptable radiation efficiency, microstrip-line excited DRA arrays are being used. Microstrip line offers the advantage of easy and cost-effective fabrication of DRA.It is a disadvantage that polarization of the array is dictated by the orientation of the microstrip line. Moreover, this excitation scheme may also generate surface waves in the dielectric substrate which is highly undesirable.

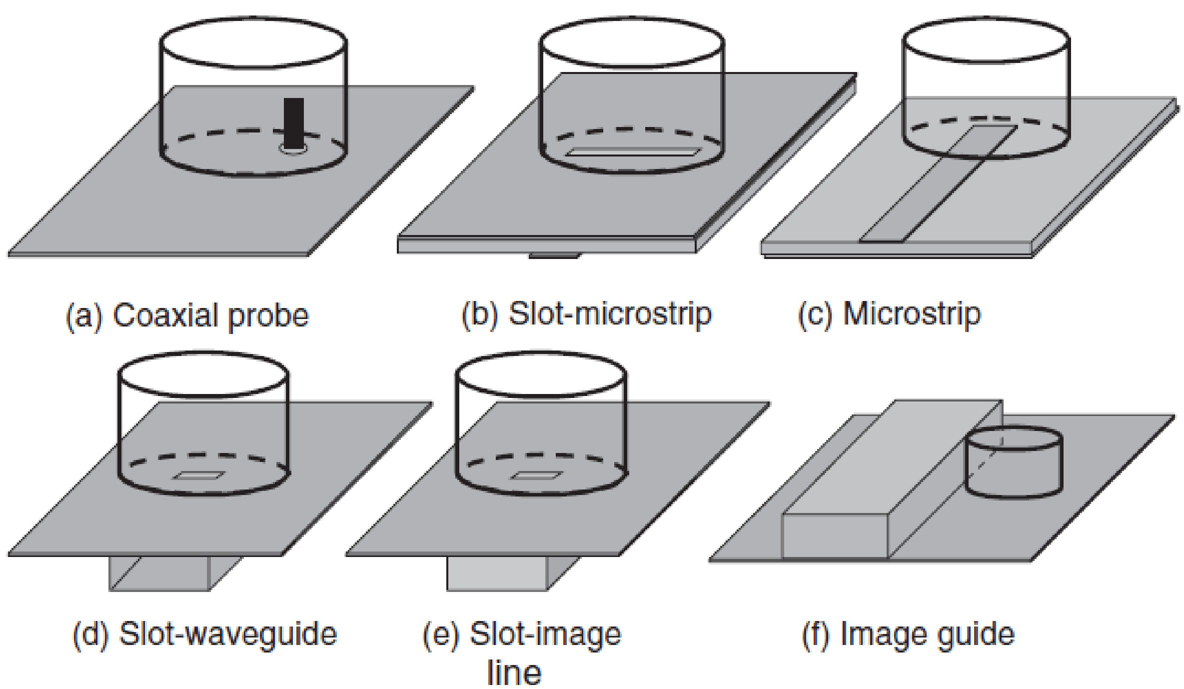

FIGURE 2.2 Different types of feeding Techniques for a DRA

2.7 Analysis of a rectangular DRA:

$$H_x = \frac{(k_y k_z)}{j\omega\mu_0} Sin(k_x x) Cos(k_y y) Sin(k_z z) \qquad \text{(I)}$$

$$H_y = \frac{(k_y k_{zz})}{j\omega\mu_0} Sin(k_x x) Sin(k_y y) Sin(k_z z) \qquad \text{(II)}$$

$$H_z = \frac{(k_x^2 + k_y^2)}{j\omega\mu_0} Cos(k_x x) Cos(k_y y) Cos(k_z z) \qquad \text{(III)}$$

$$E_x = k_y Cos(k_x x) Sin(k_y y) Cos(k_z z) \qquad \text{(IV)}$$

$$E_y = -k_x Sin(k_x x) Cos(k_y y) Cos(k_z z) \qquad \text{(V)}$$

$$E_z = 0 \qquad \text{(VI)}$$

Where,

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \qquad \text{(VII)}$$

$$k_z \, tan\left(\frac{k_z l}{2}\right) = \sqrt{(\varepsilon - 1)k_0^2 - k_z^2} \qquad \text{(VIII)}$$

$$k_0 = 2\pi k f_0 / c \qquad \text{(IX)}$$

$$k_x = n\pi / l \qquad \text{(X)}$$

$$k_y = n\pi / m \qquad \text{(XI)}$$

Chapter 3

Antenna Design

3.1 Reference Design

The size of the DRA here has 12 mm width, 13 mm length, and 5.08 mm thickness with a dielectric constant of 10.2, and it is supported by a 15x33 mm2 RT6002 substrate with a dielectric constant of 2.94 and a substrate thickness of 0.762 mm. The antenna parameters are shown in the figure, with G1=0.15, G2=0.45, G3=2, F1=6, F2=7, W1=2.16, L1=8.5, T1=2.54 and T2=1.778 mm.

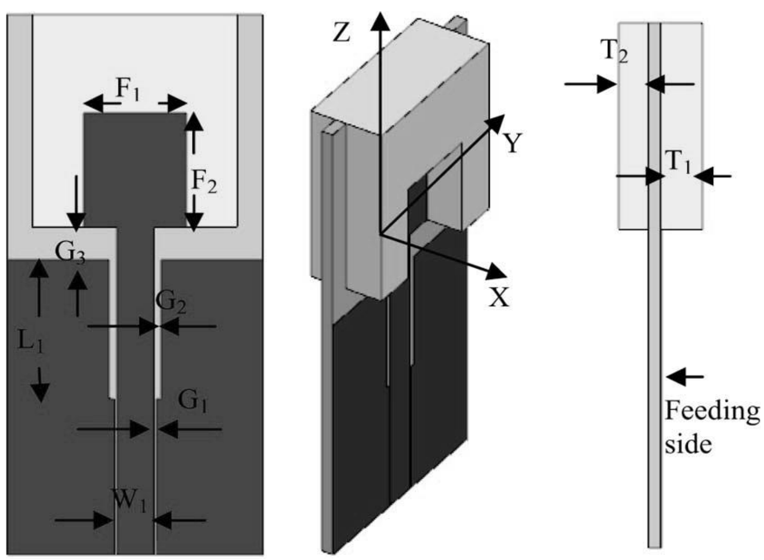

FIGURE 3.1 The Reference Antenna

3.2 Return Loss of the Reference Design

The Return losses of the reference antenna using different feeding techniques are given below:

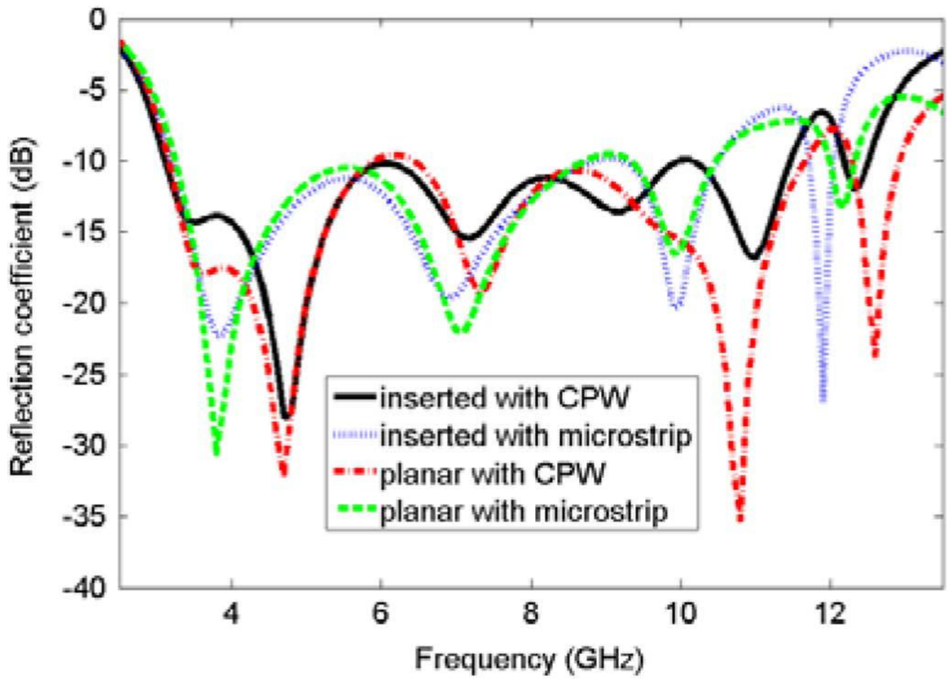

FIGURE 3.2 Return Loss of reference design using different feeding techniques

3.3 Proposed Design

The UWB DRA is excited by microstrip feed. The size of the DRA has 12 mm width, 13 mm length, and 5.08 mm thickness with a dielectric constant of 10.2, and it is supported by a 15x33 mm2 RT6002 substrate with a dielectric constant of 2.94 and a substrate thickness of 0.762 mm. The antenna parameters are shown in the figure, with G1=0.48, G2=0.78, G3=2, F1=6, F2=7, W1=1.5, L1=8.5, T1=2.54 and T2=1.778 mm.Inserting two 1X1 slots in the DRA of the above design at co-ordinates for slot1[x=(-2,-3), y=(13.5,12.5),z=(0.762,3.302)] and for slot2[x=(2,3), y=(13.5,12.5),z=(0.762,3.302)].

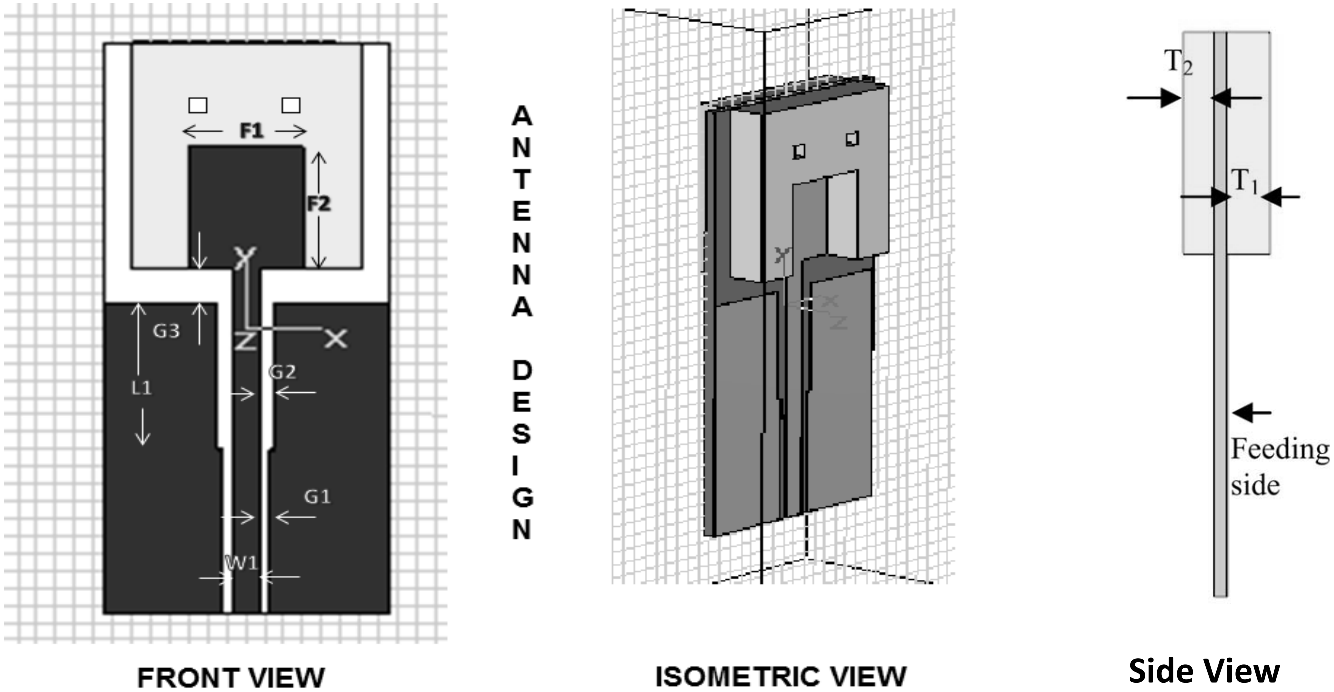

FIGURE 3.3 Proposed design

3.4 Modifications Made to the Reference Design

1. Improving the air gap between the line feed and ground.
2. Using Microstrip feed instead of CPW feed.
3. Introducing two slots of 1X1mm^2 dimension.

3.5 Simulation Results

The Antenna is designed and simulated in CST Microwave Studio to evaluate the performance of the proposed antenna. Here, we check the flexibility and the extent the antenna can be taken to give the best results possible.

3.5.1 Return Loss

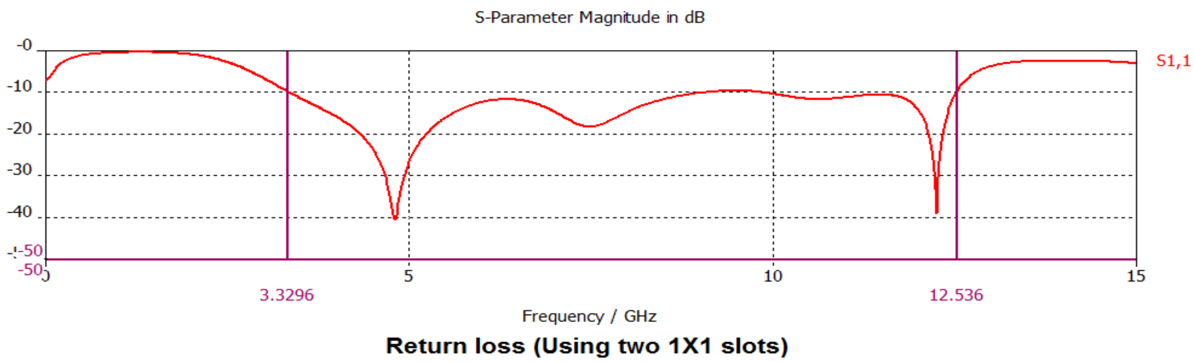

FIGURE 3.4 Return loss for the Proposed design

The return loss graph above shows the frequency bandwidth to be between 3.3296-12.536 GHz giving it a boost in the Frequency Bandwidth compared to the reference design. Return loss is loss of signal power resulting from reflection caused at a discontinuity in transmission line or optical fibre.

$$\mathbf{RL = -20\ log_{10}|\Gamma|}$$

Where, $\Gamma = reflection\ coefficient$

3.5.2 Resonance Frequency

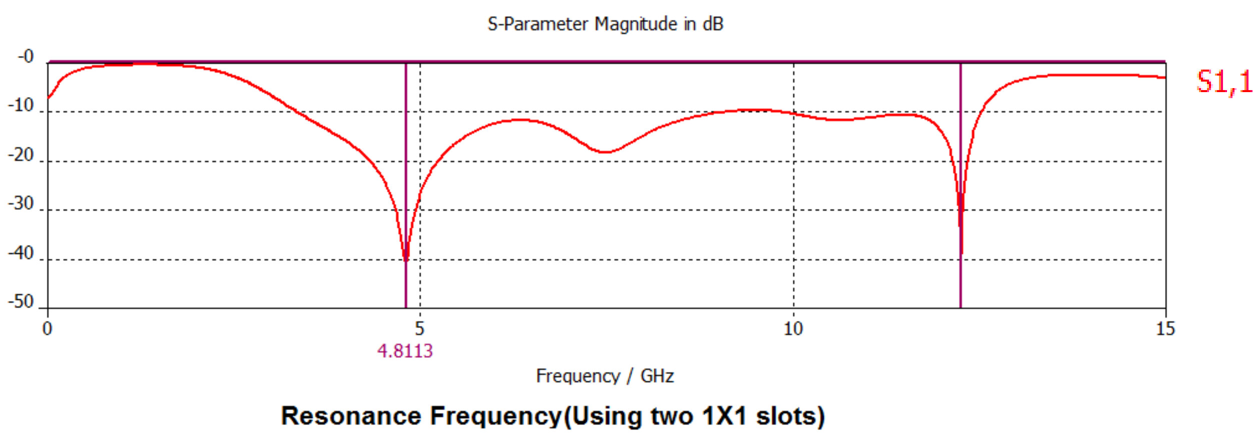

FIGURE 3.5 Resonance Frequency for the Proposed Design

The resonance frequency graph above shows the resonance frequency for the proposed design at which the antenna radiates maximum.

3.5.3 Voltage Standing Wave Ratio (VSWR) Vs. Frequency plot

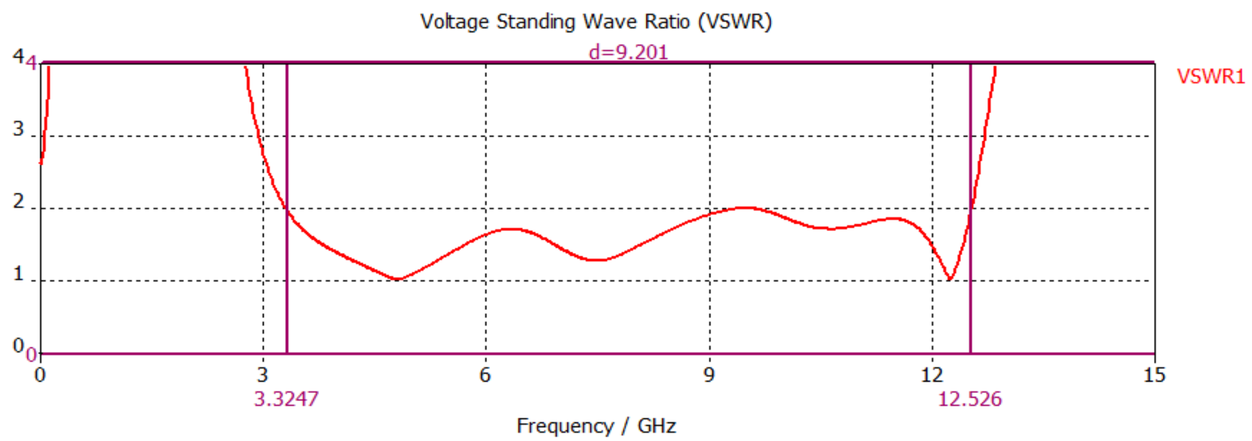

FIGURE 3.6 VSWRFrequency

VSWR tells us how well the antenna impedance is matched to the transmission line it is connect to. The lesser is the VSWR, better is the antenna matched and more is the power delivered to the antenna.VSWR is to be measured between 1 and 2 for efficient transmission as marked in the above shown graph.

When,

VSWR = 1, [no power is reflected]

3.5.4 Gain Plot

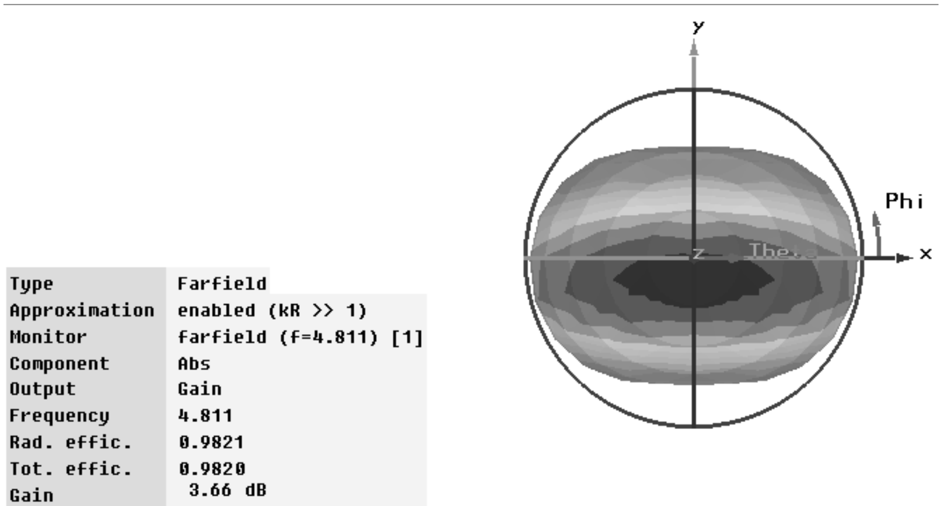

FIGURE 3.7 Gain Plot for the Proposed antenna design

Gain is the parameter which measures the degree of directivity of antenna's radiation pattern. A high gain antenna preferentially radiates in a particular direction. The Gain of an antenna should always be above 3 dB. The more is the gain, the better is the antenna.

3.5.5 E-plane and H-plane Radiation Pattern

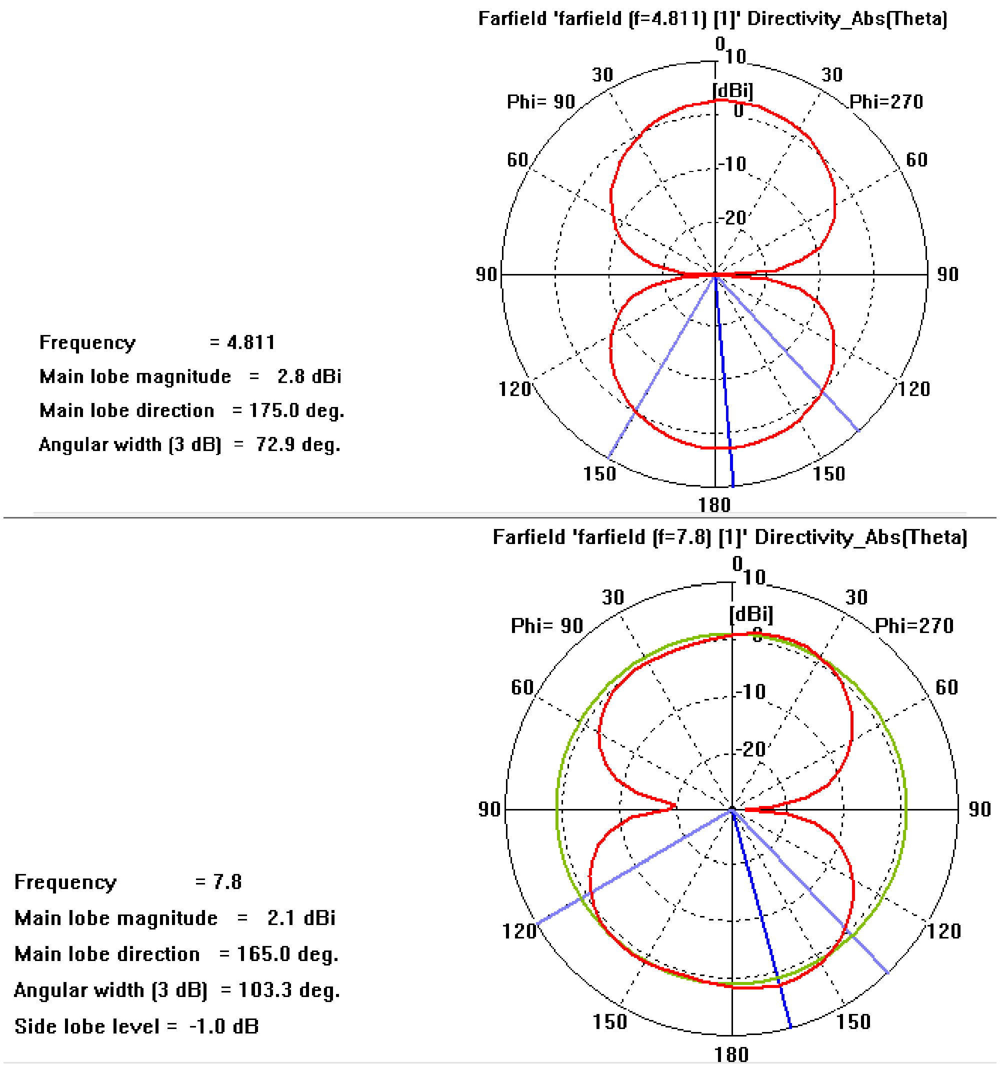

FIGURE 3.8 E-plane radiation patterns at different frequencies of the proposed design

E-plane is the plane that contains electric field and direction of maximum radiation from antenna.

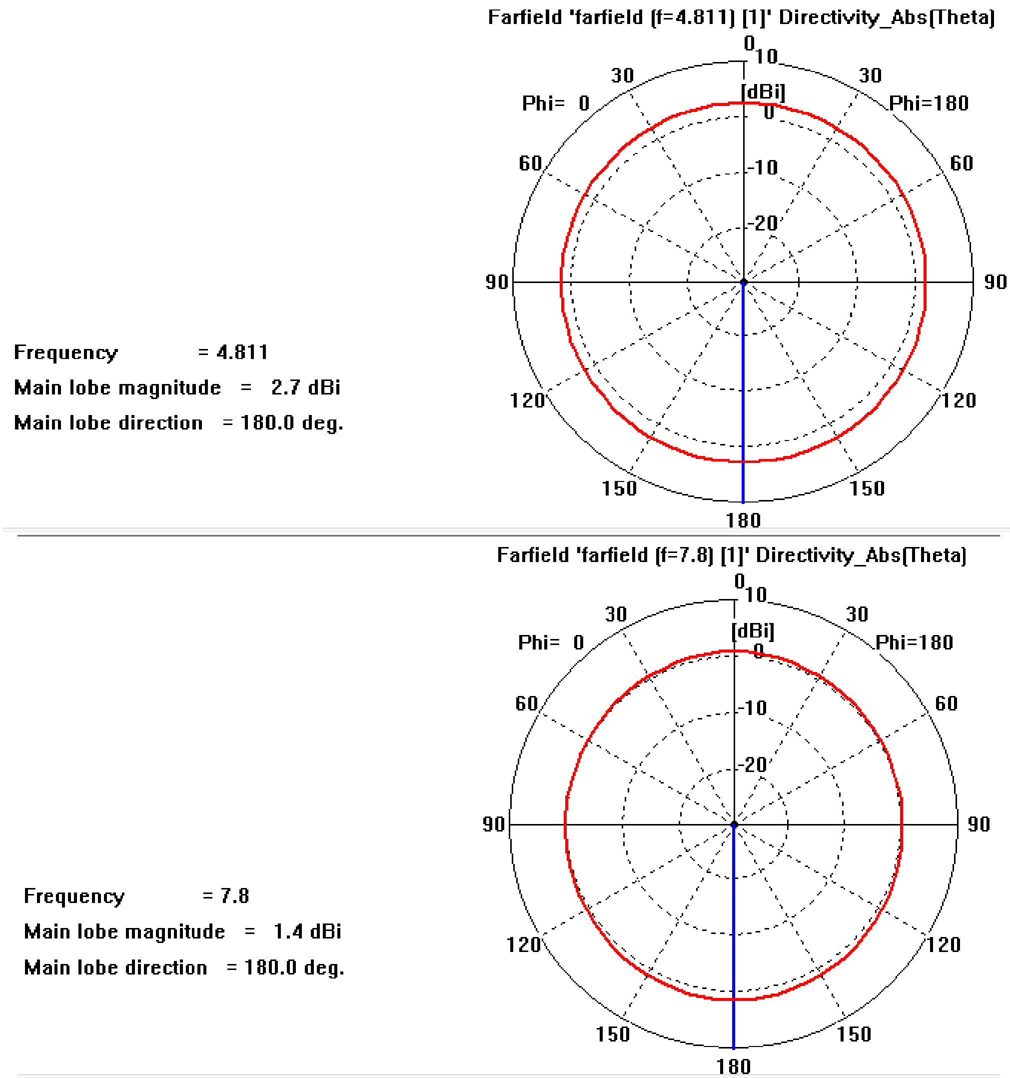

FIGURE 3.9 H-plane radiation pattern at different frequencies of the proposed design

H-plane is the plane that contains Magnetic field and direction of maximum radiation from antenna.

3.6 Comparison between the REFERENCE and the PROPOSED DESIGN

Reference Design	Proposed Design
• The Frequency BW range observed is 3.5-11.2 GHz. B.W.= 96.5%	• On increasing of the gap from the feed, the Frequency BW range increases to 3.3296-10GHz,10-12.536 GHz, B.W.=116.5%& 23.1%
• Resonant Frequency found here is 4.7GHz	• Resonant Frequency found here is 4.811 GHz
• Uses CPW feeding Technique	• Uses Microstrip line Feeding Technique
• Air Gap used is **G1=0.15**, **G2=0.45**	• Air Gap is increased to **G1=0.48**, **G2=0.78**
• No slots are used	• Two 1X1 slots are used

TABLE 1.1 Comparison between the REFERENCE and the PROPOSED DESIGN

Chapter 4

Conclusion and Future Work

4.1 Conclusion

Finally by modifying the design a bit more, i.e. increasing the air-gap of the materialfrom the feed, the Frequency BW of the Antenna is increased from (3.5-11.2) to (3.3296- 12.536). Also, the resonance frequency changes from 4.7 GHz to 4.811 GHz.The design was tested and the desired Frequency BW graph and the e-plane and h-plane radiation patterns were obtained and shown. The Frequency Bandwidth percentage in the proposed design is found to be 116.5 % from frequency range 3.3296-10 GHz and 23.10% for frequency range 10-12.536 GHz. Also, in the Reference design the simulated gain was 4.3 dB, whereas in the proposed design, the simulated gain observed is 3.66 dB.

4.2 Road to go

Fabrication of the proposed DRA will be carried out in future. The measured results will be compared with simulation results. Different shapes and feeding techniques of DRA are to be analyzed.

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