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Design and Simulation for Novel Impact Microstrip Patch Antenna

Mohamed Abdulrahman AL-Amoudi[1]and Ali Muhammad Ali Rushdi
[1]Department of Electrical andComputer Engineering
King Abdulaziz University, 108240Jeddah 21351, Saudi Arabia

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ABSTRACT

Microstrip techniques are frequently used in spectral efficiency because they are simple, lightweight, compact, conformable to planar and non-planar surfaces, and affordable to manufacture using advanced printed-circuit technology.The concept of microstrip radiators was first proposed in 1953, but it was only in 1970s that practical microstrip antennas were fabricated. With features such as low cost, lightweight and easy mounting on boards containing RF or microwave circuits, they become popular with circuit designers. The main objective of this paper is to design and simulate a single element for Compact Microstrip Resonant Patch Cell Antennaof different shapes using a standardadvancedsoftware package. The shapes considered includethe rectangular, square, circular,circular ring and non-uniform polygon shapes. Pertinent specifications, parameters and figures are displayed with each design. The results obtained coverthe return loss, radiation pattern, polarization, power, absolute fields and some other interesting outputs that can be analyzed. The theory of microstrip antenna is simply and briefly reviewed in this paper and the factors affecting the antenna design are explained. .

KEYWORDS: Mobile antennas, Multifrequency antennas, Antenna measurements, Antennas and propagation, Frequency, Acoustics, Acoustical engineering, Antenna arrays, Laboratories, Signal processing, CMRC: Compact Microstrip Resonant Cell, NIMPA: Novel Impact Microstrip Patch antenna.

I. INTRODUCTION

The market of wireless communications has been one of the highest growing markets over the past two decades. The growth in this market has been continuous both in terms of the number of subscribers and the number of telecommunication services offered. By April 2002, the number of world cellular subscribers reached 1 billion, a number comparable to that of 6.273 billions of humans then living. To connect people and improve the overall quality of life, new generations of wireless systems (up to 4G, 5G, and 6G) have been developed that offer new multimedia capabilities, better reliability, improved battery life and efficient and more cost-effective solutions. As the wireless communication continues to develop very rapidly, the number of base station antennas has grown as well. The latest generation of wireless networks would necessitate new and upgraded base station antennas in the coming years. New base station antennas would be used to replace the existing sectored panel antennas and reduce the number of antennas on a base station. These antennas will operate in the frequency band (1920 - 2170 MHz) forWideband Code Division Multiple Access(WCDMA) or may even be dual-band or multi-band and be able to cover some or all of the frequency bands of the Global System for Mobile Communications(GSM) (890 - 960 MHz), GSM1800 (1710 to 1885 MHz) and CDMA (824 – 894 MHz and 1850 – 1990 MHz).

II. MICROSTRIP PATCH ANTENNA

A Microstrip Patch Antenna uses the "microstrip" structure to construct an antenna.Microwave engineers first used "strip lines" to fabricate circuits from circuit boards. The strip line requires two ground planes, and a flat strip (circuit board trace) in-between, to guide radio frequencies or signals. As the pertinent art progressed, many circuits were found to be easily made with "microstrip" structure, which is similar to the strip line, but with one ground plane removed. One of the biggest problems with certain microstrip-implemented circuits is that of excessive radiation. Fortunately, antenna engineers picked up on this undesirable effect and started to take advantage of it. Many antennas have since been designed and implemented with the microstrip technique, ever since the groundbreaking paper by the late Professor George Deschamps in 1953 at the 3rdUSAF Symposium on Antennas, although this paper dealt with a resonant device with relatively narrow operation bandwidth [1-3].

Historical Development of Microstrip Patch Antenna

The microstrip patch antenna is dated back to as late as 1950s where famous figures like Deschamps [1] and Gutton&Boissinot [4]conceived and invented the first microstrip patch antenna. The first prototype can be imagined as a thin radiating metal piece of arbitrary shape, separated from a ground plane by a dielectric substrate, as shown inFigure 2.1

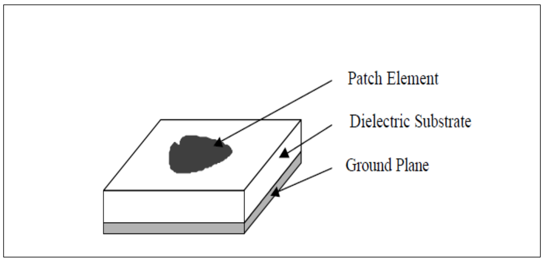


Figure 2.1: Physical structure of a microstrip patch antenna

Rapid developments later began in the late1970s (17 years after the seminal paper of Deschamps). By the early 1980s, the microstrip patch antenna technology was well established in terms of design and modeling techniques. This is credited to several of its inherent characteristics like being lightweight, inexpensive, and of low profile. It must be pointed out that, besides the microstrip patch antennas, there are two other categories of microstrip antennas, namely the microstrip traveling wave antenna and the microstrip slot antenna.

III. FACTORS AFFECTING MICROSTRIP DESIGN

This section highlights the factors affecting microstrip design [5-34]. Types of microstripdiscontinuity and losses will be discussed here. Feeding and analysis methods will also be covered. Last but not the least, the criteria for the selection of substrate will also be touched on.

3.1.Microstrip Discontinuity

When there is an abrupt change in the dimension of the strip conductor, a change in the electric and magnetic field distributions occurs. This phenomenon is known as that of microstrip discontinuity. Microstrip discontinuities include the discontinuities of open-end, gaps, step-in-width, bends, T and cross junctions. In thissection, the open-end, step-in-width and right-angle-bend discontinuities will be discussed as they are more relevant to the design of the microstrip antennas.

3.1.1.The Open-End Discontinuity

The open-end discontinuity is common in a number of circuits such as matching subs and parallel coupled filters. The equivalent circuit of the open-end discontinuity is represented by an excess capacitance or by an extension in length, as shown in Figure 3.1.

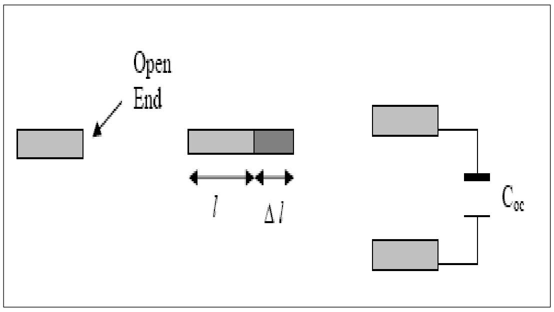


Figure 3.1:Equivalent circuit for an open-end discontinuity.

3.1.2.The Step-in-Width Discontinuity

The step-in-width discontinuity occurs when two lines having different widths are joinedtogether. It is commonly used in the design of matching transformers, couplers and filters. Theequivalent circuit consists of a shunt capacitance and a series inductance as shown in Figure 3.2.

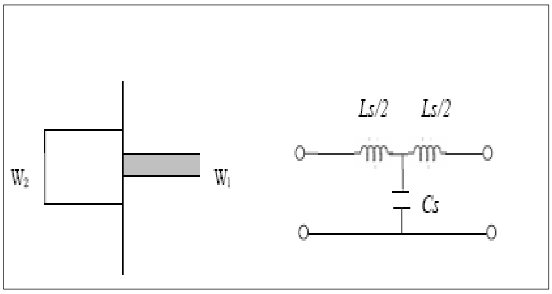


Figure 3.2: Equivalent circuit for the step-in-width discontinuity.

3.1.3.The Right-Angle-Bend Discontinuity

Bends such as right-angle bends are normally incorporated into the circuit for introducing flexibility in the circuit layout. The equivalent circuit is made up of two equal series inductances and a shunt capacitance and is shown in Figure 7. Equation for CB has accuracy to within 5% for 2.5 ≤ r_ε≤ and 0.1 ≤ ≤ 5. The accuracy for L h w/ B is about 3% for 0.5 ≤ ≤ 2. By using a method known as chamfering, discontinuity reactance can be reduce as shown in figure 3.3.

Open End

$$\frac{\Delta l}{h} = 0.412\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w}{h}+0.264\right)}{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w}{h}+0.8\right)}$$

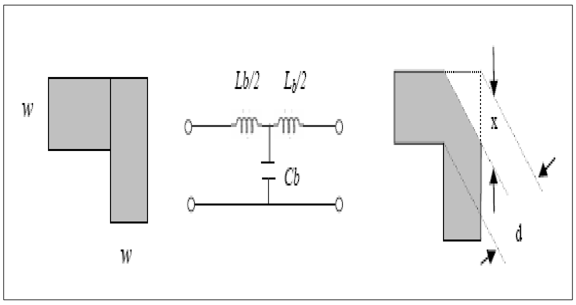


Figure 3.3: Equivalent circuit for a bend discontinuity.

Right-angle bend

$$Cb/_W\,(pF/m)=\begin{cases}\dfrac{(14\varepsilon_r+12.5)W/h-(1.83\varepsilon_r-2.25)}{\sqrt{(W/h)}}+\dfrac{0.02\varepsilon_r}{W/h} & w/h<1\\ (9.5\varepsilon_r+1.25)W/h+5.2\varepsilon_r+7 & w/h\geq 1\end{cases}$$

$$\frac{\Delta L_b}{h}(nH/m)=100\left(4\sqrt{(W/h)}-4.21\right)$$

3.2. Microstrip Losses

Loss components of a microstrip line include dielectric loss, conductor loss and radiation loss. Inherent causes such as the loss tangent and extraneous sources such as the conductor surface roughness affect the microstrip losses.

3.2.1. Dielectric Loss

The cause of dielectric loss is the loss tangent value. The loss tangent depends on the substrate properties. A substrate with a high loss tangent corresponds to a high dielectric loss and vice versa. Therefore, choosing a substrate with a low loss tangent is definitely desirable.

Dielectric loss

$$\alpha_d = 8.66\pi\left(\frac{\varepsilon_{re}-1}{\varepsilon_r-1}\right)\frac{\varepsilon_r}{\varepsilon_{re}}\frac{\tan\delta}{\lambda_g} \qquad \text{db/unit length}$$

where $\tan\delta$ = loss tangent of dielectric substrate

3.2.2. Conductor Loss

The conductor loss arises from conductor surface roughness and the skin effect. Imperfection in the fabrication process or improper handling might cause conductor surface roughness. The “skin effect is the tendency of an alternating electric current to distribute itself within a conductor so that the current density near the surface of the conductor is greater than that at its core. That is, the electric current tends to flow at the "skin" of the conductor.” As the frequency increases, the effective resistance of the conductor increases due to the skin effect.The attenuation loss due to the conductor loss is given below.

Conductor loss

$$\alpha_c = \frac{8.686R_s}{Z_cW} \qquad \text{db/unit length}$$

3.2.3. Radiation Loss

The radiation loss is caused by radiation that is propagated away or current that is induced on the enclosure of the microstrip. Similarly to the case of the dielectric loss, the radiation loss can be reduced by having a substrate with a higher dielectric constant.

3.3. Dispersion

Dispersion occurs in the micro strip, when the phase velocity is not a constant and does not depend linearly on the frequency. As a guideline, effects of dispersion should be taken into consideration and never ignored at frequencies greater than 8 GHz.

3.4. Feeding Methods

As shown in the rectangular shape patch antenna inFigure 3, there is a feedline that is used to excite the patch to radiate by direct or indirect contact. There are many different methods of feeding and the four most popular methods are microstrip line feed, coaxial probe, aperture coupling and proximity coupling. For this paper, microstrip line feed is employed, and is to be discussed below.

3.4.1. Microstrip Line Feed

Microstrip line feed is one of the easiest methods to fabricate as it is just a conducting strip connecting to the patch and therefore can be considered an extension of the patch. It is simple to model and easy to match by controlling the inset position. However the disadvantage of this method is that as the substrate thickness increases, surface waves and spurious feed radiation increases which limit the bandwidth to typically 2-5 %.

3.4.2. Coaxial Line Feed

Coaxial line feed is a feeding method, in which the inner conductor of a coaxial line is attached to the radiation patch of the antenna while the outer conductor is connected to the ground plane. The advantages of this scheme include ease of fabrication and convenience in matching. Unfortunately, this scheme has a few disadvantages including the following:

- Narrow bandwidth,
- Low spurious radiation,
- Difficulty of modelling, especially for thick substrates,
- Possess inherent asymmetries, which generate higher order modes which produce

cross-polarized radiation.

3.4.3. Aperture Coupling

Aperture Coupling consists of two different substrates separated by a ground plane. On the bottom side of the lower substrate there is a microstrip feed line whose energy is coupled to the patch through a slot on the ground plane separating the two substrates. This arrangement allows independent optimization of the feed mechanism and the radiating element. Normally the top substrate used is a thick low dielectric constant substrate, while the bottom substrate is a high dielectric substrate. The ground plane, which is in the middle (sandwiched by the two substrates), isolates the feed from the radiation element and minimizes interference of spurious radiation for pattern formation and polarization purity. The advantage of this method is independent optimization of the feed mechanism and the radiating element.

3.4.4. Proximity Coupling

Proximity coupling has the largest bandwidth together with low spurious radiation.The length of the feeding stub and the width-to-line ratio of the patch are used to control the match

3.5. Substrate Selection

As the substrate is one of the most important entities in the design of a microstrip structure, the selection of its material must be treated with extreme care. The properties of the substrate affect the dimensions and characteristics of the microstrip directly. The key parameters to take note of when selecting a substrate material are the dielectric constant, the loss tangent and the substrate thickness. The dielectric constant is the ratio of the amount of electrical energy stored in an insulator, when a static electric field is imposed across it, relative to that stored in vacuum. A high dielectric constant results in a smaller patch size, which is good in most circuits though it results in tighter fabrication tolerances. A high dielectric constant also generally reduces the bandwidth.

The loss tangent refers to the ratio of the imaginary part of the complex permittivity to its real part. Asubstrate with a low loss tangent increases antenna efficiency and reduces microstrip losses. A thick substrate tends tomaximizethe bandwidth and efficiency, but when it is too thick, surface-wave excitation occurs. Therefore, it is preferable to choose a substrate with the lowest possible dielectric constant if the physical space permits, with a low loss tangent.

3.6. Analysis Method

There are several methods of analysis for microstrip antennas, which include the transmission-line method, the cavitynethod and the full-wave method. In this paper, the transmission-line method is used, and therefore it is discussed herein.

3.6.1.The Transmission- Line Method

The transmission-line method is the easiest method compared to the remaining analysis methods. This method represents the microstrip antenna by two slots, separated by a low-impedance transmission line of a certain length. This method is used in this paper and will be further explained in the sequel. The following effects are taken into account while working with this method.

3.6.1.1. Fringing Effect

The fringing effect occurs at the edges of the patch as the length and width of the patch are finite. It is a function of the dimensions of the patch and the height of the substrate. When L/h >> 1, the fringing effect reduces considerably. For tyicalmicrostrip antennas, this conditions happens to be satisfied, but the fringing effect must still be taken into consideration as it affects the resonant frequency of the antenna.To account for the fringing effect, an effective dielectric constant $\varepsilon_{reff}$is usually used instead of the actual one. Theeffective dielectric constant is defined as the dielectric constant of the uniform dielectric material that should be incorporated so that the electric field has exact electrical characteristics, particularly a propagation constant, as the actual electric field.The formula forε_{reff} isgiven as :

$$\varepsilon_{re} = \begin{cases} \dfrac{\varepsilon r+1}{2}+\dfrac{\varepsilon r-1}{2}\left(\dfrac{1}{\sqrt{1+12\dfrac{h}{w}}}\right) & w/h \geq 1 \quad (3.1) \\ \dfrac{\varepsilon r+1}{2}+\dfrac{\varepsilon r-1}{2}\left[\left(\dfrac{1}{\sqrt{1+12\dfrac{h}{w}}}\right)+0.041\left(1-\sqrt{\dfrac{w}{h}}\right)\right] & w/h \leq 1 \quad (3.2) \end{cases}$$

3.6.1.2. Effective Length and Width

Due to the fringing effect, the patch electrical or apparent dimensions will be bigger than its actual physical dimensions. A practical approximate formula to calculate the effective length L_{eff} is shown below.

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\dfrac{w}{h}+0.264\right)}{(\varepsilon_{reff}+0.3)\left(\dfrac{w}{h}+0.8\right)} \qquad (3.3)$$

$$L_{eff} = L + 2\Delta L \qquad (3.4)$$

For the width calculation,one appropriateformula is

$$w=\frac{\lambda o}{2}\left\{\frac{\varepsilon r+1}{2}\right\}^{-1/2}$$

3.7 Summary

This sectiondeals with the different analysis methods for a microstrip structure, with a stress on the effect of discontinuity encountered. It is of paramount importance to decide which method to use for designing the microstrip antenna, and how to implement such a method. Effects of the open-end discontinuity and the step-in-width one are included in the calculations of the parameters of a microstrip antenna. In the sequel, the steps for the design of a single rectangular patch antenna will be covered.

IV. A NOVEL TRANSMISSION LINE AND ITS IMPACT ON ANTENNA DESIGN

Demand for electrically small antennas continues to soar, particularly among mobile electronic applications. Though the benefits are significant, these antennas arenotparticularlyeasy to achieve. Use of a novel composite-right/left-handed (CRLH) transmission line, however, facilitates the creation of these antennas. A CRLH transmission line incorporates a ground plane with an etched complementary single split-ring resonator (CSSRR) and a patch with two series gaps and two metal viaholes, wherein a via (Latin for path or way) is an electrical connection between metal layers in a printed circuit board..

Based on a CRLH transmission-line unit cell, an antenna was designed and fabricated, and found to provide a –10-dB impedance bandwidth of 5.63% at 3 GHz. The compact antenna patch measures only 0.2λ0 × 0.17λ0 × 0.01λ0—a 69.1% reduction in size compared to a conventional patch antenna. The compact antenna design ultimately achieved peak gain of 4.29 dB.

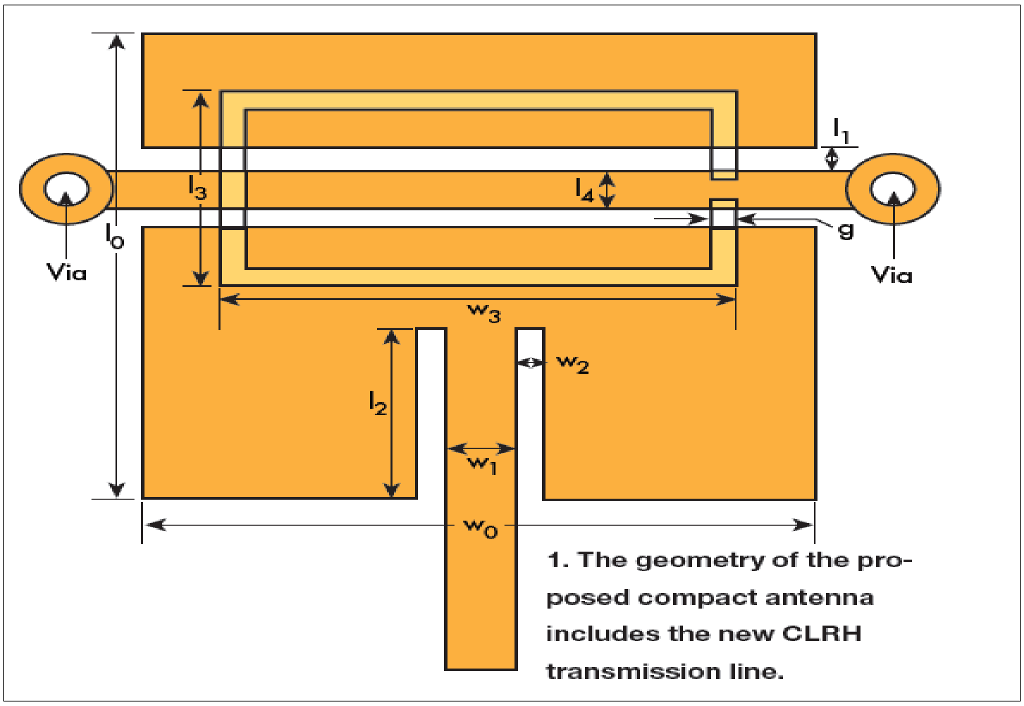


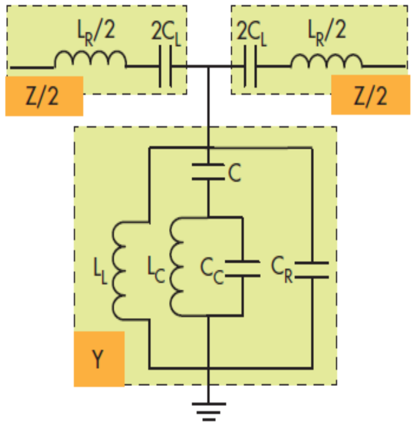
Figure 4.1.the geometry of the proposed compact antenna.

Some of these electrically small antennas exploit the electromagnetic (EM) characteristics of the CRLH transmission lines. Since the realization of a resonant frequency of a zeroth-order resonator (ZOR) is independent of its dimensions, but is determined by the configuration of the unit cells, there has been a large number of successive ZOR-based miniaturized antennas proposed recently. Unfortunately, these antennas are often limited in terms of bandwidth.

To maintain antenna performance with reduced size, a new type of CRLH transmission-line structure was developed. It reduces the resonant frequency by loading with a complementary single split-ring resonator (CSSRR) for a shunt inductance and a patch slot for a series capacitance. Furthermore, two symmetric viaholes were incorporated to change the shunt inductance. These techniques made it possible to implement a CRLH unit cell in a fully-planar technology, thereby bridging a serious gap towards the design of a really compact antenna.

Figure 4.1shows the geometry of the proposed antenna. A patch with two series gaps and two short stubs forms on the top side, and a CSSRR slot is etched on the ground plane on the bottom side. The two white circles denote metallic vias (via holes).

According to CRLH transmission-line theory, the equivalent-circuit model of the proposed antenna can be depicted as that in Fig. 4.2. Since the patch provides a series inductance and the gaps yield a series capacitance, the patch with two series gaps is represented as a series LC circuit (LR and CL), while the CSSRR slot is represented as a shunt LC resonant tank (CC and LC).On the other hand, the capacitance between the patch and the ground plane capacitance (C) connects the shunt resonant tank to the patch, while capacitance $C_R$connects the ground with the patch. The two metallic viaholes connected with two short stubs are described by a shunt inductance L_L, connecting the patch with the ground.



2. This is an equivalent-circuit model of the proposed antenna.

Figure 4.2:The equivalent-circuit model of the proposed antenna.

$$\beta_d = \cos^{-1}\left(1 + \frac{(1-\frac{\omega^2}{\omega_{se}^2})(\frac{C}{C_L}-\frac{\omega^2}{\omega_C^2})}{2(1-\frac{\omega^2}{\omega_Z^2})} - \frac{(1-\frac{\omega^2}{\omega_{se}^2})(1-\frac{\omega^2}{\omega_{sh}^2})}{2\frac{\omega^2}{\omega_L^2}}\right)$$

and

$$\omega_{se} = \frac{1}{\sqrt{L_R C_L}} \qquad \omega_{sh} = \frac{1}{\sqrt{L_L C_R}} \qquad (2)$$

$$\omega_R = \frac{1}{\sqrt{L_R C_R}} \qquad \omega_L = \frac{1}{\sqrt{L_L C_L}}$$

$$\omega_C = \frac{1}{\sqrt{L_C C_C}} \qquad \omega_Z = \frac{1}{\sqrt{L_C (C_C + C)}}$$

Based on the analysis above, one can safely conclude that a model circuit is provided by a complex CRLH transmission-line circuit: $C_L$represents the left-handed capacitance; $L_C$and $L_L$represent the left-handed inductance; C and $C_C$represent the right-handed capacitance; and L is the right-handed inductance. From the equivalent-circuit model, the dispersion relation can be expressed as Eq.4.1

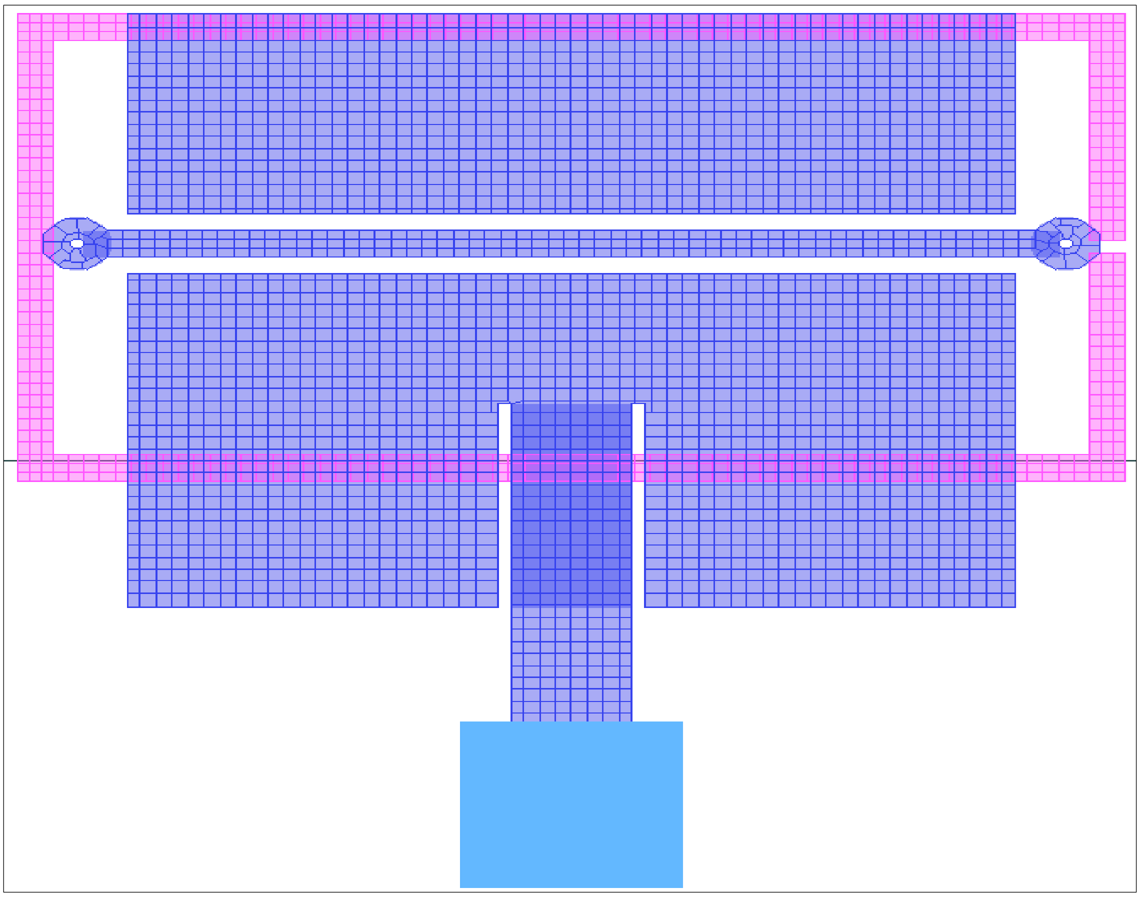
β_d= $\cos^{-1}$ (1 + $Z_{Y/2}$) (4.1)

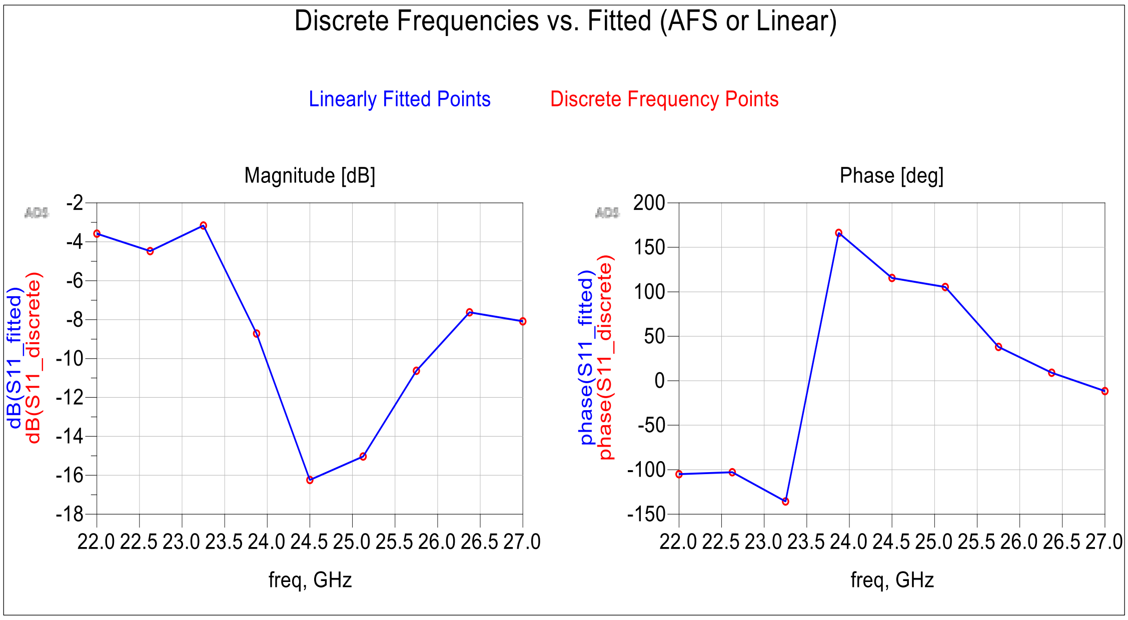
whereβ_d is the length of the unit cell.

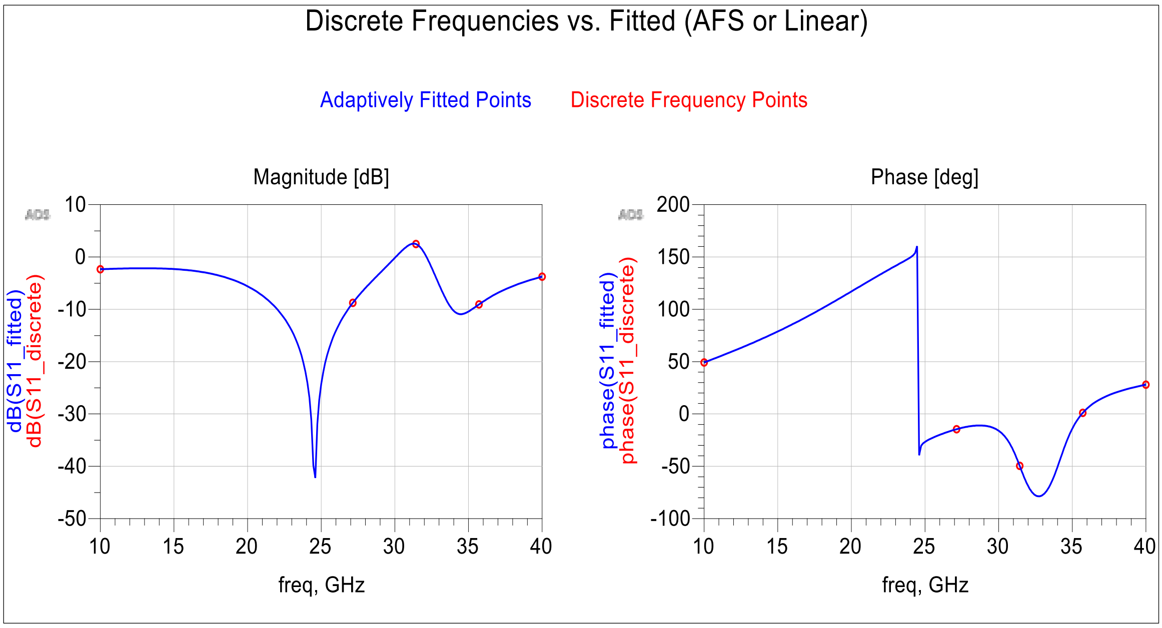
Different Designs for the Novel Transmission Line

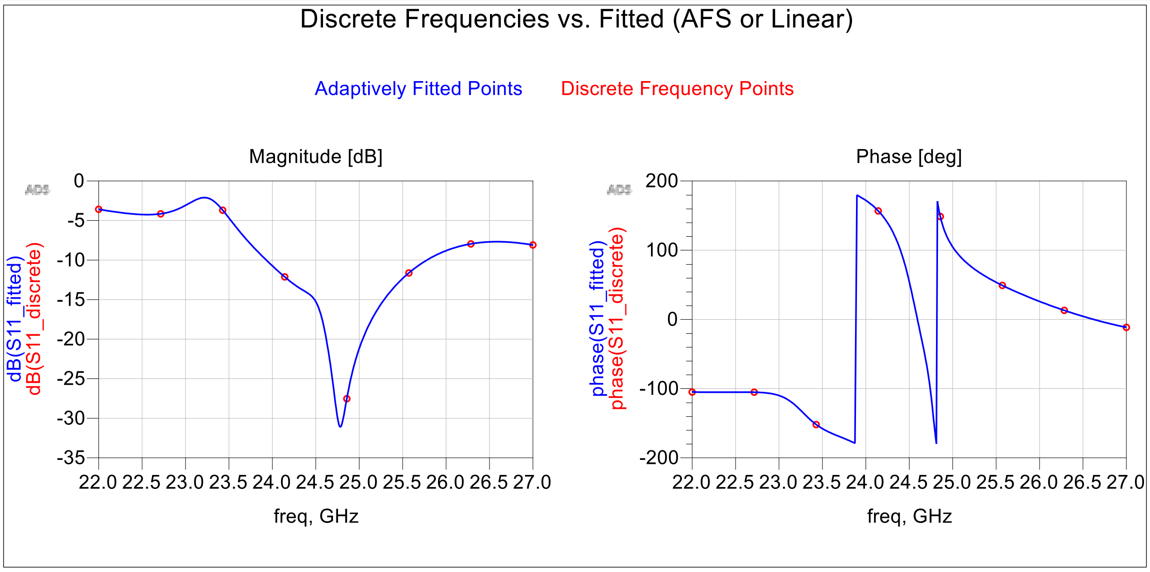
1. Design (1)

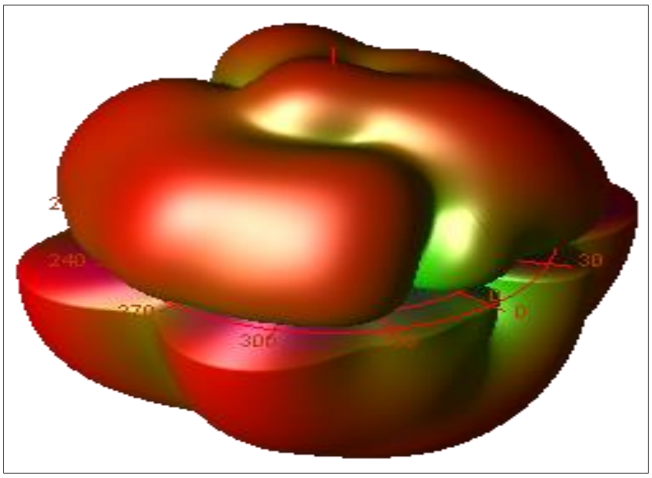
Layout



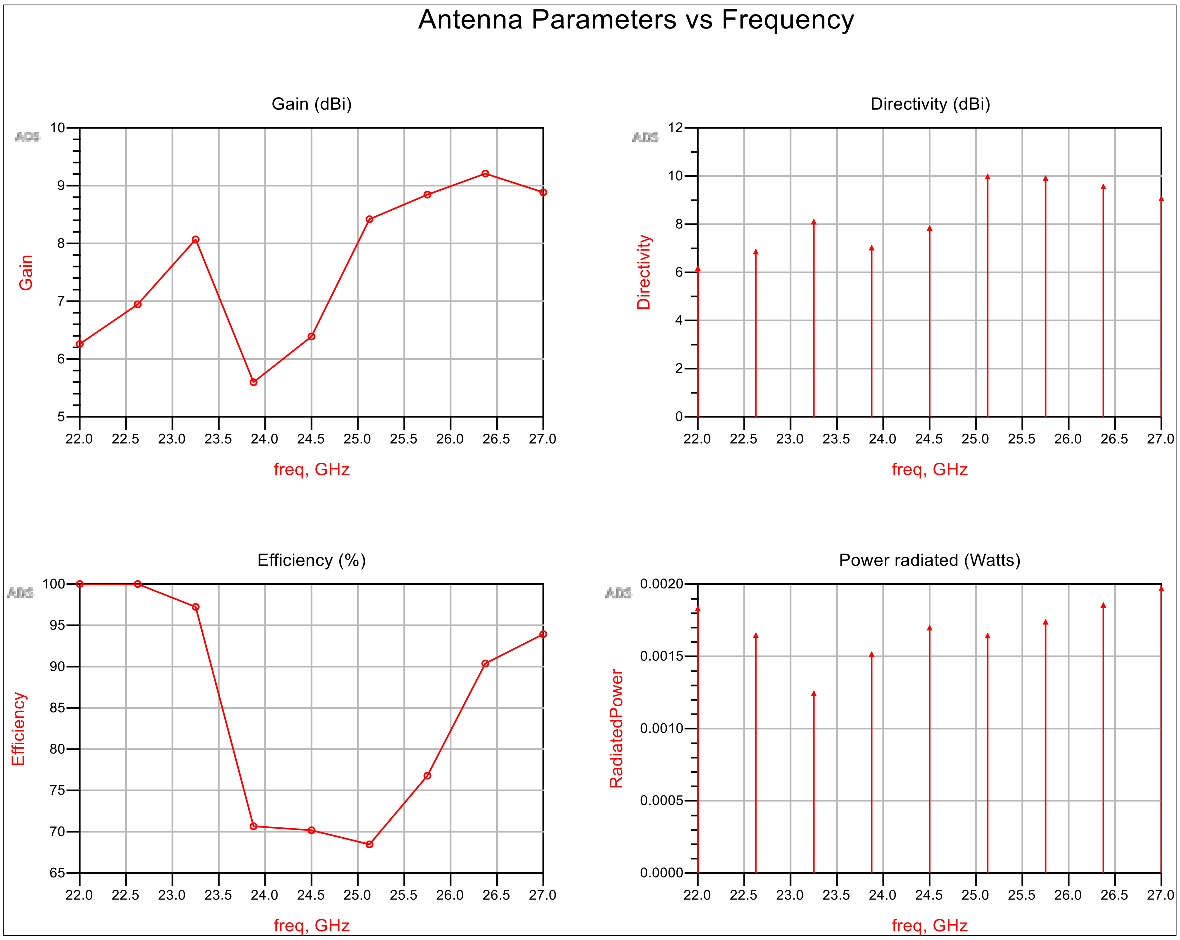

Discrete Frequencies vs. Fitted (AFS or Linear)
Linearly Fitted Points
Discrete Frequency Points
Magnitude [dB]
dB(S11_fitted)
dB(S11_discrete)
-2
-4
-6
-8
-10
-12
-14
-16
-18
22.0 22.5 23.0 23.5 24.0 24.5 25.0 25.5 26.0 26.5 27.0
freq, GHz
Phase [deg]
phase(S11_fitted)
phase(S11_discrete)
200
150
100
50
0
-50
-100
-150
22.0 22.5 23.0 23.5 24.0 24.5 25.0 25.5 26.0 26.5 27.0
freq, GHz

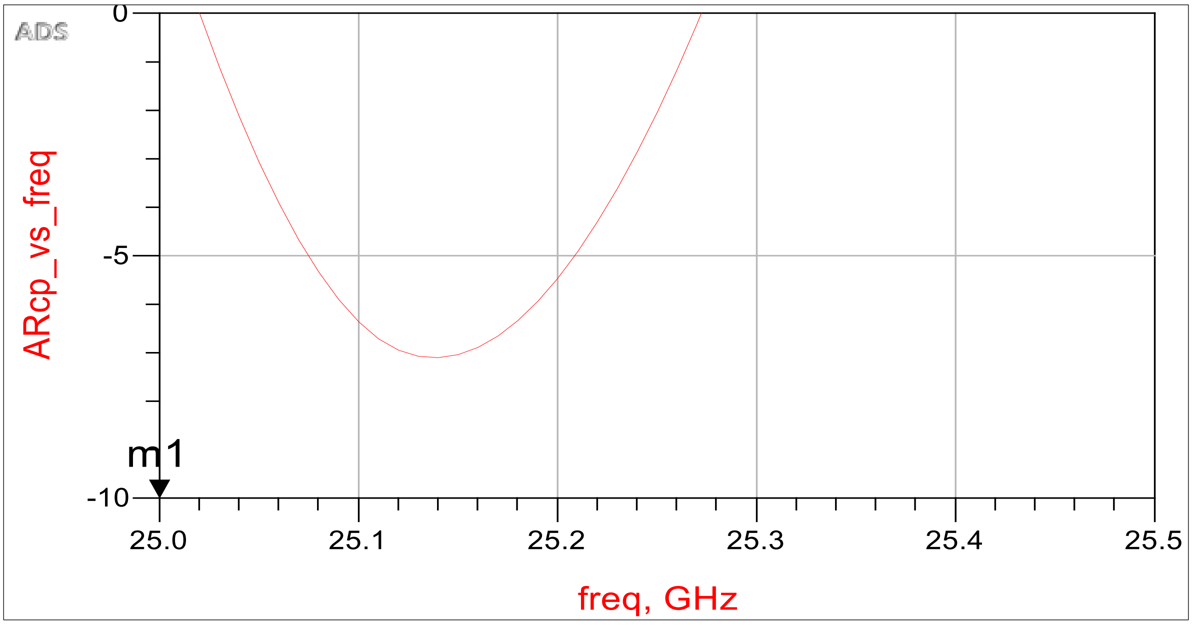






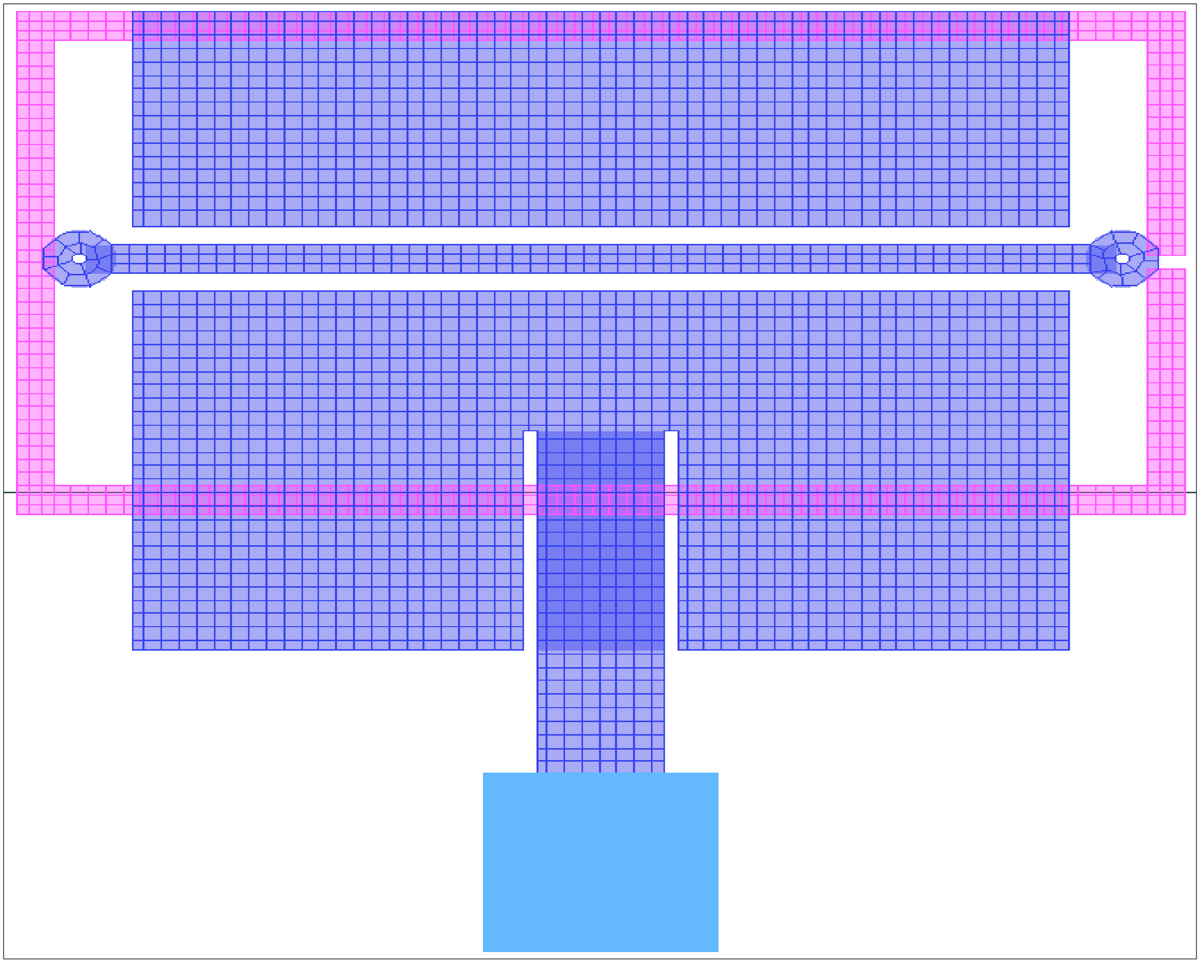
Radiation Pattern

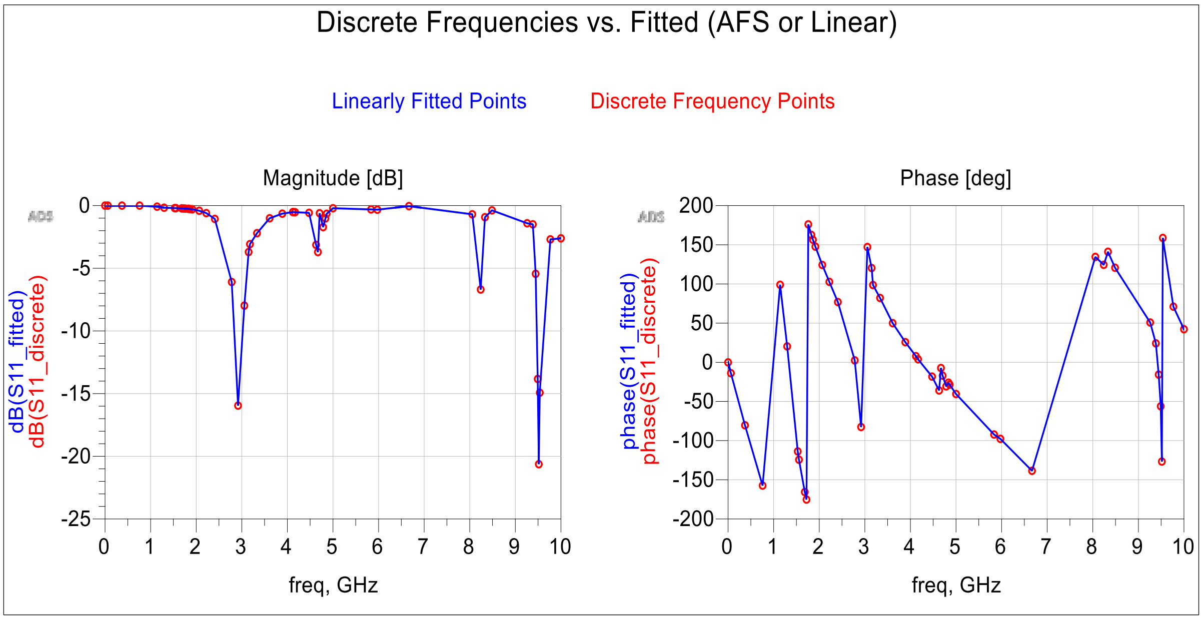


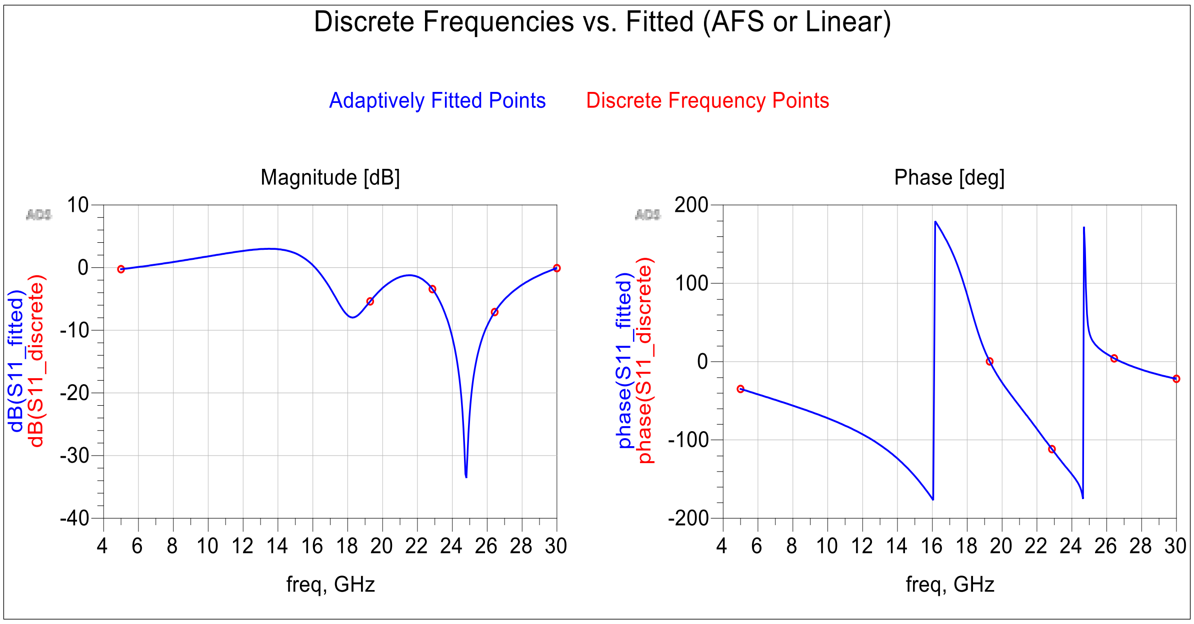


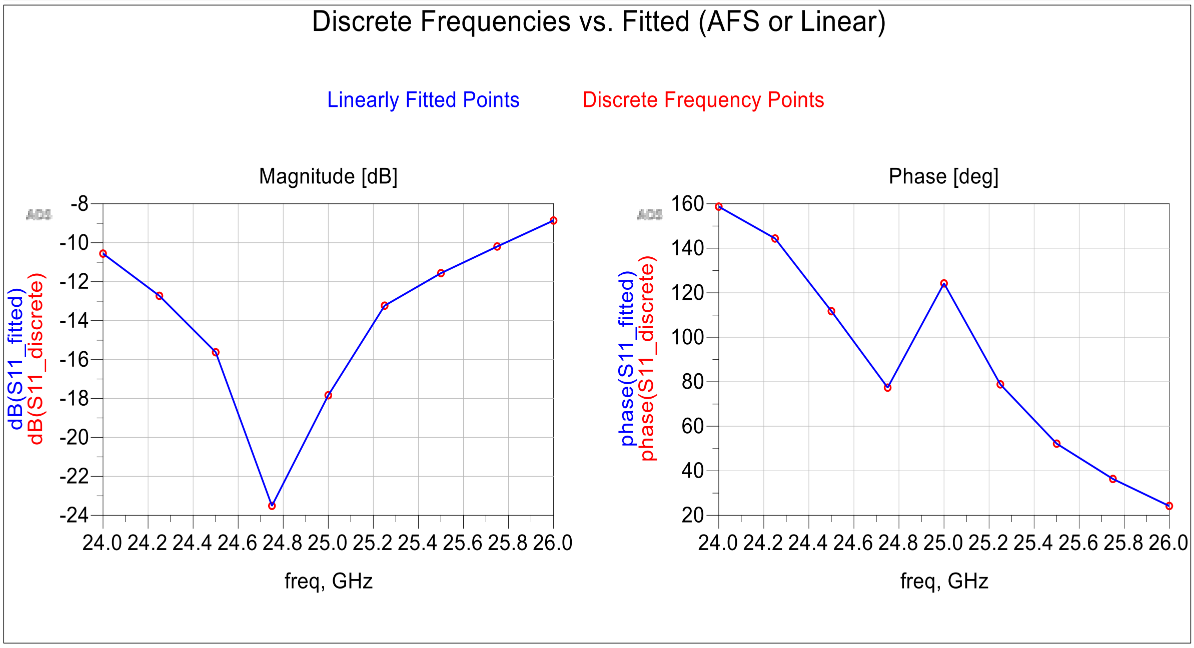
Axial ratio versus Frequency

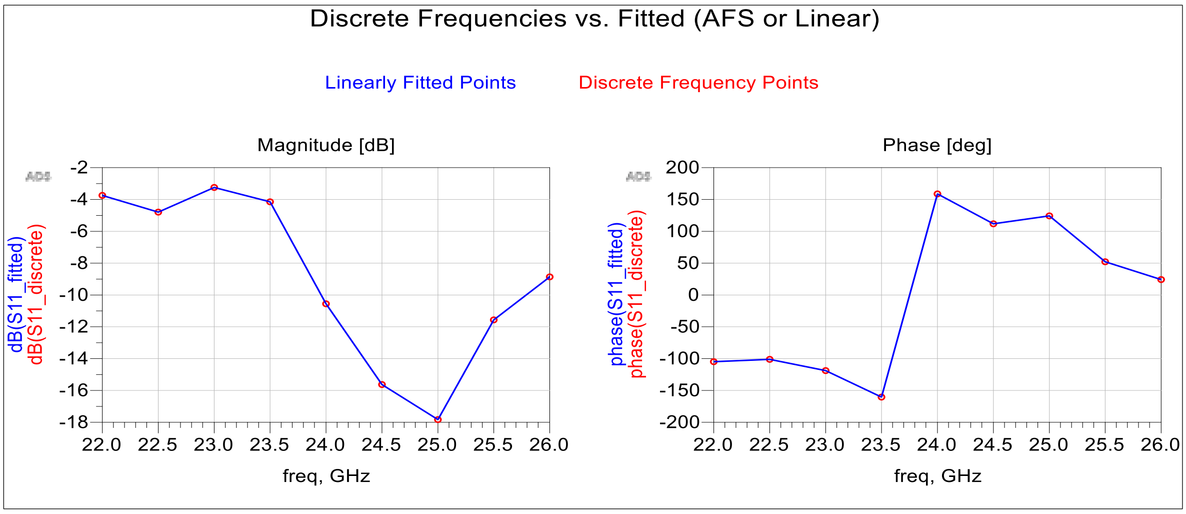
2. Design (2)

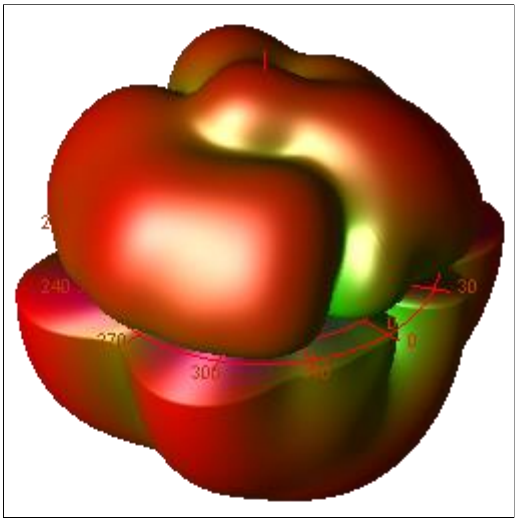



Discrete Frequencies vs. Fitted (AFS or Linear)
Linearly Fitted Points
Discrete Frequency Points
Magnitude [dB]
dB(S11_fitted)
dB(S11_discrete)
0
-5
-10
-15
-20
-25
0 1 2 3 4 5 6 7 8 9 10
freq, GHz
Phase [deg]
phase(S11_fitted)
phase(S11_discrete)
200
150
100
50
0
-50
-100
-150
-200
0 1 2 3 4 5 6 7 8 9 10
freq, GHz

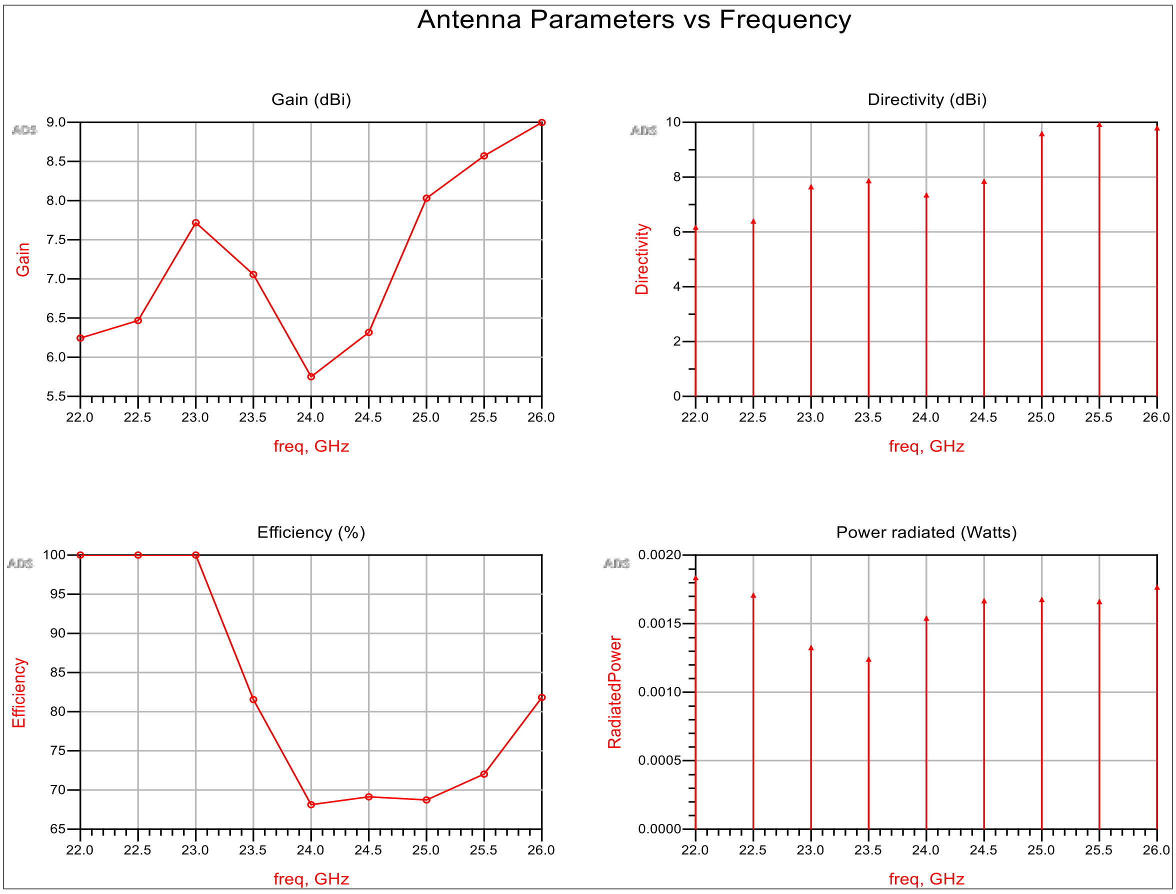

Discrete Frequencies vs. Fitted (AFS or Linear)
Adaptively Fitted Points
Discrete Frequency Points
Magnitude [dB]
dB(S11_fitted)
dB(S11_discrete)
10
0
-10
-20
-30
-40
4 6 8 10 12 14 16 18 20 22 24 26 28 30
freq, GHz
Phase [deg]
phase(S11_fitted)
phase(S11_discrete)
200
100
0
-100
-200
4 6 8 10 12 14 16 18 20 22 24 26 28 30
freq, GHz

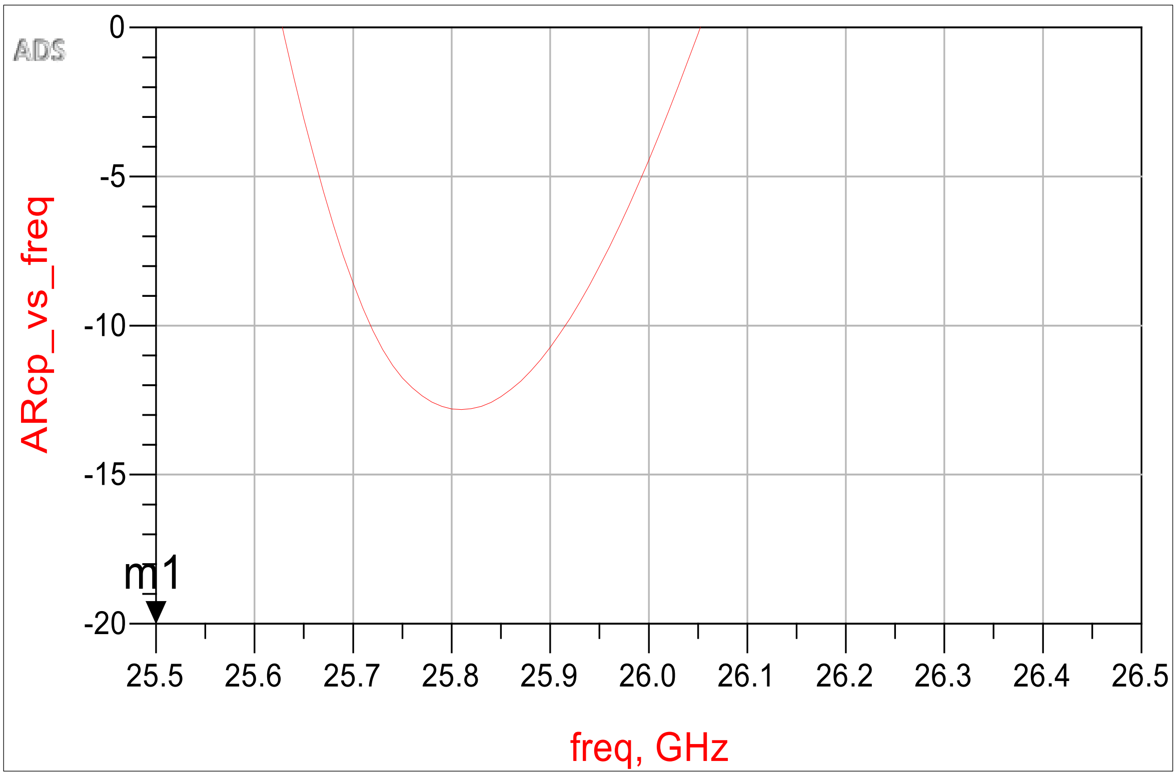

Discrete Frequencies vs. Fitted (AFS or Linear)
Linearly Fitted Points
Discrete Frequency Points
Magnitude [dB]
dB(S11_fitted)
dB(S11_discrete)
-8
-10
-12
-14
-16
-18
-20
-22
-24
24.0 24.2 24.4 24.6 24.8 25.0 25.2 25.4 25.6 25.8 26.0
freq, GHz
Phase [deg]
phase(S11_fitted)
phase(S11_discrete)
160
140
120
100
80
60
40
20
24.0 24.2 24.4 24.6 24.8 25.0 25.2 25.4 25.6 25.8 26.0
freq, GHz





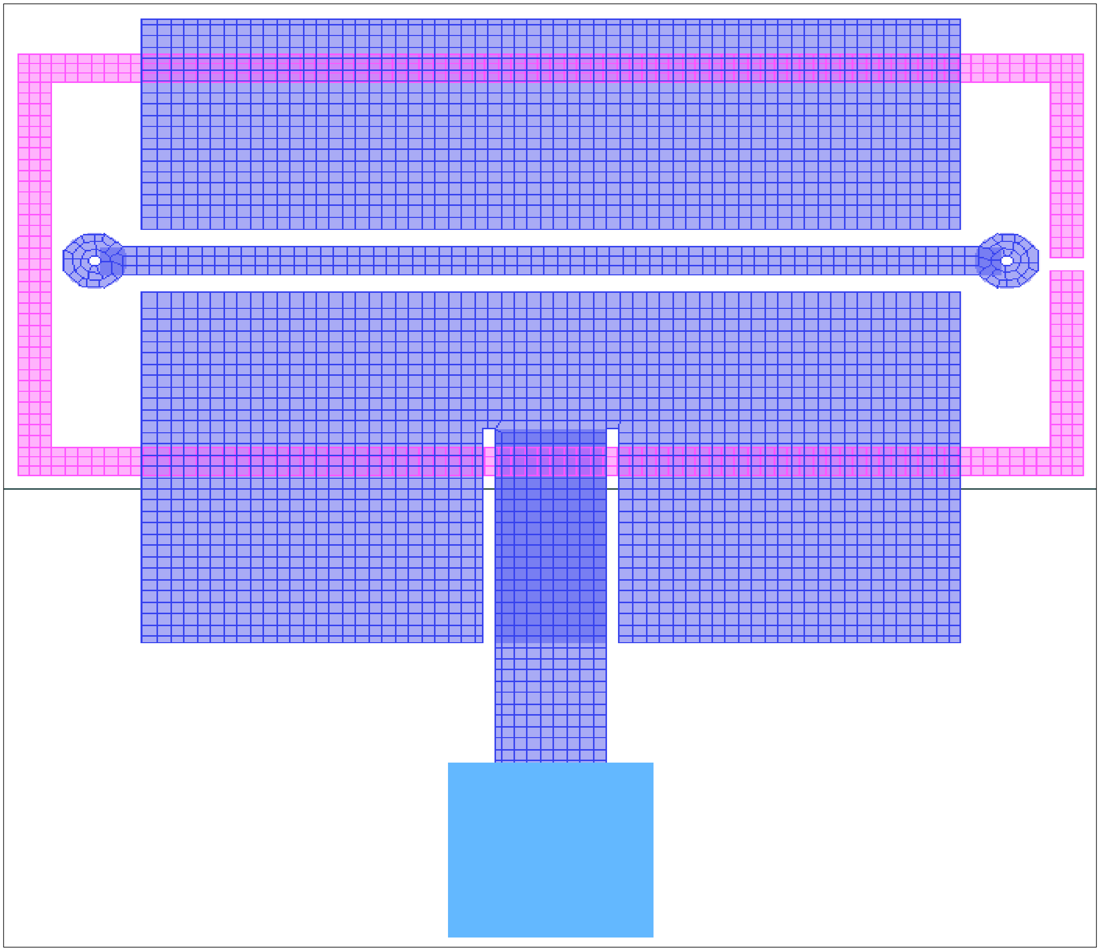
Radiation Pattern

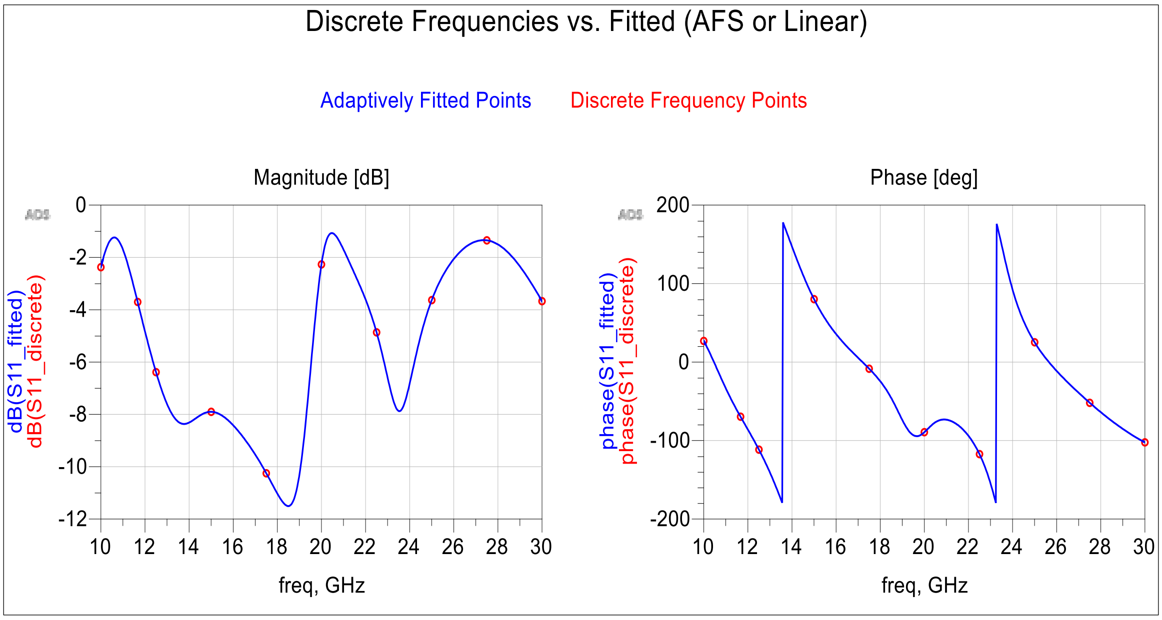


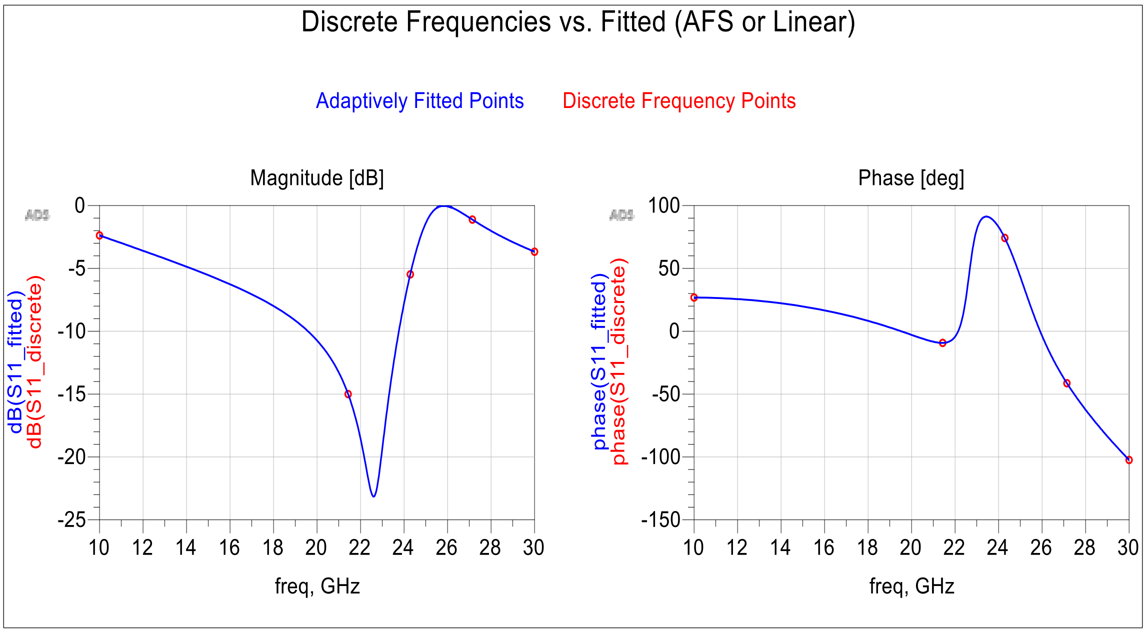


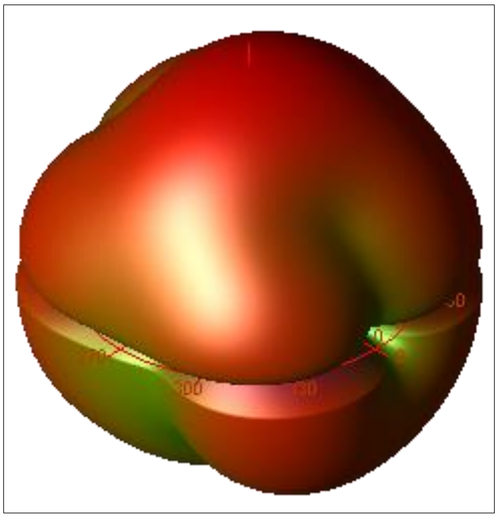
Axial ratio versus Frequency

3. Design (3)

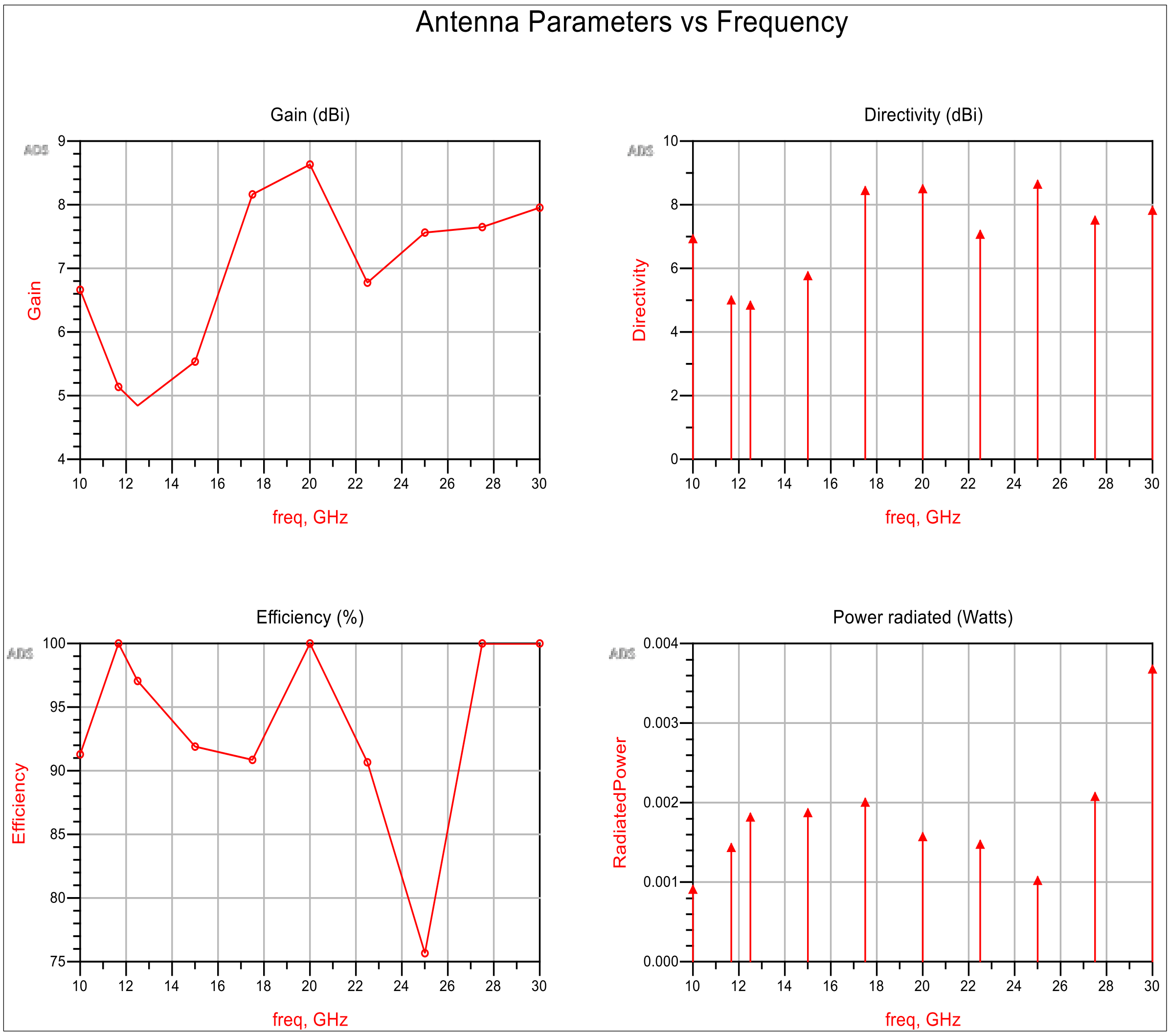


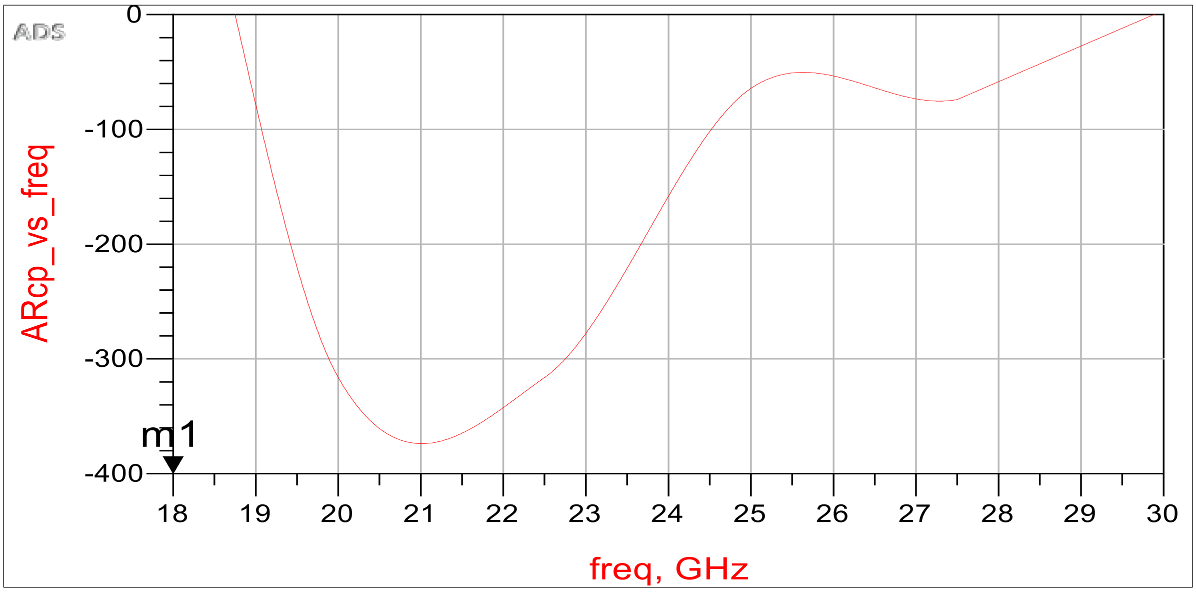

Discrete Frequencies vs. Fitted (AFS or Linear)
Adaptively Fitted Points
Discrete Frequency Points
Magnitude [dB]
Phase [deg]
dB(S11_fitted)
dB(S11_discrete)
phase(S11_fitted)
phase(S11_discrete)
0
-2
-4
-6
-8
-10
-12
200
100
0
-100
-200
10 12 14 16 18 20 22 24 26 28 30
freq, GHz
10 12 14 16 18 20 22 24 26 28 30
freq, GHz





Radiation Pattern





Axial ratio versus Frequency

Table 4.1: various aspectsof the geometry of microstrip patch antennas

Geometry Design of Microstrip patch Antenna		Parameter						
		Gain (dB)	Bandwidth (GHZ)	Polarization	Directivity (dB)	Efficiency %	Power radiated (W)	Axial ration BW (GHZ)
1	Design 1	9	3	circular	10	100	.0020	.5
2	Design 2	9	2	circular	10	100	.0015	1
3	Design 3	8.5	4	circular	8.5	100	.0035	10

V. DISCUSSION AND CONCLUSIONS

Extensive research of microwave and RF fields has been carried out over the past few decades. Microstrips have been widely used in the fields of waveguides and radiators and their advantages made them play an important role in today’s communications. In this paper, the various aspects of microstrips are surveyed and suitable methodologies are applied as shown inTable 4.1.Rectangular, square, circular, circular ring, triangle, parasitic, and polygon patch antennas have been designed. The details of design of a rectangular patch antenna are given in detailed steps. For the other designed shapes, the design formulas were not given in this paper, but anyone can obtain them from suitable references.

The simulation performed herein is done by Advanced Design System (ADS)2015.The ADS program is a very important piece of software for microwave designers and it is recommended here to learn more and more about this special software. The resulting return loss value (less than -25dB) is very attractive in the X-band but is obtained at the expense of decreasing the efficiency of the antenna. The limitations and numerical calculations of the program must be not forgotten.For future improvement of the currentdesigns, one can make a trade off of the parameters of the antenna to get the desired aim. Arrays of microstrip patch antennas can also be designed and simulated here and this is left for future work. Another direction of future work is to view the obtained antennas or arrays made thereof as multi-state reliability systems [35-42].

Antennas designed in this project used microstrip line feed and this method takesup certain amount of space in the circuit. More compact antennas can be designed using other feeding methods such as probe feed. An antenna array of beam steering capabilities could also be designed to enhance the learning knowledge of the design microstrip antennas.

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Mohamed Abdulrahman AL-Amoudi
was born in Jeddah, Saudi Arabia, He received the B.S. and M.S. degrees in Electrical engineering (Electronics & Communications) from King Abdulaziz University (KAU), Jeddah, Saudi Arabia in 1997 and 2000, respectively. From 1998 to 2000, he was a Research Engineer in the Military Sector. From 2000 up to now, he has been working on the Telecommunication Sector. In April 2019, he received the Ph.D.again in Electrical & Computer Engineering (Electronics & Communications), also from King Abdulaziz University. In his Ph.D. thesis, he investigated novel techniques for evaluating multi-state reliability systems, with an eye of applying these techniques to telecommunication systems.

Ali Muhammad Ali Rushdi was born in Port Said, Egypt, on May 24, 1951. He received the B.Sc. degree in Electrical Engineering from Cairo University, Giza, Egypt, in 1974, and the M.S. and Ph.D. degrees in Electrical Engineering from the University of Illinois at Urbana-Champaign (UIUC), USA in 1977 and 1980, respectively. He maintained a perfect GPA of 5.0/5.0 throughout his study. In 1974, he was appointed Demonstrator and Instructor in the Department of Electronics and Electrical Communications of Cairo University. From 1976 to 1980 he was Research Assistant in the Electromagnetics Laboratory of UIUC, where he studied under a potpourri of giant scholars, including professors Mittra, Deschamps, Mayes, Lo, and Lee. In 1980, he acted as Consultant to the Ionospheric Propagation Laboratory of UIUC. Since 1980, he has been with King Abdulaziz University (KAU) in Jeddah, Saudi Arabia, where he is now Distinguished Adjunct Professor of Electrical and Computer Engineering and Former Head of the Computer Engineering Programs. At KAU, he structured and taught a great number of graduate and undergraduate courses, supervised over 85 M.S. and Ph.D. theses, and contributed significantly to accreditation activities. He has served (and is serving) as an Editor or Associate Editor for several prestigious scientific journals. His research interests and contributions over the past forty five years spanned the areas of Electromagnetic Communications, Computer Engineering, Reliability, Digital Design, Engineering Pedagogy and Education, Switching Networks, Boolean Algebras and Equations, Engineering Design, Dimensional Analysis, Diagnostic Testing, Ecological Modelling, Futurology, Translation, Inferential Thinking, and Innovative Problem Solving. Prof. Rushdi is an initiated member of the Honorary Societies: Eta Kappa Nu and Phi kappa Phi. He is a Life Senior Member of the Institute of Electrical and Electronics Engineers (IEEE).