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Simulation of a Rectangular Patch Antenna

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***Abstract*— This paper is dedicated to simulate a rectangular patch antenna by using the software HFSS and ADS. Microstrip antennas have a profile which relays at the needs of new technology, such as a low profile, a flat configuration and a better gain. The simple configuration of the rectangular microstrip antenna presents generally a narrow band. This inconvenient provokes changes on this type of antenna, by integrating patches with various shapes with crack.**

Keywords– Rectangular patch antennas; L-band; ADS Memontum

I. Introduction

The telecommunication always tries to reach the best performances, the reliability and the efficiency with the lowest possible costs. In this domain, antennas establish a basic element allowing the transmission of the electromagnetic waves in free space. We find several types of antennas which different by cuts, geometrical shape, capacity of transmission [1-7].

The most serious limitations of the microstrip antenna is its narrow band, which is typically of the order of some percents 1-5 % [1]. However, the new generation of the communication, the mobile or satellite communication, provokes considerable changes in patches antennas, from which the various modern applications require a functioning in wideband and dual band [1-4].

Novel investigation of a microstrips antennas compacts conception with a wideband, a double frequency, a double band, an enhanced gain of operation, was announced during the last years [3, 7].

The first chapter presents a generality of patch antenna, concerning their characteristics and mechanism of radiation.

So, an outline on the various techniques allowing increasing the bandwidth of microstrips antennas.

This paper presents the simulation of a rectangular patch antenna, by using the software Ansoft HFSS and the Agilent ADS.

II. Theory of patch antenna

A microstrip antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side.

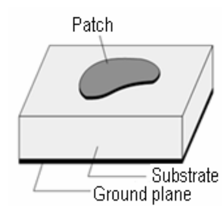

Figure 1. Microstrip antenna configuration.

- Patch: present the radiant conductive element and which can take several forms
- Substrate: allows to isolate both conductive planes, characterized by the permittivity ε_r
- Ground plane: conductor situated below the circuit on which is placed the substrate

However, other shapes shown in figure 2 are also used. The rectangular and circular shape presents a better radiation, bandwidth and polarization [3-4].

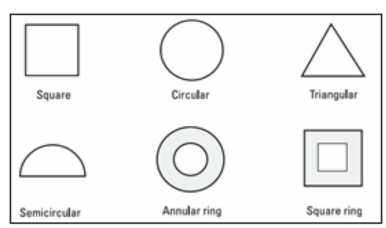

Figure 2. Different shapes of microstrip patches.

III. Characteristics of microstrip antennas

Every antenna has the characteristics specific for a type of application and not on the others. An antenna can be characterized by [8]:

- Return loss S_{11}

The reflection loss corresponds to the reflection of the power supply input. A high return loss is therefore desirable as it results in a lower insertion loss.

- Input impedance

The input impedance is an important consideration to have of better result of an antenna granted on a transmitter or a receiver. By definition, the input impedance of an antenna is the impedance view from the feed line. It is given by the following formula:

$$Z_{in} = Z_0 \frac{1 + {}_{11}}{1 - S_{11}}$$

(1)

- Gain (G)

An antenna which is badly radiate, has a low gain. The gain allow to measure how an antenna radiate compared with a reference antenna, as a dipole. The gain are the result of two effects: the directivity (D) and the return loss (η).

$$G(\theta, \varphi) = \eta * D(\theta, \varphi) \quad (2)$$

- Radiation pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a fixed or constant distance. The radiation is maximal on the main lobe and minimal on the secondary lobes. It is important to know the model of radiation of the antenna, to assure that a principal lobe is in the direction wished by communication.

IV. Rectangular patch antennas

A microstrip antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. However, the shape takes forms, but generally taken as a regular to facilitate the analysis and the understanding of the characteristics of the antenna radiation.

The rectangular patch antenna is the most used configuration because this shape requires a simple theoretical analysis (figure 7).

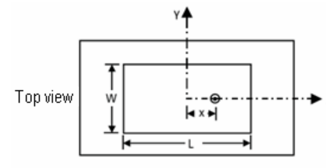

Figure 7. Top view of a rectangular patch antenna.

A. Radiation mechanism of a microstrip antenna

The radiation from microstrip line, structure similar to a microstrip antenna, can be reduced considerably if the substrate employed is thin and has a higher relative dielectric constant. Radiation from a microstrip antenna can be determined from the field distribution between the patch metallization and ground plane. The fringing fields can be modeled as two radiating slots (figure 8.c).

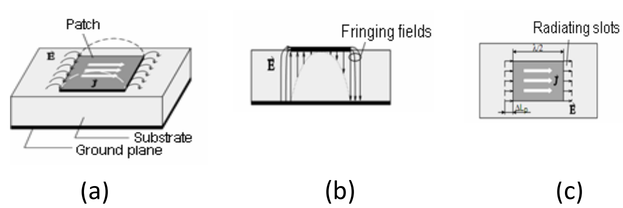

Figure 8. Configuration of a rectangular microstrip antenna

(b) side view, (c) top view.

Alternatively, radiation can be described in terms of the surface current distribution on the patch metallization.

The fundamental TM_{10} mode implies that the field varies one λ /2 cycle along the length, and there is no variation along the width of the patch. It may be observed from that the vertical components of the electric field (E-field) at the two edges along the width are in opposite direction. Therefore, the edges along the width are termed as radiating edges (figure 8.a et 8.b).

B. Parameters of microstrip antenna

The bandwidth of the microstrip antennas is directly proportional to the substrate thickness h and inversely proportional to the square root of its dielectric constant. As a result, a thicker substrate with a low dielectric constant is generally used to obtain broad bandwidth. Consequently, the substrate, whose ε_r typically between 2.1 to 2.6, are used.

This substrate has low dielectric loss (tanδ in the range of 0.0006 to 0.002) resulting in better efficiency. Sometimes, air substrates are used to enhance the bandwidth [3].

1) Radiant element

A rectangular patch is defined by its length L and width W. For the fundamental TM_{10} mode, the length L should be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium. Here, is equal to $\lambda_0/\sqrt{\varepsilon_e}$ where λ_0 is the free-space wavelength and ε_e is the effective dielectric constant of the patch.

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{10h}{W}\right]^{-1/2}$$

(3)

The value of ε_e is slightly less than ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air (figure 8). The fringing field along the edge of the patch extend beyond the physical dimensions, thereby increasing the effective width W.

In general, the resonance frequency of the RMSA excited at any TM_{mn} mode is obtained using the following expression:

$$f_0 = \frac{c}{2\sqrt{\varepsilon_e}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{\frac{1}{2}}$$

(4)

With m and n the modes along the L and W.

For an rectangular microstrip antenna to be an efficient radiator, W should be taken equal to a half wavelength.

$$W = \frac{c}{2f_{01}\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

(5)

The width of the patch plays an important role to the bandwidth and the input impedance of the antenna. So, the length of the patch determines the resonance frequency of the antenna. You should not forget to deduct the width ΔL which corresponds to the extension.

$$L = \frac{\lambda}{2} - 2\Delta L$$

(6)

2) Substrate

A dielectric substrate is a main constituent of the microstrip structure, whether it is a microstrip line, circuit, or an antenna. For microstrip antenna applications, a thicker substrate with a low dielectric constant is preferred to enhance the fringing fields and hence the radiation.

Another important substrate parameter is its loss tangent ($\tan\delta$). The tangent indicates the dielectric loss, which increases with frequency. For a higher efficiency η of the antenna, the substrate with a low $\tan\delta$ (in the range of 0.0006 à 0.002) should be used; this is costlier than the substrate with a high $\tan\delta$ [3]. Therefore, judicious selection of the substrate is required with consideration of the application and frequency of operation.

V. Broadband patch Antenna

Microstrip antennas have several advantages with regard to the other conventional microwave antennas, presenting a light weight, a small volume and a flat configuration.

Diverse methods to analyze this type of antenna are briefly described afterward. These antennas are used in the UHF bands of millimetre wavelength. The main limitation of this type of antenna is their narrow band. Fortunately, the bandwidth can be increased by using a thick substratum with a dielectric of low constant. So, piled patches electromagnetiqually coupled by line or by aperture allow to increase the bandwidth [3,5,9]. We are going to approach on this part the various methods used to increase the bandwidth.

A. Bandwidth

The bandwidth could be defined in terms of its VSWR or input impedance variation with frequency or in terms of radiation parameters. It can be defined by the variation of the input impedance, of radiation pattern and the polarization. The bandwidth may be calculated by using the frequencies lower and upper edges of the achieved bandwidth [3, 5]:

$$BW(\%) = \frac{2(f_u - f_l)}{f_u + f_l} * 100$$

(7)

With, f_u : upper frequency

f_l : lower frequency

A satisfactory impedance bandwidth is the basic consideration for all antenna design, which allows most of the energy to be transmittedto an antenna from a feed or a transmission system at a transmitter and from an antenna to its load at a receiver in a wireless communication system . As well as, a designated radiation pattern ensure that maximum or minimum energy is radiated in a specific direction. In more, a defined polarization of an antenna minimizes possible losses due to polarization mismatch within its operating bandwidth.

The bandwidth of the microstrip antenna is inversely proportional to its quality factor Q and is given by:

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}}$$

(8)

Where VSWR is defined in terms of the input reflection coefficient as:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

(9)

The Γ is a measure of reflected signal at the feed-point of the antenna.

It is defined in terms of input impedance Z_{in} in of the antenna and the characteristic impedance Z_0 of the feed line as given below:

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

(10)

The bandwidth is usually specified as frequency range over which VSWR is less than 2 (which corresponds to a return loss of 9.5 dB or 11% reflected power). Sometimes for stringent applications, the VSWR requirement is specified to be less than 1.5 (which corresponds to a return loss of 14 dB or 4% reflected power).

The expressions for approximately calculating the percentage bandwidth of the rectangular microstrip antennas in terms of patch dimensions and substrate parameters is given by:

$$BW(\%) = \frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\sqrt{\frac{W}{L}}$$

(11)

With L and W are the width and the length.

With, $A = 180$ for $\frac{h}{\lambda_0\sqrt{\varepsilon_r}} \le 0.045$

$A = 200$ for $0.045 \le \frac{h}{\lambda_0\sqrt{\varepsilon_r}} \le 0.075$

$A = 220$ for $\frac{h}{\lambda_0\sqrt{\varepsilon_r}} \ge 0.075$

The bandwidth of a single-patch antenna increases with an increase in the substrate thickness and a decrease in the ε_r of the substrate (11).

The bandwidth can also be defined in terms of the antenna's radiation parameters. It is defined as the frequency range over which radiation parameters such as the gain, half-power beamwidth (HPBW), and side lobe levels are within the specified minimum and maximum limits. This definition is more complete as it also takes care of the input impedance mismatch, which also contributes to change in the gain.

VI. Results of simulation of microstrip antennas

The advantages of antennas microstrips exceed their limits. Several applications take advantage of their performances because of their moderate cost and their dimensions reduce, among them we find the military systems such as missiles, planes and satellites, as well as commercial sector [1-12] , also in RFID technology [13]. The main difficulty of the patch antenna is her narrow band. This common antenna undergoes in several changes in their configuration. This change concerns either the feed, or the radiant element, as well as the substrate.

In this present work, we are going to simulate the various configurations by using the simulation software HFSS and the ADS-Momentum software. The purpose to show the performances and the characteristics of every configuration of microstrip antenna.

A. Conception of the rectangular microstrip antenna

The configuration of the patch antenna shown on the figure (figure 12), works on the L band.

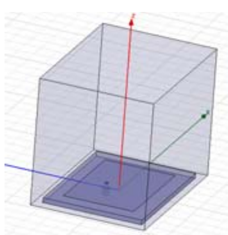

Figure 12. Configuration of the rectangular patch antenna by HFSS.

The essential parameters of the structure are:

- Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. The Personal Communication System (PCS) uses the frequency range from 1850-1990 MHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for this design is $f_0 = 1.9GHz$.
- Dielectric constant of the substrate (ε_r): The dielectric material selected for my design is Silicon which has a dielectric constant of $\varepsilon_r = 11.9$. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
- Height of dielectric substrate (h): For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not voluminous. Hence, the height of the dielectric substrate is selected as $h = 1.5mm$.

The expressions described previously in the chapter 1, which concerns the theoretical study of the rectangular microstrip antenna, are used to size this antenna (table 1).

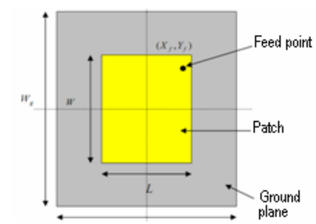

Figure 13. Microstrip patch antenna.

Table 1. The parameters of the simple rectangular antenna

$f_0\ (GHz)$	$W\ (mm)$	$\Delta L\ (mm)$	$L\ (mm)$
1.9	31.1	6.345510^{-4}	22.8

The antenna is fed by a coaxial cable, of inside and outside radius, respectively, 0.5 mm and 1.15 mm. By repetitive simulations, the coordinates of the position of the cable are determined.

B. Simulation of results

The results of simulation, made by means of software HFSS and ADS, of the rectangular patch antenna (figure 12) are shown on figure 14.

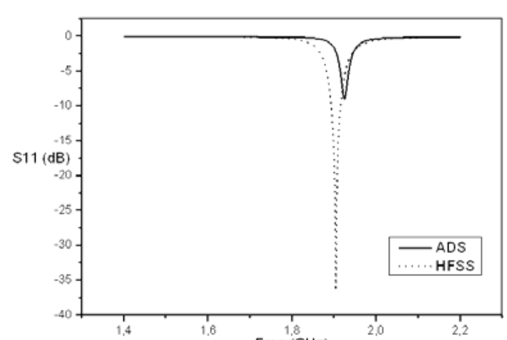

Figure 14. Variation of S_{11} according to the frequency with L=31mm, W=22mm, $\varepsilon_r = 11.9$, h=1.5mm.

The resonance frequency of the rectangular patch antenna equals to 1.903 GHz and the returne loss S_{11} equals to -37dB by using the HFSS. The bandwidth calculated at -10dB equal to 21.4 MHz corresponds to 1.12 %. This band contains the wished frequency (1.9 GHz). The structure of the rectangular patch antenna presents a narrow bandwidth around the resonance frequency , with gain about -37dB.

By using ADS, the resonance frequency is 1.925 GHz and the returne loss S_{11} equal to -8 dB. We notice that the software HFSS is more precise than ADS, HFSS allows to get closer with the wished frequency and to obtain a maximum of gain.

We can make changes on the dimensions of the antenna, to have the effect of every parameter and the validity of the expressions quoted previously.

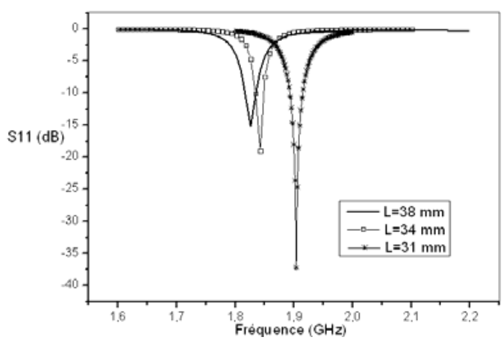

Figure 15. Variation of S_{11} according to the frequency with various values of L.

The results of the figure 15 of the various values of the length of the patch L, are represented on the table 2. For an increase from 31 mm to 38 mm, we observe a decrease of the central frequency.

Table 2. Results of simulation of the antenna

Length L (mm)	Resonance frequency (GHz)	Returne loss $\lvert S_{11}\rvert$ (dB)
38	1.82	15
34	1.84	18
31	1.9	37

The resonance frequency is inverssement proportional in the length of the patch. The variation of the frequency according to the width of the patch is shown on the figure 16.

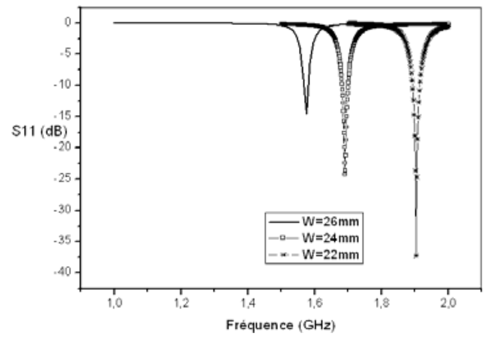

Figure 16. Variation of S_{11} according to the frequency in different Values of the width.

Table 3. Results of simulation of the antenna

Width W (mm)	Resonance frequency (GHz)	Returne loss $\lvert S_{11}\rvert$ (dB)
22	1.90	37
24	1.68	27
26	1.57	14

The resonance frequency decreases when the width W increases. Consequently, the following expression

$$W = \frac{c}{2f_{01}\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

is justified.

We diffirentiate three permittivity relative of the substrate, the Silicon ($\varepsilon_r = 11.9$), the Galium-Arsenide ($\varepsilon_r = 12.9$) and the Diamond ($\varepsilon_r = 16.5$).

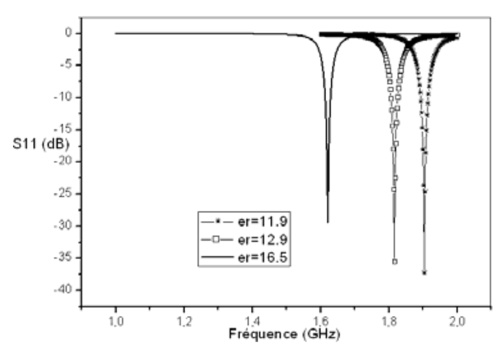

Figure 17. Variation of S_{11} according to the frequency with various values of the relative permittivity.

The resonance frequency is conversely proportional in the permittivity of the substrate (Table 4). So, the miniaturization of antennas could be assured by choosing materials in strong permittivity.

Table 4. Results of simulation

Permittivity relative ε_r	Resonance frequency (GHz)	Returne loss $\lvert S_{11} \rvert$ (dB)
16.5	1.62	29
12.9	1.82	35
11.9	1.90	37

The influence of the thickness of the substrate on the performances of the rectangular patch antenna is shown on figure 18.

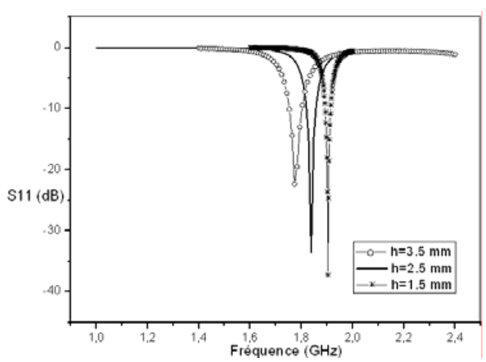

Figure 18. Variation of S_{11} according to the frequency with various values of the thickness.

The thickness of the substrate has an inverse effect on the resonance frequency. When the thickness h decreases, the resonance frequency increases.

The radiation pattern of the rectangular patch antenna with the parameters optimal of this configuration, is the following one:

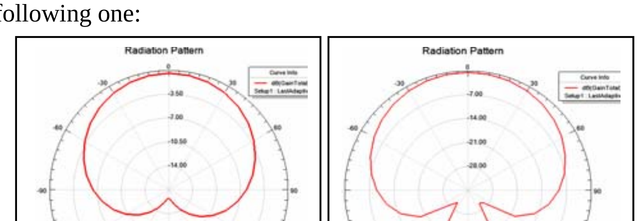

Figure 19. Radiation pattern on the planes E and H with the resonance frequency 1.9 GHz.

The performances of the rectangular patch antenna such as the resonance frequency, the gain, the radiation pattern, depend essentially in the good choices of the dimensions of the patch, the material and the thickness of the substrate and also the type of the feed. From the expressions mentioned previously, we notice that the resonance frequency depends on the width and length of the patch, as well as on the dielectric constant of substrate and its thickness. The 3D representation of the gain of the rectangular microstrip antenna is the following one:

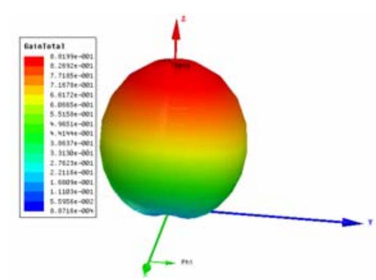

Figure 20. 3D view of radiation pattern of the rectangular patch antenna.

The 3D view of radiation pattern of the antenna shows that the antenna radiates in a single direction (according to the axis Z). So, the utility to integrate this antenna inside the mobile phone.

C. Rectangular patch antenna with aperture

The rectangular patch antenna represented previously presents a narrow band. In recent years the demand for broadband antennas has increased for use in high frequency and high speed data communication. The slot microstrip antenna allows increasing the bandwidth of the rectangular patch antenna [14]. The simulation of slotted rectangular antenna is represented using ADS-Momentum.

1) Cross slot

In cross slot microstrip antenna the two separate operation frequencies are obtained. This antenna is fed by using a single probe feed (figure 21).

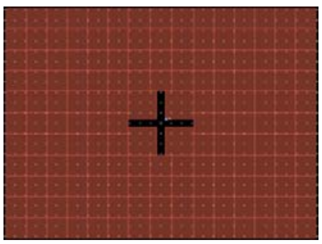

Figure 21. Layout of Cross-Slot microstrip antenna.

The result is the following one:

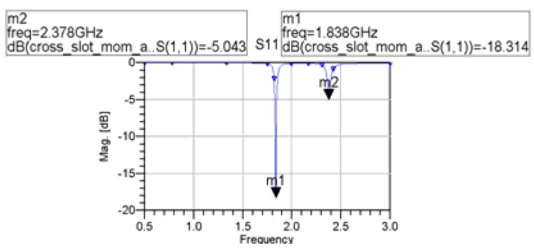

Figure 22. Plot of S_{11} of the cross-slot antenna.

We note that the existence of a slot on the patch has a considerable effect on the functioning of the rectangular microstrip antenna.

2) Square slot with stub

Considering a square slotted microstrip antenna of the square patch, as shown in fig. 23.

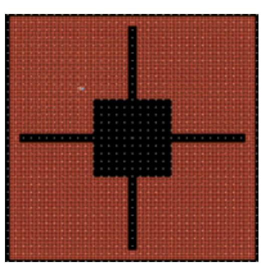

Figure 23. Layout of square slotted microstrip antenna.

The simulation result is as follows:

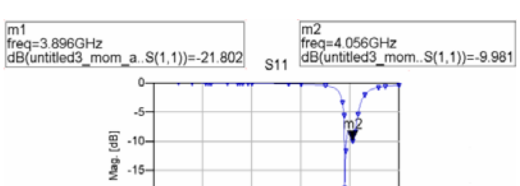

Figure 24. The square slot antenna Plot.

We notice that the gain increase by using a square slot microstrip antenna, but the bandwidth is less than the cross slotted antenna. Also, the square antenna presents a high frequency of almost 4 GHz with a return loss of -21dB.

VII. Conclusions

The study of the performances of antennas microstrips supposes the development of the conception and the simulation, which provokes a variation on the structure of this type of antenna.

The choice of the resonance frequency of the microstrip antenna depends on their dimensions of the patch, on the substrate material as well as its thickness and on the feed line. Consequently, the characteristics of the patch antenna can be adequately identified according to the application wished for a patch antenna.

The conception of antennas using the HFSS and ADS software bases essentially on the variation of the shape of the antenna, the substrate nature and thickness in order to obtain a structure which resonance frequencies wished. A small variation of each of these parameters influences the resonant frequency, as well as the coefficient of reflection, the impedance matching and voltage standing wave ratio.

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