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Reconfigurable Slot Antenna for Ku-Band Applications

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ABSTRACT

The aim of this paper is to establish a mathematical model between the integrated capacitance values on the frequency reconfigurable antenna and the achieved operating frequency. As, a frequency reconfigurable antenna is designed using HFSS software by integrating different capacitance values, to yield several resonance frequencies. The results are function of integrated capacitances which are used to set up a mathematical relationship between the capacitance values and the operating frequencies. The interpolation procedure is employed as a tool of determination for this model. The realized mathematical model allows for obtaining the desired resonance frequency by setting the integrated capacitance value.

Key words : Reconfigurable frequency antenna, Mathematical Model, Interpolation Method.

1. INTRODUCTION

With the rapid development of electronics and wireless communication, reconfigurable antennas have attracted a lot of attention. Antenna reconfiguration is defined as the capability of modifying one or more antenna parameters without perturbing the other properties. Superior characteristics such as reconfigurable capability, low cost, multipurpose functions, and size miniaturization have given reconfigurable antennas advantage to be integrated into the wireless systems [1]. Reconfigurable multiband antennas are attractive for many applications where it is desirable to have a single antenna that occupies the same real estate, but can dynamically alter its transmit and/or receive characteristics to operate at multiple frequency bands [2,3,4].

Generally, the properties of the antenna such as frequency, radiation pattern and polarization are reconfigured. Over the past two decades, intelligent solutions have been developed for one-parameter reconfiguration. Frequency agility is generally achieved by physically or electrically dimensioning the dimensions of the antenna. To design a reconfigurable device in frequency, it can be used mainly: mechanical modification of the physical dimensions, integration of microwave diodes, modification of the permittivity of the substrate [5]. In a new slot, reconfigurable frequency antenna design techniques are presented. The MEMS switch is used for its low power dissipation and low insertion loss [6], two capacitance switches are placed on the slot of the radiating element.

In the literature, several papers have proposed frequency reconfigurable antennas integrating variable capacitors without worrying about the relationship between the values of the integrated capacitances and the achieved frequencies. The goal of this paper is to build a mathematical model revealing this relationship[7].

This article consists of two principal parts. The first one is dedicated to the exposition of the design of reconfigurable antenna structure integrating capacitances and its characteristics parameters (frequency agility, reflection coefficient, bandwidth…..). The second one is devoted to show the proposed mathematical model using interpolation method giving the relationship between the integrated capacitance values and the operating frequencies.

2.ANTENNA CONFIGURATION AND DESIGN

The geometry and design parameters of the proposed antenna are shown in Figure 1. The antenna is composed of a coaxial cable, a ground plan and radiating patch element, the height rectangular slot are added to the radiating element to get the desired operating frequency band. The suggested antenna is printed on inexpensive FR4 substrate with a thickness of h=1.6 mm and a relative permittivity of $\varepsilon r = 4.4$, with the loss tangent 0.002. The geometry is then optimized using the commercial software ANSYS High Frequency Structure Simulator (HFSS). As depicted in Figure 1, the dimensions of the initial proposed antenna are: L = 12 mm, W = 12 mm, Lg = 8 mm, Wg = 8 mm, Lf1= 5 mm, Wf1=0.4

mm, Lf2 = 2.6 mm, Wf2 = 0.3 mm. In this configuration, we use a ground plane inclined with 45° to the radiation element.

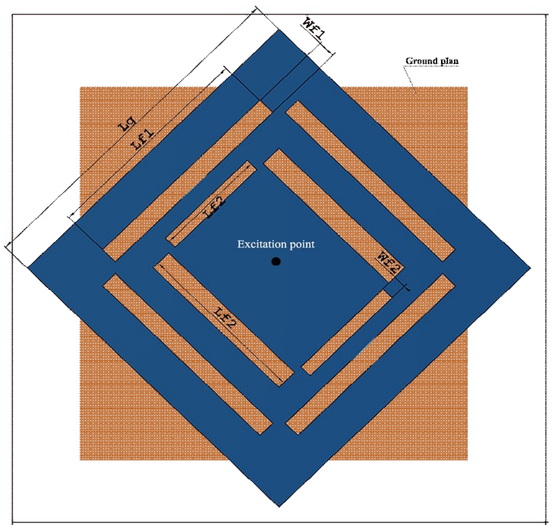

Figure 1 : Geometry of the proposed antenna structure

The antenna is excited using a coaxial cable port. This port is located under the patch center. The coaxial cable supply can be represented as a filamentary electric current, from the ground plane to the conductive plate of the antenna [8].

3.SIMULATIONS RESULTS

After implementation of the initial proposed antenna design using the (HFSS) software, the simulated reflection coefficient is extracted. Figure 2 shows the variation of (S11) as a function of frequency.

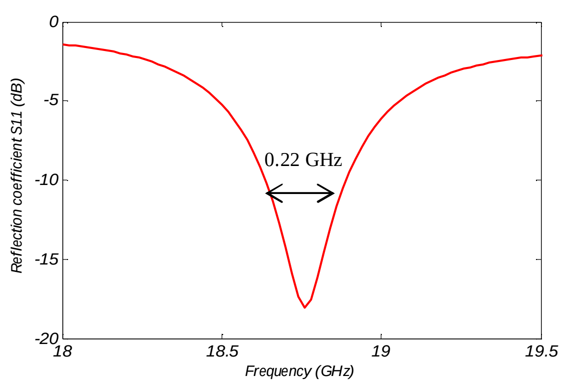

Figure 2: Simulated reflection coefficient S11 of the proposed antenna.

As illustrated in Figure 2, the simulated value of the reflection coefficient S11 parameter is (-18 dB) at the single resonance frequency of (18.77 GHz). The bandwidth at (-10 dB) is 0.22 GHz. So, the proposed antenna design can be used for the devices working at the Ku band and precisely in the sub-band 18.66 GHz– 18.88 GHz.

3.1 3D Radiation Pattern

Figure 3 shows the simulated 3 D radiation pattern of the initial antenna structure. As indicated in Figure 3, the antenna has directional radiation along the axes (ox and oy) for the resonance frequency (18.77 GHz).

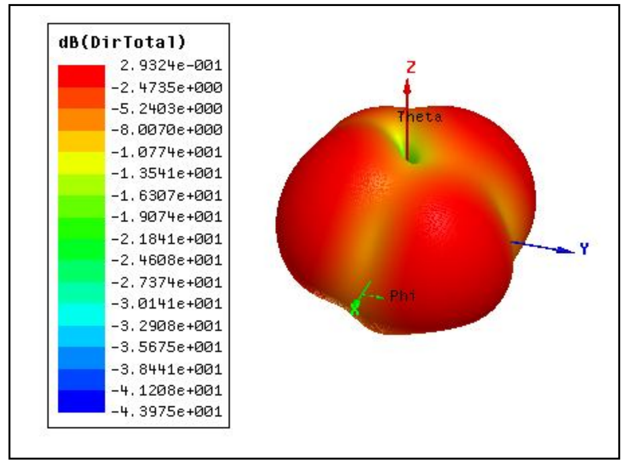

Figure 3: Simulated 3D radiation pattern at F = 18.77 GHz

3.2 Distribution of simulated surface currents

The study of the distribution of surface currents is important to identify areas of influence where the concentration of currents is highest. This study allows us to determine the locations for the integration of the active elements used, in order to redistribute the flow of the currents and thus control the frequencies of resonance.

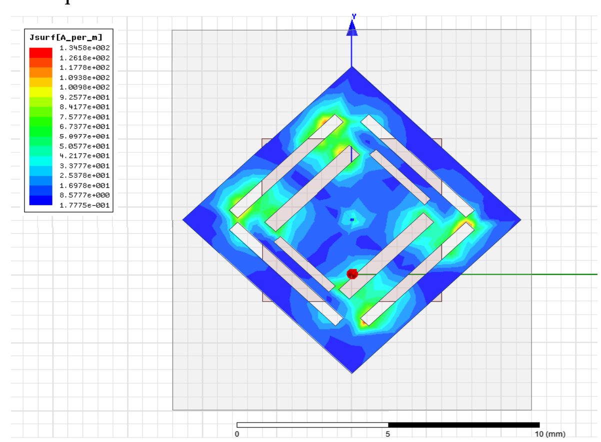

Figure 4 : Current distribution of the antenna at resonance frequency (18.77 GHz)

In Figure 4, the antenna surface current distribution indicates that the majority of the surface current distributions are asymmetrical. The distribution of surface currents is stronger at the edge of the slots which will allow to locate the locations of integration of our capacitors.

The current distribution on the 18.77 GHz antenna is illustrated in Figure 4. As previously stated, the positions of the capacitors are selected according to the current distributions. Depending on the desired frequency bands, different locations for each capacitor are tested and the best locations are selected. The current distribution on the surface of the antenna determines the radiation characteristics of the antenna. Capacitors are located where the current distribution decreases to have the most influence on the performance of the antenna. By placing the capacitors in different places, the current distribution changes, resulting in a new electrical length and a new resonance frequency band [9].

4.RECONFIGURABLE FREQUENCY ANTENNA

In this study, we will study the antenna behaviors during the insertion of variable capacitors at the ends of the slots (Figure 5). Firstly, when the two capacitors are identical, for this case we deduce the relation between the resonance frequency and the capacitance. We integrate different values of capacities and extract the relation capacity frequency. The simulation was carried out using Ansoft HFSS simulation software for the different capacities values and one also uses Matlab software to make the interpolation by the least square method of the obtained results.

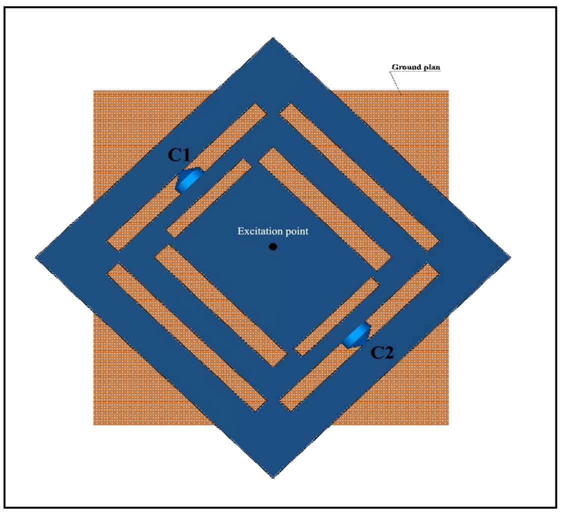

Figure 5: Proposed reconfigurable antenna with two capacitors

4.1 Antenna with equivalent capacities (C1=C2)

To simulate the capacitors in HFSS we use the equivalent geometric form. Two capacitors are inserted at the radiation element slots. The positions are the two horizontal rectangles of dimensions (0.4 × 2) mm^2 assign boundary RLC, as shown in the figure 5 [10]. In order to show the frequencies obtained using the proposed antenna structure, the S11 diagrams as a function of the frequency for different values of the capacities.

A. Simulations results

In the following case one worked on identical capacitors, which are inserted at exact positions, the dissolved figure shows the variation of the reflection coefficient for different capacities values. The integration of a capacitor allowed to control the frequency of resonance and to thus produce agility in frequency.

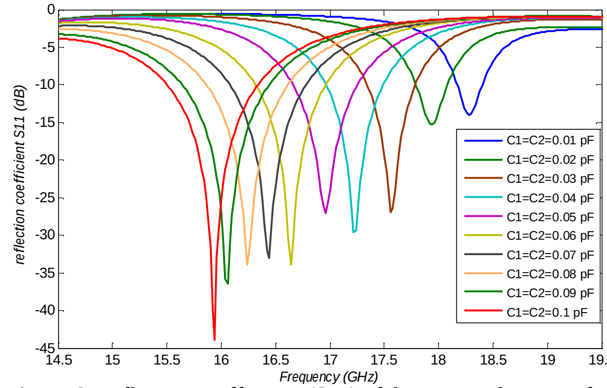

Figure 6: Reflection coefficients (S11) of the proposed antenna for different capacities value of capacitors.

Figure 6 shows the variation of the resonance frequency as a function of the capacities values. The integration of said capacitors allowed the frequency to be shifted to the desired band. As the figure above clearly shows, more than the capacities values increases the resonance frequency decreases with greater Reflection coefficient, it is clear by increasing the values of the capacities the frequency band shifts to the left. The resonance frequency varies between 15.94 GHz and 18.28 GHz (Ku band) and the capacities values of the two capacitors vary between 0.01pF and 0.1pF. The simulated bandwidths vary from 220 MHz to 0.82 GHz with a reflection coefficient of up to -44dB.

The results of the simulation of the reflection coefficient S11 are shown in the figure above. Good agreement can be observed between resonance frequency and capacities values. Indeed, the resonant frequency is shifted with respect to the resonance frequency of the base antenna following the insertion of the capacitors in the slots, as we had already predicted.

Table 1: The variation of the resonance frequency for different values of the capacities.

Capacity (C1=C2) value (pF)	Resonance Frequency (GHz)	Reflection coefficientS11(dB)	Bandwidth (GHz)
0.01	18.28	-13.92	0.22
0.02	17.94	-15.17	0.28
0.03	17.56	-26.90	0.46
0.04	17.24	-29.98	0.50
0.05	16.96	-27.71	0.58
0.06	16.64	-33.06	0.66
0.07	16.44	-32.50	0.72
0.08	16.24	-33.87	0.72
0.09	16.06	-34.52	0.81
0.1	15.94	-49.23	0.82

The table 1 displays the different frequencies obtained according to the integrated capacities values. The interpolation function can be used with the interpolation software (Matlab) to obtain the variation of the resonance frequency according to the capacities inserted in the level of the slots [11].

When a capacity variation (from 0.01 to 0.1pF), the simulated frequency varies from 15.94 to 18.28 GHz. The simulated resonant frequency shifts down to low frequencies.

B. Interpolation results

By using MATLAB to interpolate our result we apply the least square method as shown in the figure below:

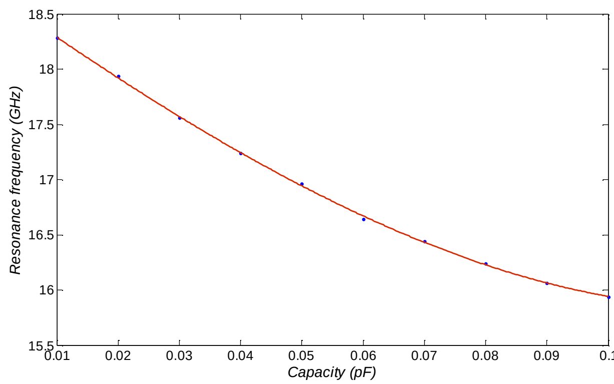

Figure 7: Variation of resonance frequency according to the capacity

Interpolation is a technique for adding new data points in a range of a set of known data points (Figure 7). We can use interpolation to supplement missing data, smooth existing data, make predictions, and more [12], to show the effect of frequency variation, we plotted the capacitance curves as a function of the resonance frequency (Figure 7). In this scenario, we assume that both capacities are identical. The variable capacitance values have an impact as a parasitic element of the equivalent circuit on the performances of the resonance frequency.
Resulting from the system of linear equations obtained by the application of the least squares method on the above measurements (table 1), we obtain the equation of the straight line above which approaches the simulated data better :

$$F = p_1 C^3 + p_2 C^2 + p_3 C + p_4 \qquad (1)$$

Coefficients:
p1 = 559.44
p2 = 62.238
p3 = -39.131
p4 = 18.673
F= resonance frequency and C= capacity

The correlation coefficient = -0.989 ≈ -1**,** There is a strong linear correlation between simulate and interpolate data.
For our antenna we can use the interpolation to know the values of the capacity at known resonance frequency belongs to the interval (15.94 GHz and 18.28 GHz) it shows the reconfigurability of the proposed antenna, therefore it is possible to deduce graphically the resonance frequency or adjust the capacitances to the desired frequency by modifying C1 and C2.

4.2 Antenna with different capacitors (C1≠C2)

In view of the current development of telecommunication systems, it has become necessary to develop millimeter antennas structures that can be adapted to the size or performance level if necessary. With the help of the two simulation software programs HFSS and CST, we will study in this part the case of different capacities to study the evolution of the resonance frequency according to C1 and C2 capacities by integrating the equivalent geometric assigned boundary (RLC). In our case we will use different values between 0.01 pF and 0.1 pF for each capacity concluding the effect of each combination at the resonance frequency [13].

4.2.1 Simulation results

From Figure 8, we can observe a reconfiguration of the frequency result by inserting two capacitors in the rectangular slot of the resonant element; the antenna can create an upper-frequency bandwidth than obtained in figure 3 the resonant frequency can be tuned continuously from 15.94 to 18.28 GHz. So, we can adjust our antenna to obtain any resonance frequency belongs to the frequency band cited above.

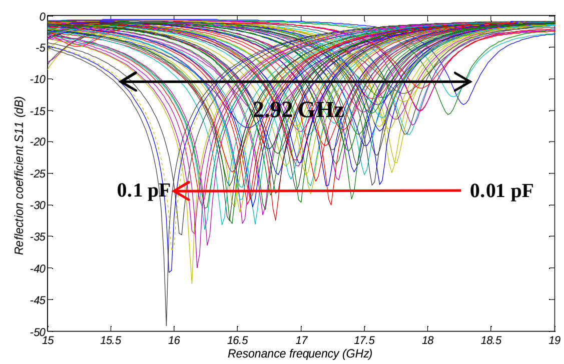

Figure 8: Frequency Agility: Antenna with low bandwidth, more bandwidth thanks to a technique of agility

Figure 8 and 3 show the difference between a standard antenna and antenna with capacitors. In figure 3, the miniaturized antenna has a low bandwidth, defined by a reflection coefficient approximately equal to -20 dB. In figure 8, by integrating capacitances at the slots, the resonance frequency of the antenna is shifted to cover the very wide frequency bands. The bandwidth of the antenna remains rather narrow, the overall bandwidth obtained by switching is much larger, and can cover the desired spectrum with reflection coefficients almost equal to -50 dB.

4.2.2 Comparison

To have the reliability of our simulated results. We compared them with measured and simulated results of published data.

Table 2: Comparison of proposed antenna with already reported antennas.

	Simulated			Measured		
Antenna mode	**Bandwidth (GHz)**	**Resonance Frequency (Ghz)**	**|S11| (dB)**	**Bandwidth (GHz)**	**Resonance Frequency (Ghz)**	**|S11| (dB)**
Antenna [2]	0.7	10.15	35	0.6	10.17	20
Antenna [3]	0.5	9.2	20	0.3	9.2	14
Antenna [4]	1.1	13	20.9	0.8	11.3	18.2
Antenna in this work	2.92	15.94 to 18.28	12 to 50	-	-	-

According to the table 2 dissuaded shows that the results obtained in measurement for different antenna mode are very satisfactory and acceptable. On the other hand, the frequency shift of a few MHz compared to the simulation is due to small manufacturing errors.

Table 2 gives performance comparison of proposed antenna with some other of antennas in [2- 4]. It is observed that the proposed antenna presents a good bandwidth characteristic and achieves better reflection coefficients characteristics in the operating band. The operating frequency of the proposed antenna can be tuned easily.

4.2.3 2D radiation pattern

To evaluate the diode integration effect on the 2D radiation patterns, the simulated E-Plan and H-Plan radiation patterns after the integration of capacities in the proposed antenna are presented in Figure 9 [14] .

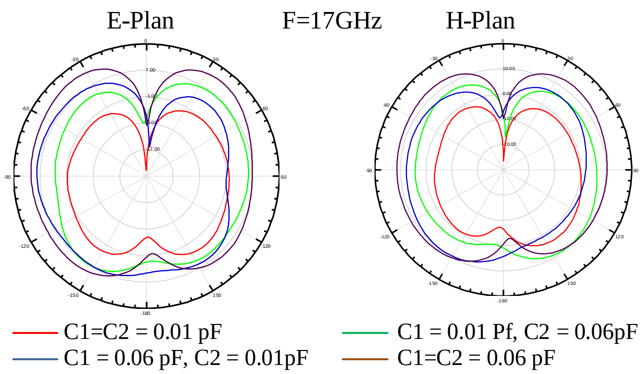

Figure 9 : Simulated 2D radiation pattern at resonant frequency of the proposed antenna

According to Figure 10, the 2D radiation patterns on E-Plan (φ = 0) and H-Plan (θ = 90°) of the proposed antenna structure with capacities have a toroidal appearance, with quasi-omnidirectional radiation. The maximum gain is 7 dBi for E-Plan and 10 dBi for H-Plan. When inserting the capacities, we observe a slight alteration of the radiation pattern. This change is accompanied by an increase in the gain values [15].

4.2.4 Interpolation

After the simulation with different value of capacities and the using of interpolation method of t results obtained, we have defied a mathematical model, which makes it possible to determine the value corresponds of the resonance frequency desired

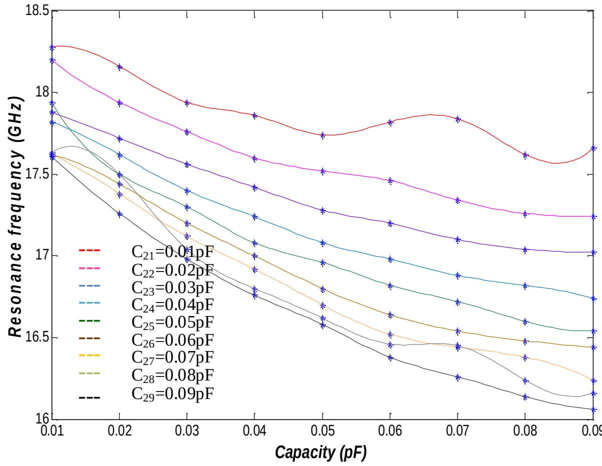

Figure 10: Variation of resonance frequency according to the capacity

By using the mathematical model, the figure above shows the variation of the resonance frequency according to the capacitances inserted in the slots, by the projection on one of the axes we obtain the corresponding value of capacity or resonance frequency, The use of different capacitance values makes it possible to study its effect on the variation of the resonance frequency.

For our work is complete, we worked on a general model that allows us to determine the resonant frequency according to the capacitances value integrated at the resonance element. Our model is valid for capacitance values range from 0.01 to 0.09 pF and operating frequencies (15.94 to 18.28 GHz)

By the use of a mathematical model is to choose the curve whose sum of squares deviations between given points and the right is as small as possible. The general model is:

$$F = \alpha + ((\beta * \exp(-65{,}7 * C_i))/(100 * C_i)) \quad (2)$$

With **0.01pF ≤ Ci ≤ 0.09pF**

F= resonance frequency and C= capacity

Table 3: The values of the coefficients corresponding to capacities values

C(pF)	0.01	0.02	0.03	0.04	0.05	0.6	0.07	0.08	0.09
α	17.66	17.24	17.02	16.74	16.54	16.4	16.24	16.16	16.06
β	1.2	1.9	1.7	2.2	2.6	2.67	2.7	2.85	3

We have shown that the introduction of slit capacitance on our antenna structure implies a displacement of the resonance frequency in a very wide frequency band with reflection coefficients of up to -50 dB.

5.CONCLUSION

This work presented an analysis of the frequency reconfigurable slot antenna for multistandard telecommunications systems was designed and studied. The proposed antenna structure achieves the desired frequency agility by integrating two capacities on the rectangular slots which have been etched on the radiating element; the frequency shifting allows a powerful sweep of the [1.65 - 2.45] GHz band. The mathematical model used helps users to define the values of the capacities to be integrated according to the desired frequency band. This study presents that simulated results of our proposed antenna will be completed in the next works by a comparison between simulated and experimental results when we realize the proposed structure.

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