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Design of Slot Antenna based on Ansoft HFSS Software

Mohanad Abdulhamid
AL-Hikma University, https://hiuc.edu.iq/
P.O. Box 20468-11345, Baghdad, Iraq
E-mail: moh1hamid@yahoo.com

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Abstract: **A micro-strip fed slot antenna array for application in the 2.4 GHz industrial, scientific and medical (ISM) band is implemented using the Ansoft HFSS software. Standard formulas are used to calculate different antenna parameters. The proposed antenna is designed to work at 2.4 GHz frequency band. A half power beam width (HPBW) of 57°. A bandwidth of around 7.7% is attained. This may have been brought about by poor impedance matching and a high level of surface waves. A way of improving the bandwidth would have been to use proximity coupling feeding method which offers the highest bandwidth and is somewhat easy to model and has low spurious radiation. However, its fabrication would have been more difficult. A directivity of 2.01 dB is achieved. This is a fairly high though directivity increase could have been studied through use of different substrate material and thickness. Adjusting length and width of narrow slot loop antenna will influence on the resonance frequency and bandwidth. By using HFSS software, the characteristics of antenna are investigated and analyzed, including voltage standing wave ratio(VSWR), return loss and far field radiation patterns.**

Keywords: **MIMO, spatial multiplexing, algebraic codes, precoding, Golden code, maximum likelihood, ML, MMSE**

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CONTENTS

1. INTRODUCTION

An antenna is generally a bidirectional device, that is, the power through the antenna can flow in both directions, coupling electromagnetic energy from the transmitter to free space and from free space to the receiver, and hence it works as a transmitting as well as a receiving device, that is, by reciprocity. Transmission lines are used to transfer electromagnetic energy from one point to another within a circuit and this mode of energy transfer is generally known as guided wave propagation. An antenna can be thought of as a mode transformer which transforms a guided-wave field distribution into a radiated-wave field distribution.

A slot antenna consists of a metal surface, usually a flat plate, with a hole or slot cut out. When the plate is driven as an antenna by a driving frequency, the slot radiates electromagnetic waves in a way similar to a dipole antenna. The shape and size of the slot, as well as the driving frequency, determine the radiation distribution pattern. A slot antenna's main advantages are its size, design simplicity, robustness, mechanically robust when mounted on rigid surfaces, compatible with monolithic microwave integrated circuit (MMIC) designs and convenient adaptation to mass production using PC board technology. Unique features of these antennas are horizontal polarization and omnidirectional gain around the azimuth. Slot antennas exhibit wider bandwidth which is approximately 10-20%, lower dispersion and lower radiation loss compared to micro-strip antennas. The slot antennas can be fed by micro-strip line, slot line or Coplanar Waveguide (CPW). In this paper, the design of slot antenna is fed by micro-strip line.

In a conventional micro-strip line-fed slot antenna, a narrow rectangular slot is cut in the ground plane and the slot is excited by a micro-strip feed line with a short or an open termination. With this feed configuration, a good impedance match has been achieved with a narrow slot, and a bandwidth of approximately 7.7% has been obtained. However, as the width of the slot increases, the radiation resistance of the slot antenna also increases proportionately. This, in turn, reduces the impedance bandwidth of the antenna, even though the size of the slot is larger. There is a possibility of increasing the bandwidth of a wide slot antenna by terminating the open end of the feed line within the width of the slot, although substantial bandwidth improvement has not been achieved. The conventional feeding structures of conventional transverse slot antennas are center feeding and offset feeding. The center feed has a larger value of radiation impedance than an offset feed. It means that the bandwidth of a center feed antenna is less than for an offset fed antenna. Some works discuss the design of slot antenna can be found in [1-6].

2. DESIGN METHODOLOGY

A rectangular slot is chosen as the basis of the design because of its ease of fabrication and analysis. The micro-strip line is used as the feeding method as it is easy to fabricate, simple to match by controlling the inset feed position and rather simple to model. The antenna is designed to work in the 2.4 GHz ISM band which has a frequency range of 2.5-2.6 GHz, a center frequency of 2.58 GHz, and a bandwidth of 100 MHz.

2.1. Design Procedure

The Flame Retardant (FR4) Glass Epoxy, whose loss tangent is 0.002, is chosen as the dielectric material substrate.

To commence the design procedure assumes, specific information had to be included: dielectric constant of the substrate ε_r, the resonant frequency f_r and the height of the substrate, h.

$\varepsilon_r = 4.3$, $f_r = 2.4$ GHz, $h = 1.6$ mm.

For an efficient radiator, the practical width that leads to good radiation efficiencies is

$$W = 0.1\,\lambda_g = 7 \text{ mm}, \tag{1}$$

where λ_g is the dielectric wavelength.

The initial values (at low frequencies) of the effective dielectric constant are referred to as the static values, and they are calculated as

$W / h > 2$,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} = 3.27. \tag{2}$$

The actual length of the slot is determined by solving L as,

$$L = 0.5\,\lambda_g = 35 \text{ mm}. \tag{3}$$

For efficient transfer of power from a transmission line to the slot antenna, the input impedance of the slot antenna needed to be matched to the characteristic impedance of the transmission line. It is observed that impedance seen by a transmission line attached to the radiating edge increased as one moved towards the center of the slot. Therefore, depending on the characteristic impedance of the transmission line, an appropriate point on the slot is chosen through calculation as the feed point. An off-the center feed is used with distance from the edge calculated as:

$$0.05\,\lambda_g = 3.5 \text{ mm}. \tag{4}$$

2.2. Ground Plane

As part of the antenna, the ground plane should be infinite in size as for slot antenna but in reality this is not easy to apply besides a small size of ground plane is desired. In practice, it has been found that the micro-strip impedance with finite ground plane width is practically equal to the impedance value with infinite width ground plane, if the ground width > $3W$. The size of the ground plane is chosen as 100 mm length by 97.5 mm width.

2.3. Microstrip Discontinuities

Surface waves are electromagnetic waves that propagate on the dielectric interface layer of the microstrip. The propagation modes of surface waves are practically transverse electric (TE) and transverse magnetic (TM). Surface waves are generally at any discontinuity of the microstrip. Once generated, they travel and radiate, coupling with other microstrip of the circuit, decreasing isolation between different networks and signal attenuation. Surface waves are a cause of crosstalk, coupling, and attenuation in a multi-microstrip circuit. For this reason surface waves are always an undesired phenomenon.

A discontinuity in a microstrip is caused by an abrupt change in geometry of the strip conductor, and electric and magnetic field distributions are modified near the discontinuity. The altered electric field distribution gives rise to a change in capacitance, and the changed magnetic field distribution to a change in inductance.

2.4. Micro-strip feed and distance between elements

For the 2-element array of **Fig. 1** to implement an even number of in-phase slot elements, the feed network needed to be carefully designed. The distance from the 50-ohm Sub-Miniature version A (SMA) source to each slot element needed to be identical or multiples of λ. Unequal line lengths would have produced phase shifts, which would yield fixed beams that would be scanned away from the broadside. The 50-ohm micro-strip line is fed using a 50-ohm SMA. In the design of an effective in-phase radiator, the distance between the slot elements needed to be optimized to yield a peak gain. A separation distance of $\lambda/2$ as providing the optimal gain. In the design, this separation is used as 35 mm.

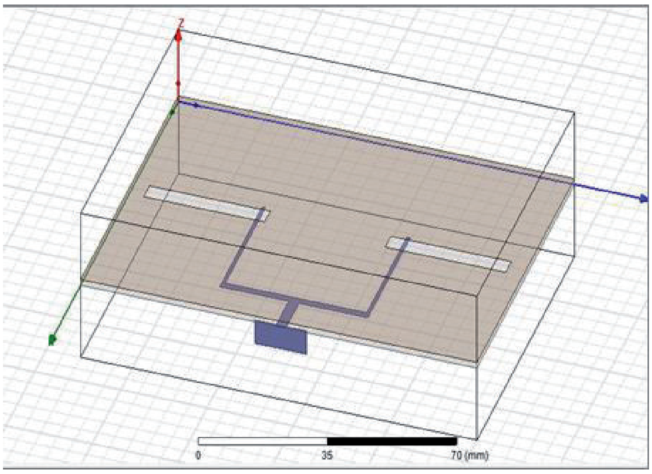


Fig. 1. *2-element slot antenna HFSS model.*

2.5. Matching Microstrip Lines to Source

The characteristic impedance of a transmission line of the micro-strip feed was designed with respect to the source impedance. The characteristic impedance of the transmission line from the source with respect to the source impedance was

$$Z_0 = Z_s,\ Z_0 = 50 \text{ ohms}. \tag{5}$$

2.6. Quarter-Wave Transformer

For the input impedance of a transmission line of length L with a characteristic impedance Z_0 and connected to a load with impedance Z_A:

$$Z_{in}(-L) = Z_o\left[\frac{Z_A + jZ_o\tan(\beta L)}{Z_o + jZ_A\tan(\beta L)}\right], \tag{6}$$

When the length of the transformer is a quarter wavelength

$$Z_{in}\left(L = \frac{\lambda}{4}\right) = \frac{Z_o^2}{Z_A}. \tag{7}$$

Hence by using a transmission line with a characteristic impedance of 50-ohms, the 50 ohm inset feed line is matched to

$$Z_0 = \sqrt{50\cdot 50} = 50\ ohms,$$

where Z_0 = characteristic impedance of the quarter-wavelength transformer.

This ensured that no power would be reflected back to the SMA feed point as it tried to deliver power to the antenna.

The length of the quarter wavelength transformer is calculated as

$$L = \lambda_g/4 = 17.5 \text{ mm}. \quad (8)$$

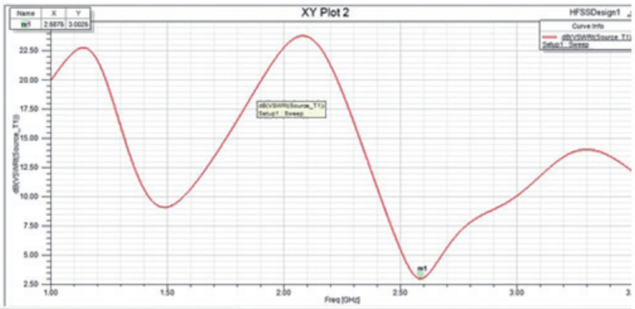
2.7. SIMULATION

The antenna array is designed using the Ansoft HFSS 13.0 software. HFSS is a 3*D* full wave electromagnetic field simulator. HFSS uses a numerical technique called the Finite Element Method (FEM). This is a procedure where a structure is subdivided into many smaller subsections called finite elements. The finite elements used by HFSS are tetrahedra, and the entire collection of tetrahedra is called a mesh. A solution is found for the fields within the finite elements, and these fields are interrelated so that Maxwell's equations are satisfied across inter-element boundaries yielding a field solution for the entire, original, structure. Once the field solution has been found, the generalized S-matrix solution is determined. It can calculate and plot both the near and far field radiation and compute important antenna parameters such as gain and radiation efficiency. This software is used to vary the sizes of the slot. Fig. 1 illustrates the 2-element slot antenna HFSS model.

3. HFSS SIMULATION RESULTS AND ANALYSIS

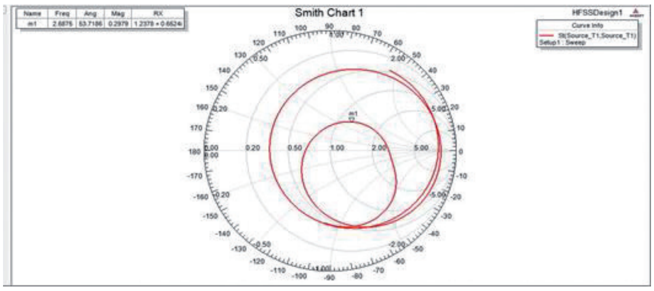
3.1. VSWR PLOT

Fig. 2 shows the VSWR plot for the designed antenna. The value of the VSWR should lie between 1 and 2. VSWR is used as an efficiency measure for transmission lines, electrical cables that conduct radio frequency signals, used for purposes such as connecting radio transmitters and receivers with their antennas.



Name	X	Y
m1	2.6875	3.0026

Fig. 2. *VSWR Plot.*



Name	Freq	Ang	Mag	RX
m1	2.6875	53.7186	0.2979	1.2378 + 0.6524i

Fig. 3. *Smith Chart for the slot antenna array.*

3.2. SMITH CHART

The smith chart is a graphical representation of the normalized characteristic impedance. It provides the information about the impedance match of the radiating slot. The smith chart for the designed slot antenna array shown in **Fig. 3**, shows an input impedance of 50.78 + 10.5*i* ohms at resonant frequency 2.58 GHz. The magnitude of the input impedance is 51.85 which showed that accurate matching is not achieved. This is due to shifting of the inset feed position away from the edge of the ground plane.

3.3. REFLECTION COEFFICIENT AND BANDWIDTH

Fig. 4 shows the reflection coefficient [S11] of the proposed antenna in dB. S11 gives the reflection coefficient at the inset feed position where the input to the micro-strip slot antenna is applied. It should be less than –10 dB for an acceptable operation. It shows that the

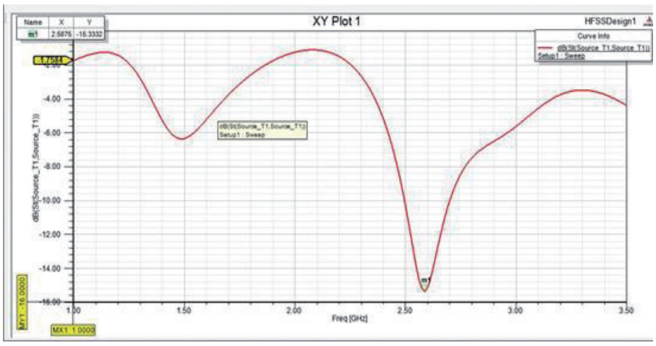


Fig. 4. *Return loss S11 obtained for the slot antenna array.*

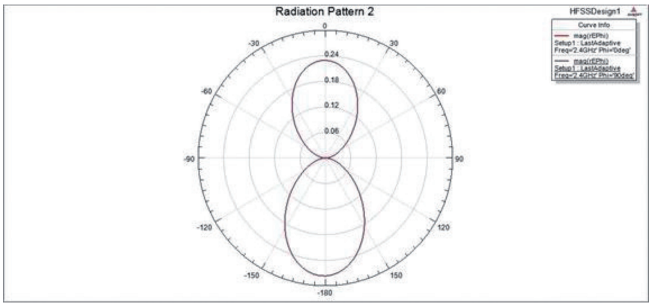


Fig. 5. *Radiation pattern of E-total at 2.58 GHz xz plane (Φ = 0°).*

proposed antenna had a frequency of resonance of 2.58 GHz.

The simulated impedance bandwidth of about 200 MHz (2.5022-2.7023 GHz) is achieved at −10 dB reflection coefficient (VSWR ≤ 2). The reflection coefficient value that is achieved at this resonant frequency was equal to –15.33 dB. This reflection coefficient value suggested that there is good matching at the frequency point below the –10 dB region.

3.4. VARIATION OF SLOT LENGTH AND WIDTH

Dimensions calculated in the design procedure are used to create a 2-element slot antenna array. In order to shift the S11 minima towards the desired center frequency, the length and width of the slot are varied.

At designed frequency of 2.58 GHz, the width of slot antenna is varied in five values beginning from 5.0 mm to 7.0 mm by step up 0.5 mm, and length is adjusted for match impedance. The simulation results of return loss S11, resonance frequency and bandwidth are tabulated in **Table 1**. It shows that the changing in width of slot antenna will affect the resonance frequency. When the width of slot is increased, the resonance frequency will decrease and bandwidth is wider. Therefore, if we increase the width of slot, the length of slot should be decreased in order to achieve the same resonance frequency and wider bandwidth.

Table 1
Simulation results of slot antenna by adjusting width

Width, mm	Resonance frequency, GHz	Return loss S11, dB	Bandwidth, MHz
5.0	2.71	-10.5	165
5.5	2.68	-14.9	173
6.0	2.64	-25.5	188
6.5	2.62	-18.74	195
7.0	2.58	-15.33	200

3.5. RADIATION PATTERN

The radiation patterns in the E-plane, Φ = 0° and Φ = 90° are shown in **Fig. 5** and **Fig. 6**, respectively.

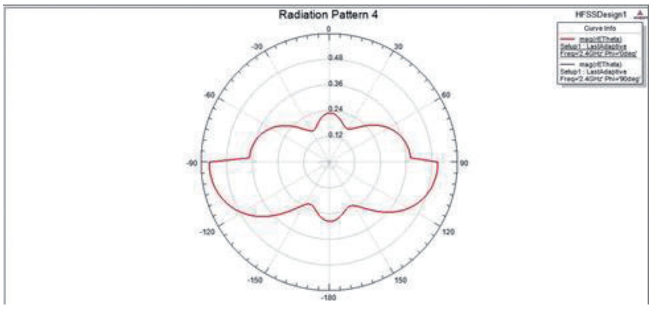
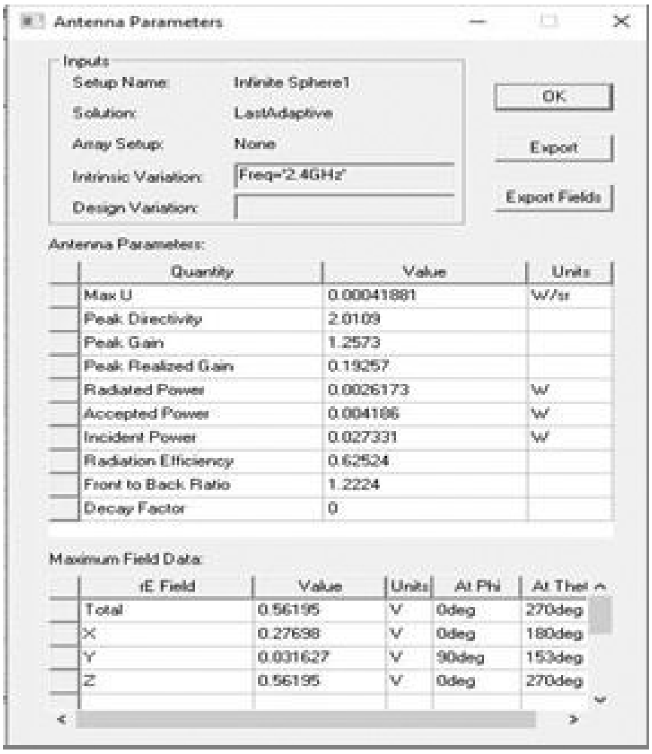


Fig. 6 *Radiation pattern of E-total at 2.58 GHz yz plane (Φ = 90°).*

Table 2

Summary of antenna parameters



Inputs

Setup Name:	Infinite Sphere1
Solution:	LastAdaptive
Array Setup:	None
Intrinsic Variation:	Freq='2.4GHz'
Design Variation:	

Antenna Parameters:

Quantity	Value	Units
Max U	0.00041881	W/sr
Peak Directivity	2.0109	
Peak Gain	1.2573	
Peak Realized Gain	0.19257	
Radiated Power	0.0026173	W
Accepted Power	0.004186	W
Incident Power	0.027331	W
Radiation Efficiency	0.62524	
Front to Back Ratio	1.2224	
Decay Factor	0	

Maximum Field Data:

rE Field	Value	Units	At Phi	At Thet
Total	0.56195	V	0deg	270deg
X	0.27698	V	0deg	180deg
Y	0.031627	V	90deg	153deg
Z	0.56195	V	0deg	270deg

3.6. Other antenna parameters

Table 2 shows a summary of the antenna parameters from the HFSS software. The directivity and efficiency are 2.0109 and 62.5%, which gave a gain of the antenna as 1.25. The front to back ratio is 1.2224.

The **Fig. 7** shows E-plane and H-plane from which the antenna has two main lobes which were 180° out of phase with each other. It is used to determine the half-power beam widths for the radiation patterns as the peaks and 3 dB points below them could easily be picked.

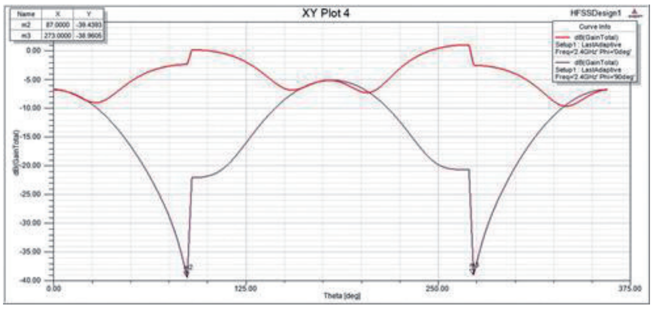


Fig. 7. *E-Plane and H-Plane patterns in rectangular coordinates.*

4. CONCLUSION

A modified slot antenna fed by a 50 Ω micro-strip line was presented in the paper. In addition, the size of the implemented antenna array can be increased. Moreover, the two rectangular slots are embedded on the ground plan to increase antenna gain. With optimized antenna geometry, the implemented antenna offers a bandwidth of 7.7%. By properly calculating slot dimensions and tuning the dimension parameters with simulation software, improvements can be made on the gain, bandwidth and radiation pattern. The implemented antenna is feasible for use as a low profile, low cost antenna for wireless applications in the ISM band.

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