Study of Microstrip Feed Line Patch Antenna

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Abstract

This paper contains design microstrip patch antenna with feed line connector. The antenna is mainly intended to be used for reception of a signal transmitted from an unmanned aircraft, and can be used in many applications in communication systems such as satellite technology and military applications.

A microstrip feed line patch antenna is designed for 2.5GHz center frequency have successfully been built. Measurement show that the half power beam width (HPBW) is 60^o with VSWR lower than 1.5, and return losses equal to -33.6dB at center frequency. Next, the results of microstrip feed line patch antenna is designed by using CAD (Microwave office 2000 version 3.22). Finally, the results obtained from the simulations are demonstrated.

Keywords: Microstrip feed line patch antenna, half power beam width (HPBW), voltage standing wave ratio (VSWR), and return losses.

دراسة لهوائي رقعة الشريحة الدقيقة بخط تغذية

الخلاصة

هذا البحث يتضمن تصميم هوائي رقعة الشريحة الدقيقة بوجود خط توصيل مغذي. الهوائي معد ليستعمل لاستقبال الاشارة المرسلة من طائرة مسيرة بدون طيار وتستعمل في عدة تطبيقات في انظمة الاتصالات مثل تكنولوجيا الاقمار الصناعية والتطبيقات العسكرية.

هوائي الشريحة الدقيقة بوجود خط النقل صمم على 2.5 كيكاهيرتز كتردد وسيط وهو بناء ناجح. القياس يبين عرض الحزمة لمنتصف القدرة هو 60^o، نسبة فولتية الموجة الواقفة (VSWR) اقل من 1.5 ، وخسائر الارتداد مساوية الى 33.6dB- عند التردد الوسيط. وبالتالي، نتائج هوائي الشريحة الدقيقة ذو خط التغذية صمم باستخدام برنامج حاسوبي تصميمي (المايكروويف اوفس). واخيرا، النتائج المستحصلة من المحاكاة تم عرضها.

Notations

Symbol	Meanning	Symbol	Meanning
AR	Axial Ratio	L_{eff}	Effective Length
CAD	Computer Aided Design	L_f, L_g	feed Line Length, Ground Plane Length
c	Speed of Light (3. 10^8 m/s)	mm	millimeter
dB	decibel	Q	Quality factor
ε_r, ε_{reff}	Relative Permittivity, Effective Relative Permittivity	S-Band	Band of Frequencies (2 - 4)GHz
f_0	Resonant Frequency	s	Thickness of Gap
GHz	Giga Hertz (10^9 Hz)	VSWR	Voltage Standing Wave Ratio
h	Height of Dielectric Substrate	W	Width of the Patch Element
HPBW	Half Power Beamwidth	W_f, W_g	Feed Line Width, Ground Plane Width
L	Actual length	ΔL	Length Extension

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Introduction

The transmitting antenna used to radiate electromagnetic waves into free space. The power is supplied by a feeder which is often a length of transmission line or waveguide having that is characteristic impedance. One can regard an antenna as a kind of transducer to turn generated electrical energy into radiating energy. Antennas are also used in receiver to collect radiation from free space and deliver the energy contained in the propagating to the feeder and receiver.

There are many types of antennas used in sensitive applications such as radar, mobile [1, 2]. One of these is microstrip or patch antennas these are becoming increasingly popular for microwave application as they are small and easily fabricated. An area (almost any shape is possible) of conductor is excited on the surface of a dielectric substrate having a backplane conductor. The excitation can be by means of microstrip transmission line.

Different feeding techniques and polarization types have been introduced in [3]. This report then covers the results from the design of a rectangular broadband antenna, a triangular broadband antenna and results from a comparison between these two designs and a commercial antenna.

A novel method to develop broadband microstrip (patch) antennas using substrates containing photonic crystals has been investigated in [4]. In addition, it is also proposed that the behavior of the photonic crystals will lead to a reduction in pattern sidelobes resulting in improvements in radiation pattern front-to-back ratio and overall antenna efficiency.

A feasibility study on optically transparent patch antennas with microstrip line and probe feeds has been presented in [5]. The two antennas operate at 2.3GHz and 19.5GHz respectively. They are constructed from a thin sheet of clear polyester with an AgHT-8 optically transparent conductive coating.

In this paper a design of a microstrip patch antenna with feed line connector for use in military applications has been presented. It is supposed that the presented antenna will operate at resonant frequency of 2.5GHz with a band of 400MHz.

Three essential parameters for design of a feed line microstrip Patch Antenna are;

First, the resonant frequency (fo) of the antenna must be selected appropriately. The frequency range is used from (2.3-2.7) GHz. Hence the antenna design must be able to operate in this frequency range. The resonant frequency selected for this design is 2.5GHz with band width 400MHz.

Second, the dielectric material of the substrate (εr) selected for this design is RT- Duroid 5880 which has a dielectric constant of 2.2 and loss tangent equal to 0.0009. The dielectric constant of the substrate material is an important design parameter. Low dielectric constant is used in the prototype design because it gives better efficiency and higher bandwidth, and lower quality factor Q. The low value of dielectric constant increases the fringing field at the patch periphery and thus increases the radiated power. The proposed design has patch size independent of dielectric constant. So the way of reduction of patch size using higher dielectric constant. Therefore, substrates with dielectric constant less than 2.5 can be preferred in the proposed dual band antenna. A small value of loss tangent is always preferable in order to reduce dielectric loss. RT/Duroid 5880 is good in this regard. The small loss tangent was neglected in the simulation. Substrate thickness is another important design parameter. Thick substrate increases the fringing field at the patch periphery like low dielectric constant and thus increases the radiated power. It also

gives lower Q and so higher bandwidth [6].
Third, the height of dielectric substrate (h) of the microstrip patch antenna with feed line to be used in S-band range frequencies. Hence, the height of dielectric substrate using in this design of antenna is h= 1.44mm.
Theoretical analysis and calculations
From figure (1) all dimensions will be obtained;
The width of the patch element (W) is given by [7]:

$$W \approx \frac{c}{2 f_o \sqrt{\frac{(e_r + 1)}{2}}} \quad ..... (1)$$

Substituting c = 3x108 m/s, ε r = 2.2 and f o = 2.5 GHz, then W ≈ 47.4mm.

The effective of the dielectric constant (εreff) depending on the same geometry (W, h) but is surrounded by a homogeneous dielectric of effective permittivity εreff, whose value is determined by evaluating the capacitance of the fringing field [7].

$$e_{reff} \approx \frac{e_r + 1}{2} + \frac{e_r - 1}{2}(1 + 10\frac{h}{W})^{-ab} \quad . (2)$$

$$a \approx 1 + \frac{1}{49}\ln\frac{(\frac{W}{h})^4 + (\frac{1}{52}\frac{W}{h})^2}{(\frac{W}{h})^4 + 0.432} + \frac{1}{18.7}\ln\left[1 + (\frac{1}{18.1}\frac{W}{h})^3\right] \quad ... (3)$$

$$b = 0.564 (\frac{e_r - 0.9}{e_r + 3})^{0.053} \quad ... (4)$$

Substituting εr = 2.2, W ≈ 47.4 mm, and h =1.44 mm, then εreff ≈ 2.114
The effective length (L eff) is given by:

$$L_{eff} \approx \frac{c}{2 f_o \sqrt{e_{reff}}} \quad .... (5)$$

Substituting εreff =2.114, c =3x108m/s, and fo = 2.5GHz, then get the value
L eff ≈41.27mm.
The length extension (ΔL) is given by:

$$\Delta L \approx 0.412h \frac{(e_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(e_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad .....(6)$$

Substituting εreff = 2.114, W=47.4mm and h=1.44mm, then get the value ΔL≈ 0.76mm.
The actual length (L) of patch is obtained by:

$$L \approx L_{eff} - 2\Delta L \quad ..... (7)$$

Substituting Leff ≈ 41.27mm and ΔL= 0.76mm , then get L = 39.75mm.
The ground plane dimensions in the lower region (Lg and Wg) are given by:

$$L_g \approx 6h + L \approx 48.4\text{mm} \quad .... (8)$$

$$W_g \approx 6h + W \approx 56\text{mm} \quad .... (9)$$

Determination of feed line dimensions (Lf, Wf), that is the feeding line between input port and patch, in this design that is approximately equal to $\frac{L_f}{W_f} \approx 3.96$.
The thickness of the dielectric substrate is usually kept to a small fraction of a wavelength where [1]

$$h \leq \frac{0.3c}{2p f_o \sqrt{e_r}} \quad .... (10)$$

Common manufacturer specifications include dielectric constant, dissipation factor (loss tangent), and thickness. The values for dielectric constants 2.2 ≤ εr ≤12 for operation at frequencies ranging from 1 to 100 GHz [9,10]. Substrates with higher dielectric constants allow size reduction of the element at the expense of antenna efficiency (due to increased losses) [8].
So the thickness of the metallization is very small (t « 0 where 0 is

defined as wavelength in free space). The length of the metallic patch (L) is selected, so that the antenna resonates at a particular operating frequency (0/3 L 0/2). The length of the metallic patch needs to be tuned to account for the fringing fields at the edges of the patch. Finally, the width of the patch (W) is used to adjust the input impedance of the antenna [8].

There are several techniques available to feed or transmit electromagnetic energy to a microstrip antenna. The most popular methods are the microstrip transmission line as shown in figure (2), coaxial probe, aperture coupling, and proximity coupling [11, 12].

The new case in this design is adding layer between substrate and the ground plate that's have thickness s equal to 1mm and εr equal to 1.06 (near to air gap), the gap thickness is ($0 < s < 0.14\lambda$) experience impedance bandwidth up to 13% of the center frequency fo [13]. That is reducing the insertion loss and VSWR. The new dimensions of feed line patch antenna are Lg =60mm, Wg =68mm, L=45 mm, W =57.3mm, and the dimensions of feed line Lf =8.43mm, and Wf =2.125mm. The antenna is matched to a 50Ω system interfacing via a single coaxial SMA female connector. The layout design of feed line microstrip patch antenna shown in figure (3).

Antenna Performance Evaluation

The design of this work gives the following results:

The return losses in the resonance frequency 2.5GHz is equal to -33.6dB. The accurate value of return losses with respect to band of frequencies (2.3–2.7) GHz that is illustrate in figure (4). The center frequency is selected at the minimum return loss. The bandwidth can be calculated from the return loss plot, where the bandwidth of the antenna over range of frequencies which the return loss is greater than -9.5dB corresponding to a VSWR of 2 which is an acceptable value.

VSWR is a measure of how well matched an antenna is to the cable impedance. A perfectly matched antenna would have a VSWR of 1:1. This indicates how much power is reflected back or transferred into a cable. If a cable with 50Ω impedance is used to connect to an antenna that has an impedance of 100Ω then the VSWR would be 2:1 which translates to about 0.5dB transmission loss. An antenna with 50Ω impedance should be used with 50Ω cable [14]. Figure (5) shows the VSWR is equal to 1.04 at the frequency 2.5GHz.

A microstrip feed line patch antenna radiates normal to its patch surface, the elevation pattern for ø = 0o and 90o. By using antenna plot chart, the electric radiation and power radiation pattern are shown in figure (6).

The scattering parameter S11 for this design at the range of frequencies (2.3-2.7) GHz on the smith chart is shown in figure (7).

Discussion the Results

The final results of this design are illustrated in table (1). The antenna is a resonant circuit therefore; energy will be stored in the system. This energy stored is inversely proportional to the dielectric height, and also the energy stored by the parameter Q, Where Losses in the antenna will allow energy to leak away and such an antenna will have a lower Q factor [9].

Conclusions

From the results of this paper, the following conclusions are obtained; we show some difference between the mathematical and simulation design, so the results in microwave frequencies (up to 1GHz) need some cut and paste that is applied on design layout to find accurate results. In other hand in manufactured of substrate materials the region between the conductor plate and the substrate material that is have properties differ from two regions.

Finally, the soldering between the probe and feed line and ground plate adding factors due to the output results because it is added stray capacitive and inductive.

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Table (1) The requirements of design feed line microstrip patch antenna

f_o (GHz)	ε_{r1}	ε_{r2}	h (mm)	s (mm)	W (mm)	L (mm)	W_g (mm)	L_g (mm)	W_f (mm)	L_f (mm)
2.5	2.2	1.06	1.44	1	57.3	45	68	60	2.125	8.43

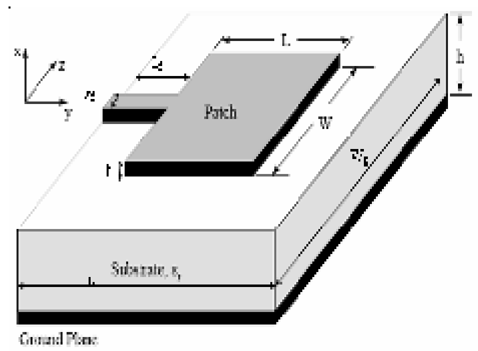

Figure (1) Three dimensions of feed line patch antenna

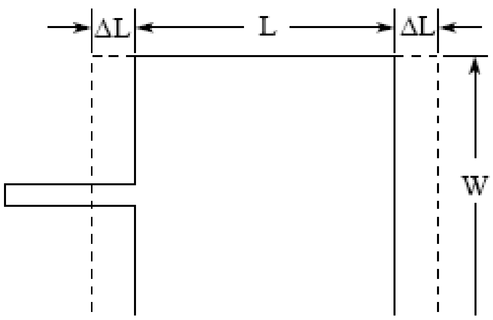

Figure (2) Two dimensions of feed line patch antenna

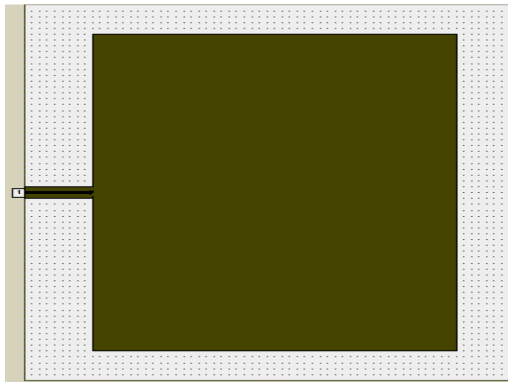

Figure (3) Layout of feed line patch antenna

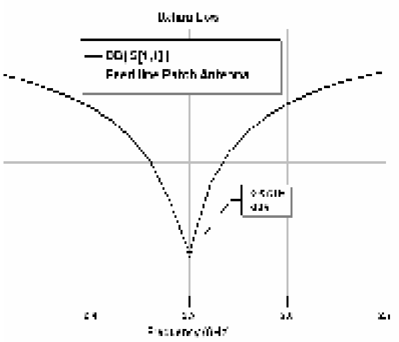

Figure (4) Return loss versus frequency of feed line patch antenna

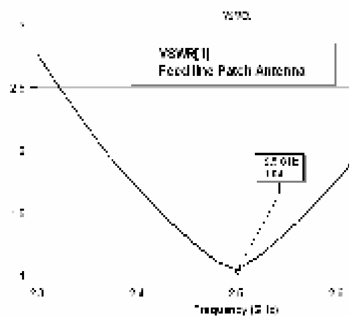

Figure (5) VSWR versus frequency for feed line patch antenna

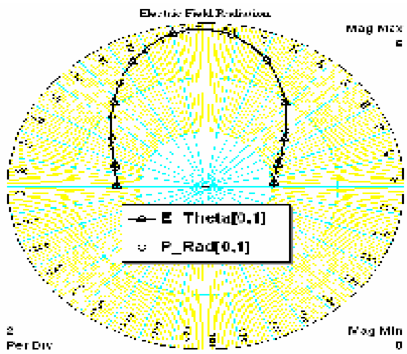

Figure (6) Electric field and power radiation of feed line patch antenna

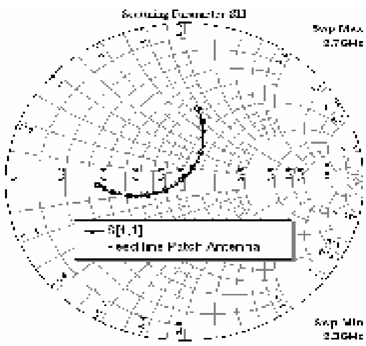

Figure (7) Scattering parameter S_{11} versus frequency on the Smith chart