2.4 GHz ANTENNA INTEGRATED SOLAR PV CELL

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ABSTRACT

In this work, a novel 2.4 GHz ISM band microstrip patch antenna integrated with photovoltaic (PV) solar cell is designed, built and measured. Solar PV cell serves as a ground plane for the microstrip antenna. The antenna is a part of a wireless node and transceiver circuit which performs sensing and communication functions. An existing wireless node is used and hooked to the antenna to measure certain performance metrics of the wireless node. The antenna is designed with a 3D electromagnetic solver. Measurements of the prototyped antenna exhibit very good agreement with the simulation results. The DC converter circuit for the solar cell is also designed and built. PV cell current-voltage measurements are also performed. With this system, the energy provided by the solar cell is enough to operate a standalone wireless node without any external power source.

ÖZET

Bu çalışmada 2.4 GHz lisanssız frekans bandında çalışan, fotovoltaik güneş hücresi üzerinde yeni bir mikroşerit yama anten tasarlandı, prototipi yapıldı ve ölçümleri gerçeklendi. Güneş hücresi mikroşerit anten için toprak görevi gördü. Anten, iletişim ve ölçme işlemlerini gerçeleştiren kablosuz duyarganın alıcı/verici devresine bağlı çalışmaktadır. Varolan kablosuz bir duyarga kullanılarak, anten ve kablosuz duyarga performans parametreleri ölçülmüştür. Anten 3 boyutlu elektromagnetik benzetim program kullanılarak tasarlanmıştır. Prototipi yapılan antenin ölçüm sonuçları benzetim sonuçları ile örtüşmektedir. Güneş hücresinin DC çevirici devresi de tasarlanıp, gerçeklenmiştir. Fotovoltaik hücrenin akım-gerilim ölçümleri yapılarak güç eğrisi de çıkartılmıştır. Bu sistemle, güneş hücresinden gelen enerji kablosuz bir duyargayı, pil gibi harici bir güç kaynağı olmaksızın çalıştırabileceği gösterilmiştir.

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LIST OF SYMBOLS

NiMH:	Nickel-metal hydride
NiCd:	Nickel cadmium
mAh:	mili ampere hour
Γ:	reflection coefficient

1. INTRODUCTION

An increasingly large number of electronic devices are now portable. Many advances allow for portable devices, including smaller and lighter electronics, electronics which use less power, improved batteries and power supplies, etc. These technological advances allow many types of electronic devices to operate without requiring wired connection to communications networks or power grids [1].

Recently, communication systems integrated with photovoltaic technology for low cost and stand alone applications received much interest. The photovoltaic systems of power generation when combined with communications systems can provide compact and reliable autonomous communication systems for many applications. A stand alone remote base station is one such application where PV technology can be used. But these devices often involve the use of separate solar cells and antennas, which necessitate a compromise in the utilization of the limited surface available. Integrating the base station antennas into photovoltaic solar cells can provide compact and reliable solution [5].

The device in this project operates without connection to an outside power source for extended periods of time. A solar cell is desirable for facilitating operation without an outside source of power. Batteries are often utilized, but the batteries capable of operating the device for extended periods of time (such as weeks or months) are typically much too large to be conveniently included in the device. Thus, solar panels are often used to power devices. Solar panels are often used in combination with batteries to provide energy to the device and to charge the batteries during the day and thereby extend the time period for which the device may operate. If the solar panel is large enough, the device may operate indefinitely. It is thus often desirable to have a solar panel which is large enough to meet the energy requirements of the device.

It is free to use 2.4 GHz ISM band is abundantly used for WLAN, portable electronics communication and sensor networks. A communication antenna and a tranceiver system are usually isolated from DC supply such as battery or PV cell. Here, Our goal is to integrate communication/sensor antenna with PV cell and utilize PV cell as a back-up power source.

2. BATTERY CHARGING WITH SOLAR PV CELL

Stand alone applications like environmental monitoring systems or satellite systems need a net-independent power supply which is preferably realizable by photovoltaics, an advanced technology distinguished by reliability, longevity and eco-friendliness [6].

In this project, we have two 1.2V rechargeable batteries to feed the module of microstrip patch antenna. One of our goals is to charge these batteries with solar energy.

2.1 Solar PV Cells

A solar cell or a photovoltaic cell is a device that converts photons from the sun's radiation into electricity. In general, a solar cell that includes both solar and non solar sources of light is termed as photovoltaic cell.

The development of the thin amorphous silicon on polymer substrate solar cell technology made it possible to easily cut and fit the solar cells to various shapes such as slot antennas, leading to optimized use of the available area, without affecting the radiating characteristics of the antenna [3].

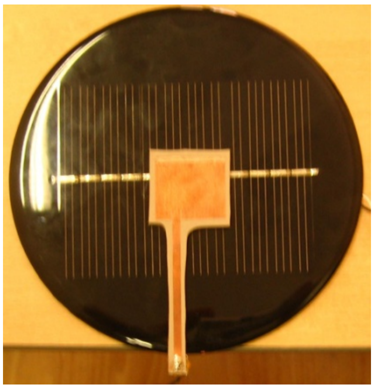


Figure 2.1 Our PV cell with the antenna

Our PV cell integrated with the antenna serves as a back-up power source and also as a ground plane. We had a measurement of PV cell in a sunny day to understand how much power PV cell can produce with different resistors which are 1, 10, 15, 100, 510, 1kΩ.

The table below shows the data from the measurement. The measurement is made at 3 o'clock, so the position of the sun is not 90° to the earth. We rotated PV cell to the sun. Here you can see the results:

Table 2.1 The result table of power measurement of PV cell

	Horizontal			Towards Sun		
	Volt (V)	I(mA)	Power(mW)	Volt (V)	I(mA)	Power(mW)
open circuit	6.95			7.05		
1Ω	0.086	95	8.17	0.180	184	33.12
10Ω	0.97	95	92.15	1.86	193	358.98
15Ω	1.97	132	260.04	2.86	196	560.56
100Ω	6.47	62.7	405.67	6.73	65.5	440.82
510Ω	6.84	13.28	90.84	7.05	13.51	95.25
1kΩ	6.96	6.73	46.84	7.12	6.93	49.34

The data in the red tone show the maximum power produced by PV cell. When PV cell is horizontal position, the maximum power is 405 mW and in towards sun position, the maximum power is 560 mW. When I got these results, I got really excited. Because the produced power is enough to charge the batteries in the project.

2.2 Rechargeable Batteries

2.2.1 Charging of Ni-MH Batteries

The charging voltage is in the range of 1.4–1.6 V/cell. A fully charged cell measures 1.35–1.4 V (unloaded), and supplies a nominal average 1.2 V/cell during discharge, down to about 1.0–1.1 V/cell (further discharge may cause permanent damage). In general, a constant-voltage charging method cannot be used for automatic charging. When fast-charging, it is advisable to charge the NiMH cells with a smart battery charger to avoid overcharging, which can damage cells and cause dangerous conditions. A NiCd charger should not be used as an automatic substitute for a NiMH charger [2].

2.2.2 Comparison with Other Battery Types

NiMH cells are not expensive, and the voltage and performance is similar to primary alkaline cells in those sizes; they can be substituted for most purposes. The ability to recharge hundreds of times can save money and resources.

They accept both higher charge and discharge rates and micro-cycles thus enabling applications which were previously not practical [5].

2.3 Buck Converter

If you need an output voltage that's smaller than the input voltage, then the Buck Converter is your choice. The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess power as heat; also, output voltage isn't regulated (varies with input voltage). A buck converter, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating.

2.3.1 Explanation of Buck Converter Circuit with LM2574

Since the LM2574 converter is a switch–mode power supply, its efficiency is significantly higher in comparison with popular three–terminal linear regulators. In most cases, the power dissipated by the LM2574 regulator is so low, that the copper traces on the printed circuit board are normally the only heatsink needed and no additional heatsinking is required.

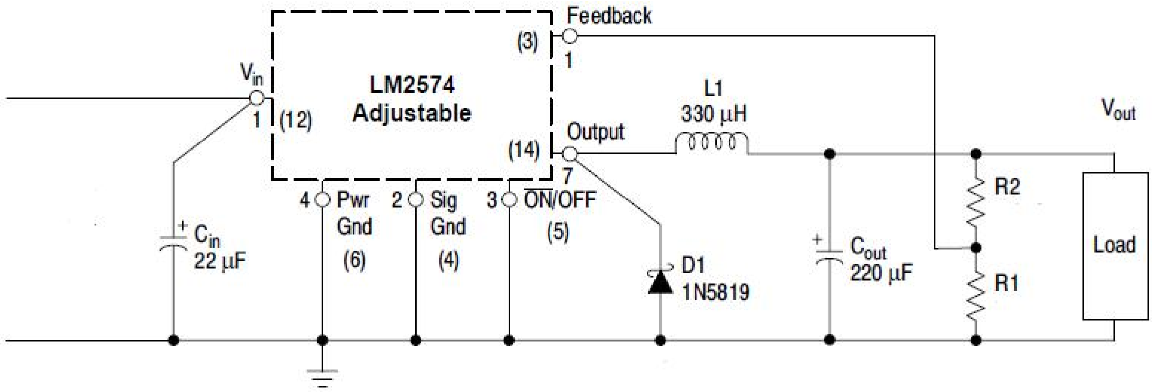


Figure 2.2 Adjustable output voltage version of LM2574 [7]

V_{in} pin is the positive input supply for the LM2574 step–down switching regulator. In order to minimize voltage transients and to supply the switching currents needed by the regulator, a suitable input bypass capacitor must be present (C_{in} in Figure 2.3). C_{in} is to prevent large voltage transients from appearing at the input and for stable operation of the converter, an aluminum or tantalum electrolytic bypass capacitor is needed between the input pin $+V_{in}$ and ground pin “Gnd”.

Feedback pin senses regulated output voltage to complete the feedback loop. The signal is divided by the internal resistor divider network R2, R1 and applied to the non–inverting input of the internal error amplifier. In the Adjustable version of the LM2574 switching regulator, this pin is the direct input of the error amplifier and the resistor network R2, R1 is connected externally to allow programming of the output voltage.

ON/OFF pin allows the switching regulator circuit to be shut down using logic level signals, thus dropping the total input supply current to approximately 80 mA. The input threshold voltage is typically 1.5 V. Applying a voltage above this value (up to +Vin) shuts the regulator off. If the voltage applied to this pin is lower than 1.5 V or if this pin is left open, the regulator will be in the "on" condition.

C_{out} is important component, since the LM2574 is a forward–mode switching regulator with voltage mode control; its open loop 2–pole–1–zero frequency characteristic has the dominant pole–pair determined by the output capacitor and inductor values. For stable operation and an acceptable ripple voltage, (approximately 1% of the output voltage) a value of 220 μF is suitable.

Catch diode (D1) must be located close to the LM2574 using short leads, The LM2574 is a step–down buck converter, and it requires a fast diode to provide a return path for the inductor current when the switch turns off.

Finally we can get the desired value by changing R2/R1 ratio. So we settle a potentiometer instead of two separate resistors.

The realized circuit is here. We used two extra capacitors which are both 100 nF for low pass filter in input and output and also used a potentiometer instead of using two separate resistors as R1 and R2.

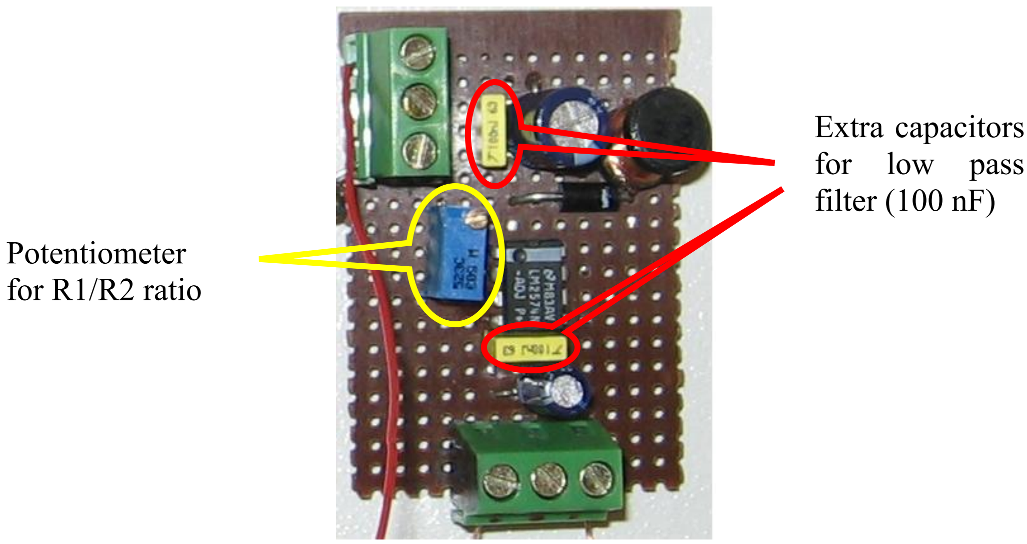


Figure 2.3 The charger circuit

2.3.2 Measurements of Buck Converter Circuit

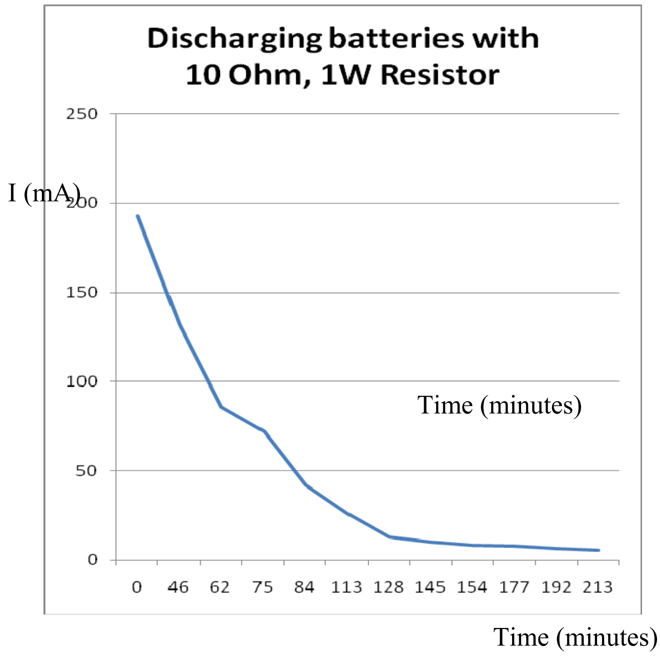
It was tested that whether our circuit charges the batteries or not. First, the batteries were discharged with 10Ω (5W) resistance connected by two 1.2V Ni-MH rechargeable batteries[1] and the values were recorded as given in the below:

Table 2.2 Discharging values

Current (mA)	**Time**	**Current (mA)**	**Time**
193	11:55	13	14:05
132	12:41	10	14:22
86	12:57	8.4	14:31
72	13:12	7.6	14:54
42	13:21	6.3	15:09
26	13:50	5.5	15:30

This graph shows the discharging current values taken after a certain time intervals. In the beginning, the flowing current is nearly 200 mA and after 3.5 hours, the batteries discharged.

[1] Before that time the batteries were not fully charged.

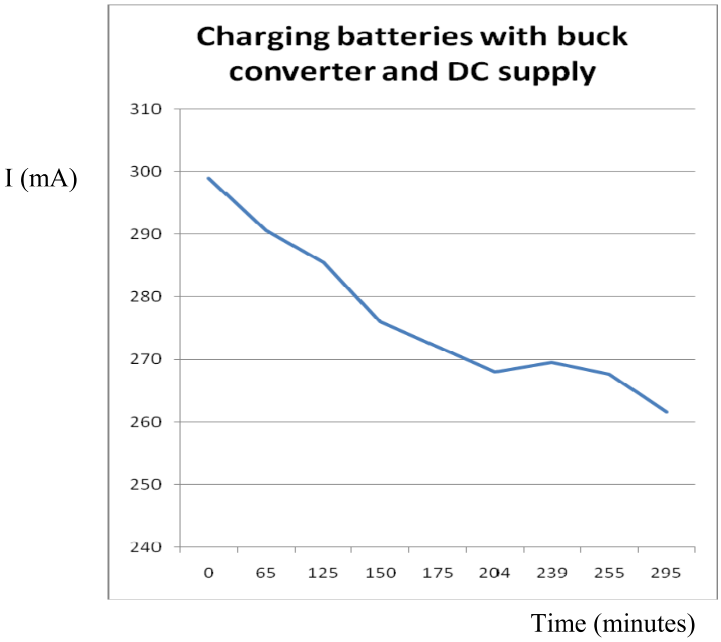


Then, to determine whether our circuit charges the batteries or not, output of the circuit was connected to the batteries and input is connected a DC source 5V and 200 mA_{max}. The current values are tested as below[2]:

Table 2.3 Charging values

Current (mA)	**Time**	**Current (mA)**	**Time**
299	18:05	267.7	22:20
290.6	19:10	261.7	23:00
285.5	20:10	52	14:05
276	20:35	38	14:40
272	21:00	32.3	15:15
268	21:29	23	15:45
269.6	22:04	18	16:10

[2] Charging test processed between two time intervals which are from 6:05 to 23:00 and from 2:00 to 16:10.



It charged for nearly 5 hours and again I took the data as you can see in the figure in the previous page. When I returned the laboratory in the morning after that night, only 50mA was flowing to the batteries and in a some while it returns to 10 mA and I understood that the batteries are fully-charged. I also noted the open-circuit of voltage of two batteries as 2.66 V.

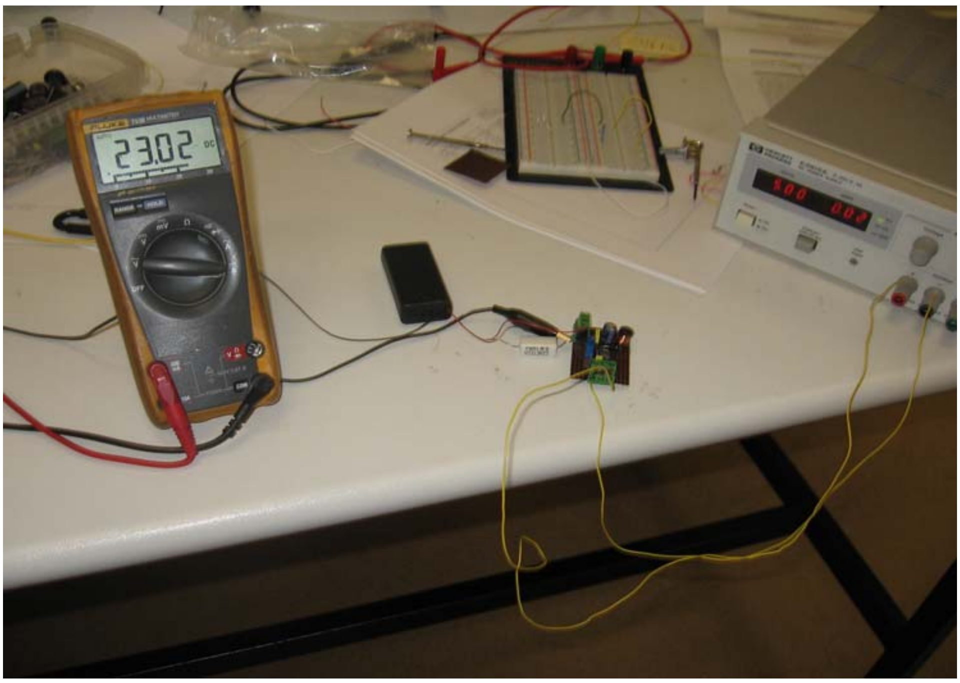


Figure 2.4 The charging circuit while the batteries at about saturation

3. OVERVIEW OF MICROSTRIP PATCH ANTENNA THEORY

3.1 Introduction to Microstrip Patch Antennas

Size miniaturization of microstrip patch antenna is increasingly essential in many practical applications, such as mobile cellular handsets, cordless phones, direct broadcast satellites (DBS), wireless local area networks (WLAN), global position satellites (GPS) and other next-generation wireless terminals.

Applications in present-day mobile communication systems usually require smaller antenna size in order to meet the miniaturization requirements of mobile units. Thus, size reduction is becoming major design considerations for practical applications of microstrip antennas. For this reason, studies to achieve compact microstrip antennas have greatly increased. Much significant progress in the design of compact microstrip antennas has been reported over the past several years.

The antenna physical sizes are an important factor in the design process owing to the miniaturization of the modern mobile terminals. Any technique to miniaturize the sizes of the microstrip patch antenna has received much attention. Electrical requirements for these mobile antennas are sufficient bandwidth, high efficiency, impedance matching, omni-directional radiation patterns, and minimum degradation by the presence of near objects, etc.

In general, the size miniaturization of the normal microstrip patch antenna has been accomplished by loading, which can take various forms, namely;

i. Use of high dielectric constant substrates

ii. Modification of the basic patch shapes;

iii. Use of short circuits, shorting-pins or shorting-posts; and

iv. A combination of the above techniques.

Employing high dielectric constant substrates is the simplest solution, but it exhibits narrow bandwidth, high loss and poor efficiency due to surface wave excitation. Modification of the basic patch shapes allows substantial size reduction; however, some of these shapes will cause the inefficient use of the available areas. In contrast, shorting posts, which were regarded as a more efficient technique, were used in different arrangements to reduce the overall dimensions of the microstrip patch antenna.

3.2 Basic Patch Antenna Shapes and Geometries

In its most basic form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate, which has a ground plane on the other side as shown in Figure 3.1.

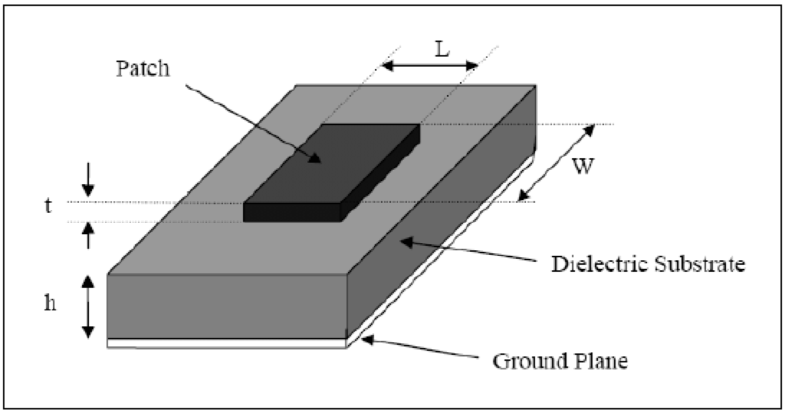


Figure 3.1 Structure of a microstrip patch antenna [8]

The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate [8].

3.3 Basic Antenna Parameters

An antenna is a device that converts a guided electromagnetic wave on a transmission line to a plane wave propagating in free space. Thus, one side of an antenna appears as an electrical circuit element, while the other side provides an interface with a propagating plane wave. Antennas are inherently bi-directional, they can be used for both transmit and receive functions [4].

3.3.1 Directivity

The directivity of an antenna has been defined by as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions”. In other words, the directivity of a nonisotropic source is equal to the ratio of its radiation intensity in a given direction, over that of an isotropic source.

$$D= U/U_i = 4\pi U/P \tag{3.1}$$

where D is the directivity of the antenna, U is the radiation intensity of the antenna, U_i is the radiation intensity of an isotropic source, and P is the total power radiated.

Sometimes, the direction of the directivity is not specified. In this case, the direction of the maximum radiation intensity is implied and the maximum directivity is given by as:

$$D_{max}= U_{max}/U_i = 4\pi U_{max} \tag{3.2}$$

where D_{max} is the maximum directivity, U_{max} is the maximum radiation intensity.

3.3.2 Input Impedance

The input impedance of an antenna is defined by as “the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”. Hence the impedance of the antenna can be written as:

$$Z_{in}=R_{in}+jX_{in} \tag{3.3}$$

where Z_{in} is the antenna impedance at the terminals, R_{in} is the antenna resistance at the terminals, X_{in} is the antenna reactance at the terminals.

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance R_r and the loss resistance R_L. The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses.

3.3.3 Voltage Standing Wave Ratio (VSWR)

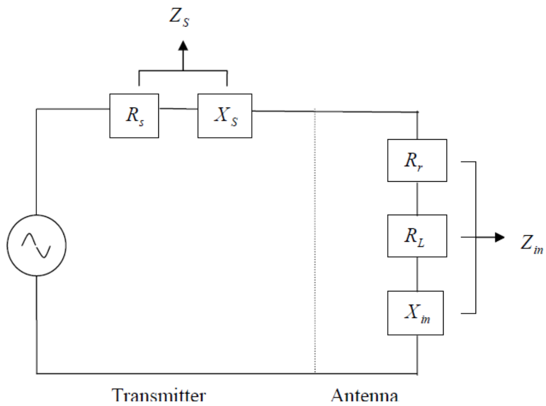


Figure 3.2 Equivalent circuit of transmitting antenna [9]

In order for the antenna to operate efficiently, maximum transfer of power must take place between the transmitter and the antenna. Maximum power transfer can take place only when the impedance of the antenna (Zin) is matched to that of the transmitter (Zs).

If the condition for matching is not satisfied, then some of the power maybe reflected back and this leads to the creation of standing waves, which can be characterized by a parameter called as the Voltage Standing Wave Ratio (VSWR). The VSWR can be expressed as:

$$VSWR=(V_{max}/V_{min})=(1+\Gamma)/(1-\Gamma) \quad (3.4)$$

where Γ

$$\Gamma = V_r/V_i=(Z_{in}-Z_s)/(Z_{in}+Z_s) \quad (3.5)$$

The VSWR expresses the degree of match between the transmission line and the antenna. When the VSWR is 1 to 1 (1:1) the match is perfect and all the energy is transferred to the antenna prior to be radiated. In an antenna system, its reflection coefficient is also its S11. In addition, for an antenna to be reasonably functional, a minimum VSWR≤1.5 is required.

The VSWR is basically a measure of the impedance mismatch between the transmitter and the antenna. The higher the VSWR, the greater is the mismatch. The minimum VSWR which corresponds to a perfect match is unity. A practical antenna design should have an input impedance of either 50 Ω or 75 Ω since most radio equipment is built for this impedance.

3.3.4 Antenna Efficiency

The antenna efficiency is a parameter which takes into account the amount of losses at the terminals of the antenna and within the structure of the antenna. These losses are given by as:

- Reflections because of mismatch between the transmitter and the antenna
- I^2R losses (conduction and dielectric)

Hence the total antenna efficiency can be written as:

$$e_t=e_r e_c e_d \tag{3.6}$$

where e_t = total antenna efficiency, $e_r = (1- |\Gamma|^2)$= reflection (mismatch) efficiency

e_c= conduction efficiency, e_d= dielectric efficiency

Since e_c and e_d are difficult to separate, they are lumped together to form the e_{cd} efficiency which is given as:

$$e_{cd}= e_c\, e_d= R_r / (R_r+ R_L) \tag{3.7}$$

e_{cd} is called as the antenna radiation efficiency and is defined as the ratio of the power delivered to the radiation resistance R_r, to the power delivered to R_r and R_L.

3.3.5 Antenna Gain

Antenna gain is a parameter which is closely related to the directivity of the antenna. We know that the directivity is how much an antenna concentrates energy in one direction in preference to radiation in other directions. Hence, if the antenna is 100% efficient, then the directivity would be equal to the antenna gain and the antenna would be an isotropic radiator. Since all antennas will radiate more in some direction that in others, therefore the gain is the amount of power that can be achieved in one direction at the expense of the power lost in the others. The gain is always related to the main lobe and is specified in the direction of maximum radiation unless indicated. It is given as:

$$G(\theta, \varphi) = e_{cd} D(\theta, \varphi) \quad (3.8)$$

3.3.6 Bandwidth

The bandwidth of an antenna is defined by as "the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." The bandwidth can be the range of frequencies on either side of the center frequency where the antenna characteristics like input impedance, radiation pattern, beamwidth, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency.

The bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency. According to these definitions can be written in terms of equations as follows:

$$BW_{broadband} = f_H / f_L \quad (3.9)$$

$$BW_{narrowband}(\%) = (f_H - f_L) \times 100 / f_C \quad (3.10)$$

where f_H= upper frequency, f_L= lower frequency, f_C = center frequency.

4. MICROSTRIP PATCH ANTENNA DESIGN

In this novel design, some certain equations were used to determine approximate dimensions of the antennas and dielectric substrates. Then an antenna design program called FEKO was used to determine the most suitable dimensions and radiation pattern, input impedance, VSWR, polarization characteristics, resonant frequencies.

After using some certain formulas, the approximate values about the dimensions of the patch was obtained and put in the program FEKO to get more realistic values and simulate and we get the antenna with the following configuration:

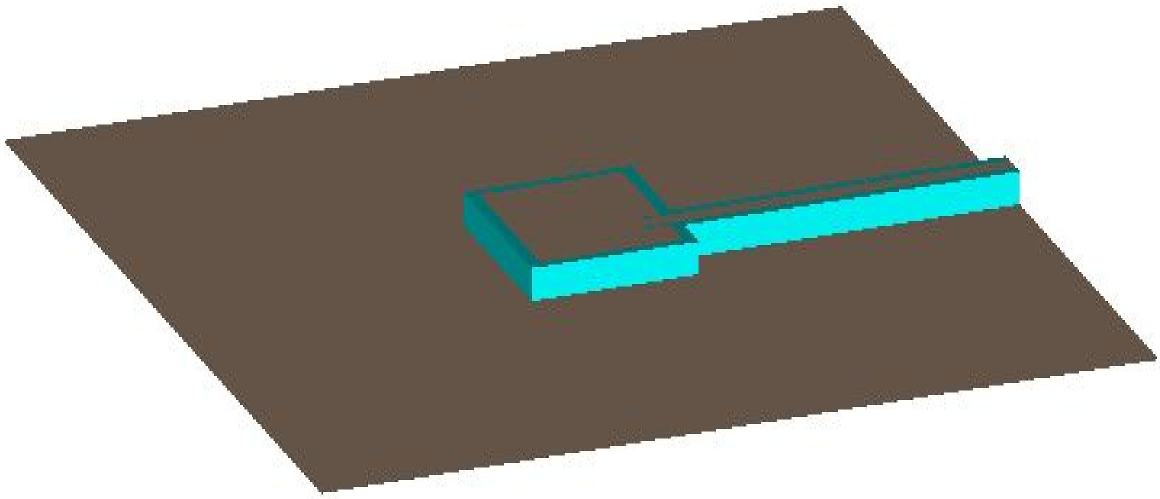


Figure 4.1 Side view of the antenna

This is the view of our designed antenna in FEKO which is simulation program. There is a ground plane which is square. Its one side is 140 mm which is equal to diameter of PV cell since it is used as a ground. We had a feed line whose dimensions are 30 mm and 28 mm to connect the antenna with its wireless module. At the end of the feed line we have a feed point.

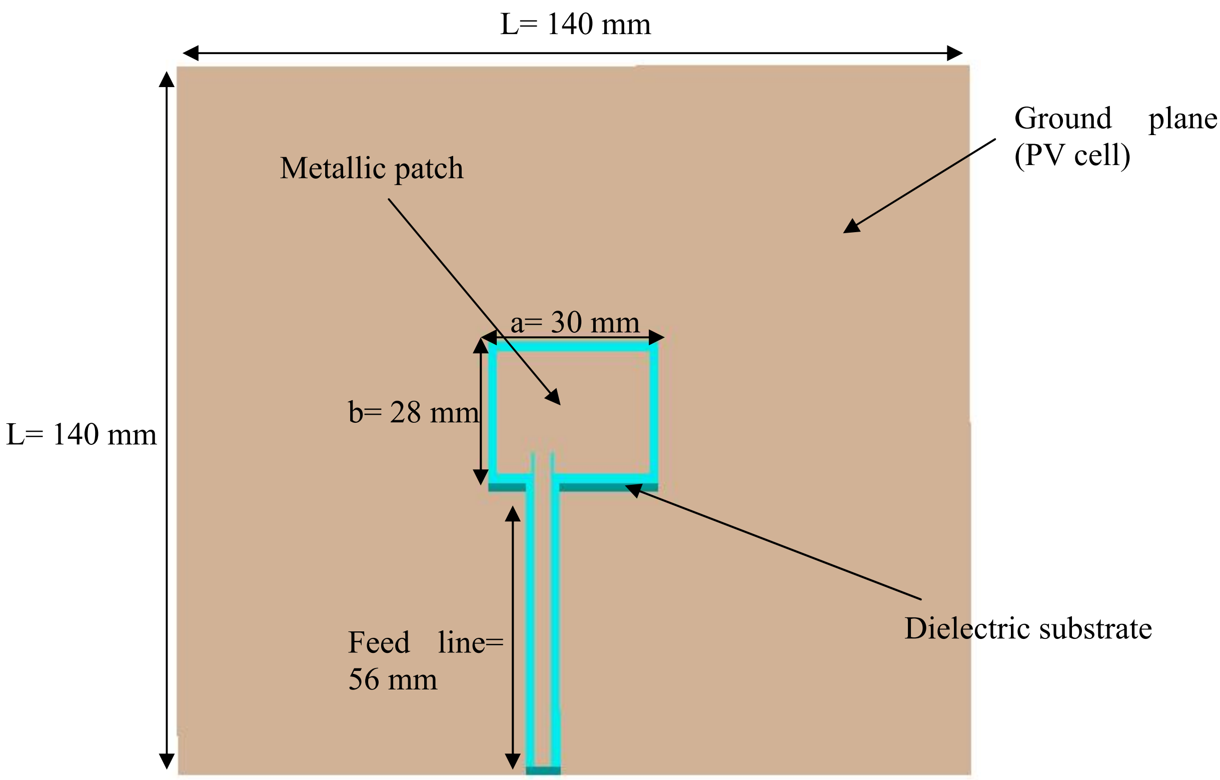


Figure 4.2 Geometry of the antenna

We have an offset for feed line to adjust the imaginary part of input impedance as possible as 0. The offset is 3.5 mm in y-axis from the origin of the antenna.

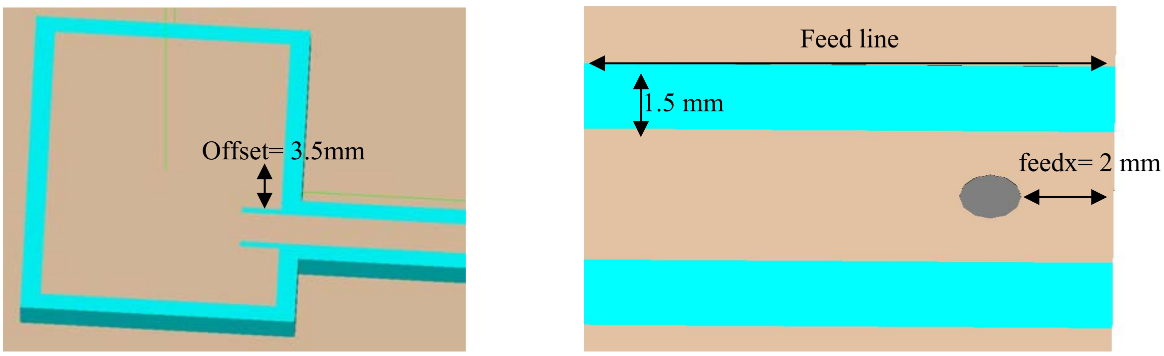


Figure 4.3 Feedline geometry

The material we have is 3.175 mm, so we set it. Here, you can see the coaxial probe feed. It has an offset in x-axis from the end of the feed line. It helps us to adjust the input impedance.

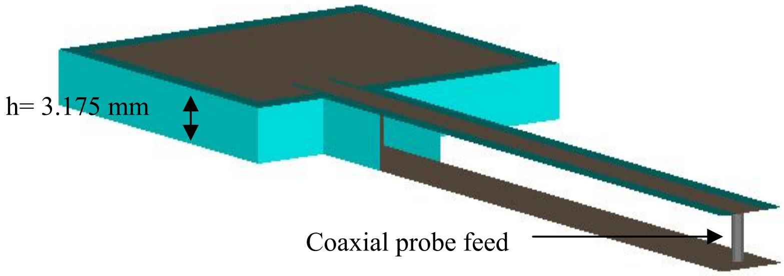


Figure 4.4 Side view of the antenna with coaxial probe feed

After getting a success in simulation the antenna design in FEKO, it is drawn again in EAGLE PCB drawing program and it is sent to be manufactured in Metaş Electronic.

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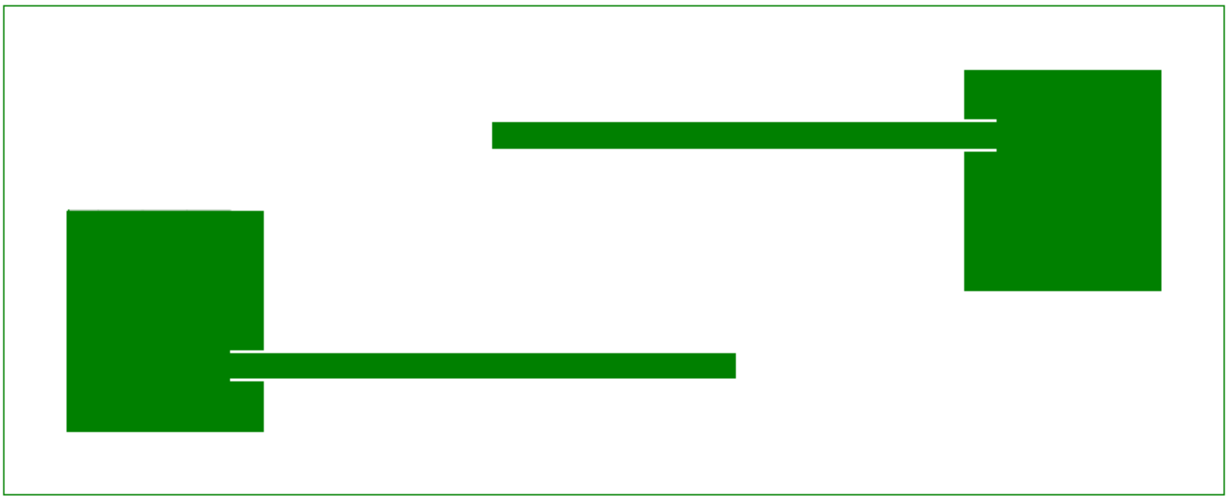


Figure 4.5 Representation of the antenna in EAGLE PCB drawing program.

4.1 Efficiency, Impedance and VSWR

The efficiency values are suitable for our application especially at our frequency band the efficiency is around %90.

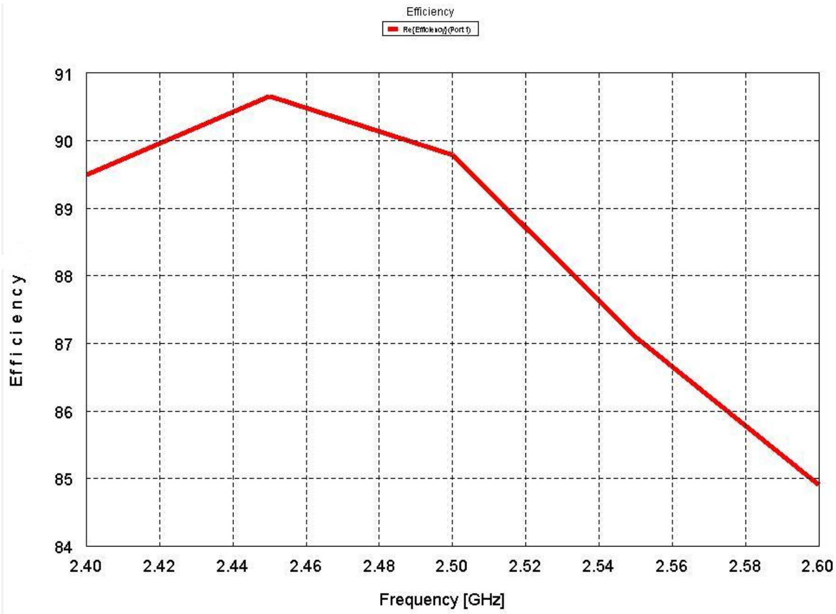


Figure 4.6 Efficiency of antenna in FEKO

Since the impedance of the coaxial cable feeding the antenna is 50Ω, the real part of the impedance value of the antenna is designed to have a value around 50Ω. The matching of the input impedance of the antenna with the coaxial cable will keep the VSWR value small.

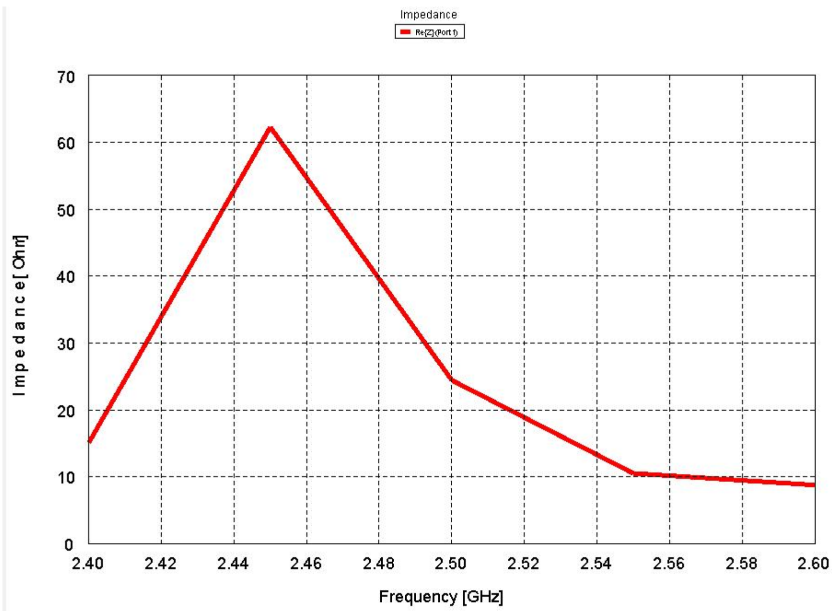


Figure 4.7 Real impedance of antenna in FEKO

In figure 4.6 the real part of the input impedance for the antenna is around 50Ω between 2.43 and 2.48 GHz. Thus VSWR value of the antenna at the frequency band around 2.4-2.5 GHz is expected to be low. VSWR graph of the antenna versus frequency is given in figure 4.8.

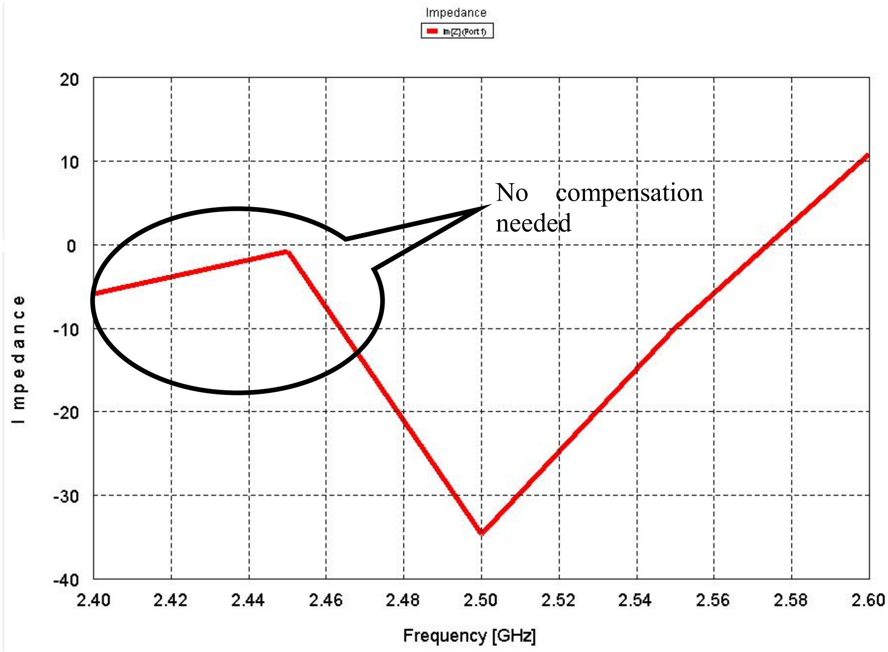


Figure 4.8 Imaginary impedance of antenna in FEKO

At desired frequency gap, the imaginary part of the impedance is acceptable, so we do not need an external device like capacitor or inductor to get compensation.

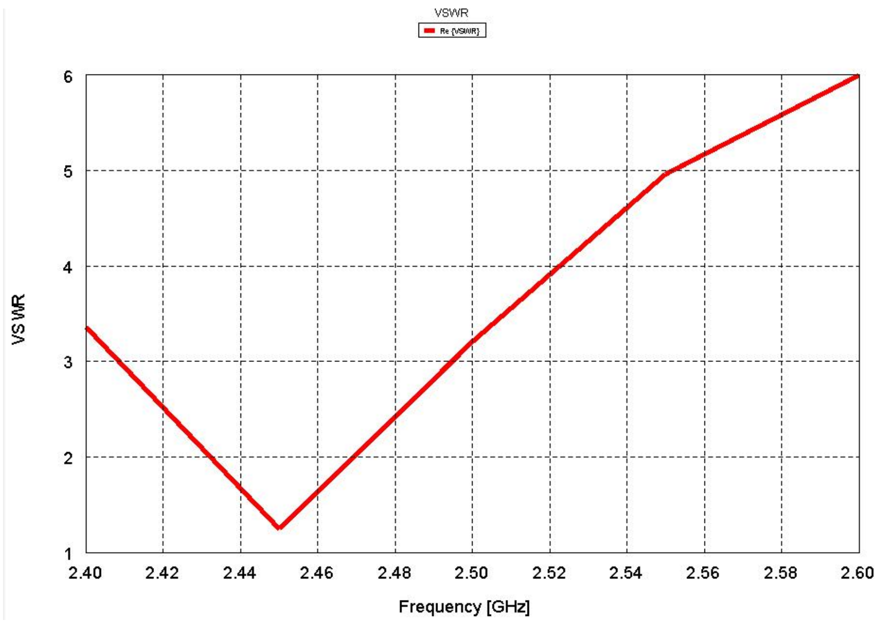


Figure 4.9 VSWR of antenna between small frequency band

4.2 Parameters of the Antenna

The antenna is designed to operate at 2.45GHz as center frequency. The behavior of square patch antenna at that center frequency is observed and summarized in table 4.2. Three dimensional radiation pattern of the antenna is shown in the figure 4.9.

Table 4.1 Summary of microstrip patch antenna at 2.45GHz

Gain (dB)	**Theta**	**Phi**	**LHC**	**RHC**	**Total**
	7.08697	7.03921	5.36144	2.69663	7.2059

Input impedance	62.2991- j0.780675
VSWR	1.24653

	Width	**Length**	**Height**
Dielectric Substrate	27	24	3.175
Metallic Patch	30	28	

Here you can find E-field of antenna and gains after simulation in FEKO.

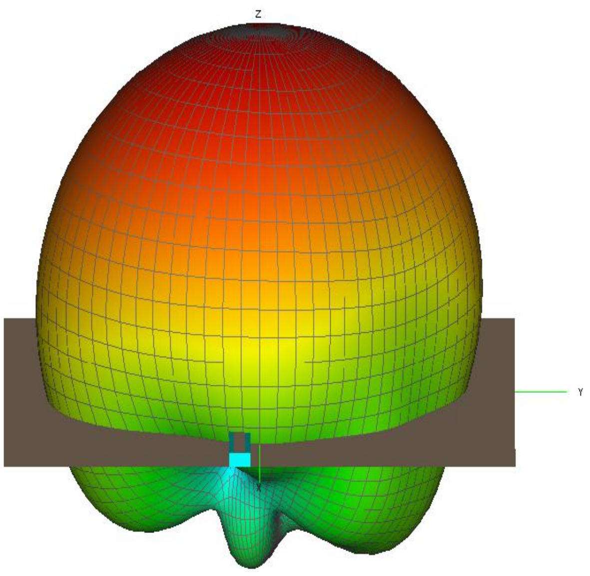


Figure 4.10 Three dimensional Gain of antenna at 2.45 GHz

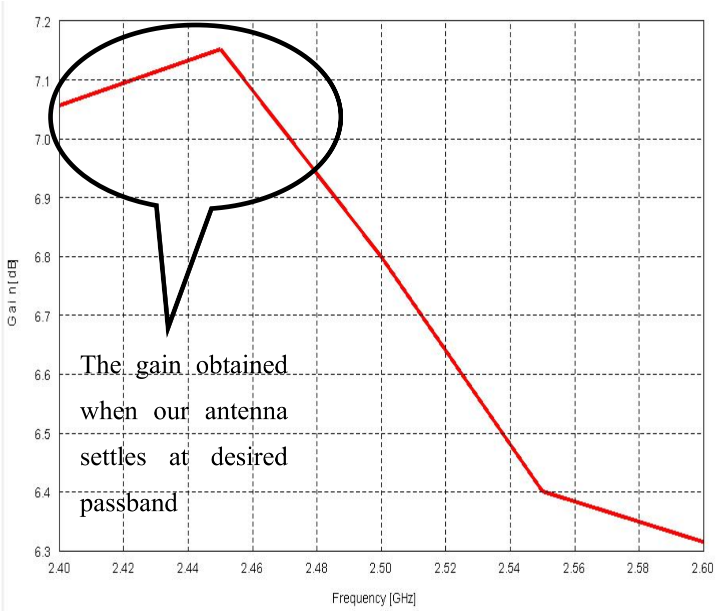


Figure 4.11 Gain graph of the antenna

4.3 Measurements

4.3.1 Grounding The Antenna and Wireless Module

To use PV cell as a ground plane, we put a connector into the feed point of the antenna and connector into the feed point of PV cell is connected by copper sticky tape. Therefore their grounds are same and PV cell becomes ground plane of the antenna.

We needed a wireless module to set the antenna as a receiver or a transmitter, took an inverted F antenna with module and allocated them and used its module as our antenna's one by connecting them.

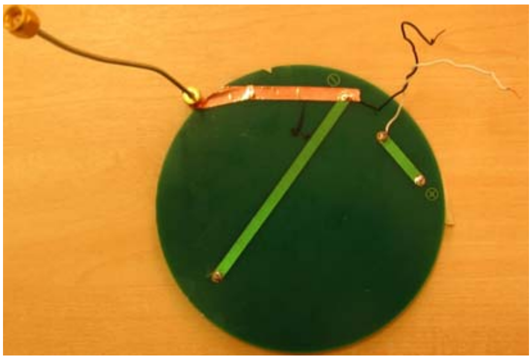


Figure 4.12 Back side of the module

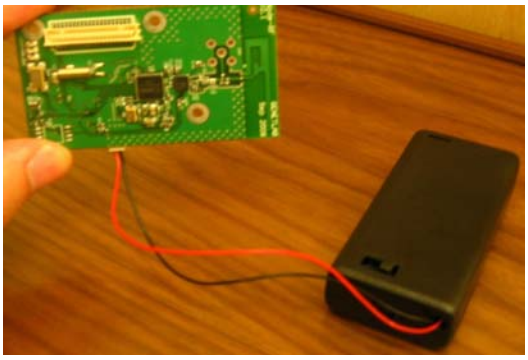


Figure 4.13 Wireless module

4.3.2 Determination of VSWR

We used the network analyzer to view how much VSWR has the antenna at different frequencies. Before the measurement of VSWR, we made some arrangements. We used the calibration kit to eliminate the effect of measurement cable. We can think about calibration job as putting an offset and we put an offset. The sticky tape is special dielectric material which does not affect the measurements, to integrate the antenna with PV cell. The dielectric material is used for holding the antenna, it is also for good measuring.

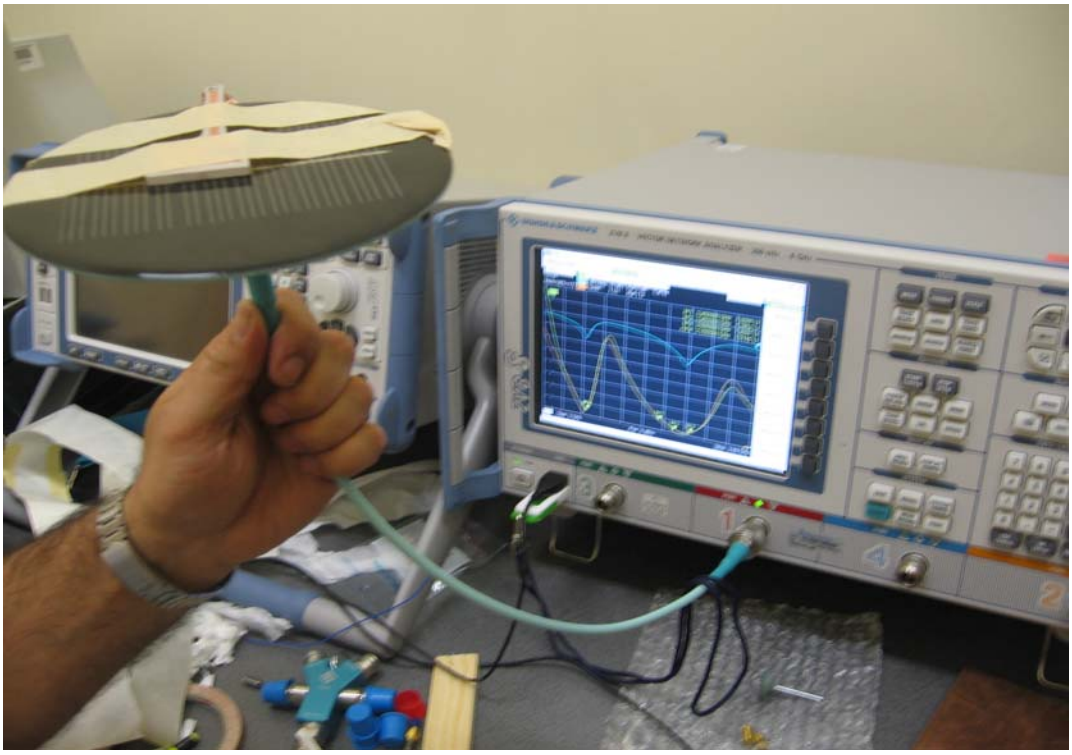


Figure 4.14 antenna VSWR measurement setup

After measurements with network analyzer, we have this graph. It shows that at the passband VSWR values are enough for our design. It also says that at passband, VSWR is samller than even 2 which is very good result for matching.

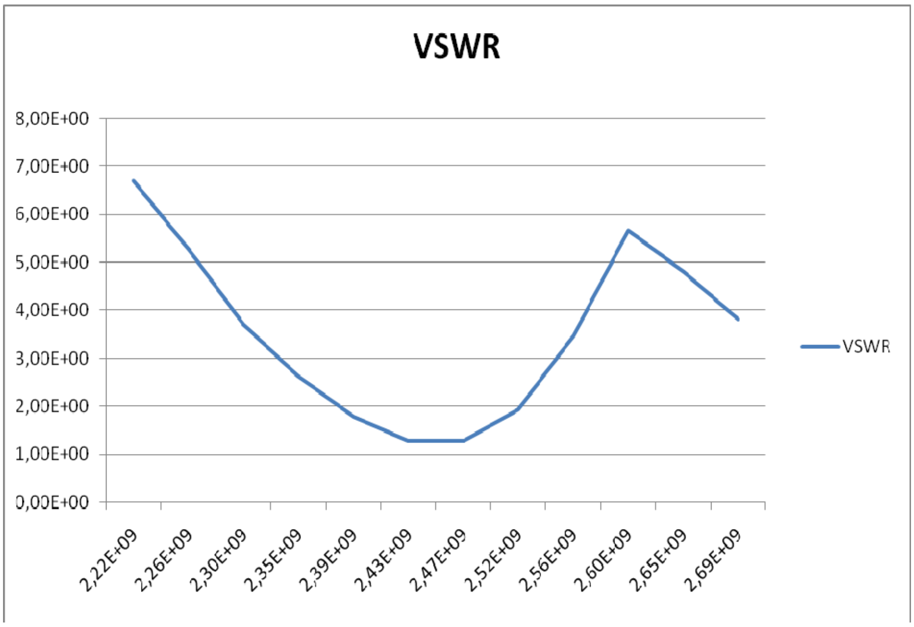


Figure 4.15 VSWR measured by network analyzer

This table compares the desired values with the simulated values:

Table 4.2 Comparison table between desired and simulated values

Parameters	Desired Value	Simulated Value
Directivity	>6dBi	7.6 dBi @2.45 GHz
Input Impedance	~50Ω	62 – j0.3 @2.45 GHz
VSWR	<3	1.4
Antenna Efficiency	%85	%90.5
Antenna Gain	>5dBi	7.2 dBi
Bandwidth	2.4-2.5 GHz	OK
Max Gain Ripple	<0.5 dB	0.35 dB

So, our simulated values are better than desired values.

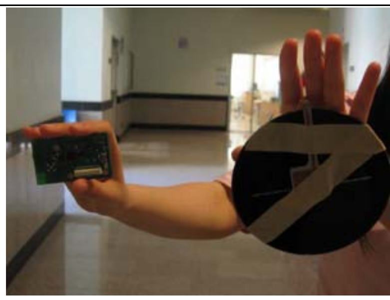
4.3.2 Measurement of Antenna Directivity Using Spectrum Analyser

In this section, the goal is to understand our antenna works sufficiently or not by using different kinds of receiver and transmitter antennas.

Here is the placements of the antennas:

270 degree elevation

back to back

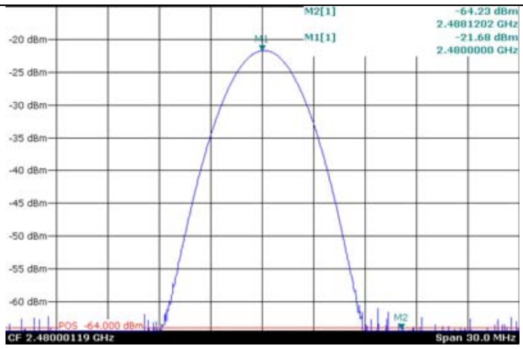


side by side

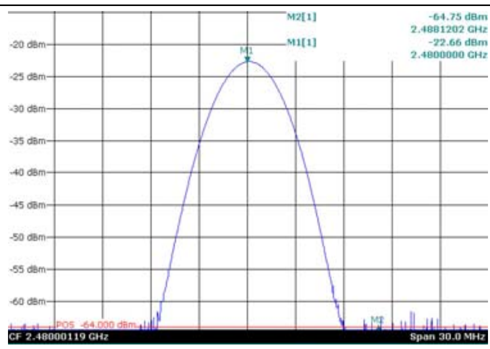
Monopole antenna

Figure 4.16 Placements of the antennas

We do not have a device measuring radiation pattern, so transmitter and receiver powers are taken to have an idea about radiation of the antenna.



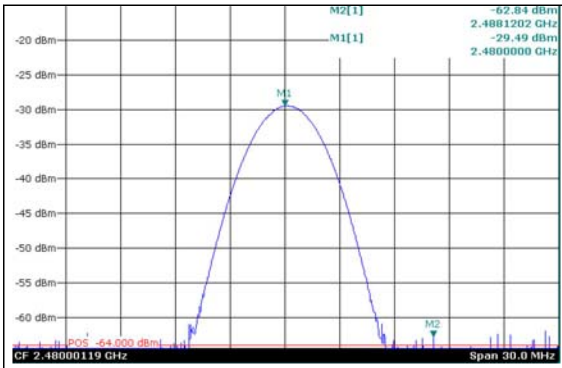
Trans. Inv. F-Rec. Inv. F / bb[3]



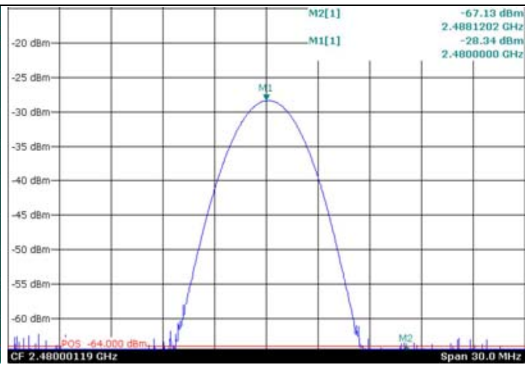
Trans. Inv. F-Rec. Our antenna/ bb

Figure 4.17 VSWR Graphs of The Antenna - Section 1

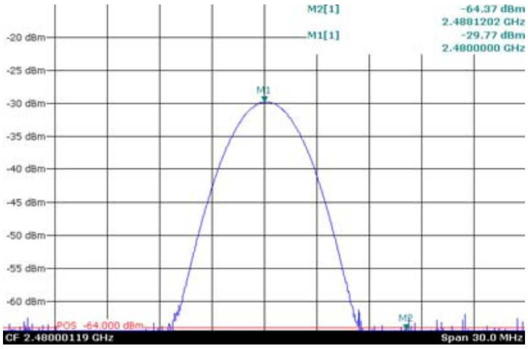
[3] bb:back to back



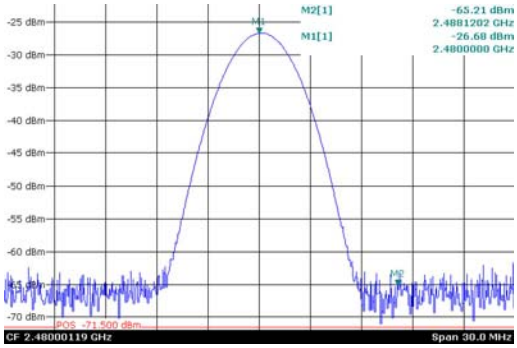
Trans. Inv. F[4]-Rec. Inv. F/ss[5]



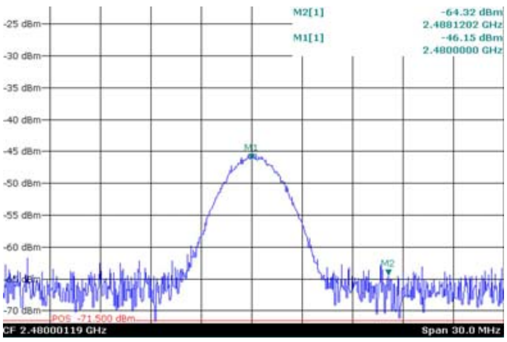
Trans. Inv. F-Rec. Our antenna /ss



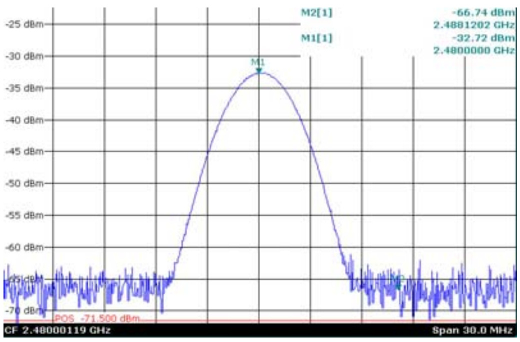
Trans. Inv. F-Rec. Our antenna 90°ele[6]



Trans. Our antenna -Rec. Mon./ 0°



Trans. Our antenna -Rec. Mon[7] /90



Trans. Our antenna -Rec. Mon/90°ele

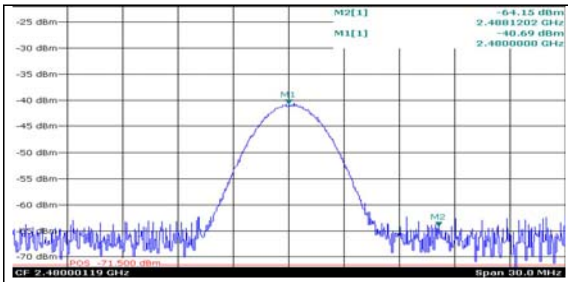
Figure 4.18 VSWR Graphs of The Antenna - Section 2

[4] Inv. F: inverted F antenna

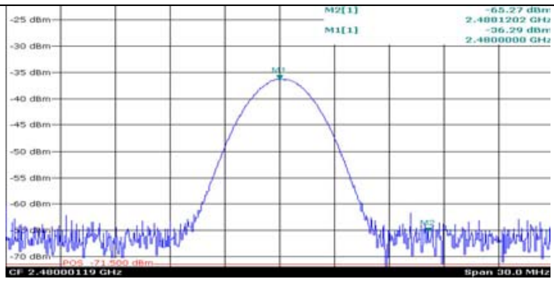
[5] ss: side to side

[6] ele: elevation

[7] Mon: monopole antenna



Trans. Our antenna -Rec. Mon/270°deg



Trans. Inv. F- Rec. Mon

Figure 4.19 VSWR Graphs of The Antenna - Section 3

Table 4.3 Summary of measurement of antenna directivity

Transmitter Inverted F with 18 dBm Power			
Received Power	Receiver Inverted F	Receiver Our antenna	Receiver Monopole
face-to-face (bb)	-21.68	-22.66	-36.29
side-to-side (ss)	-29.49	-28.34	

Transmitter Our antenna with 18 dBm Power				
Received Power at Monopole Antenna	0°	90°	90° Elevation	270° Elevation
	-26.68	-46.15	-32.72	-40.69

5. CONCLUSIONS

The solar panel is modified to function both as a solar panel and as a patch antenna. The combined use of solar cell and patch antenna allows for dual usage of antenna ground and solar cell, which otherwise, becomes practically challenging due to limited space.

PV cell does not lose its main characteristics when integrated with edge-fed microstrip patch antenna. It still provides enough power for the rechargeable batteries. This means our antenna integrated with solar module can stay operational without an external power source, which, in turn, extends the life of the transmitter module tremendously. A charging circuit is also designed and tested to prove that the solar module indeed charges the battery system and can be used as a power supply module for the wireless sensor node.

The directivity and VSWR of the antenna, impedance matching are optimized especially by changing the placement of feed line in FEKO. Using solar module as a ground plane of the antenna is an important factor to obtain an improved gain when compared to on-board antenna modules.

Due to unavailability of an anechoic chamber at the university and at the neighboring institutions, we were able to make received-power measurements which are directly related to antenna gain. Received power measurements of the designed antenna exhibits much better performance when it is compared to inverted-F and monopole antennas.

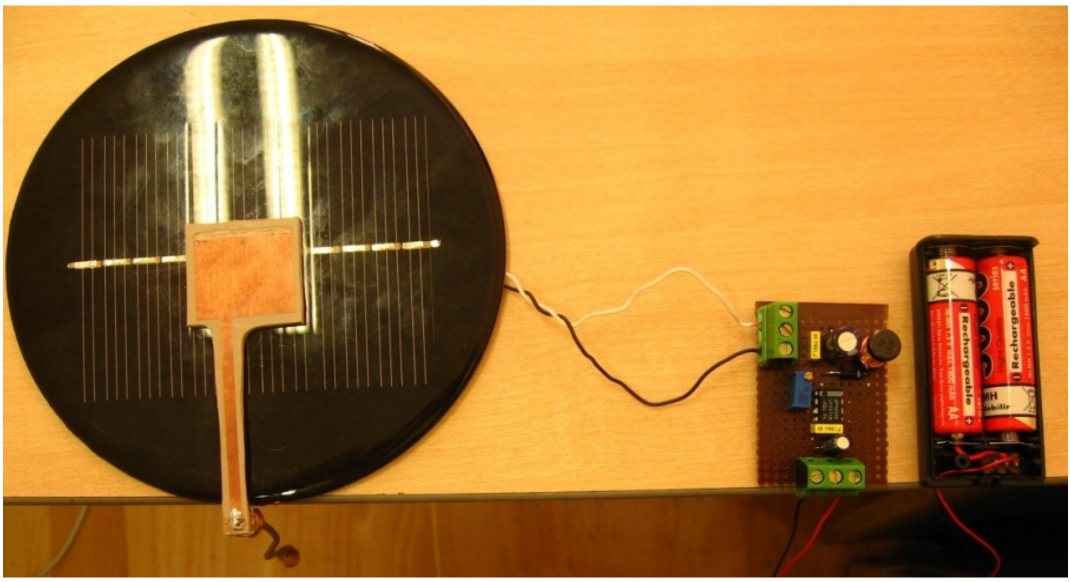


Figure 5.1 The microstrip patch antenna integrated PV cell with charger circuit

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