Performance Analysis of 6.8 GHz Active Integrated Photonic Antenna

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ABSTRACT:

Recent advances in technology have stimulated wireless communication systems to move towards higher frequencies such as 5 GHz band for IEEE standard 802.11a and HIPERLAN type 2 (H/2) standards. Considering the practical difficulties such as propagation losses and high feeder in the coaxial cable, Integrated Photonic antenna has attracted most of the wireless system designers. This paper, presents the results of the investigation of broad band active Integrated Photonic antenna consisting of photodiode integrated directly with the microstrip patch radiator. This photonic antenna designed to operate at 6.8GHz within 750MHz frequency band. Antenna structure consists of 'S' shaped microstrip patch and its various parameters are analyzed for using it in ROF application. An equivalent circuit model for the photodiode is developed to estimate the input impedance (Z_{PD}) as a function of frequency to assist in the impedance matching between the photodiode and the patch radiator. The main purpose of this study is to increase the effective radiated power of photonic antenna to the level useful for indoor applications. The input impedance Zi of the microstrip patch radiator that depends on feeding point position (d_f) which provides the highest antenna efficiency within the widest frequency band. The return loss is more than at –10dB level over the entire operating (750 MHz) frequency band. The performance of this photonic antenna in the frequency range 6.8 GHz is studied both theoretically and experimentally.

Keywords: ROF network technology, photonic antenna, input impedance, s-shape microstrip structure, return loss, gain

I. Introduction: As wireless communication systems move to higher frequencies such as 5GHz band for IEEE 802.11a and HYPERLAN type-2 (H/2) standards, the coaxial cable based signal distribution for inbuilding distribution antenna systems become impractical because of high feeder and propagation losses. In recent years the research works have focused on using photonic technologies to improve the parameters of antenna elements or array of elements. Wireless over optical fiber techniques can be successfully used to deliver microwave communications signals between, for example, the Radio Network Controller and the antenna points for mobile communications systems. Besides carrying digital data, optical fiber can also transmit radio signals for wireless communication. So-called "radio-over-fiber" technology has been used to provide access to radio dead zones, but new research is looking into using this technology to broadcast wireless closer to home. Radio over fiber (RoF) modulates an optical wavelength in the fiber with a radio signal. This solves the attenuation problem during transport of the signal. As wireless signal can be simply relayed down the fiber to remote antennas that cost relatively little to install and should be immune to upgrades. RoF is already being used to transmit wireless signals into hard to reach areas like tunnels and stadiums.

1.1 RoF communication technology: RoF into homes and buildings along the optical access infrastructure, as part of a general trend toward merging wired and wireless communication. Fiber in this case would already be carrying Internet traffic, but it could also carry cell phone conversations transmitted over a remote antenna installed in the premises. In a multi-user scenario, the radio signals would pass directly onto the fiber without any processing. However, for a single home, it would make more sense to set up a "femtonode" that converts the radio waves from wireless devices into Internet data and uses the home Internet connection to connect to other mobile users. In any case, this network sharing could provide indoor wireless coverage at a fraction of the cost of relying solely on outdoor base stations. In the future, wireless home networks may be built on a RoF skeleton. As of now, most homes and businesses use WiFi to connect to laptops, but soon TVs and other media devices may need a wireless hook-up. One way to get more bandwidth is to trade WiFi for ultra-wideband (UWB) [3], which can support data rates that are 1,000 times faster. The trouble is that UWB can only travel approximately 10 meters and is unable to penetrate walls, so there needs to be a way to distribute the signal throughout a house or building.

One solution is to use optical fibers. The Radio over Fiber (RoF) communication technology combines the technical advantages of both fiber communication and wireless mobile communication to solve the problems of bandwidth, flexibility and electromagnetic interference. Research of the technology is drawing wide concerns around the world. However, high cost becomes a drawback of this technology at present.

In this article it shows the results of the investigation of the broadband active integrated photonic antenna. The main goal of this is to increase the effective radiated power of the photonic antenna to the level useful for indoor applications.

II. Photonic antenna concept: Conventional microwave antenna usually has a microstrip or coaxial feeding line finished by the microwave connector. The microwave power is transmitted to and from the antenna by means of RF cable. In the photonic antenna, the RF cable is replaced by optical fiber; therefore it is necessary to use optoelectronic components, such as lasers and photodiodes, for the conversion of microwave signal to the modulated optical signal and vice-versa. Photonic antenna can be hybrid or monolithic (Fig.1 & 2). Hybrid photonic antenna consists of two independent parts: fiber-optic photodiode module and conventional microwave antenna, which are connected together by means of microwave connectors. In the monolithic photonic antenna, the photodiode is integrated with microwave antenna, and the photocurrent generated by photodiode directly excites the antenna.

Photonic monolithic antennas have the following advantages:

- light weight and small size as photonic antenna does not require metal RF cables and connectors;
- the possibility of the remote antenna control due to low loss in optical fiber below 0.2 dB / km;
- wide bandwidth, which is limited only by the antenna itself;
- immunity to electromagnetic interference, which is important to the large antenna systems;
- the possibility to use optical signal processing and optical generation of microwaves in the antenna systems

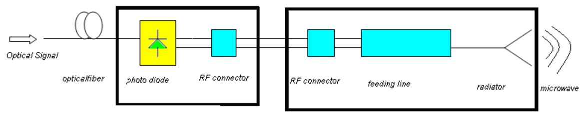


Fig. 1. HYBRID

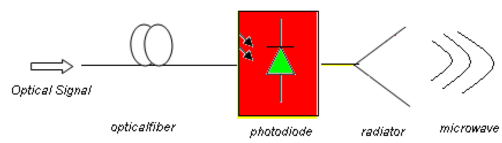


Fig.2. INTEGRATED

III. Active Integrated Photonic Antenna: In case of the integrated photonic antenna, the photodiode is loaded directly with the input impedance of the microstrip patch radiator as shown in fig.3. The microwave signal is fed to the photonic antenna by means of a single mode optical fiber. The radiator is a rectangular S-shaped microstrip patch designed to operate at 5.8 GHz within 750 MHz frequency band. (fig.4, Table 1)

The photodiode used in photonic antenna is very high speed and low capacitance InGaAs PIN Photodiode with 10.5GHz bandwidth and 1.A/W sensitivity at the wavelength 1520 nm PIN photodiode. The diameter of photosensitive area is 50 µm. It is very high speed and low capacitance InGaAs PIN double-lens optical system is designed for single-mode fiber as well as for multimode fiber. This photodiode is ideal for datacom, telecom and general purpose applications. Fig.5 shows the Spectral characteristics of the InGaAs PIN photodiode.

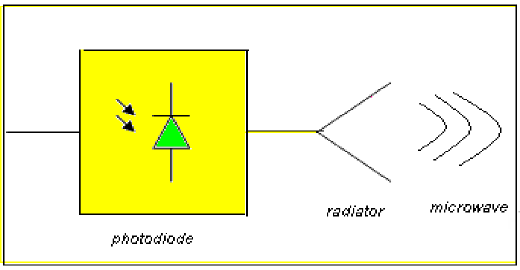


Fig 3 PHOTONIC ANTENNA

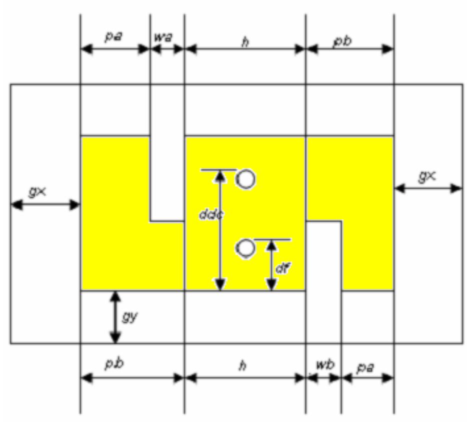


Fig. 4 S-SHAPED MICROSTRIP PATCH

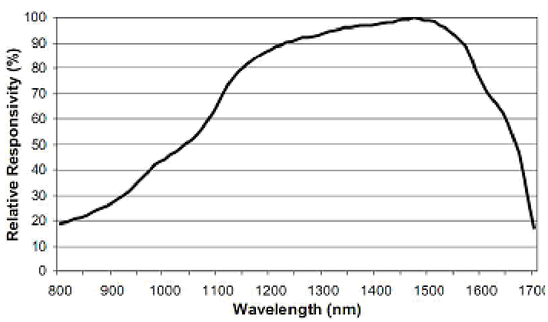


Fig.5 SPECTRAL CHARACTERISTICS OF THE InGaAs PIN PHOTODIODE

Fig 6 & 7 shows the front view of antenna with S-shaped structure and back view of the photonic antenna which has photodiode directly linked with the patch radiator which is designed and fabricated. A microstrip substrate is used to mount the photodiode, which is soldered onto the backside of the antenna. The photodiode current can flow across the patch. It can be seen that 750 MHz frequency band is achieved at greater than -10dB level.

Fig.8 shows the equivalent electrical circuit of the investigated active integrated photonic antenna for high frequencies. The micro strip patch is represented as complex impedance Z_i. The photodiode is represented by current source $I_{ph,}$ p-n junction capacitance C_{pn} (0.07 pF), p-n junction resistance R_{pn}, series resistance R_s (3Ω), bonding wire inductance (0.5nH), package inductance Lp (3nH).

From equivalent circuit one can see that the effective radiated power of the photonic antenna depends on the impedance matching between the photodiode and the microstrip patch. Since input impedance Z_i of the micro strip patch radiator depends on the feeding point position d_f(Fig.4), there is optimal feeing point providing the highest antenna efficiency within the widest frequency band. In order to find optimal feeding point, a detailed knowledge of input impedance of, both the photodiode and the micro strip patch radiator the desired frequency band is required.

Fig.6.

FRONT VIEW OF PHOTONIC ANTENNA

TABLE 1

PARAMETERS OF S – SHAPED MICROSTRIP PATCH

Fig 7.

BACK VIEW OF PHOTONIC ANTENNA

3.1 EQUIVALENT CIRCUIT OF PhAIA

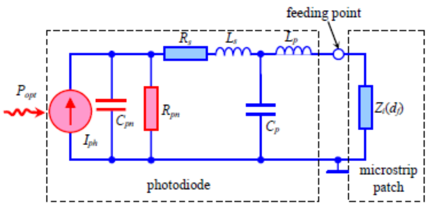


Fig.8.

EQUIVALENT CIRCUIT OF PhAIA

The input impedance of the photodiode Z_{PD} can be calculated via elements of the equivalent electrical circuit:

REACTANCE AND RESISTANCE CALCULATION:

FORMULA:

$$Z_{PD} = j\omega L_P + \left(\frac{1}{R_S + \frac{R_{Pn}}{(1 + j\omega C_{Pn} R_{Pn})} + j\omega L_S} + j\omega C_P \right)^{-1}$$

```
clear all;
lp=3.*10^-9
rs=3;
rpn=1*10^3;
cpn=.07*10^-12;
ls=.5*10^-9;
cp=.5*10^-12;
% real part simulation
f=4.5*10^9:.2*10^9:7*10^9;
w=2*3.14*f;
r1=(rs-w.^2*ls*cpn*rpn).*(1-w.^2*cp*(rs*cpn
*rpn+ls))
r2=w.^2*(rs*cpn*rpn+ls).*(cpn*rpn+cp*rs-w.^
2*cp*ls*cpn*rpn+cp*rpn)
rn=r1+r2
dr1=(1-w.^2*cp*(rs*cpn*rpn+ls)).^2+w.^2.*(c
pn*rpn+cp*rs-w.^2*cp*ls*cpn*rpn+cp*rpn).^
2
r=(rn./dr1)
figure(1)
stem(f,r)
xlabel('FREQUENCY IN GHz');
ylabel('RESISTANCE IN OHMS');
title('GRAPH ILLUSTRATING THE
RESISTANCE VARIATION');
clear all;
lp=3.*10^-9
rs=3;
rpn=1*10^3;
cpn=.07*10^-12;
ls=.5*10^-9;
cp=.5*10^-12;
%imaginary part simulation
f=4.5*10^9:.2*10^9:7*10^9;
w=2*3.14*f;
dr1=(1-w.^2*cp*(rs*cpn*rpn+ls)).^2+w.^2.*(c
pn*rpn+cp*rs-w.^2*cp*ls*cpn*rpn+cp*rpn).^
2
im1=w*(rs*cpn*rpn+ls).*(1-w.^2*cp*(rs*cpn*
rpn+ls))
im2=-w.*(rs-w.^2*ls*cpn*rpn+rpn).*(cpn*rpn
+cp*rs-w.^2*cp*ls*cpn*rpn+cp*rpn)
im=w.*lp+im1+im2/dr1
dr1=(1-w.^2*cp*(rs*cpn*rpn+ls)).^2+w.^2.*(c
pn*rpn+cp*rs-w.^2*cp*ls*cpn*rpn+cp*rpn).^
2
figure(2)
plot(f,im)
xlabel('FREQUENCY IN GHz');
```

```
ylabel('REACTANCE IN OHMS');
title('GRAPH ILLUSTRATING THE REACTANCE VARIATION');
```

This is simulated by using MATLAB software. The simulation results are shown below. Fig.9. shows the resistance variation and Fig. 10. shows reactance variation.

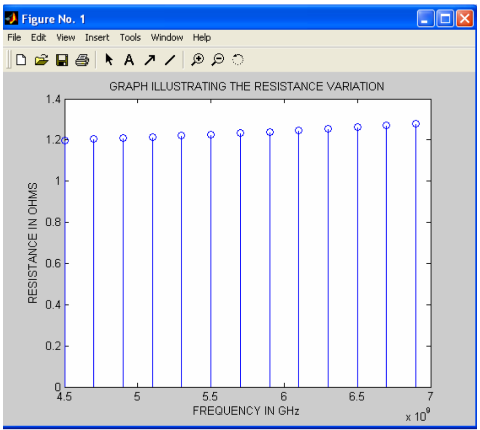


Fig. 9. RESISTANCE VARIATION WITH FREQUENCY

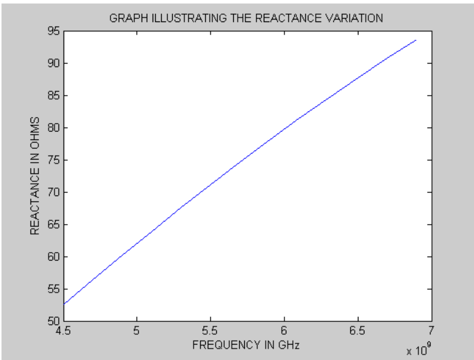


Fig.10. REACTANCE VARIATION WITH FREQUENCY

Since p-n junction resistance R_{pn} is larger than 1 kΩ at the bias voltage -5v the input impedance of photodiode Z_{pd} posses the imaginary part, which is varying from 52Ω to 80Ω at the frequency range from 4.5 GHz to 6.5 GHz which is as shown in Fig.9 & Fig.10.

Fig 12 presents the measured reflection coefficient of the designed microstrip patch antenna. It can be seen that 750 MHz frequency band is achieved at greater than -10dB level. A microstrip substrate is used to mount the photodiode, which is soldered onto the backside of the antenna. The photodiode current can flow across the patch.

The structure is created by using HFSS (HIGH FREQUENCY STRUCTURE SIMULATOR-3D SIMULATOR SOFTWARE)

The return loss is shown in the following figure. At 5.95 GHz the loss is -33.53 dB.

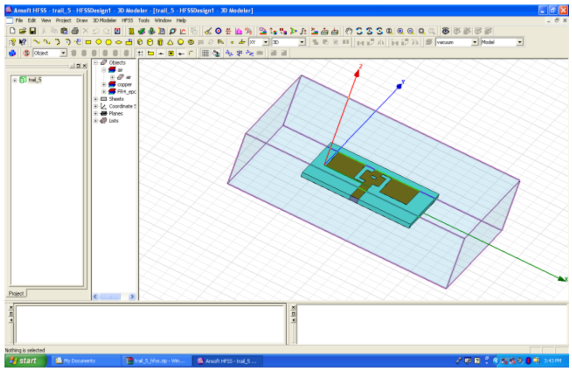


Fig.11. simulation of s- shape structure

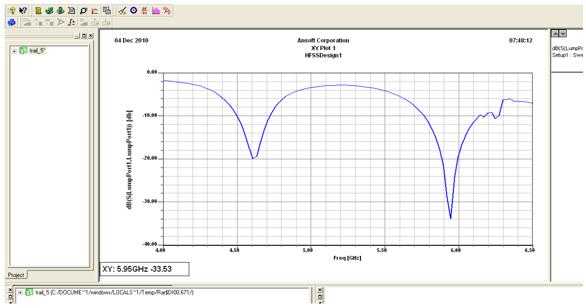


Fig 12: RETURN LOSS (5.95 GHz -33.53dB)

The bias voltage is -5v is given. The feed point position has been set to df = 0.7mm. In this case the power supply position has been set to ddc = 8.2 mm where active resistance equals to zero and microwave signal is rejected. It shows that the input impedance Z_i increases for higher frequency causing favorable conditions for matching photodiode. The input impedance Z_i of the microstrip patch radiator that depends on feeding point position (d_f), which provides the highest antenna efficiency within the widest frequency band. Both the resistance and reactance change with frequency, causing the antenna efficiency to be frequency dependent.

IV.Experimental setup: Fig.13 shows the experimental setup for the measurement of the antenna gain. The measurement system consists of planar scanner and rotary table placed into the anechoic chamber and the block of measuring instruments from Agilent Technologies. The whole system is managed by the computer. Source microwave signal is converted to intensity modulated optical signal by means of high

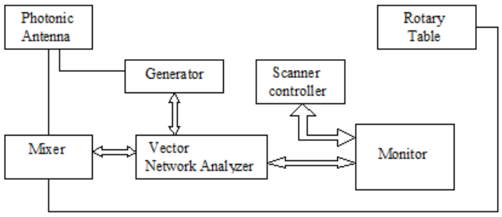


Fig.13. BLOCK DIAGRAM OF EXPERIMENTAL SETUP

speed photo diode module. Then the optical signal is fed to the photonic antenna by means of single mode fiber optic cable. Measurement microwave signal is fed from antenna under test to the microwave receiver. So in our experimental setup the photonic antenna (as a probe) is the radiating antenna and the antenna under test is the receiving antenna. The fabricated structure (S-shape) is tested by using network analyzer which is connected as shown in the fig.14.

Fig 14. DESIGNED STRUCTURE UNDER TEST

This antenna is tested in Network Analyzer. The result shows at 6.8 GHz the return loss is -31.284 dB as shown in fig.15. Its radiation pattern is shown in Fig.16 which is tested in RF anechoic chamber. From this we can understand that this structure can be suited to use in high frequency broad band applications.

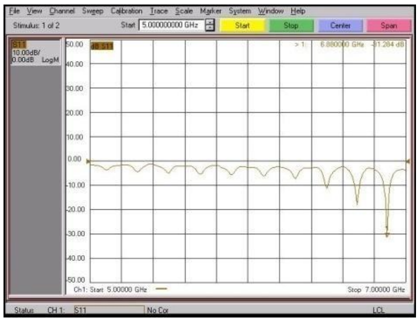


Fig. 15 RETURN LOSS TEST REPORT FOR ANTENNA UNDER TEST

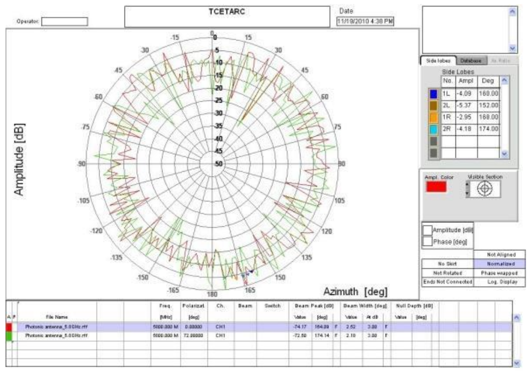
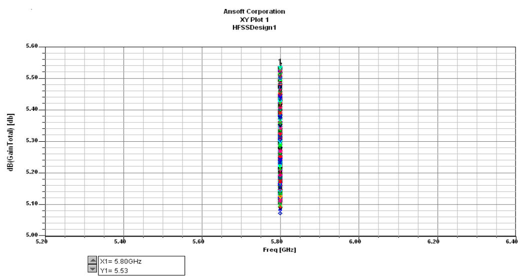
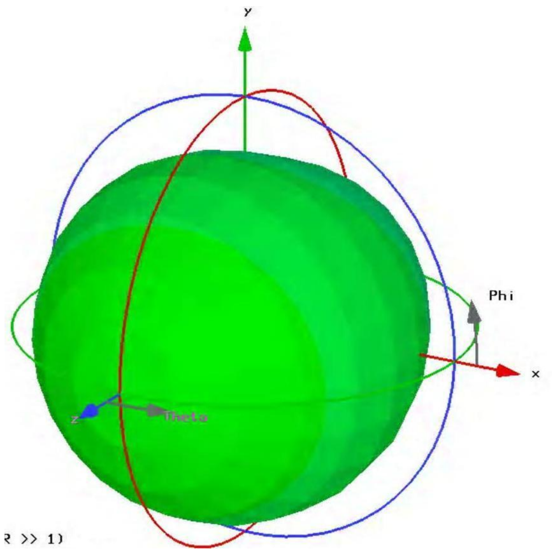


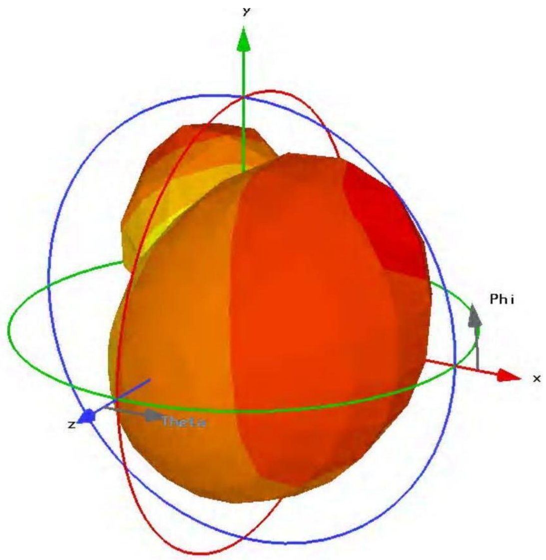
Fig.16.RADIATION PATTERN

V: Results :

3D plot Gain with its components (abs, theta, phi)




y
Phi
x
z
Theta
R >> 1)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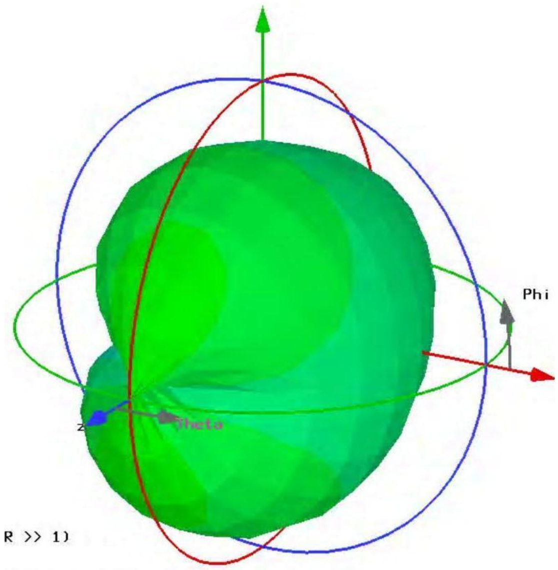
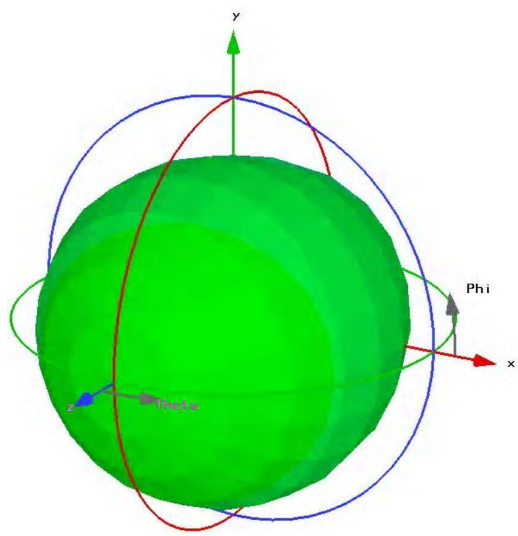
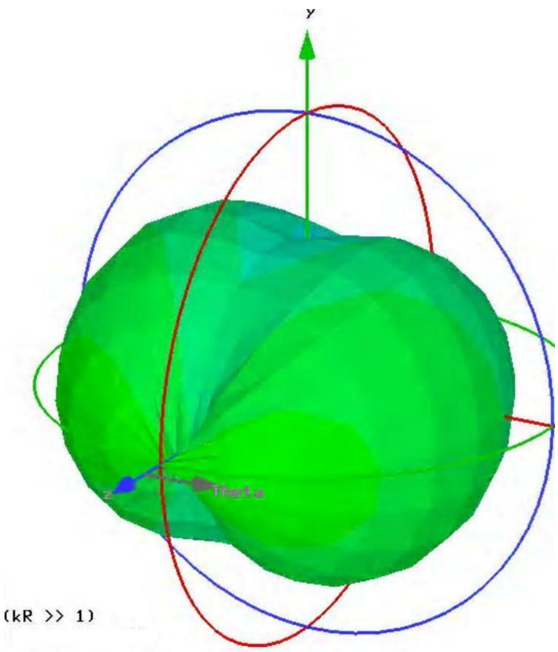
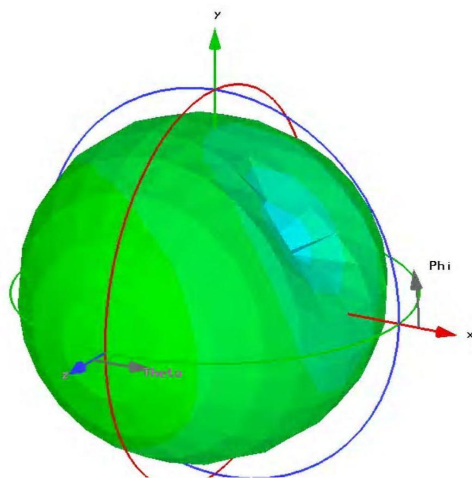

Phi
z
Theta
R >> 1)


y
Phi
x
z
Theta


y
z
Theta
(kR >> 1)


y
Phi
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z
Theta

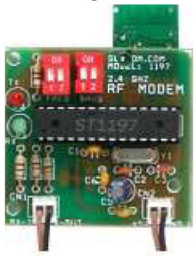
TABLE 2

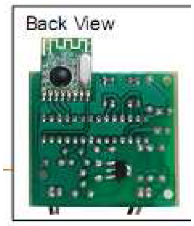
S-SHAPE GAIN RESULTS								
Type	Approximation	Monitor	Component	output	Rad. efficiency	Tot. efficiency	Gain (Abs)	Gain
Farfield	Enabled (kR >>1)	Far field	Abs	Gain	0.1576	0.0008007	-2.607 dB	_
Farfield	Enabled (kR >>1)	Far field	Theta	Gain	0.1576	0.0008007	-2.607 dB	-3.047 dB (Theta)
Farfield	Enabled (kR >>1)	Far field	Phi	Gain	0.1576	0.0008007	-2.607 dB	-3.047 dB (Phi)

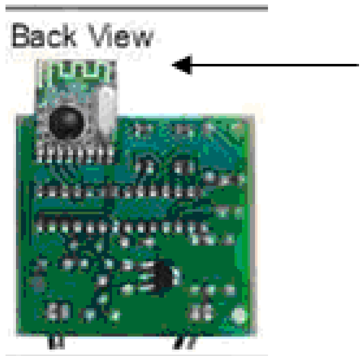
VI. Conclusions

The Active Integrated Photonic Antenna was designed to operate at 6.8 GHz within 750 MHz frequency bandwidth. The optimal feedint point position was designed by using MATLAB. The agreement between measurement and circuit model results for the impedance is very good. The parameters and characteristics of the broad band active integrated photonic antenna have been presented. The different patch antenna analysis of E-shape and S-shape was designed by using Ansoft HFSS software. The photonic antenna characteristics such as return loss, gain of simulation results as well as anechoic chamber results, network analyzer reports have been presented. This project shows that it is best suited for RoF communication in home appliances. The efficiency of the integrated photonic antenna can be increased by means of optimal matching of the photodiode with the radiator with no matching networks and no RF amplification. The different feeding point analysis is shown in the report. Finally the designed antenna can be effectively used for RoF communications in broadband home appliances.

RF modem can be used for applications that need two way wireless data transmission. In future this antenna can be embedded to this RF modem so that wireless communication can be set up easily for longer transmission distance. Its prototype is shown in fig.







The parameters and characteristics of the broadband active integrated photonic antenna have been presented. The reflection coefficient, radiation pattern characteristics and enhanced gain characteristics are shown. It is shown that the efficiency of the photonic antenna can be increased by means of the optimal matching of the photodiode with the radiator, with no matching networks and no RF amplification.

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