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Design of Backhual Radio System for Outdoor to Indoor Signal Distribution

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Abstract

A simple design of integrated system for wireless backhaul network that can work as a wireless bridge and access point had been developed in this paper. This system has a circular polarization (CP) patch antenna built for IEEE 802.11b/g standard (2.4GHz ~ 2.4835 GHz frequency band) and intended to point to multi point link. Another antenna is designed on frequency range 5.725 ~ 5.825GHz unlicensed band IEEE802.11a standard to point to point link. Therefore, two antennas on different frequencies and polarizations have been developed and finally incorporated on one router board. First antenna is a single-feed microstrip. The antenna substrate has an air-layer with thickness about 2.5% of the wavelength at a resonant operating frequency. The two truncated opposite corners technique are used to obtain the circular polarized operation by selecting an optimal size of truncating. A flat ground plane with an optimal position for the probe pin is used to generate an impedance matching with a wide bandwidth. Measured -10dB bandwidth is 14.3%, maximum gain and half-power beamwidth are, -41dB, 8.3 dBi, 60° respectively. Second antenna used is Radial Waveguide Slot Array Antenna (RWSA), which is directional antenna and used for main internet source. Return loss, gain and radiation pattern simulated by software which is developed on Borland C++ 5.0. Tests were setup in different environments, in the lab and outdoors and practical measurements have been taken to validate the simulation results and performance. The proposed design can find its applications in wireless communication systems, especially where cost-effective high-speed wireless Internet access service is required.

Keywords: *RWSA, Wireless Backhaul, circularly-polarized antenna, WLAN*

پوختە

ئەم توێژینەوەیە بایەخ بە مەخشەسازی و پەرەپێدانی سیستەمی بێتەل دەکات کە وەک تاوەرێک و لە هەمان کاتدا وەک خاڵی دابەشکردن کار دەکات. سیستەمەکە پێکهاتووە لە دوو ئانتێن کە یەکێکیان بۆ دابەشکردنی ناوخۆیە و خاوەن جەمسەربەندیەکی بازنەییە و کار لەسەر فریکوێنسی 2.4GHz ~2.4835 GHz band) دەکات، ئانتێنەکەی تریش کار لەسەر فریکوێنسی 5.725 ~ 5.825GHz band. ئەنتێنای یەکەم گۆڕاوێکی خاوەن یەک فیدەرە، خەسڵەتی سەرەکی ئەم ئەنتێنایە بوونی چینێکی هەوایە بە ئەستوورایی ٢.٥% ی درێژە شەپۆلەکە لە کارکردنی فریکوێنسیەکە. هەرچی ئەنتێنای یەکەمە تەکنیکێک دەخاتە کار کە پێچەوانەی گۆشەکانە بۆ گەیشتن بە کرداری جەمسەربەندی بازنەیی لە ڕێگای دیاریکردنی بارستەی نموونەیی بڕینەکە. توێژێکی کانزایی رووتەختیش بەکار دێت لەگەڵ شوێنگەیەکی نموونەیی و گونجاوی دەرزییەکە بۆ بنیادنانی بەرگریەک گونجاو لەگەڵ ڕووتەختی چێوە فراوانەکە. پێوەری چێوەی فریکوێنسی 14.3% 10db زۆرترین بڕی بەدەستهاتوو لە تیشکەکانی نیوە-هێز

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8.3dBi, 41db بریتیە لە ٦٠ پلەی یەکبەدوایەک . ئەنتێنای دووەمی خراوەکار بریتیە لە تیشکە ڕێنمای شەپۆلیە کە خاوەن دەرچەیەکە و وەک سەرچاوەی یەکەمی ئینتەرنێت بەکار دێت. نەخشەڕێژی کراوە بەهۆی بەرنامەی بۆرلاند C++5.0 ئەزموونەکانی ئامادەکردن لەناو تاقیگە و لە هەوای کراوەشدا جێبەجێکراوە و پێوەری کرداری وەرگیراوە بۆ دڵنیا بوون لە ئەنجامەکانی کارکردن. نەخشەسازی پێشنیارکراو دەکرێت لە سیستمی پەیوەندیەکانی بێتەل بەکاربێت، بە تایبەت لە کاتێکدا کە چوونە ناو تۆڕەکانی ئینتەرنێتی بێتەل (وایەرلێس) ی خێرا و گونجاو لە ڕووی ئابووریەوە، پێویستە.

الملخص

هذا البحث هو تصميم وتطويرلشبكة لاسلكية تعمل كبرج ونقطة توزيع في آن واحد. النظام متكون من هوائيين احدهما للتوزيع الداخلي ذو استقطاب دائري، يعمل على التردد (2.4GHz ~2.4835 GHz band). والهوائي الاخر يعمل على تردد 5.825GHz band ~ 5.725 . الهوائي الأول هو متغير ذو تغذية واحدة. الركيزة الاساسية للهوائي لديها طبقة الهواء ذات سمك 2.5٪ من طول الموجة على تردد تشغيل الرنين. بالنسبة للهوائي الاول تستخدم تقنية عكس الزوايا للحصول على عملية الاستقطاب الدائري عن طريق تحديد الحجم الأمثل للاقتطاع. وتستخدم طبقة معدنية مسطحة مع الموقف الأمثل للإبرة لتوليد مقاومة مع عرض النطاق الترددي الواسع. عرض النطاق الترددي -10db هو 14.3٪، والحد الأقصى للربح على إشعاع نصف القدرة هي 41db-، 8.3dBi،عند 60 درجة على التوالي. الهوائي الثاني المستخدم هو شعاعي الدليل الموجي ذو فتحة الصفيف، ويستخدم لمصدر الإنترنت الرئيسي. صمم بواسطة برنامج البورلاند .5.0 ++ C وكانت اختبارات الإعداد مطبقة في المختبر وفي الهواء الطلق واتخذت القياسات العملية للتحقق من صحة نتائج المحاكاة والأداء. التصميم المقترح يمكن استخدامه في أنظمة الاتصالات اللاسلكية، وخاصة التي تتطلب خدمة الدخول إلى شبكة الإنترنت اللاسلكية عالية السرعة الاقتصادية من حيث التكلفة.

1. Introduction

In practically any multi-location application using Internet technology or wireless, backhaul is required. As wireless technology evolves beyond traditional T-1capabilities, wireless backhaul is emerging as a versatile and integral component of sending data from one point to another, where it can be distributed to many points of access. While it could be a choke point for the network, backhaul can also be its strength when designed correctly. Wireless backhaul in commercial or enterprise networks has become very attractive with the high data rates, ease of installation and scalability. Immense efforts exert to combine different systems into one system in order to reduce cost and increase the performance, efficiency, and reliability. Higher levels of integration are required to drive prices lower for commercial wireless systems. Wireless backhaul links are fast emerging as a flexible, quickly deployable, and high capacity substitute for T1 and other traditional wired links. Antennas play a major role to establish this kind of links.

In a communication system that uses circularly polarized radiation the rotational orientations of the transmitter and the receiver antennas are insignificant in relation to the received signal strength. With linearly polarized signals, on the other hand, there will be very weak reception if the transmitter and receiver antenna orientations are nearly orthogonal. Also in circularly polarized, after reflection from metallic objects, the sense of polarization reverses from left-hand circularly polarized (LHCP) to right-hand circularly polarized (RHCP) and vice versa to produce predominantly orthogonal polarization. The system then tends to discriminate the reception of such reflected signals from other signals arising from direct paths. Cutting off two diagonally opposite corners makes the resonance frequency of the mode along this diagonal to be higher than that for the mode along the uncut diagonal. The patch is fed along the central axis so that the orthogonal modes are generated. In case of comparison between the circularly polarized and linearly polarized antenna; we can say; since circular polarized antennas send and receive in all planes, the signal strength is not lost, but is transferred to a different plane and is still utilized and circular polarized antennas give higher probability of a successful link because it is transmitting on all planes (R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon2001). The circularly-polarized signals are much better at penetrating and bending around obstructions. Also circular polarization is more resistant to signal degradation due to inclement weather conditions. Finally circular polarization is much more effective than linear polarization for establishing and maintaining communication links. To provide a wide impedance bandwidth, a thick air-layer substrate can be used (N. Herscovici, Z. Sipus, and D. Bonefacic2003). To excite antennas that have thick air-layer substrates some modifications on the probe to compensate the large inductance introduced by the long probe pin in the thick air-layer substrate. For a better bandwidth of a single-feed single-element patch antenna, the antenna structure is usually designed to have a thick air-layer. For a circularly polarized bandwidth to be greater than 10%, an air-substrate thickness of about 20% of the operating wavelength is desired. The conventional dimension of CP patch antenna is much less than this dimension. The required bandwidth for WLAN systems operated at the 2.4 GHz band is about 3% of the centre operating frequency (Y. Li, J. Ou Yang, and P. Yang, 2013). The required antenna air-layer substrate thickness is less than 10% of the operating wavelength for achieving 3% bandwidth. A novel broadband RHCP patch antenna designed using a simple feed structure was implemented for this system. The air-substrate thickness of the proposed antenna is about 2.5% of the wavelength at a resonant operating frequency.

On the other hand, annular slot array antenna enjoys all the advantages of planar structure, while they have high gain to contribute significantly towards this proposed system. Well, these types of antennas started at the end of the 1950s, when Mr. Kelly (K.C. Kelly 1957) proposed a radial waveguide as a feeding network for a twodimensional distribution of slots and demonstrated its use in the early 1960s (Goebels, F. J. Jr. and Kelly, K. C,1967). In 1964, Kelly et al.(Kelly, K. C. and Goebels, F1964) introduced the annular slot monopoles planar arrays with linear polarization which was limited only to the 900 sectoral radial waveguides instead of a full radial waveguide. This model has its feeding mode controlled to give an arbitrary polarization. Afterward, Goto and Yamamoto (Goto, N., and Yamamoto, M., 1980) were the first to propose the commercial use of RWSA operating in a traveling TEM wave excitation for 12 GHz band. Shortly In 1980, Goto and Yamamoto proposed the modified concept of the slotted waveguide antenna by introducing an alternative slot arrangement that would allow for circular polarization to be obtained from a double layer radial cavity, fed by a simple probe feeding structure centrally located in the lower level of the double-layer cavity. Other researchers Tharek and Farah (Tharek, A. R., Farah Ayu, 2002) analyzed on the linearly polarized small aperture RWSA at 5.5GHz band based on IEEE 802.11a standard. The RWSA antenna belongs to the slotted waveguide arrays family, which is the only and the most promising candidates for high gain planar antennas, having the smallest conductor losses among all the planar feeding structures such as the microstrip lines(M. Ando, T.Numuta, J. Takada, & N.Goto, 1988). In the contrast small aperture CP patch Antenna Design for Wireless Local Area Network Application the design made to be high directivity and more functional for indoor WLAN applications. Based on the literature review, this considered as first time when RWSA and CP Patch antenna combined together for wireless backhaul networks.

2. System Description

This integrated system contains of three parts, first part is the Radial Waveguide slot array antenna. It is a kind of slotted waveguide array that is filled with dielectric material that suppresses the grating lobes. The slots are arrayed so that their radiation is added in phase in the beam direction. The structure of the investigated multilayer linearly polarized, RWSA antenna layers are shown in Figure 1.

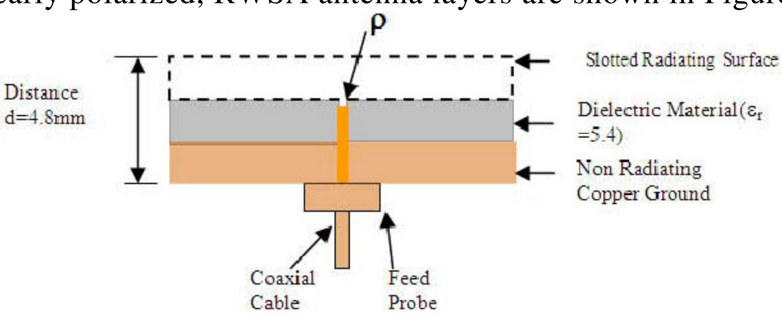

Figure1. RWSA antenna structure.

RWSA antenna consists of three layers FR-4 spaced a distance d apart, the upper plate bearing a radiating slot pattern and the rear plate has additional non radiative slots. The radial cavity formed between these plates is filled with a dielectric material of relative permittivity $\varepsilon_r>1$. In this design $\varepsilon_r=5.4$ has been used. The operation of the antenna can be considered in either receive or transmit modes of operation. Both are equally valid due to the reciprocity theorem. In the transmit

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mode of operation, energy fed to the antenna via the coaxial cable is launched by the feeding mechanism into an outward traveling axially symmetric wave inside the radial cavity. The final prototype is shown in Figure 2.

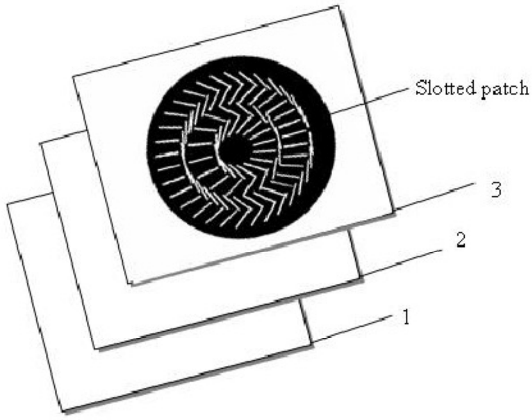

Figure 2. Final prototype of RWSA using 3 layers FR-4.

Figure 3 depicts the geometry of a single-feed circularly polarized microstrip antenna, which is the second part of this project. The patch antenna with a square area of (51x51 mm^2) was printed on a substrate with a thickness of 1.6 mm and a relative permittivity of 4.6. This radiating patch was located on the other h mm thickness of the air substrate layer and on 1.6 mm thickness of a ground plane. The feeder for this radiating patch was a short a short probe pin (h mm).

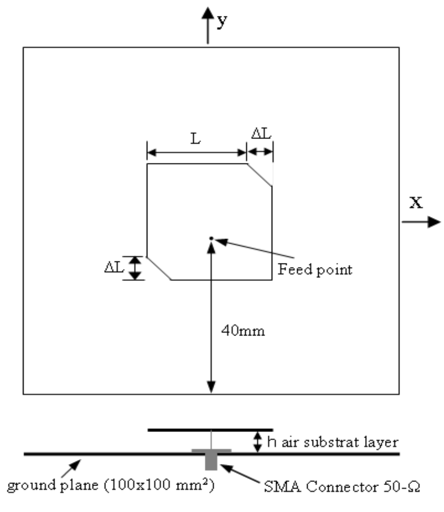

Figure 3. The geometry of the CP microstrip antenna with a thick air substrate layer.

A power splitter or a coupler can be used to feed square patch antenna to achieve a circular polarization. A single probe or a microstrip as the feed element can be used to obtain more compact CP antenna structure. However, the using of single probe feed to create and achieve the circular polarization operation; some change mechanism should be introduced (F. S. Chang and K. L. Wong 2001). The change for the circularly polarized patch antenna should be able to cause the

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fundamental mode to be split into two degenerate modes, namely, the TM0l and TMl0 modes. These two modes are equal in magnitude and ±90° out of phase to establish the necessary conditions for circular polarization. The level of change of the square patch antennas is determined by the ratio of truncated portion length (ΔL) to length of the square patch (L) and the position of the feeding probe, as shown in Figure 3. The antenna gain is enhanced by a thicker air-layer substrate and the ratio (P. L. Teng, C. L. Tang, and K. L. Wong 2001),(Zhang, P.-F., S.-Z. Liu, and S. Zhao, 2015) and (Park, J.-S. and H.-K. Choi, 2015). The right-hand Circular Polarized operation is generated for the antenna geometry shown in figure 3. The centre wavelength is about the double of the length of square patch and eight times of the length of the truncated portion. In the third part of this system two wave guide antennas have been integrated on wireless router with multiple radios which can support two frequencies, one for point to point at 5.8GHz and another for point to multipoint antenna at 2.4GHz.

3. Simulation and Measurement Results

An experiment had been setup to measure the return-loss of RWSA antenna using Marconi 6204 Microwave test set. In order to validate the measured result, the result is compared with simulated result and has been depicted in figure 4.

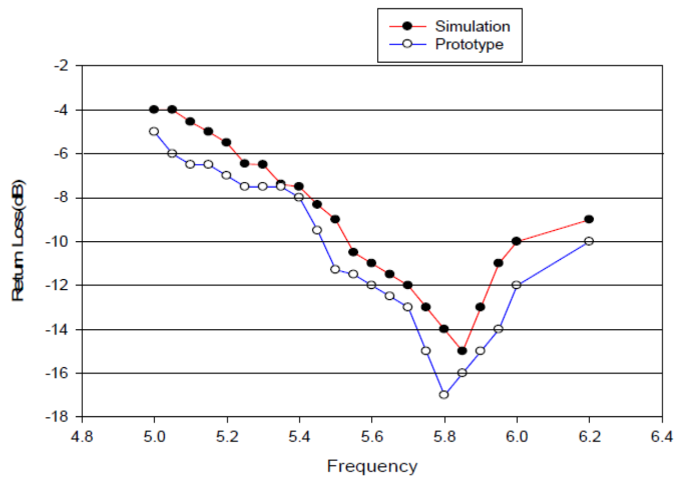

Figure 4. Return loss comparison between simulation and measured results.

To measure the Received Signal Strength Index (RSSI) a test bed was setup at different distances. Figure 5 shows the comparison of RSSI between RWSA and commercial on board Router Antenna.

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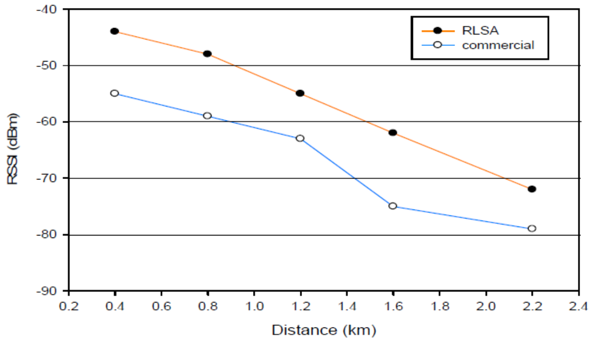

Figure 5. RSSI comparison between RWSA and commercial one.

Table 1 shows the antenna specification of RWSA.

Table 1. RWSA 5.8 GHZ Antenna Specification.

Operating Frequencies	5-6 GHz
Impedance	50Ω
Return Loss	15.5dB ~ 17dB
VSWR	1.4 : 1
Gain	18 dBi
Polarization	Linear

Prototypes of the proposed antenna with a centre frequency at about 2.45 GHz and for WLAN operation in the 2.4 GHz band (2.4–2.484 GHz), with a different substrate thickness were fabricated and investigated. Figure 6 shows the measured and simulated (Using AWR Microwave Office Software) return loss of the proposed antenna. Good agreement between the simulated and measured results were observed, and the obtained 10 dB return-loss impedance bandwidth can be about 350 MHz (2.3~2.65 GHz) or 14.2% of the designed centre frequency at 2.46 GHz for the simulated result and 10 dB return-loss impedance bandwidth can be about 300 MHz (2.3~2.6 GHz) or 12.3% of the designed centre frequency at 2.45 GHz for the measured result. This is wide enough to cover the 2.4 GHz WLAN operating band. Also note that for the operating frequencies within the 2.4-GHz WLAN band, the measured return loss is even better than 6 dB.

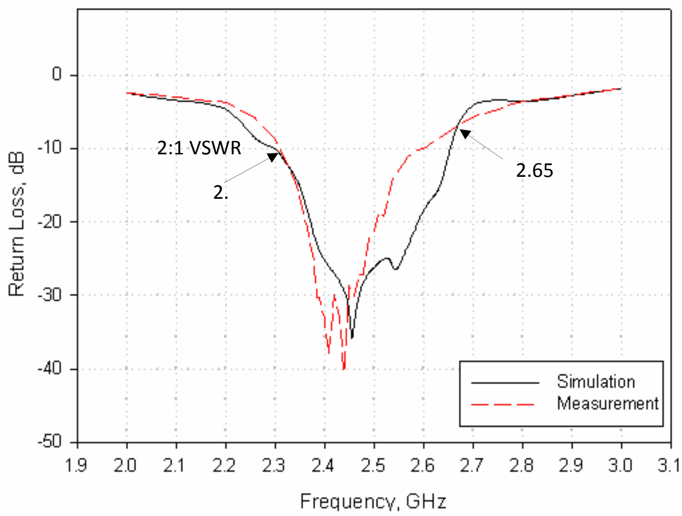

Figure 6. Measured and simulated return loss of the proposed Microstrip antenna.

Figure 7 presents the measured axial ratio in the broadside direction. It shows that the CP bandwidth determined by 3-dB axial ratio is about 220 MHz (2.37~2.59 GHz) or 8.9% of the designed center frequency at 2.475 GHz. The axial ratio comes to a minimum around the center frequency, with the minimum value of about 0.6 dB. This demonstrates that the proposed antenna has good purity of circular polarization at 2.4 GHz.

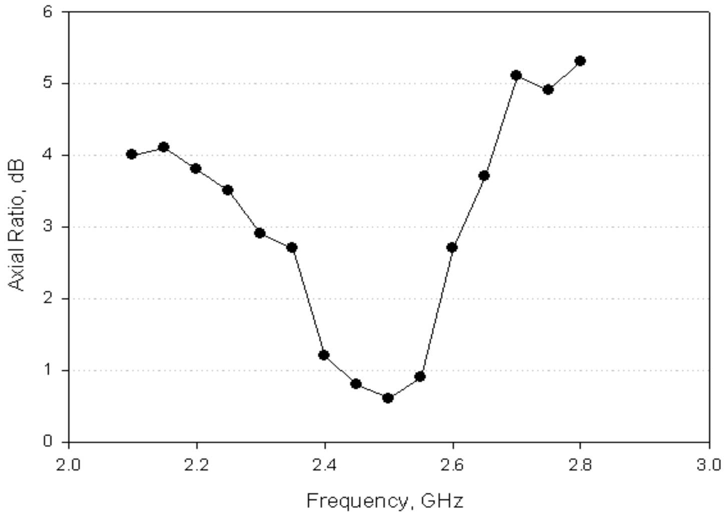

Figure 7.: The measured axial ratio of Microstrip Antenna.

The right hand circular polarized antenna gain is shown in Figure 8 at boresight. The figure shows the results of both measured and simulated CP antenna gain, in the band 2.45-2.6 GHz the simulated gain results better than measured results in 0.4 dBic. The maximum gain of 8 dBic was measured at (2.4-2.6) band GHz and for the simulation result is 8.6dMic at 2.6 GHz. It is more than 7.5 dBic over the 3 dB AR bandwidth.

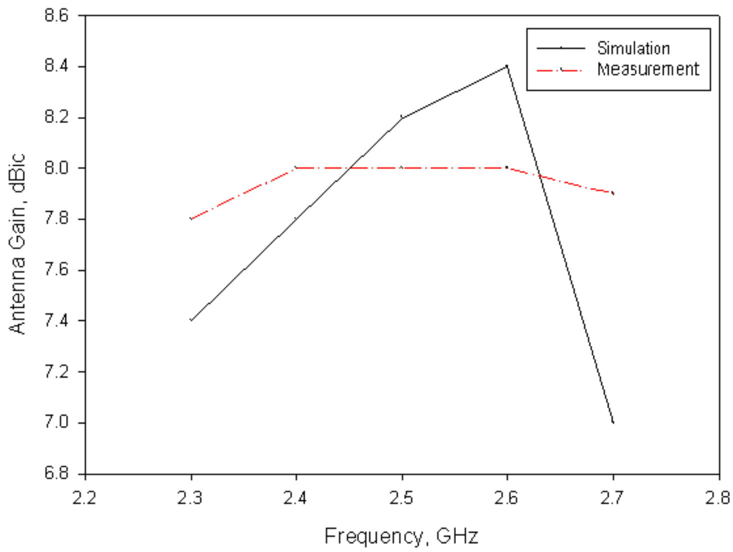

Figure 8. Microstrip Antenna Gain.

Figure 9 depict the measured radiation patterns in two principle planes at 2.4 GHz. In the broadside direction, good CP radiation (right-hand) is obtained. The conclusions

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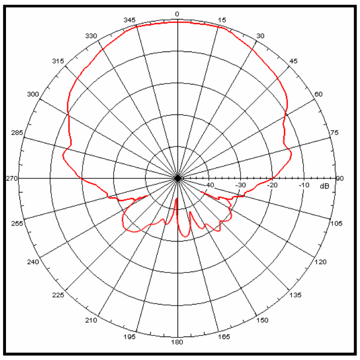
obtained from the graph are; Main lobe magnitude is 8.64 dB, Main lobe direction is 0.87 deg, Angular width (HPBW) (3dB) is 88.6 deg and Directivity is 10.241 dB.

z-y Plane



z-x Plane

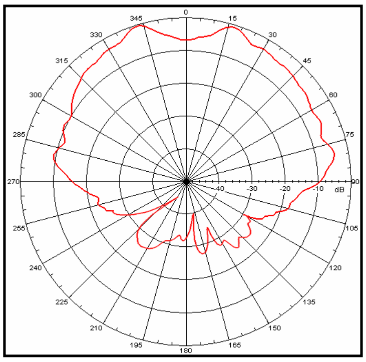


Figure 9. Measured radiation patterns of the proposed antenna

4. Conclusion

The system design parameters, initial calculation results, simulation tools, and antennas design modeling have been presented in this paper. Simulation analysis was performed and the optimum results were obtained for RWSA and Circularly Polarized Patch Antenna for the wireless system. Radial Waveguide and Circularly Polarized Patch Antenna were successfully fabricated with a router board to make the wireless system for backhaul network. Then, measurement parameters such as return loss and received signal strength were measured and performed. There was a good agreement between simulation and prototype measurements. Receive signal strength results proved that the RWSA and Circularly Polarized Patch Antenna have better transmission quality than the commercialized antennas. Therefore, this integrated wireless system can operate at both indoor and outdoor environment for backhaul networks with high speed, gain, and good capability of data transmission. The fabricated prototype of Circularly Polarized Patch Antenna showed a wide 2:1 VSWR impedance bandwidth of about 14.2% and a wide 3-dB axial-ratio CP bandwidth of about 8.9%. Antenna gain level of about 8.5 dBic across the operating bandwidth is obtained with a small variation less than 0.6 dB. This indicates that the proposed antenna has well stable gain across the 2.4 GHz operating band.

Through the test bed setup using developed RWSA Circularly Polarized Patch Antenna versus commercially wireless router antenna, it had been shown that this system can perform as internet source with 5.8 GHz base station and AP for 2.4 GHz clients. In the conclusion it can be said, the performance has been evaluated for the system and can be used as broadband internet access. However, separately measurements were taken for every radiation part to prove that the system performing properly as low profile, lightly weight, simple but effective, easy to design and fabricate with reasonable cost efficient. Finally, experiment was conducted to validate the performance.

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