26 GHz Open Ended Air Gap Cavity RLSA Antenna for Next Generation Broadband Wireless Access

I.M. Ibrahim[1,2], T.A.Rahman[2], Z. Zakaria[1]
[1]*Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, 75450 Hang Tuah Jaya, Melaka.*
[2]*Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.*
imranibrahim@utem.edu.my

***Abstract*—The demand of large bandwidth has pushed the wireless backbone into the mm-wave frequency range. A compact wireless terminal has been suggested at 26 GHz over the decade. A small and high gain antenna has been introduced because of the scenic point of view and for the environment. Next generation Fixed Wireless Access has been proposed at 26 GHz frequency band as a backbone carrier. A Radial Line Slot Array Antenna at 26 GHz frequency band has been developed. The air gap cavity approach has made the fabrication simpler and light. The gain exceeds 23 dBi has been realized at a frequency of 26 GHz with overall dimensions of 200 mm x 200 mm x 3.6 mm. The reflection coefficient better than -10 dB has been successfully achieved at operating frequencies between 25.5 GHz to 26.5 GHz.**

***Index Terms*—Millimeter Wave RLSA; Next Generation FWA; Open Ended Air Gap Cavity RLSA; Wide Band RLSA Antenna.**

I. Introduction

One of the potential frequency carriers for next generation of Fixed Wireless Access (FWA) is 26 GHz frequency. The 26 GHz frequency band is allocated to FWA in many parts of the world [1]. The 26 GHz band offers advantages such as relatively high bandwidth resulting in a much higher bit rates available to individual users when compared to frequency of around 10 GHz used typically in tropical regions [2]. It also allows the reuse of spectrum with a higher density of smaller cells resulting in a higher network capacity in urban and rural areas. These networks are particularly suited for network connection to small offices or suburban homes to high-capacity public switching and backbone networks for wireless multimedia services. Wireless information required by customers on the move includes internet, multimedia, and voice. Normally, parabolic antenna is used at this frequency due to minimum loss and pencil beam characteristic.

Recently, more research and development of RLSA in frequency above 20 GHz has been done. A multilayer structure design with honeycomb cavity spacer was design at 32 GHz for data link space exploration [3-5]. This design has contributed over 40 dBi gain of the antennas. An elliptical beam of 300mm diameter RLSA at 22 GHz was designed and performs a 33dBi gain [6]. The research on optimization of RLSA is still being carried out to produce better performance [7].

RLSA antenna was designed for Point to Multipoint FWA at the frequency range of 5725 – 5875 MHz by few researchers [8-9]. A promising result at that frequency range has motivated the researcher to researched and developed RLSA antenna for Point to Multipoint communication system at 26 GHz. The air gap cavity technique has been introduced with the aim of making the antenna simpler, easy to fabricate and light in term of weight.

II. Open Ended Air Gap Cavity Structure

The RLSA at 26 GHz antenna for Point to Multipoint FWA was designed based on Linear Polarised Beam Squint technique. The RLSA antenna structure normally consists of a dielectric material sandwiched by copper plate. The front plate bears the radiating element while rear plate acts as a ground plane with feed element at the centre. The dielectric constant Ɛr> 1 was chosen to suppress the grating lobes. The radiating elements are arrayed so that their radiation are added in phase along the beam direction [10-11]. The structure of the investigated single-layer RLSA antenna is shown in Figure 1. The orientation of slots is in such a direction so as to transmit and receive waves of proper polarization, linear, and proper coupling inside the cavity.

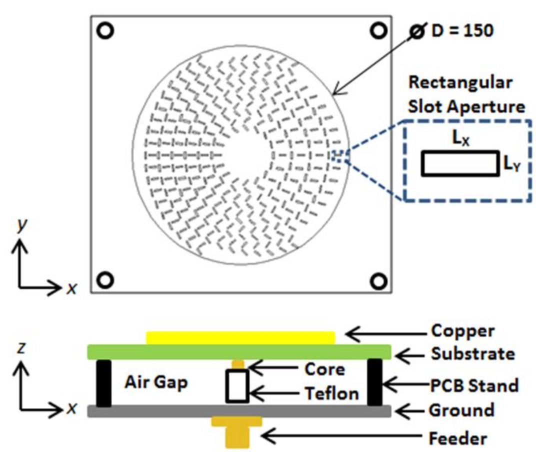

Figure 1: Open ended air-gap structure of RLSA antenna

The antenna parameters is explained in Table 1. The thickness of overall cavity is 3.6 mm where the thickness of open air gap is 2 mm. A 50 Ω single coaxial probe coated with Teflon is used to feed the signal into the cavity. The aluminum plate is used as a platform to hold the antenna and also become a ground plane. The FR4 with 1.6 mm thickness with 5.4 permittivity value is used as a first layer substrate to the radiating surface.

Table 1
RLSA Air Gap Parameters

Specification Parameters	Symbol	Value Hybrid FR4 and Air Gap
Centre frequency	*f*	26 GHz
Wavelength inside the cavity	λ_g	9.8 mm
Slot length	*L*	0.5 λ_g
Slot width	*W*	1 mm
Spacing between unit radiators in radial directions	*Sρ*	λ_g /2 (mm)
Number of rings	*n*	6 ring
Number of slot pairs in first ring	*Z*	16 pairs
Number of slots	*N*	552 slots
Radius of antenna	*R*	100 mm
Cavity material	-	Air Gap and FR4
Radiating plate material	-	Copper
Ground plate material	-	Copper
Cavity thickness	D_T	3.6 mm
Cavity permittivity	ε_{req}	1.13
The thickness of FR4 board	D_1	1.6 mm
The permittivity of FR4 board	ε_{r1}	5.4
The thickness of Air Gap	D_2	2 mm
The permittivity of PP	ε_{r2}	1

The concept of utilizing air gap cavity has been introduced in reference [12], however the antenna operating frequency reported at 5.8 GHz. In this research, the extremely higher frequency is chosen to apply the concept of air gap cavity into mm-wave application.

III. Simulation

The simulated return loss result is shown in Figure 2. The simulated result show the resonant frequency response beginning from 22.2 GHz. Return loss at 26 GHz for simulation is 21.4 dB.

The radiation pattern has been simulated to predict high characteristic performance on mm-wave air gap RLSA. Figure 3 illustrates the 3D radiation pattern of the Air Gap RLSA at 26 GHz. From the 3D pattern, it clearly shows that the concentration of the radiated energy is on the main beam.

The E and H plane radiation pattern is shown in Figure 4. The antenna directivity gain recorded at 23.45 dBi meets the design specification. The 10 dB side lobe level is recorded at E plane while 18.5 dB at the H plane. This antenna also provides 24 dB front to the back lobe ratio at E and H plane. The main lobe is squinted at 9 degree from 0 degree. The radiation pattern shows high directivity characteristic that is suitable for the wireless backhaul application. In overall, the radiation pattern shows directive characteristics with a potential for point to point application. The results is been summarized in Table 2.

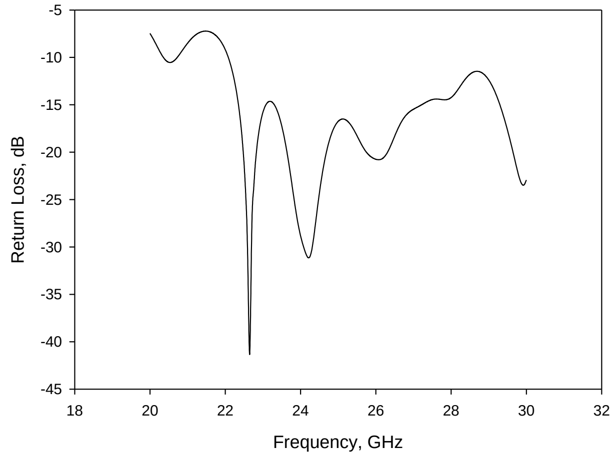

Figure 2: Simulated reflection coefficient of Air Gap RLSA

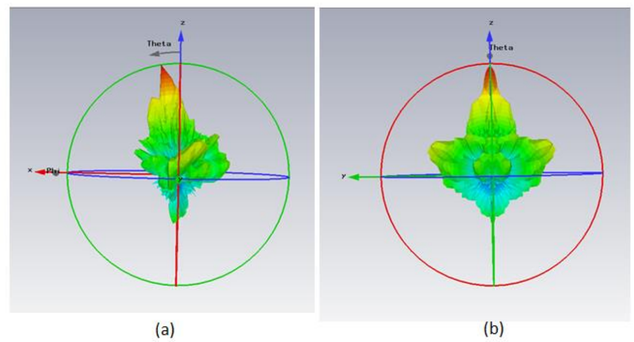

Figure 3: 3D Simulated Radiation pattern for Air Gap RLSA (a) without structure; (b) with structure

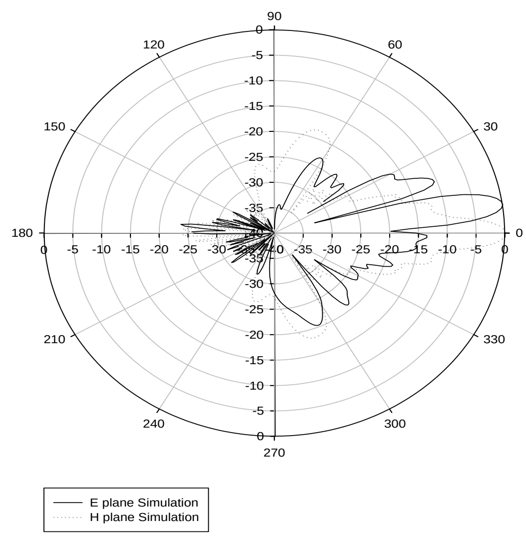

Figure 4: Simulated Radiation pattern on E and H plane for 26 GHz Air Gap RLSA

IV. Measurement

The 200 mm diameter of air gap RLSA has been successfully designed and fabricated. The equivalent dielectric value influenced the number of slots and the slots length on the surface of the antenna. The radial arrangement of slots pair was constructed in the area of 150 mm diameter as shown in

Figure 5. It is also influenced by the dielectric air gap thickness as shown in Figure 6.

Table 2
The Summary of the Simulated Radiation Pattern Results

Antenna Parameter	Simulation
Directivity Gain (dB)	27
Gain (dB)	23.8
Beamwidth at -3dB	
▪ E-plane (degree)	6.6
▪ H-plane (degree)	6.5
Front to Back Ratio (dB)	
▪ E-plane	24
▪ H-plane	24
Main to Side Lobe Ratio (dB)	
▪ E-plane	10
▪ H-plane	18.5
Return Loss (dB)	21.4

Figure 5: The slots on the surface of Air Gap RLSA prototype

Figure 6: Side view of Air Gap RLSA at 26 GHz band

The return loss of fabricated air gap RLSA has been measured to verify the simulation results. The measurement has been done using PNA-X Agilent Network Analyzer N5242A (10 MHz - 26.5 GHz). Since this network analyzer only measures up to 26.5 GHz frequency, the measurement beyond 26.5 GHz cannot be performed.

The measured and simulated result was compared as shown in Figure 7. The starting measured resonant frequency response occurs at 25.4 GHz. The return loss at 26 GHz for simulation is 21.4 dB while 20 dB is recorded for the measurement. The graph shows the measured frequency has shifted to the right which is 3 GHz to the higher frequency range. The frequency shift are due to the variation of substrate permittivity (dielectric constant Ɛr) as well as tolerance of substrate thickness The measured bandwidth of at least 1000 MHz (25.5-26.5 GHz) is achieved.

In millimetre wave, the small changes (in millimetre) on slot width and air gap distance can change the resonant frequency. That might cause the frequency to be shifted to the higher range of frequency. However, the comparison has shown the same pattern of return loss on simulation and measurement. It proofed that the air gap cavity concept can be applied in millimetre wave frequency range.

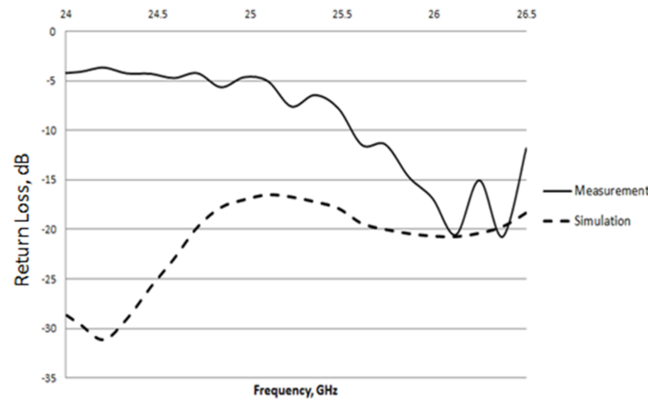

Figure 7: Detail simulated and measured reflection coefficient of Air Gap RLSA

Figure 8 and 9 compare the simulated and measured radiation pattern and parameters of the Air Gap RLSA at E and H plane. The results of measured pattern show a better directivity characteristic as compared to the simulation. Measurement data also shows a good gain achieved at 25.8 dBi which is 2 dB higher than simulation. The 6.5o beamwidth is obtained from the measurement. This is very close to the simulated result. The 12 and 17 dB measured side lobe level recorded from the measurement on E and H plane which is close to the predicted value. The 22 and 24 dB measured back lobe level recorded on E and H plane which is also close to the predicted value. The overall result shown in Table 3.

V. Conclusion

The Open Ended Air Gap Cavity RLSA is proposed as a new candidate for FWA application at 26 GHz band. A model of Air Gap RLSA has been simulated using hybrid air gap and FR4 dielectric material. The 1000 MHz measured bandwidth obtained from 25.5 GHz to 26.5 GHz. A 25.8 dBi directive gain is recorded from the measurement. The less than 10 degree beamwidth of the radiation pattern is sufficient for high directional application. The overall radiation pattern result shows a good agreement between simulation and measurement.

However, the measured and simulation return loss does not show the agreement except at 26 GHz. Therefore, it is suggested to conduct a study and analysis to further investigate on this differences. Therefore, it is suggested to conduct a study and analysis to further investigate on this differences.

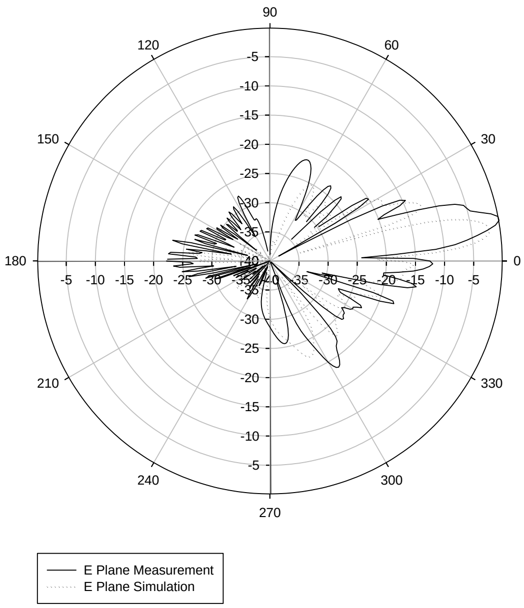

Figure 8: Simulated and measured radiation pattern on E plane at 26 GHz

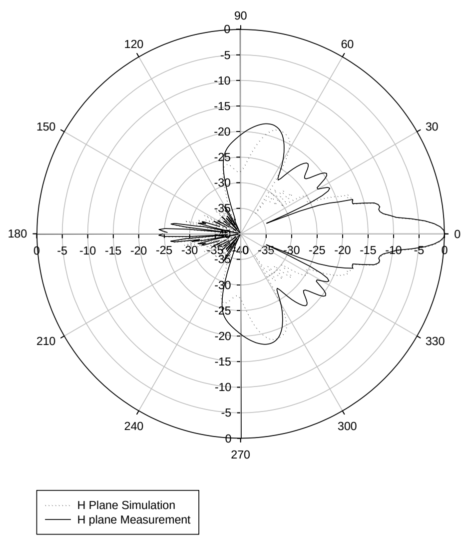

Figure 9: Simulated and measured radiation pattern on H plane at 26 GHz

Table 3
The Summary of the Simulated and Measured Radiation Pattern Results

Antenna Parameter	Simulation	Measurement
Directivity Gain (dB)	27	27.4
Gain (dB)	23.8	25.8
Beamwidth at -3dB		
▪ E-plane (degree)	6.6	6.5
▪ H-plane (degree)	6.5	6.5
Front to Back Ratio (dB)		
▪ E-plane	24	22
▪ H-plane	24	24
Main to Side Lobe Ratio (dB)		
▪ E-plane	10	12
▪ H-plane	18.5	17
Return Loss (dB)	21.4	20

ACKNOWLEDGMENT

The author would like to acknowledge and express sincere appreciation to Universiti Teknologi Malaysia and Ministry of Higher Education Malaysia (MOHE) for funding this project. The acknowledgement also goes to Universiti Malaysia Perlis for the equipment used for the measurement. Appreciation also goes to University Teknikal Malaysia Melaka and MOHE for funding the author's scholarship. My gratitude also goes to Mohd Fauzi Kamarudin from The Centre for Human Development, Centre for Languages and Human Development, Universiti Teknikal Malaysia Melaka for the proofreading of this paper. Sincerely to express the appreciation to UTeM, MOHE and MOSTI for funding this research work under 06-01-14-SF0103 grant.

REFERENCES

[1] X. Zhang, S. Kado, T. Hiruta, and Y. Miyane, "Development of a 26GHz band High Gain Flat Antenna for FWA Systems," *Journal of Hitachi Cable Rev*, no. 22, pp. 16-19, 2003.

[2] B. Fong, A. C. M. Fong, G. Y. Hong, and H. Ryu, "Measurement of Attenuation and Phase on 26-GHz Wide-Band Point-to-Multipoint Signals Under the Influence of Rain," *Antenna and Wireless Propagation Letter*, vol. 4, pp. 20-21, 2005.

[3] Nguyen, T. X., S. J. Rushanthi, et al., "An equivalent two-layer model for a fast design of a high gain multi-layer Radial Line Slot Antenna using MoM", in *Proc. Microwave* (APMC), 2012, Asia-Pacific.

[4] Nguyen Xuan, T., R. Jayawardene, et al., "Characteristics of a high gain and light weight radial line slot antenna with honeycomb structure in 32GHz band for data link in space exploration", Antennas and Propagation (ISAP), 2012 International Symposium on Antenna and Propagation, 2012, Nagoya.

[5] T. Nguyen, R. S. Jayawardene, et al., "Study of a high gain radial line slot antenna in Ka-band for space uses. Electromagnetic Theory (EMTS)", in *Proc. URSI International Symposium on Electromagnetic Theory*, 2013.

[6] T. Nguyen, H. Ueda, et al., "A Radial Line Slot Antenna for an Elliptical Beam", *IEEE Transactions on Antennas and Propagation* vol. 60, no. 12, pp. 5531-5537, 2012.

[7] M. Albani, A. Mazzinghi, et al., "Circular polarized RLSA optimization: A physics based approach," in *Proc. 7th European Conference on Antenna and Propagation*, 2013.

[8] Imran Mohd Ibrahim, Tharek Abdul Rahman, S. W. Pak, Johari Ahmad, Ab Ghani Che Wahab, "A Study on Effectiveness of FR4 as a Dielectric Material for Radial Line Slot Array Antenna for Wireless Backhaul Application", in *Proc. 17th Asia-Pacific IEEE Conference on Communications (APCC2011)*, Sutera Harbour Resort, Kota Kinabalu, Sabah, Malaysia, 2-5 October 2011.

[9] M.I. Imran, A.R. Tharek, and A. Hasnain, "An Optimization of Beam Squinted Radial Line Slot Array Antenna Design at 5.8 GHz," in Proc. RF and Microwave Conference (RFM2008), Kuala Lumpur, Malaysia, 2008.

[10] M. Ando, K. Sakurai, and N. Goto, "Characteristics of a radial line slot antenna for 12 GHz band satellite TV reception", *IEEE Transactions on Antennas and Propagation*, vol. 34, no. 10, Oct 1986, pp. 1269 – 1272.

[11] T. Yamamoto, M. Takahashi, M. Ando, and N. Goto, "Measured performances of a wide band radial line slot antenna," *Antennas and Propagation Society International Symposium*, vol. 3, AP-S. Digest, 1994, pp. 2204-2207.

[12] I. M. Ibrahim, T. A. Rahman, et al. "A Novel Wide Band Open Ended Air Gap Radial Line Slot Array Antenna at 5.8-GHz Frequency Band." *Microwave and Optical Technology Letters*, vol. 56, no. 4, pp. 938-944, 2014.