Simple Printed Array for Microwave Power Rectenna

Mazlina Esa, Mohd Rizal Jasman, Suhaila Subahir,
Mohd Wazir Mustafa, Faridah Taha and Faridah Hussin
Fakulti Kejuruteraan Elektrik
Universiti Teknologi Malaysia
81310 UTM Skudai, Johor DT, Malaysia
e-mail: mazlina@suria.fke.utm.my

Abstract: A simple printed Yagi-Uda antenna (YUDE) operating at 2.45 GHz is proposed in this paper for wireless microwave power transmission. The antenna has an electromagnetic coupling feed, through a printed power splitter/combiner. The antenna is compared with two corresponding single structures having coaxial (YUSC) and electromagnetic coupling feed (YUSE), respectively. All antennas are well-matched at the corresponding frequency of operation with -10 dB reflection bandwidth of less than 2 %. The antennas exhibit directional far-field E-plane radiation pattern. YUDE has the smallest 3 dB beamwidth indicating the highest directivity. The relative gain of the YUSE was found to be 7 dB better than YUSC. However, YUDE showed the least relative gain. This could be due to the imperfect feed location of the power splitter/combiner which was rather difficult to be achieved.

Keywords:
Rectenna, wireless microwave power, Yagi-Uda antenna.

I. INTRODUCTION

Wireless power transmission has a promising future as an alternative method of energy transmission in Malaysia. It involves the conversion of DC power into microwave power at the transmitting end and forming the microwave power into electronically steerable microwave beams. The microwave energy is then launched into space through a transmitting antenna. At the receiving end, the receiving antenna captures it back and the energy is then converted back into DC power. Conversion into AC power is also possible. Loads requiring AC or DC power can be separated, but they can be fed from the same microwave received signal. An example of such transmission is the Solar Power Satellite system which is an alternative method of obtaining an efficient and optimum electrical energy [1]. The chosen microwave frequency has to be from the Industrial, Scientific and Medical band so as to avoid any possibility of interference with existing communication system. One such frequency is the 2.45 GHz which will experience a very low attenuation through the atmosphere under all atmospheric conditions. The rectenna comprises of a receiving antenna and an integrated rectifying structure which will convert the microwave energy into DC.

This paper proposes an electromagnetically coupling feed simple printed array of two microstrip Yagi-Uda structures operating at 2.45 GHz. The array is compared with two corresponding single structures operating at the same frequency. The single structures are fed coaxially and electromagnetically, respectively. Simulation of the driven element is carried out using an electromagnetic software. All antennas have been built and experimentally tested.

II. RADIATING STRUCTURE AND FEEDS

The conventional Yagi-Uda structure [2] is highly directional. The printed version in the form of microstrip has the advantage of being light, flat, low-profile and easily integrated with other components [3], [4] such as the electronic circuitry especially at the receiving end. The structure has been employed in a 4 element array of a proposed mobile satellite receiver [5].

In this design, four elements of printed square patches are employed; one each of the reflector and driven element, and two directors. Two directors are sufficient in providing optimum performance due to the existence of surface waves [3]. The process of delivering electromagnetic energy from the driven element of a transmitting antenna to the parasitic elements (i.e., the reflector and directors) is similar to that of the conventional structure. The same applies for the receiving antenna. The single and two-element array microstrip Yagi-Uda structures are illustrated in Fig. 1(a) and (b), respectively. The feed locations are also shown. The design dimensions of the reflector and directors are based on that proposed in [4]. The reflector and driven elements are spaced 0.35 wavelength apart between the centres whilst the adjacent three patches are spaced 0.3 wavelength between the corresponding adjacent centres. The reflector has to be between 1.1 to 1.3 wavelength whilst the two directors between 0.8 to 0.95 wavelength. The microwave laminate chosen is the RT Duroid 5880 material having relative permittivity = 2.2, thickness of substrate = 0.79 mm, loss tangent = 0.0009, thickness of copper = 35 μm, surface roughness = 0.0024 and conductivity of copper = 5.882 x 10^7 S/m.

Numerical simulation of the driven element using Micropatch 2.0 [6] SPDESIGN command optimised the size to be 40.72 x 40.72 mm^2 with the coaxial feeding point at y = 13.87 mm, x = 20.36 mm. The designed single Yagi-Uda is given in Fig. 2. The same location was also used for the electromagnetic coupling feed of the single and array structures. The printed microstrip version [7] of the 3 dB Wilkinson power splitter/combiner [8] was employed as the electromagnetic coupling feed for the array structure. The feed line of the power splitter/combiner is a 50 ohm microstrip structure. The impedance of each quarter wavelength long branch line is 70 ohm. The lines that electromagnetically couple the array structure is of 50 ohm impedance. The array shared the same ground plane as the power splitter/combiner. Low permittivity plastic screws were used to carefully attach both structures together, ensuring minimum amount of air gap between them.

III. FABRICATION AND MEASUREMENTS

The hardware implementations were realised using the photolithography wet etching method. 50 ohm SMA connectors were used at the inputs of the antennas. Single port measurement of the antennas and power splitter/combiner were carried out using the Marconi Instruments 6583 scalar network analyser. The far-field radiation patterns were measured using the Gigatronics 6100 synthesized microwave signal generator (set at 0 dBm RF power) and Advantest R4131 series spectrum analyser in an enclosed room. Unavoidable reflections from the surrounding equipments was kept to a minimum.

IV. RESULTS AND DISCUSSION

Numerical simulation of the driven square patch using Micropatch 2.0 software optimises the antenna at an operating frequency of 2.45 GHz with a well matched input of a very low –56.7 dB return loss. The corresponding efficiency is 68.9 %. The antenna exhibit broad beamwidth unidirectional far field radiation pattern which is normal to the plane of the antenna.

The measured antennas were placed 1 m apart, well beyond the Fraunhofer distance [4]. The YUSC antenna is observed to operate at 2.4625 GHz with an low input return loss of about –30 dB and almost perfect voltage standing wave ratio (VSWR) of 1.07. The corresponding –10 dB reflection bandwidth is about 1.8 %. The slight difference in the frequency of operation compared to the designed value may be attributed to the soldering of the connector. The co-polarisation E- and H-plane far-field radiation patterns are unidirectional and normal to the plane of the antenna. These are presented in Fig. 3. It exhibits a broad beamwidth of about 144^0 which indicates low directivity. The back radiation is also low.

The YUSE antenna was found to operate at 2.45 GHz with a corresponding low return loss of about –20 dB. The VSWR is 1.23 and the corresponding reflection bandwidth is 2.77 %. Far-field radiation patterns similar to that of YUSC antenna were observed but with a higher level of received signal power. The HPBW is 185^0.

The YUDE antenna is also well matched at its input with an operating frequency of 2.615 GHz. The difference in the operating frequency may be attributed to the sensitive feeding position of the power splitter/combiner. The corresponding –10 dB reflection bandwidth is about 1 %. Similar far-field radiation patterns as that of the YUSE and YUSC antennas were observed. However, the measured HPBW is 74%, indicating a directive directional antenna. However, the received signal power level in the co-polarisation E-plane is about 18 dBm less than that of the YUSE antenna. This may be attributed to the imperfect location of the electromagnetic coupling feed as well as reflection from the surroundings.

V. CONCLUSION AND FUTURE WORK

The design of the driven element of the antennas has been achieved using the Micropatch 2.0 simulation software. The single Yagi-Uda structures were experimentally found to be well-matched at their operating frequency of operations near 2.45 GHz, with -10 dB reflection bandwidths of less than 2 %. Both structures exhibit unidirectional far-field radiation patterns in the E-plane configuration. The YUDE antenna operates at a higher 2.615 GHz, indicating a 33 % shift. The –10 dB reflection bandwidth is also less than 2 %. The shift in frequency could be due to the inaccuracy of the feed location which was difficult to be achieved. Thus, the antenna exhibit a lower relative gain. It is anticipated that the aperture

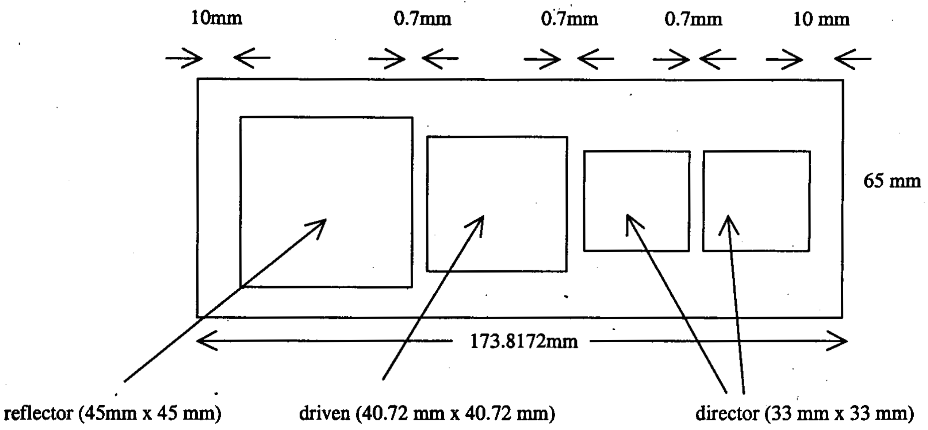
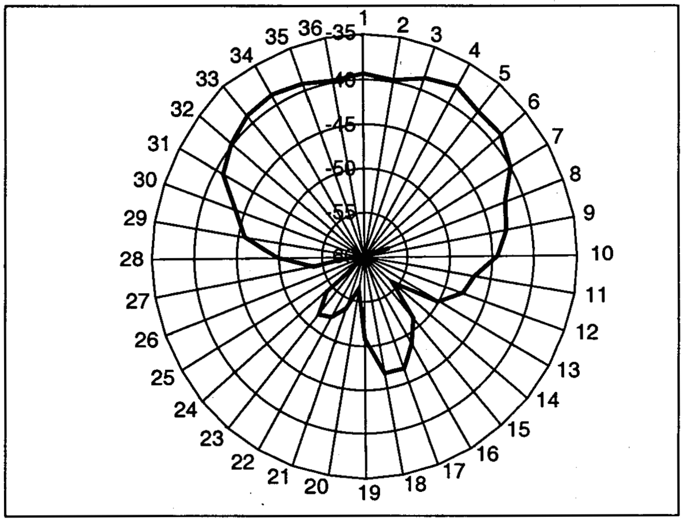


Fig. 2. Designed dimensions of the single microstrip Yagi-Uda.



(a)

Fig. 3. Co-polarisation radiation patterns of YUSC antenna (a) E-plane (b) H-plane.

coupling feed will reduce the back lobe, thus increasing the relative gain. Work is currently under way in realising this. Plastic screws will be employed to securely attach both the array radiating structure and the power splitter/combiner layers. In addition, other possible structures are being considered for the wireless power transmission application. Full rectenna structure is being constructed in converting the microwave power into DC power. Summary of the measured characteristics is presented in Table 1.

VI. REFERENCES

[1] P. E. Glaser and F. P. Davidson, Solar Power Satellite – The Emerging Energy Option, West Sussex: Ellios Horwood, 1993.

[2] J. L. Lawson, Yagi Antenna Design, American Radio Relay League, 1986.

[3] J. R. James and P. S. Hall, Handbook of Microstrip Antennas, London: Peter Peregrinus, 1989.

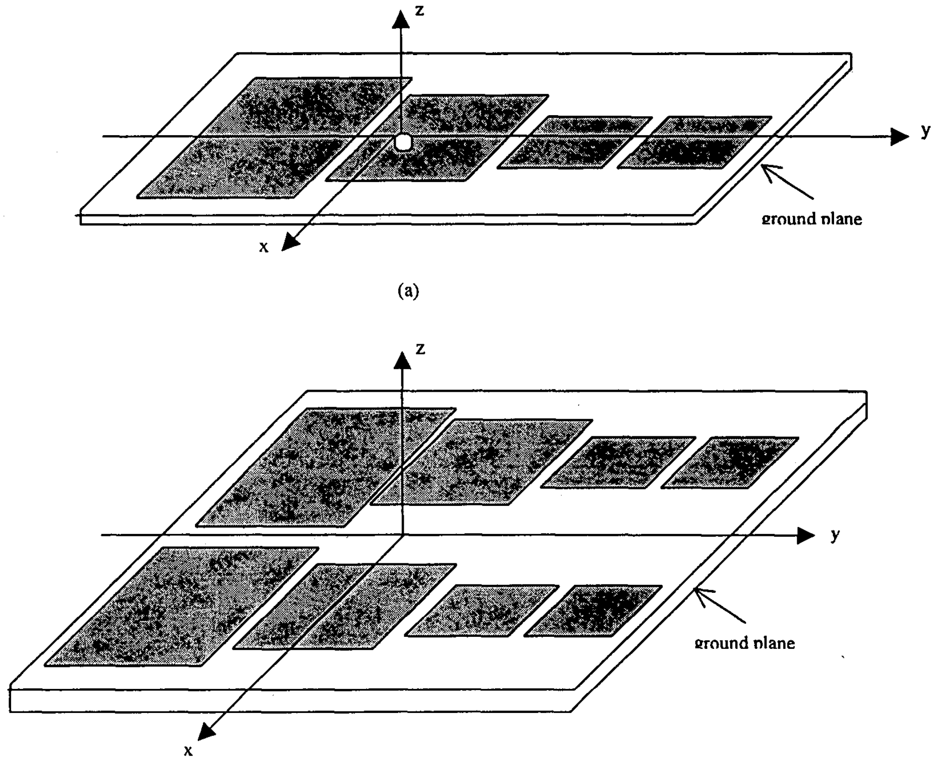
[4] C. A. Balanis, Antenna Theory: Analysis & Design, 2nd edition, New York: Wiley, 1997.

[5] J. Huang, "Microstrip Yagi-Uda Array Antenna for Mobile Satellite Vehicle Application", IEEE Trans Antennas Propagat., Vol. 39, No. 7, pp. 1024-1030, 1991.

[6] A. Benalla, C. H. Thang and K. C. Gupta, Computer Aided Design and Analysis of Microstrip Patch Antenna, User's Manual, Boulder: Microstrip Designs, 1993.

[7] I. J. Bahl and P. Bhartia, Microstrip Antennas, Deedham: Artech, 1986.

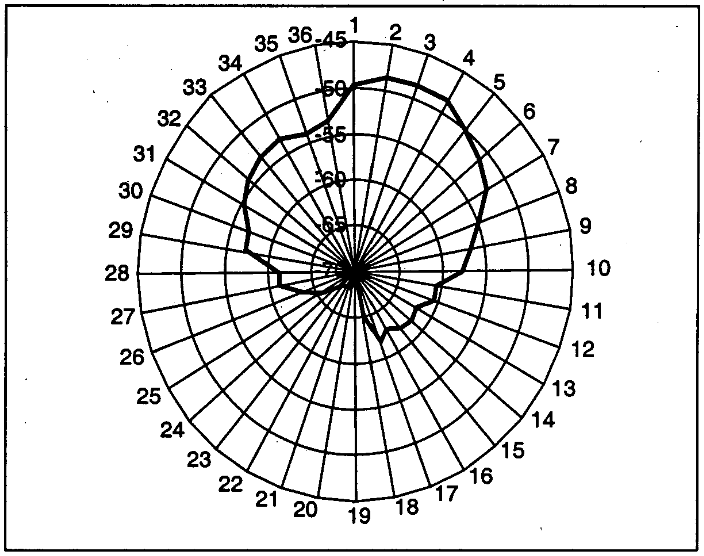
[8] K. Chang, Handbook of Microwave and Optical Components, New York: Wiley, 1989.



(a)

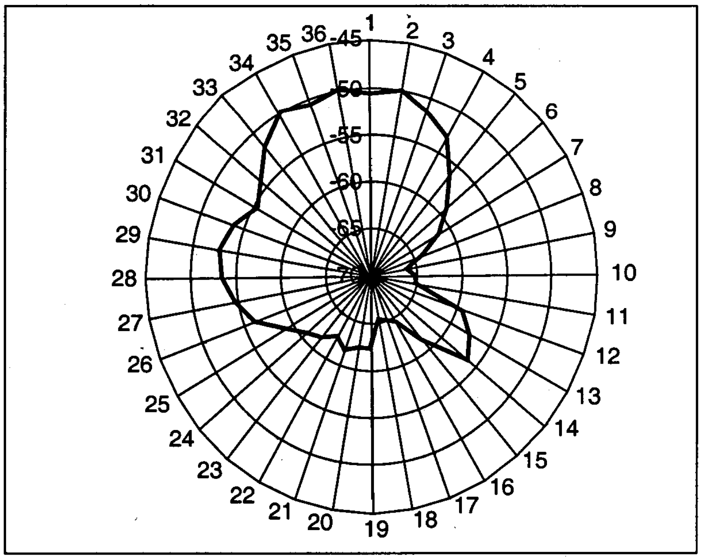
(b)

Fig. 1. Microstrip Yagi-Uda antennas (a) single (b) two-element array.



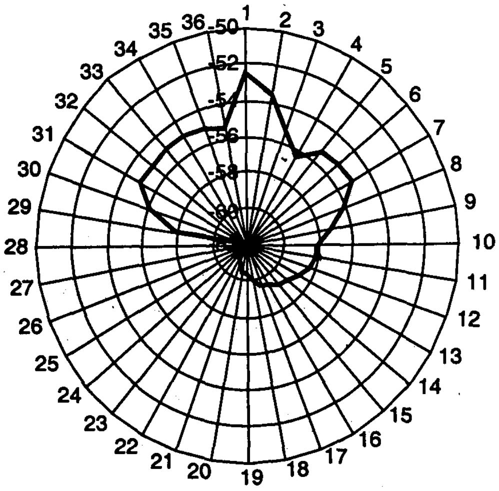
(b)

Fig. 3. Co-polarisation radiation patterns of YUSC antenna (a) E-plane (b) H-plane (contd.).



(a)

Fig. 4. Co-polarisation radiation patterns of YUDC antenna (a) E-plane (b) H-plane.



(b)

Fig. 4. Co-polarisation radiation patterns of YUDE antenna (a) E-plane (b) H-plane (contd.).

Table 1. Measured performance of all antennas.
P_{max} ; received power at 0° alignment

Configuration	Received P_{max}, dBm	HPBW, °	Relative gain, dB
YUSC	-39	144	-7
YUSE	-32	185	0
YUDE	-50	74	-12