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A Feed Network for a Novel E-H Shaped Microstrip Patch Antenna Array

[1,2]N. Misran, [2,3]M. Tariqul Islam and [1]K.J. Ng
[1]Department of Electrical, Electronics and System Engineering,
[2]Institute for Space Science, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia
[3]Faculty of Engineering and Technology, Multimedia University,
Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia

Abstract: This research presents a beamforming feed network for a novel E-H shaped microstrip patch antenna array. The broadband microstrip antenna array was developed based on the novel L-probe fed inverted hybrid E-H (LIEH) shaped element design arranged into 4×1 uniform linear array antenna, fed by a feed network. The corporate 4-ways Wilkinson power divider which was fabricated in-house covering the frequency range from 1.83-2.29 GHz (460 MHz) were integrated to form the beamforming feed network. The beamforming feed network comprises of commercial variable attenuators (KAT1D04SA002), variable phase shifters (KPH35OSC000) and the corporate 4-ways Wilkinson power divider which was developed in-house. The developed 4-ways Wilkinson power divider achieves bandwidth of 22.33% at VSWR 1.25. The measured isolation and insertion loss are 30.72 and 0.32 dB correspondingly. The feed network developed and fabricated in-house has been shown to function well within its design ability.

Key words: Broadband, array, feed network, microstrip antenna, isolation

INTRODUCTION

The evolution of wireless communications has a deep impact on the field of antenna design. One essential component of the antenna array is its feeding technique. In an antenna array multiple radiating elements are assembled in an electrical and geometrical configuration. The antenna array provides beamforming capability to extract the desired signal and simultaneously filtering out the unwanted interference signal and environmental noise.

In designing array antenna, dipole, horn, waveguide slot or microstrip antenna can be used as radiating elements. However such radiating elements are unable to meet the requirements to be aesthetic and light weighted if implemented on the cell sites. To be aesthetic, the radiating element of the antenna array is desired to be small in size, low profile, conformal and compatible with integrated circuit and etc. Therefore, the radiating elements are preferred to be fabricated by microstrip technology that offers its non-electrical characteristic advantages (Pozar and Schaubert, 1995). Microstrip antennas are low profile and light weight. They can also be made conformable and well suited to be integrated with microwave integrated circuit (Lau *et al*., 2006; Zhang and Wang, 2006). In terms of fabrication, such system offers simplicity, which allows mass production and cost-effective manufacturing as well as high performance.

A combination of X- and C-band slots and patches were investigated and it was concluded that C-band patch/X-band slot concept had the greatest merit. In that design, the C-band feed network was on the same plane with the patches while the X-band feed was behind the ground plane. A combination of stacked perforated L-band patch overlaid over an array of C-band patches to achieve shared-aperture L/C-band operation was reported in Shafai *et al*. (2000). Employing similar feeding principles, the C-band feed network behind the ground plane was aperture-coupled to the patches. The L-band feed network was on the same plane with the lower L-band perforated patch. This idea was further developed and applied to L- and X-band array in Pozar and Targonski (2001).

In their studies, Targonski and Pozar (1998) noted that it was impossible to accommodate two linear polarizations for two separate frequencies on a single feed layer. Maci and Gentili (1997), adding that single feed network for two frequencies was the most critical problem to solve for a dual-band array. Current dual-band shared-aperture technology suggests employing the higher-frequency feed network behind the ground plane

Corresponding Author: Dr. Mohammad Tariqul Islam, Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia Tel: 606-2523023 Fax: 606-2316552

(aperture-couple) and the lower-frequency feed network above the ground plane (coplanar feed). This may be because higher frequency feed produces higher spurious radiation, due to shorter wavelength and longer layout length. In a small array, feed layout above the ground plane may not produce excessive spurious radiation. However, in a larger array, feed line radiation may not be ignored.

In this research, the beamforming feed network was constructed using a four-way Wilkinson power divider of corporate structure type and a phase shifter-attenuator networks, connected in series to the ports to examine the scanning capability of the array. Due to the high cost and complexity of the design for planar and high resolution array, the design focuses on the development of a four-element (4×1) array antenna.

BEAMFORMING FEED NETWORK

A feed network is integrated with the antenna array. The radiating element of the antenna array is based on the LIEH shaped Microstrip Patch Antenna (MPA) that is arranged in a 4×1 linear array configuration which is termed as Broadband Microstrip Patch Antenna Array (BMPAA). The antenna array is constructed using two dielectric layer arrangement where a thick air-filled substrate was sandwiched between top-loaded dielectric substrate or superstrate with inverting radiating patch and an aluminium ground plane. The antenna array is used contemporary design techniques namely, the L-probe feeding, inverted patch and slotted patch techniques to meet the design requirement.

The difference in amplitude and phase of the array is fed to each element by feed network. This causes the radiating field of each element combines constructively in the intended direction and cancel out each other at other undesired directions in the far field (Balanis, 1997). Thus higher power gain and more flexibility in controlling the shape of the beamwidth and sidelobe levels can be achieved from this method. Moreover, the feed network allows the radiation pattern to be varied for beam scanning without any physical antenna motion.

Arrays can be fed in many ways, but the two general types of feed arrangement for microstrip patch arrays are series feed and corporate feed. Microstrip patch array in a series feed network is fed by a single transmission line, whereas patch array in a corporate feed network is fed by multiple transmission lines. Series feed network is much easier to design and fabricate compared to the corporate feed network. However this method will result in progressive phase delay between elements thus making unsuitable for phase scanning. Another problem with series feed arrangement is the high VSWR that is caused by the additive mismatches at the various junctions between the elements (Zurcher and Gardiol, 1995).

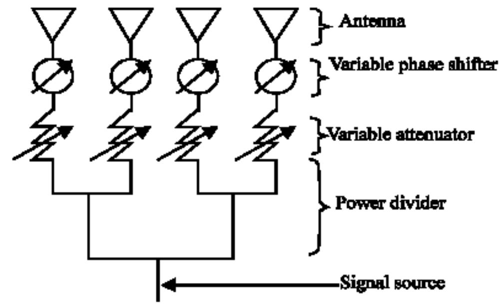

Fig. 1: Schematic diagram of a beamforming feed network

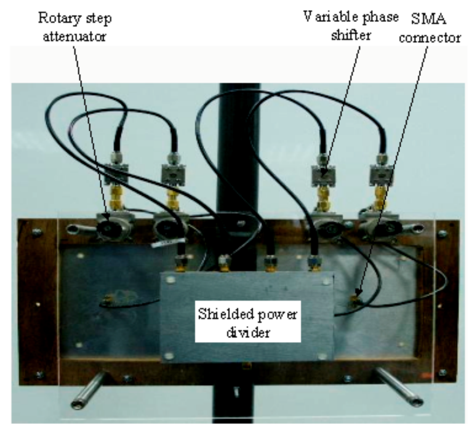

Fig. 2: Rear view of the 4×1 LIEH shaped BMPAA with a beamforming network

Corporate feed network is more flexible and offers better phase control over the performance of each array element. It is best suited for scanning phased array, multi beam arrays or shaped beam arrays. However, the use of corporate feed network is more preferable over series feed network as it is less affected by frequency scan. A corporate feed network supplies excitation individually to each array element and use equal line lengths and power dividers for each element.

The beamforming feed network for the BMPAA consists of a 4-ways corporate structure Wilkinson power divider and a network of phase shifter-attenuator as shown in Fig. 1.

The phase shifter-attenuator network comprises of a commercial off-the-shelf (COTS) variable phase shifter KPH350SC00 and step-rotary attenuator KATID04SA002, both are from KMW Inc. The 4-way Wilkinson power divider was developed and fabricated in-house by using Taconic RF-35 with the dielectric permittivity, ϵ_{r1} of 3.5, thickness h = 0.76 mm and with the dimension 25×20 mm. Table 1 gives the summary of the beamforming feed network design and its electrical parameters.

Figure 2 shows the fabricated beamforming feed network connected to the antenna array. As shown in the

Table 1: Summary of the beamforming feed network

Parameters	Values
A. Wilkinson Power Divider	
Substrate	Taconic RF -35 (ϵ_{r1} = 3.5, h = 0.76 mm)
B. Phase shifter	
Insertion loss	0.25 dB (1-2 GHz)
0.35dB (2-3GHz)	
VSWR	1.25
Phase shift	35° @ 2 GHz
C. Attenuator	
Frequency range	DC~3 GHz
Insertion loss	0.2 dB
VSWR	1.15
Attenuation step	10 attenuation step of 1 dB

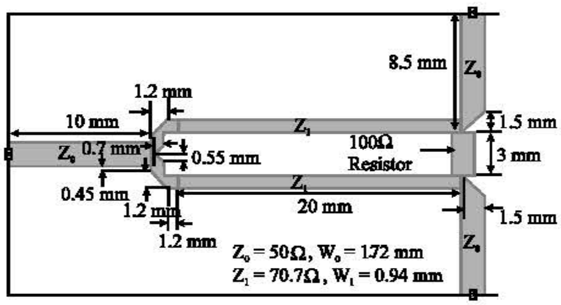

Fig. 3: The layout of 2-ways Wilkinson power divider on substrate Taconic RF 35 (ε_{r1} of 3.5, h = 0.76 mm and δ = 0.0018)

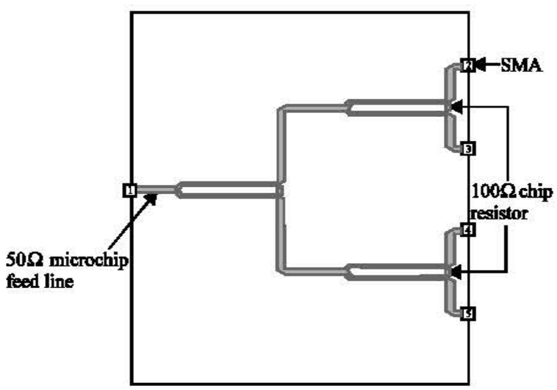

Fig. 4: The layout of 4-ways Wilkinson power divider

Fig. 2, the power divider is covered by an aluminium shield and the antenna array is behind the power divider.

A 4-ways power divider is designed as a corporate feed network to feed the radiating elements with equal amplitude and phase. This power divider is based on Wilkinson power divider which offers good matching in all ports with good isolation between the output ports. The Wilkinson power divider has a useful property of being lossless when the output ports are matched, that is, only reflected power is dissipated (Pozar, 1990). The design schematic for the 2-ways Wilkinson power divider layout is shown in Fig. 3 and the layout of a 4-ways Wilkinson (3 dB) power divider is shown in Fig. 4.

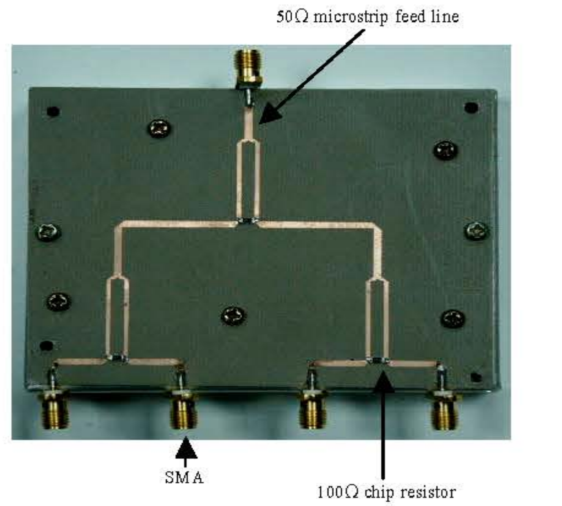

Fig. 5: Fabricated 4-ways Wilkinson power divider

Figure 5 shows the fabricated 4-ways Wilkinson power divider which is fabricated on Taconic RF-35.

RESULTS AND DISCUSSION

The antenna array and the power divider are simulated by *Sonnet® Suite em* simulator. The fabricated antennas and power divider are measured using the Agilent PNA E8358A network analyzer, Agilent ESG-DP Series E4436B signal generator, Advantest R3131A spectrum analyzer and the standard gain LPDA-0803 log periodic dipole antenna. SMA connector calibration kit, SMA male to male cable and automatic controlled rotator are also required for the measurement. Measurement is conducted in the UKM microwave lab and the UKM open field. The return loss measurement of 4-ways Wilkinson power divider is taken by using the Agilent PNA E8358A network analyzer. Return loss of every terminal is measured by terminating other element with 50 Ω load. Figure 6 shows the return loss at 1st terminal in 4-ways Wilkinson power divider. The measurement result shows higher value than the simulation results. This is due to the effect from SMA connector of every terminal. The aluminium ground plane is used to support SMA connector that is not been grounded properly. This installation problem causes the higher value of measurement; besides the used SMA connector, probe pin is not tapered. Simulated and measured return loss results are in good agreement in all terminals. The operating range for power divider is from 1.83-2.29 GHz (460 MHz) with bandwidth 22.33% at VSWR 1.25 considering all terminals.

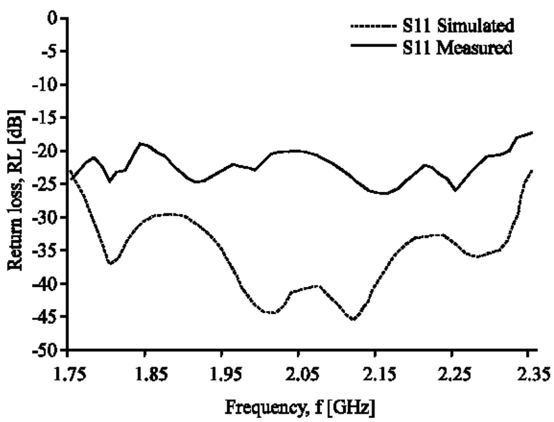

Fig. 6: Measured and simulated return loss of port 1 of the 4-ways Wilkinson power divider

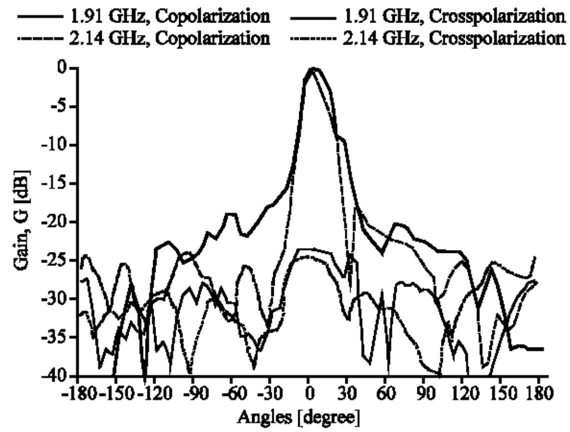

Fig. 8: Measured E-plane radiation patterns for the LIEH shaped BMPAA at 1.91 and 2.14 GHz

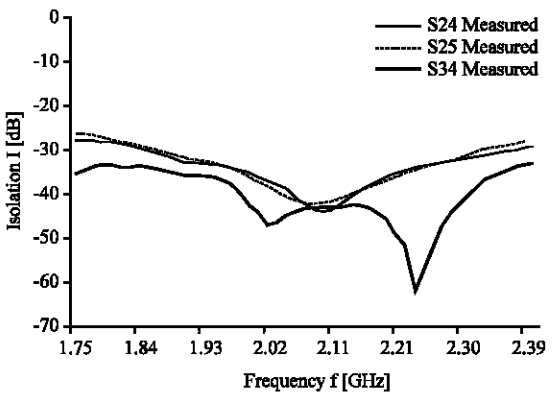

Fig. 7: Measured isolation of the 4-ways Wilkinson power divider

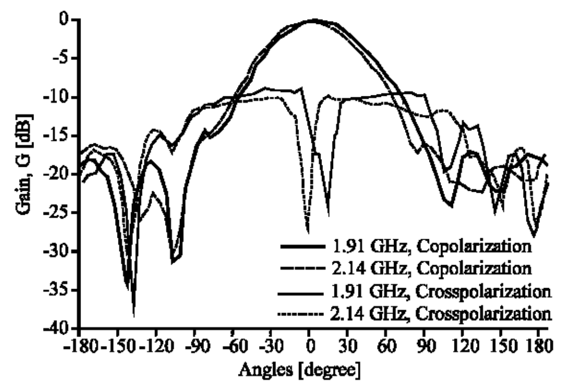

Fig. 9: Measured H-plane radiation patterns for the LIEH shaped BMPAA at 1.91 and 2.14 GHz

Table 2: Summarized result of power divider

Properties	Measurement results
Bandwidth	460 MHz (1.83-2.29 GHz at VSWR = 1.25)
Isolation	30.72 dB
Insertion loss	0.32 dB
Amplitude balance	0.70 dB
Phase balance	5.40°

Isolation of 4-ways Wilkinson power divider is shown in Fig. 7. The maximum value of isolation in the operating frequency range is at 30.72 dB. The measurement results of power divider are shown in Table 2.

Figure 8 and 9 show the E-plane and H-plane radiation patterns of the antenna array at 1.91 and 2.14 GHz (resonance frequencies) by using feed network. Chebyshev amplitude distribution is used to have narrow beamwidth and low equal side lobe level (-20 dB). Chebyshev distributions value is shown in Table 3 as normalized in dB.

Table 3: Chebyshev distributions for each element of 4×1 BMPAA

Element-1	Element-2	Element-3	Element-4
0.48312 (3.1594 dB)	1(0 dB)	1(0 dB)	0.48312 (3.1594 dB)

Table 4: Amplitude and phase value for measurements

0° Scanning			
Element-1	Element-2	Element-3	Element-4
-10.06 dB	-6.5 dB	-7.5 dB	-9.65 dB
100.0°	-50.85°	149.3°	2.55°

However, the exact amplitude and phase distribution were unable to obtain due to the limitation of the available variable attenuator and phase shifter. Therefore, the antenna radiation pattern result is expected to be distorted from the desired performance.

Scanning pattern is measured for 0°.Amplitude and phase values are chosen by considering the following initial phase angle and by employing progressive phase shift equations. Amplitude and phase values for measurement are shown in Table 4.

Initial phase angle: Port 1: 100°
Port 2: 105°
Port 3: 101°
Port 4: 105°

The phase in each element of the array is progressively shifted by $\alpha = -\beta d\cos\theta$, where β is the phase shift factor and d is the inter-element spacing.

The radiation patterns show some fluctuations due to the reflection from some obstacles in the field, however, they have good beam patterns and crosspolarization level, which is shown in Fig. 8 and 9. The 3 dB beamwidth is closed to 25° for the E-plane while the 3 dB beamwidth is about 65° for the H-plane. The H-plane radiation pattern is virtually symmetrical, while the E-plane radiation pattern exhibits some asymmetries, which is similar in the report by Huynh and Lee (1995) using a thick substrate. As shown in Fig. 8, the sidelobe levels are unequally distributed. The first side lobe levels at 1.91 and 2.14 GHz are -18.9 dB (at -60°) and -20.47 dB (at 45°), respectively. This result is due to the amplitude/phase unbalances in the beamforming feed network. The maximum crosspolarization of the array is in the order of -23.47 and -10 dB for E-plane and H-plane, respectively.

CONCLUSION

The beamforming feed network was constructed using a four-way Wilkinson power divider of corporate structure type and off the shelf variable phase shifter (KPH350SC00@ KMW Inc) attenuator (KATID04SA002@ KMW Inc) networks to measure the beamforming capability of the array antenna. Due to the high cost and complexity of the design for planar and high resolution array, the design focused on the development of a uniform four-element (4×1) array antenna. The array designed by employing novel hybrid E-H shaped design, inverted patch, slotted patch and L-probe. The developed 4-ways Wilkinson power divider enjoys the bandwidth of 22.33% at VSWR 1.25. The measured isolation and insertion loss are 30.72 and 0.32 dB correspondingly.

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