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Compact Microstrip Feeding Network for Mobile Base Station Antenna

[1]Mohamed S. El-gendy, [1]Haythem H. Abdullah, [1]Esmat A. Abdallah, [2]Hadia M. El-Hennawy
[1] Electronics Research Institute, Giza, Egypt.
[2] Faculty of Engineering, Ain-Shams University, Cairo, Egypt.
mohamadalgendy2004@yahoo.com

Abstract: Most mobile base station antennas constituted from an array of radiating elements fed by a feeding network circuit that satisfy shaping the radiation pattern to meet the desired specifications. In this paper, a feeding network circuit is designed to feed mobile base station antenna array. The number of antenna array elements that satisfies the desired beamwidth and side lobe level is ten. The base station antenna covers the operating band from 0.2 GHz to 2.57 GHz, so it supports GSM380, GSM410, GSM450, GSM480, GSM 710, GSM750, GSM810, GSM850, GSM900, GSM1800 / DCS1800, GSM1900 / PCS1900, UMTS2100, and some used LTE bands. Two feeding circuits are designed one for lower band that extends from 200 MHz to 960 MHz and the other is used for upper band that extends from 1.71 GHz to 2.17 GHz. A compact dual-band microstrip equal Wilkinson power divider looks like zigzag shape yields a size reduction of 45.68 % than the conventional shape is utilized in the feeding network circuit. Two cascaded stages of unequal Wilkinson power divider (UWPD) with certain power division ratios at the out ports are proposed. A three unit hippocampus - shaped defected ground structure (DGS) pattern etched on the ground plane and placed underneath one of the microstrip branch line of both cascaded unequal Wilkinson power divider is used to realize 102 Ω lines with a wider width of 1.6 mm. The feeding network is designed and fabricated on FR4 dielectric substrate with dielectric constant of ε_r = 4.5, loss tangent 0.025 and substrate height of 1.5 mm.

Keywords: Wilkinson unequal power divider, defected ground structure, dual-band, isolation, mobile base station.

I. Introduction

Power splitters and combiners are one of passive microwave components used for wide range of applications such as power division, power combining, signal mixing, and as a feeding network in various antenna array systems. In power division circuitry, an input signal is divided by the power divider circuit into two or more signals with lesser power (equal outputs or not) and vice versa for power combining. There are several forms of power dividing networks such as the T junction, directional coupler, hybrid coupler and Wilkinson power divider. This paper focuses on the Wilkinson power divider. The reason for using Wilkinson power divider is that it has high port isolation compared to other dividers. Wilkinson power divider was invented by E. J. Wilkinson [1], as a method of distributing power or splitting the power of the input equally between two output ports, ideally without loss. A feeding network with two-section dual-band Chebyshev impedance transformer is printed in [2]. The network divides the input power to four output ports with equal power division and equal phase in order to excite four antenna elements placed in a linear array. It supports GSM900, DCS1800, PCS1900, and UMTS2100 bands. In order to achieve an appropriate matching over the operating bands, a two-section dual-band Chebyshev impedance transformer, which has matching capability at two arbitrary frequencies, was designed [3, 4]. Design parameters for this transformer, which consist of characteristic impedance and lengths of each section, were determined at central frequencies of 920 MHz and 1940 MHz to match a 100Ω line to a 50 Ω line. After determining impedances, the widths of the microstrip line sections of the feed network were calculated for FR4 dielectric material with dielectric constant of ε_r = 4.4, loss tangent equals 0.025 and substrate height of 1.6 mm.

In this paper, a compact single stage dual-band microstrip Wilkinson equal power divider that looks like zigzag shape is utilized with size reduction of 45.68 % than the conventional shapes in the feeding network circuit as a unit. Two cascaded stages of unequal Wilkinson power divider (UWPD) with 2:1 power division ratios at the out ports are presented. A three unit hippocampus - shaped defected ground structure (DGS) pattern etched on the ground plane and placed underneath one of the microstrip branch line of both cascaded unequal Wilkinson power divider is used to realize 102 Ω microstrip lines with a wider width of 1.6 mm. The proposed feeding network circuit is suitable for exciting ten antenna elements placed in a linear array with unequal power ratios and equal phase. It Supports GSM380, GSM410, GSM450, GSM480, GSM 710, GSM750, GSM810, GSM850, GSM900, GSM1800/ DCS1800, GSM1900/ PCS1900, UMTS2100, and most used LTE bands. Two feeding circuits are designed one for lower band and the other is used for upper bands.

II. Excitation Coefficients of the Antenna Array

One of the efficient algorithms for synthesizing antenna arrays is the MoM/ GA algorithms [5]. In this context, a brief description of the algorithm is described for the sake of clarity. The array factor of a linear antenna array consisting of M isotropic elements located at Z = d_n along the -axis is given by

$$AF_s(\theta) = \sum^{M} a_n \exp\ (jkd_n \cos\Theta)\ \approx AF_d(\Theta) \qquad (1)$$

AFs(θ) is the synthesized array factor, AFd(Θ) is the desired array factor, a_n is the excitation coefficient of the n^{th} element, and k = 2π / λ is the free-space wave number. The algorithm is based on a combination between the method of moments (MoM) [6] and the genetic algorithm (GA) [7], [8]. The

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proposed algorithm provides a number of elements reductions using either uniform or non-uniform element spacing. The MoM provides a deterministic solution for the excitation coefficients. The GA is used to estimate the optimum element locations to obtain the required radiation pattern within a minimum tolerance. The MoM transforms the problem to the form

$$[Z]_{M\times M}[I]_{M\times 1} = [V]_{M\times 1} \qquad (2)$$

The synthesized excitation coefficients are determined by solving (2) for $[I]_{Mx1}$. The elements of the matrix $[Z]_{MxM}$ are given by,

$$z_{mn} = \int_0^{\pi} e^{j(d_n-d_m)k\cos\Theta}\, d\Theta \qquad (3)$$

and the elements of the vector $[V]_{Mx1}$ are given by,

$$V_m = \int_0^{\pi} AF_d(\Theta)\, e^{-jkd_m\cos\Theta}\, d\Theta \qquad (4)$$

The excitation coefficients a_n are determined by solving the linear system of (2), where a_n are the elements of the matrix $[I]_{Mx1}$, and $[I]_{Mx1} = [a_1,a_2,a_3, \ldots,a_n]^T$

III. Single Stage of Zigzag Dual-Band Wilkinson Power divider.

In dual-band operation, the Wilkinson equal power divider consists of two cascaded quarter wavelength sections operated at two arbitrary different frequencies. The input port (50Ω line) is connected to a two cascaded sections of transformer, each section consists of two quarter wavelength transmission line with characteristic impedances and lengths of Z_1, Z_2, l_1, and l_2, respectively, as shown in Figure 1. The output ports are connected to a resistor $R = 2Z_0$. The parameters for designing the dual-band Wilkinson power divider are obtained from [9].

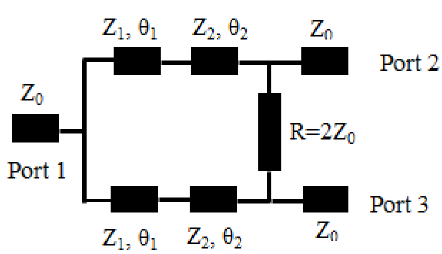


Fig.1 Circuit diagram of dual-band Wilkinson power divider

Since the two interesting bands are GSM900 (880 – 960) MHz and DCS1800/PCS1900/UMTS2100 (1710 – 2170) MHz then, the design frequencies should be f_1 = 915 MHz and f_2=1940 MHz. The design parameters for the conventional dual band Wilkinson power divider realized on FR4 dielectric material with dielectric constant of $\varepsilon_r = 4.5$, loss tangent equals 0.025 and substrate height of 1.5 mm are shown in Figure 2(b). The physical lengths and widths for the conventional dual band Wilkinson power divider are tabulated in Table 1.

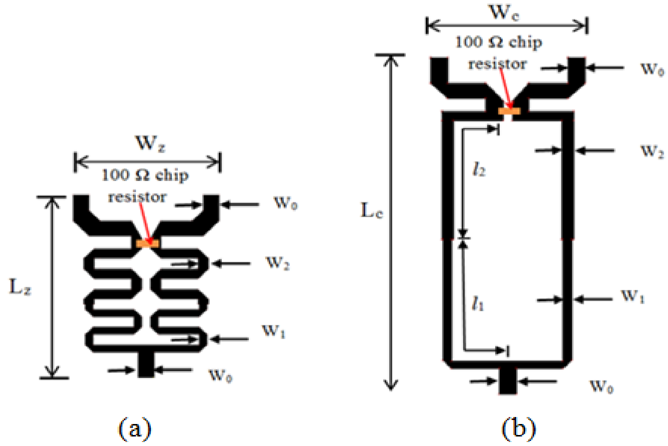


Fig.2 Dual-frequency Wilkinson power divider design (a) zigzag, (b) conventional.

The zigzag shape shown in Figure 2(a), yields a size reduction of 45.68 % than the conventional shape. An internal chamfer is added at the two output ports and an optimization in length l_1 is used to improve the matching at the upper/second band.

Table 1: The physical lengths and widths for the conventional and zigzag dual band Wilkinson power divider.

Parameter	Value	Parameter	Value
Z_0	50 Ω	W_2	1.87 mm
Z_1	78.37 Ω	l_2	33.97 mm
Z_2	63.8 Ω	L_C	64.68 mm
l_1	33.38 mm	L_Z	35.13 mm
W_0	2.82 mm	W_C	25.64 mm
W_1	1.4 mm	W_Z	25.64 mm

The value of the resistor (R) that has the best symmetrical reflection and isolation at the two operating frequencies is found to be around 100 Ω. The physical lengths and widths for the zigzag shaped dual band Wilkinson power divider are depicted in Table 1. The measured return loss at the input port $|S_{11}|$ and the isolation between the two output ports $|S_{23}|$ are compared with the simulated results as shown in Figure 3. The measured and simulated return loss at the two output ports ($|S_{22}|$ and $|S_{33}|$) are shown in Figure 4. The measured and simulated power division ratios for zigzag shape are presented in Figure 5.

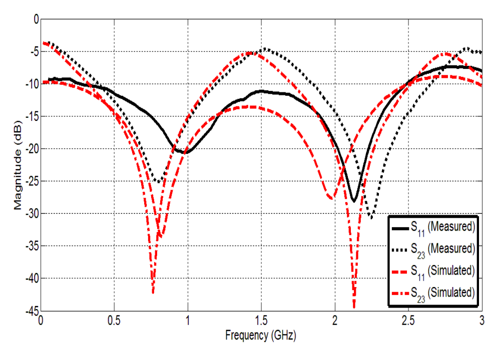


Fig. 3 Measured return loss at input port and isolation between the two output ports compared with simulated ones for zigzag dual-band Wilkinson power divider.

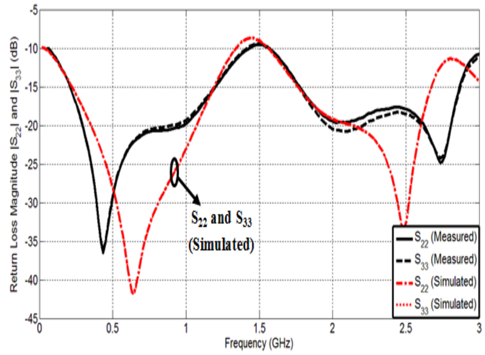


Fig. 4 Measured return losses at the two outputs ports compared with simulated ones for zigzag dual-band Wilkinson power divider.

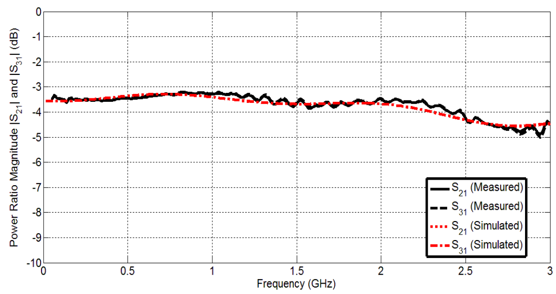


Fig. 5 Power ratio at the two output ports for zigzag dual-band Wilkinson power divider.

IV. Unequal Wilkinson Power Divider.

An unequal Wilkinson power divider unit with power division ratios of 2:1 is presented. The unequal Wilkinson power divider needs quarter-wavelength transmission lines with 102 Ω and 51.04 Ω characteristic impedances. The design parameters is realized on FR4 dielectric material with dielectric constant of ε_r = 4.5 and loss tangent equals 0.025 and substrate height of 1.5 mm. The simulation is done using IE3D - Zeland ver. 12 electromagnetic software package. The width of 102 Ω characteristic impedence is 0.58 mm which is not wide enough for power handling. A three unit hippocampus - shaped DGS pattern etched on the ground plane and placed underneath the microstrip line to reduce the equivalent capacitance and increase highly the limitation of realization up to 102 Ω with a wider microstrip line of 1.6 mm. Figure 6 shows the proposed 1-D periodic DGS pattern etched on the metallic ground plane and placed underneath a quarter wavelength microstrip transmission line.

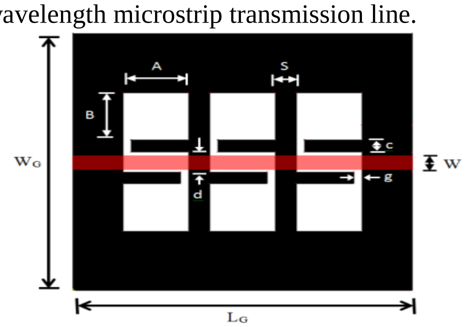


Fig. 6 Layout of the hippocampus - shaped pattern DGS unit etched on the metallic ground plane underneath a quarter wavelength microstrip transmission line.

The values of the parameters shown in Figure 6 are: L_G = 20.5 mm, W_G = 21.71 mm, W = 1.6 mm, A = B = 4 mm, S = 1.25 mm, c = 1 mm, d = 1.71 mm, and g = 0.5 mm.

The characteristic impedances of the unequal Wilkinson power divider shown in Figure 7 can be calculated as; Z_2 = 51.49 Ω, Z_3 = 102.988 Ω, Z_4 = 42.045 Ω, Z_5 = 59.46 Ω and the isolation resistor R = 106 Ω according to [10]. The isolation resistor R = 106 Ω is approximated to a commercial resistor value of 100 Ω. Figure 8 shows the unequal Wilkinson power divider design. The simulated reflection coefficient at the input port $|S_{11}|$ and the output two ports ($|S_{22}|$, $|S_{33}|$) beside the isolation between the two output ports $|S_{23}|$ are shown in Figure 9(a). The simulated power ratios at the two ports ($|S_{21}|$, $|S_{31}|$) are shown in Figure 9(b).

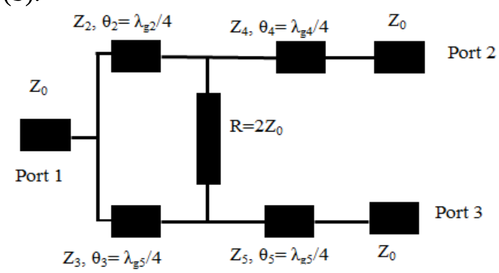


Fig. 7 The schematic diagram of an unequal Wilkinson power divider with impedance transformers

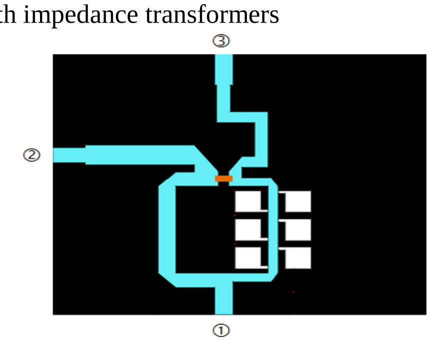
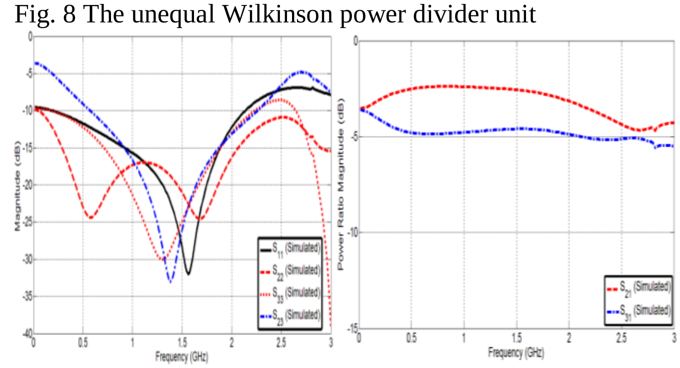


Fig. 8 The unequal Wilkinson power divider unit



(a) (b)

Fig. 9 (a) The reflection coefficient at the input port $|S_{11}|$ and the output two ports ($|S_{22}|$, $|S_{33}|$) beside the isolation between the two output ports ($|S_{23}|$), (b) The simulated power ratios at the two output ports ($|S_{21}|$, $|S_{31}|$).

V. Feeding Network Circuits

The feeding network circuit is designed to excite ten elements in a linear antenna array with unequal power ratios and equal phase. It is composed of three stages of equal Wilkinson power divider and two stages of unequal Wilkinson power divider. Two feeding network circuits are presented; one is used to excite the lower band (LB) linear antenna array operated at GSM380/ GSM410/GSM450/GSM480/GSM710 /GSM750/ GSM810/GSM850/GSM900 with ten unequal power coefficients and equal phase, and the other used to excite an upper band (UB) linear antenna array operated (DCS1800/ PCS1900/ UMTS2100) in order to get ten output ports equal in phase for each circuit. The design of both feeding network circuits are realized on FR4 dielectric material with dielectric constant of $\varepsilon_r = 4.5$, loss tangent equals 0.025 and substrate height of 1.5 mm and simulated using IE3D-Zeland ver. 12 electromagnetic software package.The dimensions of both LB - feeding network and UB-feeding network are 23.774 mm x 15.79 mm. The design composed of six zigzag dual-band equal Wilkinson power dividers and four unequal Wilkinson power dividers as shown in Figure 10.

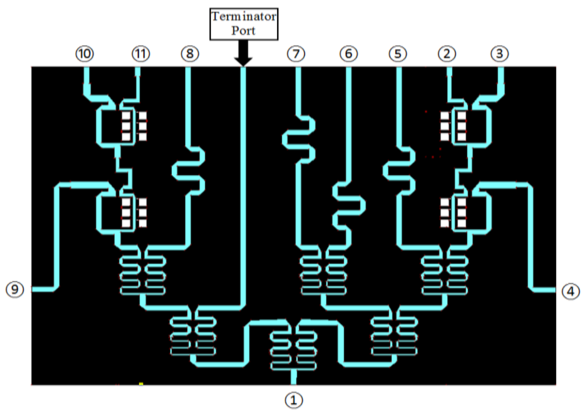


Fig. 10 The feeding network circuit for the lower band.

Ten 100 Ω chip resistors are used to improve the isolation between the output ports. Each one is connected between the output ports for each power divider. The design parameters are obtained using the three stages of equal Wilkinson power divider and the two stages of unequal Wilkinson power divider as shown in the previous section. Figure 10 shows the feeding network circuit for the lower band linear antenna array. Figure 11 depicts the measured reflection coefficient $|S_{11}|$ compared to the simulated one for the lower band feeding network circuit. It is clear that the meaured operating bands extend from 0.202 – 2.54 GHz so, it supports most of the interesting bands of mobile communication i.e GSM850, GSM900, DCS1800, PCS1900, and UMTS2100, etc.

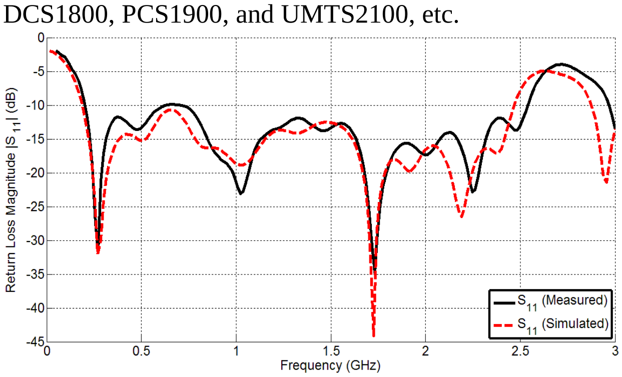


Fig. 11 The measured and simulated reflection coefficient at the input port $|S_{11}|$, for the lower band.

Table 2 shows the excitation coefficients / the power ratios and the phase at each output port of the lower band (f = 915 MHz) feeding network. The differnece between measured and simulated phase is due to the adaptor connection used for measurment at the input port. Figure 12 shows the photo of the feeding network circuit for the lower band linear antenna array.

Table 2: The power ratios and the phase at each output port of the lower band feeding network (f = 915 MHz).

Port	Power Ratio |S| (dB)		Phase (degree)			Δ phase
	Sim.	meas.	Sim.	meas.	Meas. shift	meas.
S_{21}	-19.87	-19.6	-90.78	-73.5	17.28	-----
S_{31}	-17.35	-16.93	-90.59	-71.65	18.94	-1.85
S_{41}	-12.56	-12.01	-90.54	-76.94	13.6	3.44
S_{51}	-10.88	-10.32	-90.75	-75.76	14.99	2.26
S_{61}	-10.88	-10.32	-91.07	-75.46	15.61	1.96
S_{71}	-10.81	-10.3	-90.62	-76.16	14.46	2.56
S_{81}	-10.68	-10.24	-90.58	-74.61	15.97	1.11
S_{91}	-12.41	-11.98	-90.5	-72.83	17.67	-0.67
$S_{10,1}$	-17.2	-16.72	-90.66	-71.95	18.71	-1.55
$S_{11,1}$	-19.69	-19.42	-90.83	-74.31	16.52	0.81

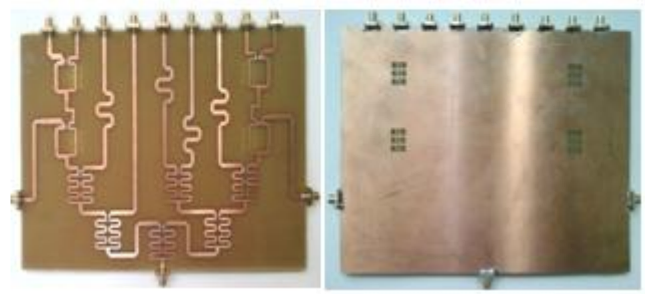

(a) (b)

Fig. 12 The photo of the feeding network circuit for the lower band linear antenna array (a) Top view, (b) Bottom view.

Figure 13 shows the feeding network circuit for the upper band linear antenna array. Figure 14 depicts the measured reflection coefficient $|S_{11}|$ compared with the simulated one for the feeding network circuit of the upper band linear antenna array. It is clear that the meaured operating band extends from 0.199 – 2.548 GHz so, it supports most of the interesting bands of mobile communication i.e GSM850, GSM900, DCS1800, PCS1900, and UMTS2100, etc.

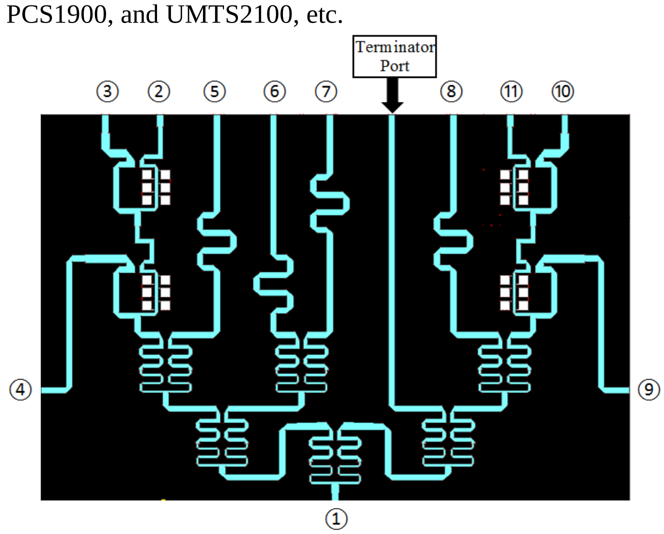


Fig. 13The feeding network circuit for the upper band.

Table 3 shows the excitation coefficients / the power ratios and the phase at each output port of the lower band feeding network. The differnece between measured and simulated phase is due to the adaptor connection used for measurment at the input port. Figure 15 shows the photo of the feeding network circuit for the upper band linear antenna array.

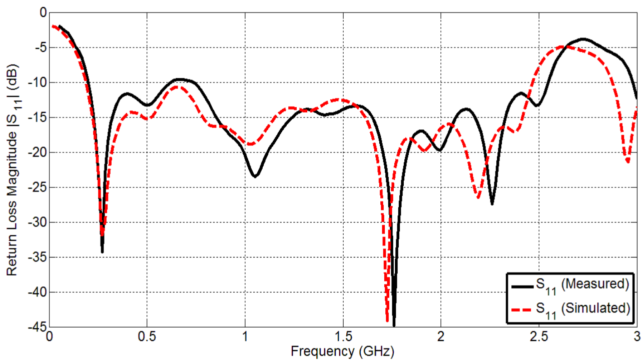
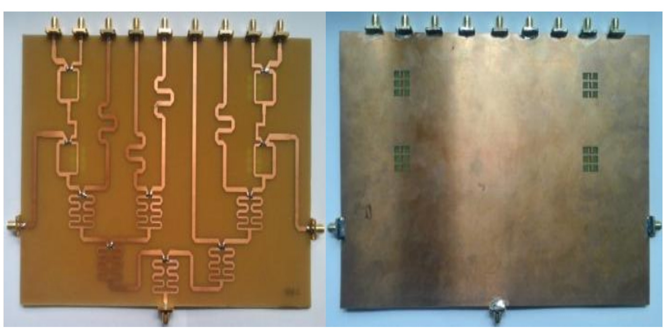


Fig. 14 Measured and simulated return loss at the input port$|S_{11}|$.

Table 3: The power ratios and the phase at each output port of the upper band feeding network.

Port	Power Ratio |S| (dB)		Phase (degree)			Δ phase
	Sim.	meas.	Sim.	meas.	Meas. shift	meas.
S_{21}	-21.56	-20.37	41.24	81.69	40.45	--------
S_{31}	-19.45	-18.24	41.21	80.45	39.24	1.24
S_{41}	-14.94	-14.13	41.21	77.5	36.29	4.19
S_{51}	-12.43	-11.35	41.26	79.66	38.4	2.03
S_{61}	-12.06	-11.23	41.16	79.25	38.09	2.44
S_{71}	-12.33	-11.32	42.83	80.15	37.32	1.54
S_{81}	-12.51	-11.22	41.36	81.73	40.37	-0.04
S_{91}	-14.87	-13.93	41.19	77.36	36.17	4.33
$S_{10,1}$	-19.4	-18.04	41.24	83.97	42.73	-2.28
$S_{11,1}$	-21.48	-20.16	41.27	83.08	41.81	-1.39



(a) (b)

Fig. 15 The photo of the feeding network circuit for the lower band linear antenna array (a) Top view, (b) Bottom view.

VI. Conclusion

In this paper, a compact single stage dual-band microstrip Wilkinson equal power divider looks like zigzag shape which yields a size reduction of 45.68 % compared to the conventional shape was presented. Two cascaded stages of unequal Wilkinson power divider (UWPD) with 2:1 power division ratios at the out ports are presented. A three unit hippocampus - shaped defected ground structure (DGS) pattern etched on the ground plane and placed underneath one of the microstrip branch line of both cascaded unequal Wilkinson power divider is used to realize 102 Ω microstrip lines with a wider width of 1.6 mm. The feeding network is designed and fabricated on FR4 dielectric substrate with dielectric constant of ε_r = 4.5, loss tangent 0.025 and substrate height of 1.5 mm. The proposed feeding network circuit is suitable for exciting ten antenna elements placed in a linear array with unequal power ratios and equal phase. It Supports GSM380, GSM410, GSM450, GSM480, GSM 710, GSM750, GSM810, GSM850, GSM900, GSM1800/ DCS1800, GSM1900/ PCS1900, UMTS2100, and most used LTE bands. Two feeding circuits are designed one for lower band and the other is used for upper bands.

References

i. *E. J. Wilkinson, "An n-way hybrid power divider", IRE Trans. Microwave Theory Tech., vol. 8, pp. 116–118, Jan. 1960.*

ii. *K. Moradi and S. Nikmehr, "A dual-band dual-polarized microstrip array antenna for base stations," Progress In Electromagnetic Research, vol. 123, pp. 527-541, 2012.*

iii. *R.-Y. Yang, H. Kuan, C.-Y. Hung, and C.-S. Ye " Design of dual-band bandpass filters using a dual feeding structure and embedded uniform impedance resonators," Progress In Electromagnetic Research, vol. 105, pp. 93-102, 2010.*

iv. *S. J. Orfanidis, "A two-section dual-band Chebyshev impedance transformer," IEEE Microwave and Wireless Components Letters, vol. 13, no. 9, pp. 382-384, Sep. 2003.*

v. *A. Hussein, H., H. H. Abdullah, A. M. Salem, S. Khamis, and M. Nasr, "Optimum design of linear antenna arrays using a hybrid MoM/GA algorithms," IEEE Antennas Wireless Propag. Lett., vol.10, pp. 1232-1235, 2011.*

vi. *R. F. Harrington, Field Computation by Moment Methods, New York: IEEE Press, 1993.*

vii. *Y. Rahmat-Samii and E. Michielssen, Electromagnetic Optimization by Genetic Algorithms. New York: Wiley, 1999.*

viii. *R. L. Haupt and D. H. Werner, Genetic Algorithms in Electromagnetics, Piscataway, NJ: IEEE Press–Wiley-Interscience, 2007.*

ix. *C. Monzon, "A small dual-frequency transformer in two sections," IEEE Trans. Microwave Theory Tech., vol. 51, no. 4, pp. 1157-1161, April 2003.*

x. *D. M. pozar, " Microwave engineering," John Wiley & Sons, 4th edition, 2012.*