

line elements were used with shorting vias to ensure good connectivity between the upper and lower ground planes and prevent the excitation of spurious modes. The return loss at the resonant frequency was measured to be 21dB, with a 2:1 VSWR bandwidth of 2.7%. By comparison, an ordinary probe-fed or microstrip-line fed patch antenna on the same substrate would yield a bandwidth of the order of 1.5%. The impedance bandwidth of this element could be increased by increasing the substrate thickness, as long as the coplanar waveguide line does not become too wide.

Fig. 2 also shows results of modelling this antenna with Momentum, for the case of three vias per side. The resonant frequency and resonant resistance are predicted quite well, although the calculated points do not match the measured data over the entire locus. Nevertheless, considering the complexity of the problem caused by the presence of the vias, the calculations are surprisingly good, and should be more than adequate for design purposes.

The principal plane patterns of the antenna (with three vias per side) is shown in Fig. 3. The measured back radiation in the E-plane is 18dB down, and in the H-plane it is 15dB down. These results are similar to those obtained in [4] for a proximity-coupled circular patch at 5GHz.

Conclusions: A simple structure of a printed antenna fed by slot-coupled GCPW on a single layer substrate is presented. The minimum number of shorting vias required to prevent spurious modes is demonstrated. The measured characteristics of the antenna include the radiation pattern, bandwidth, and front-to-back ratio. Measurements show that the antenna has a good radiation pattern and bandwidth.

© IEE 2000

10 April 2000

Electronics Letters Online No: 20000776
DOI: 10.1049/el:20000776

S. Hudson and D. Pozar (ECE Department, University of Massachusetts, Amherst, MA 01003, USA)

References

- 1 POZAR, D.M.: 'Microstrip antenna aperture coupled to microstrip line', *Electron. Lett.*, 1985, **21**, pp. 49–50
- 2 MENZEL, W., and GRABHER, W.: 'A microstrip patch antenna with coplanar feed line', *IEEE Microw. Guided Wave Lett.*, 1991, **1**, pp. 340–342
- 3 SIMONS, R.N., and LEE, R.Q.: 'Coplanar waveguide aperture coupled patch antennas with ground plane/substrate of finite extent', *Electron. Lett.*, 1992, **28**, pp. 75–76
- 4 RAHARDJO, E.T., KITAO, S., and HANEISHI, M.: 'Planar antenna excited by electromagnetically coupled coplanar waveguide', *Electron. Lett.*, 1993, **29**, pp. 870–872
- 5 DUFFY, S.: 'Design and analysis of microwave/millimeter wave active arrays using a multilayered packaging architecture'. PhD thesis, University of Massachusetts, Amherst, 1999

Multiobjective genetic algorithm approach for a dual-feed circular polarised patch antenna design

B. Aljibouri, E.G. Lim, H. Evans and A. Sambell

A design procedure for a dual feed network is presented to produce a circular polarised matched antenna involving eight design parameters with associated constraints. Determination of such design parameters has been made possible by utilising a multiobjective genetic algorithm (MGA) approach. The conditions for circular polarisation and impedance matching were the objective functions employed in the MGA. The associated constraints were the lengths and characteristic impedance values of the feed network. The return loss and axial ratio for a 5.8GHz antenna were investigated and good agreement was obtained between simulated and practical measurements.

Introduction: Microstrip patch antennas are used in a variety of communication systems, especially when the receiver needs to be

compact and have a low profile. Further, for applications such as radio frequency identification (RFID) systems in which the receiver may be placed in any orientation, circular polarisation is used. Circular polarisation can be realised by using either a single [1] or a dual feed [2, 3]. In many cases, owing to the simplicity of design and manufacture a dual-feed arrangement is preferred.

An MGA programme has been developed to optimise the design of the dual-feed network, involving eight variables, which are required to meet the conditions for circular polarisation and matching at the feed port. Two constraints on the design parameters have also been applied, one to ensure that the widths of the feed lines are as narrow as possible yet realisable, and the other constraint to ensure that the lengths of the feed lines are sufficient to fit the network around the square patch antenna.

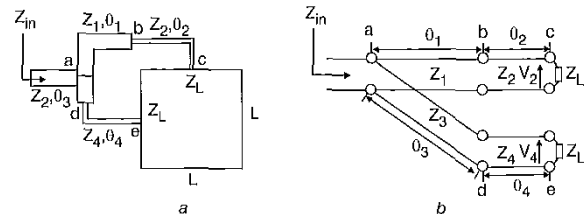


Fig. 1 Dual-feed LHCP square patch antenna and equivalent circuit

Design of feed network using multiobjective genetic algorithm approach: A dual feed network based on a power divider to produce circular polarisation is shown in Fig. 1a and its transmission line model in Fig. 1b.

It is possible, using a transmission line approach, to match a complex load impedance to a complex source impedance by relaxing the constraint length of a traditional $\lambda/4$ transformer [4]. Consequently, by varying the impedance and lengths of the transmission lines of the feed network, both matching and circular polarisation conditions can be satisfied. For the structure shown in Fig. 1 the design variables' parameters (characteristic impedances and element lengths of the feed network) are $Z_1, \theta_1, Z_2, \theta_2, Z_3, \theta_3, Z_4, \theta_4$ and constitute the parameter set in the MGA. The two objective functions employed in the MGA are given by eqns. 1 and 2 below and give the conditions required for circular polarisation and impedance matching, respectively. For circular polarisation

$$\frac{V_2}{V_1} = \frac{e^{-j(\theta_1+\theta_2)}[1+\Gamma_1][1+\Gamma_2]}{[1+\Gamma_1e^{-2j\theta_1}][1+\Gamma_2e^{-2j\theta_2}]} \times \frac{[1+\Gamma_3e^{-2j\theta_3}][1+\Gamma_4e^{-2j\theta_4}]}{e^{-j(\theta_3+\theta_4)}[1+\Gamma_3][1+\Gamma_4]} = \mp j \quad (1)$$

where $\Gamma_1, \Gamma_2, \Gamma_3$ and Γ_4 are the reflection coefficients at junctions b, c, d, and e, respectively (see Fig. 1).

For the impedance matching

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = 0 \quad (2)$$

where Γ_{in} is the input reflection coefficient at junction 'a'.

For microstrip realisation, search intervals between 120 Ω and 140 Ω were used for the parameters Z_1, Z_2, Z_3, Z_4 . The 120 Ω impedance was chosen to reduce the coupling between the feed lines and the antenna and also to minimise the step discontinuities at the feed lines junctions, thereby reducing spurious radiation. The 140 Ω impedance represents the maximum impedance that can be realised. To fit the feed network around the antenna, the lengths $\theta_1, \theta_2, \theta_3, \theta_4$ were constrained to an interval between $\pi/4$ and π .

The tolerance for $|V_2/V_1|$ was 1 ± 0.1 and for $\arg(V_2/V_1)$ was $90^\circ \pm 4^\circ$, so as to ensure good circular polarisation, while the tolerance for Γ_{in} was ± 0.02 in order to produce good matching conditions.

Results and discussion: The MGA approach, based on a nondominating sorting genetic algorithm [4], was developed to produce sets of feasible solutions. Selection was made from these solutions, using additional factors, such as a preference for similar characteristic impedance values of the feed line network.

The operating frequency of the patch antenna was 5.8GHz, and

the feed network was optimised to produce left- and right-hand circular polarisation (LHCP and RHCP) with a 50 Ω matched input impedance condition. The two sets of solutions for the optimised feed network are shown in Table 1.

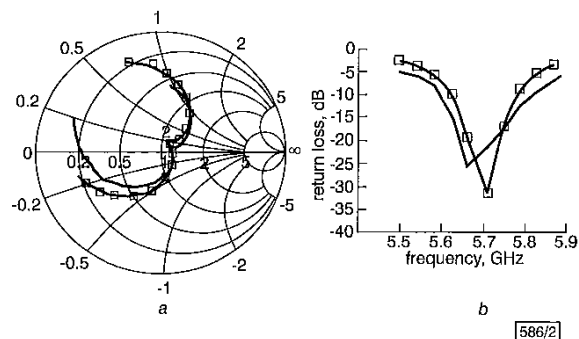


Fig. 2 Simulated and practical results of dual-feed square microstrip patch antenna

--- - practical
—□— simulated
 $h = 0.79$, $\epsilon_r = 2.33$

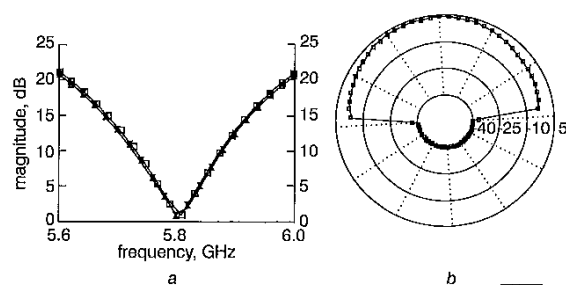


Fig. 3 Simulated results for LHCP and RHCP designs

a Axial ratio
b Radiation pattern
—□— LHCP
—×— RHCP

Table 1: Two sets of solutions for optimised feed network

| θ_1 | Z_1 | θ_2 | Z_2 | θ_3 | Z_3 | θ_4 | Z_4 | Z_{in} | $ V_2/V_4 $ | $\arg(V_2/V_4)$ | CP |
|------------|-------|------------|-------|------------|-------|------------|-------|-----------|-------------|-----------------|----|
| 2.31 | 135.0 | 1.96 | 132.4 | 0.8 | 135.2 | 1.16 | 134.3 | 50 0.5i | 0.97 | 86 | RH |
| 1.2 | 137.4 | 0.74 | 137.1 | 2.3 | 135.7 | 1.97 | 138.6 | 49.5+0.5i | 1.08 | 89.7 | LH |

As can be seen in Table 1, it is possible to use an average value of impedance for all four feed lines as this value is within the design and typical manufacturing tolerances. This makes the design particularly attractive as the effect of the step discontinuity is eliminated and also spurious radiation is reduced.

Practical and simulated (full-wave analysis software) results for the reflection coefficient of the LHCP solution using 137.2 Ω are shown in Fig. 2 and indicate that a good matching condition at 5.8GHz has been obtained.

The simulated results of the axial ratio and radiation pattern of the LHCP and RHCP designs are shown in Fig. 3 with a good axial ratio and the expected radiation patterns.

Conclusion: It has been shown that the design of a dual-feed network for a square patch antenna for circular polarisation involves eight variables and that a closed form solution to the problem cannot be obtained. An MGA with specified constraints has been successfully implemented to optimise the design of a dual-feed network. A feed network with single feed impedance has been realised. The practical and simulated results for the return loss, axial ratio and radiation pattern show good agreement and confirm the validity of the approach.

© IEE 2000
Electronics Letters Online No: 20000766
DOI: 10.1049/el:20000766

B. Aljibouri, E.G. Lim, H. Evans and A. Sambell (Communication Systems Research Group, University of Northumbria, United Kingdom)

References

- 1 LIM, B., KOROLKIEWICZ, E., and SCOTT, S.: 'Optimised design of corner microstrip fed nearly square patch antenna for circular polarisation', *Electron. Lett.*, 1996, **32**, pp. 610–612
- 2 HOWELL, J.Q.: 'Microstrip antennas', *IEEE Trans.*, 1975, **AP-23**, pp. 90–93
- 3 SOLIMAN, E.A., BREIBEL, S., BEYNE, E., and VANDENBOSCH, G.: 'Circularly polarised aperture antenna fed by CPW and built in MCM-D technology', *Electron. Lett.*, 1999, **35**, pp. 250–251
- 4 DAY, P.L.: 'Transmission line transformation between arbitrary impedances using the smith chart', *IEEE Trans. Microw. Theory Tech.*, 1975, pp. 772–773
- 5 SRINIVAS, N., and KALYANMOY, D.: 'Multiobjective optimization using nondominating sorting in genetic algorithms', *Evol. Comput.*, 1995, **2**, (3), pp. 221–248

Independent component analysis of saccade-related electroencephalogram waveforms

L. Vigon, R. Saatchi, J. Mayhew, N. Taroyan, J. Frisby, D. Johnston and O. Pascalis

A methodology based on the signal separation technique of extended independent component analysis (ICA) is devised to analyse saccade-related electroencephalogram (EEG) waveforms. The methodology enables saccade-related components to be successfully extracted from the EEG mixtures and the brain regions responsible for their generation to be identified.

Introduction: Saccades are rapid changes in the orientation of the eyes that are used to realign the visual axes on objects of interest. Dysfunction in this system may lead to difficulties in various visual functions such as depth perception and reading. Different neural signal components are involved in preparation and execution of saccadic eye movements. One of these is described as a pre-saccadic potential related to motor commands for saccade generation. Others, such as efferent feedback from saccade generating centres to visual cortex, are believed to provide visual stability of the surrounding world across the eye movements. The saccadic movement is accompanied by an EEG signal associated with visual information processing called the lambda-wave [1].

The investigation described in this Letter required the obscuring ongoing background EEG as well as the electrooculogram (EOG) signal caused by eye movements to be separated from the saccade components of interest. A popular signal separation technique is independent component analysis (ICA) [2]. ICA is an extension of principal component analysis (PCA) that deals with higher-order statistical dependencies. It is based on the assumption that the signal sources are statistically independent. The extended version of ICA (hereafter referred to as ICA) can handle both super- and sub-Gaussian signals [2]. In this Letter, an analysis of the saccade-related EEG waveforms is carried out by applying an ICA-based procedure. The study provides information about how the brain deals with the problem of vision with moving eyes.

Experimental procedure: EEG and EOG data were recorded for six healthy human adults using a network of 64 silver-silver chloride electrodes. All electrodes were referred to the vertex. The data were filtered (bandpass frequency range from 0.1 to 100Hz) and digitised with a sampling rate of 250. The subjects were instructed to fixate a red square that appeared randomly on the screen of a computer at one of five predefined checkerboard locations: centre, left, right, up and down. For each location 50 trials were recorded. The duration of each trial was 2s.

Analysis procedure: The recorded signals were digitally lowpass filtered at 45 Hz and their baselines were adjusted to zero. To preserve the saccade-related EEG components, the waveforms in each trial were time synchronised with reference to the EOG signal in that trial. The synchronised averaged waveforms were decorrelated using PCA and sphered [2]. The EEG waveforms recorded from the locations close to the international 10-20 system of electrode