References

1 CORRAL, J.L., MARTI, J., REGIDOR, S., FUSTER, J.M., PASTOR, D., CAPMANY, J., LAMING, R.I., and COLE, M.J.: 'True time delay scheme for feeding optically controlled phased array antennas using chirped fibre gratings', *IEEE Trans. Microw. Theory and Tech.*, to be published

2 COWARD, J.F., YEE, T.K., CHALFANT, C.H., and CHANG, P.H.: 'A photonic integrated-optic RF phase shifter for phased array antenna beam-forming applications', *J. Lightwave Technol.*, 1993, **11**, pp. 2201–2205

3 SUN, C.K., ORAZI, R.J., PAPPERT, S.A., and BURNS, W.K.: 'A photonic-link millimeter-wave mixer using cascaded optical modulators and harmonic carrier generation', *IEEE Photonics Technol. Lett.*, 1996, **8**, pp. 1166–1168

4 GOPALAKRISHNAN, G.K., BURNS, W.K., and BULMER, C.H.: 'Microwave-optical mixing in $LiNbO_3$ modulators', *IEEE Trans. Microw. Theory Tech.*, 1993, **41**, pp. 2383–2391

Stripline-fed printed triangular monopole

Kin-Lu Wong and Yi-Fang Lin

Indexing terms: Monopole antenna arrays, Antenna arrays

A design of stripline-fed printed triangular monopole with broadband operation is presented. Results show that the triangular monopole with a flare angle of 60° (i.e. an equilateral triangular monopole) has the widest bandwidth, ~2.1–3.0 times that of a simple strip monopole, and this equilateral triangular monopole also operates at a length of only ~0.63 times that of a simple strip monopole. Details of the results are presented.

Introduction: Owing to their flat geometry and omnidirectional radiation, printed dipoles or monopoles on a dielectric substrate with no ground plane have recently received much attention for applications in mobile communications systems [1 – 3]. To meet the requirements for modern mobile applications, such printed antennas with reduced size and broadband operation are of particular interest. For this purpose, we present in this Letter a simple design of a printed triangular monopole for improving the operating bandwidth and reducing the length of a printed strip monopole. By choosing a suitable flare angle of the triangular monopole, it is expected that the impedance matching of the monopole to the feeding stripline can be significantly improved. Furthermore, due to the increased effective current path in the triangular monopole, as compared with a simple strip monopole of the same length, the required monopole length at a fixed operating frequency can be reduced. The design and characteristics of the printed triangular monopole are presented and discussed.

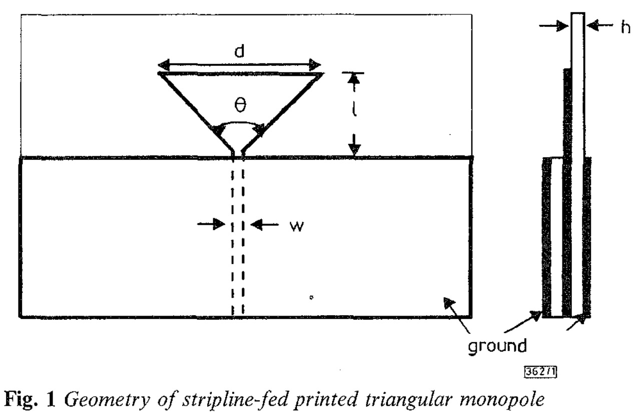

Fig. 1 *Geometry of stripline-fed printed triangular monopole*

Antenna design and experimental results: Fig. 1 shows the geometry of a printed triangular monopole of length ℓ and width d. The monopole is fed by a 50Ω stripline and has a flare angle of θ. The two planar conducting ground planes of the stripline have a length of $\sim 0.4\lambda_0$, where λ_0 is the free-space wavelength, and serve as the ground plane for the triangular monopole. The conducting strip of the 50Ω feeding stripline has a width of w and is centred between the two conducting ground planes of separation $2h$. The case of using a Duroid microwave substrate is first studied. The relative permittivity ε_r and thickness h of the dielectric substrate are 3.0 and 0.762mm, respectively. The triangular monopoles of various flare angles are printed on such a substrate. Fig. 2 shows typical results of the measured return loss for the cases of θ = 30, 60, 90, and 110°. The width of the centre conductor of the feeding stripline is 1.0mm (w), and the result for a simple strip monopole (θ = 0°) is also plotted for comparison. The centre frequency is at 1.78GHz (λ_0 = 16.86cm). From the results, it can be seen that the

Table 1: Bandwidths of various printed triangular monopoles at 1.78GHz

θ [deg]	0	30	60	90	110
ℓ/ℓ_{strip}	1.0	0.73	0.63	0.53	0.46
BW [%]	15.5	27	32.5	27	25

ε_r = 3.0, h = 0.762mm

triangular monopoles with a flare angle of 30–110° all show a wider operating bandwidth as compared with that of the strip monopole. The antenna bandwidths determined from a 10dB return loss are shown in Table 1. It is clearly seen that the monopole length required for operating at 1.78GHz decreases with increasing flare angle, and the maximum attainable bandwidth is ~32.5% for the case with θ = 60° (equilateral triangular monopole), which is ~2.1 times that (15.5%) of the strip monopole. It is also noted that the equilateral triangular monopole has a length of $\sim 0.127\lambda_0$ which is only 0.63 times that ($0.2\lambda_0$) of the strip monopole. (Here, due to the presence of the dielectric substrate, the length of the strip monopole is less than that ($\sim 0.25\lambda_0$) required for the case in a free-space environment.) By comparing the antenna size ($0.127\lambda_0$ in length and $0.147\lambda_0$ in width) of the equilateral triangular monopole with that ($0.12\lambda_0$ in length and $0.22\lambda_0$ in width) of the tab monopole reported in [2], it can be seen that the equilateral triangular monopole is more compact than the tab monopole.

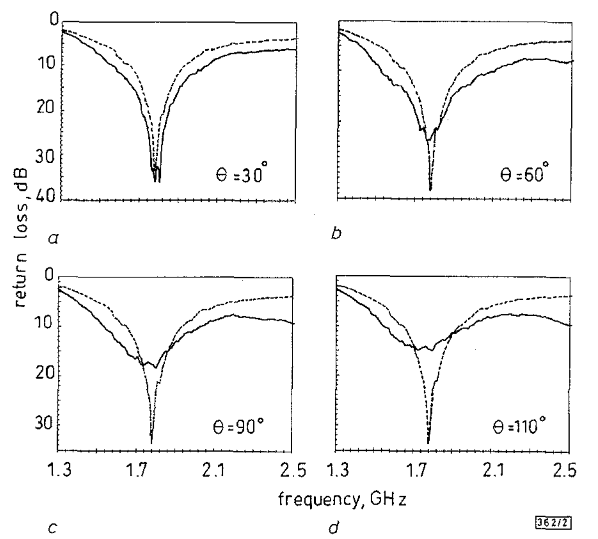

Fig. 2 *Return loss against frequency for printed triangular monopoles operated at 1.78GHz (λ_0 = 16.86cm)*

ε_r = 3.0 and h = 0.762mm
a θ = 30°, $\ell = 0.145\lambda_0$
b θ = 60°, $\ell = 0.127\lambda_0$
c θ = 90°, $\ell = 0.106\lambda_0$
d θ = 110°, $\ell = 0.09\lambda_0$
– – – – result of strip monopole with $\ell = 0.20\lambda_0$

Since the presence of the dielectric substrate affects the required monopole length at a fixed operating frequency, another case of fabricating the triangular monopole on an FR-4 substrate (ε_r = 4.4, h = 1.6mm) was also studied. Similar behaviour as observed for the Duroid substrate is seen. The maximum antenna bandwidth also occurs for an equilateral triangular monopole (θ = 60°). The antenna bandwidths and lengths for various flare angles are listed in Table 2, and the measured return loss for θ = 60° is presented in Fig. 3, where the result of a strip monopole is also shown for comparison. In this case, the centre frequency is at 1.9GHz (λ_0 = 15.79cm), and the conducting strip of the 50Ω feeding stripline has a width of 1.5mm. An antenna bandwidth of

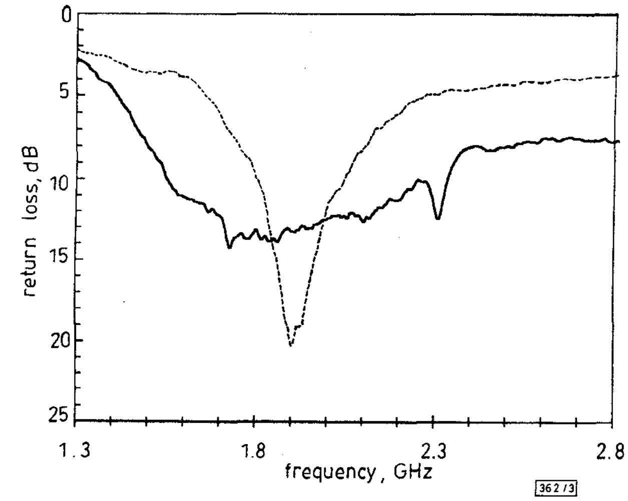

Fig. 3 *Return loss against frequency for printed triangular monopole operated at 1.9GHz*

ε_r = 4.4, h = 1.6mm, θ = 60° and ℓ = 0.12λ_0
Dashed line shows result of strip monopole with ℓ = 0.19λ_0

36.3% is observed, which is ~3.0 times that (~12%) of the strip monopole, and the antenna length is 0.12λ_0, 0.63 times that (0.19λ_0) of the strip monopole. It seems that the antenna bandwidth is better for using the dielectric substrate with a larger permittivity. However, the effect in reducing the monopole length is about the same for using either the Duroid (ε_r = 3.0) or the FR-4 (ε_r = 4.4) substrate. Finally, for the equilateral triangular monopole, the radiation patterns are also studied. The obtained results are found to be similar to those reported in [2] for a tab monopole. No special distinction is observed.

Table 2: Bandwidths of various printed triangular monopoles at 1.9GHz

θ [deg]	0	30	60	90	110
ℓ/ℓ_{strip}	1.0	0.78	0.63	0.58	0.53
BW [%]	12	32.5	36.3	32.8	22.6

ε_r = 4.4, h = 1.6mm

Conclusions: A simple design of the stripline-fed printed triangular monopole has been described and studied. With an optimal flare angle of 60°, the printed triangular monopole can have a much improved antenna bandwidth (~32.5–36.3% for the study here), and the antenna length is also reduced to ~0.63 times that of a simple strip monopole. This monopole design is suitable for applications in mobile and telecom communications systems, where omnidirectional coverage is required.

19 May 1997

Electronics Letters Online No: 19970960

Kin-Lu Wong and Yi-Fang Lin (*Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan 804, Republic of China*)

References

1 LIN, Y.D., and TSAI, S.N.: 'Coplanar waveguide-fed uniplanar bow-tie antenna', *IEEE Trans. Antennas Propag.*, 1997, **45**, (2), pp. 305–306

2 JOHNSON, J.M., and RAHMAT-SAMII, Y.: 'The tab monopole', *IEEE Trans. Antennas Propag.*, 1997, **45**, (1), pp. 187–188

3 TILLEY, K., WU, X.-D., and CHANG, K.: 'Coplanar waveguide fed coplanar strip dipole antenna', *Electron. Lett.*, 1994, **30**, (3), pp. 176–177

BIST test pattern generator for delay testing

P. Girard, C. Landrault, V. Moréda and S. Pravossoudovitch

Indexing terms: Built-in self test, Digital circuits

To detect delay faults in a digital circuit requires a test sequence applied at the nominal frequency of the circuit. Built-in self-test (BIST) is a technique that provides such testing possibilities at speed, without expensive test equipments. A BIST test pattern generator (TPG) design, targeting the detection of delay faults is proposed.

Introduction: To detect delay faults requires a pair of test patterns. The first pattern applied on the primary inputs of the circuit under test (CUT) initialises the lines in the circuit to the desired initial value and the second pattern generates transitions and propagates them through the circuit. The response of the circuit is captured on the primary outputs after the normal stabilisation time (which is defined from the propagation delay of the longest path). The control of the timing aspect of such test sequences requires expensive high speed testers. An alternative for reducing the cost of delay testing is to decrease the reliance on expensive test equipment by using built-in self-test (BIST) techniques.

Different categories of BIST test pattern generators target the generation of two-pattern tests [1–7]. They differ with respect to the fault coverage, the area overhead and the test length. An exhaustive two-pattern count for an n-input circuit under test is $2^n(2^n - 1)$, but it has been shown in [8] that only $n2^n$ test pairs that differ on a single bit are sufficient to detect all robustly [9] detectable path delay faults. Moreover, to generate SIC pattern pairs is particularly efficient for BIST in terms of applicability and test length.

This Letter presents a BIST test pattern generator design (TPG) targeting the robust detection of delay faults. This TPG is based on a single input change (SIC) principle. The TPG design is optimised according to the CUT structure in order to reduce the area overhead and the length of the test sequence. The proposed optimisation which does not modify the robust delay fault coverage leads to multiple input change (MIC) test sequences.

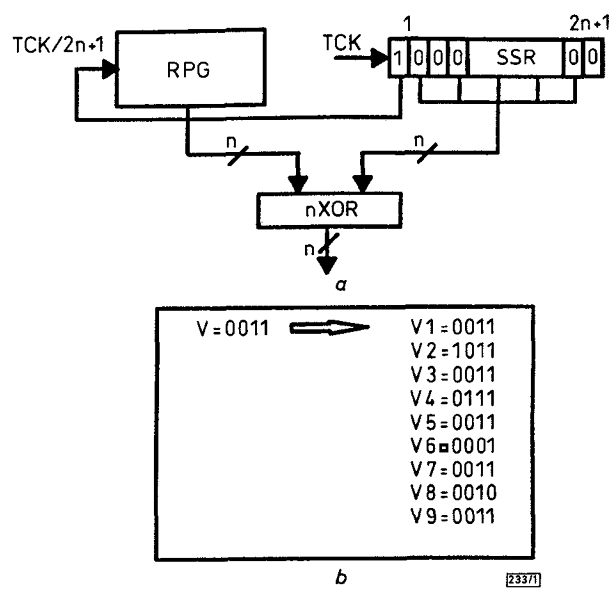

Fig. 1 *SIC TPG design and subsequence*

a Design
b Subsequence

SIC TPG design: The principle of the SIC TPG design considered is shown in Fig. 1*a* [7]. A random pattern generator (RPG) produces random patterns of n bits. A scan shift register (SSR) with $2n$ + 1 stages is initialised with (10...0). The 1 is shifted through the register at each cycle of the test clock TCK (walking one). The outputs of the even stages of the SSR are connected to n XOR