Conclusions: We have demonstrated the feasibility of using a silicon micromachined waveguide with a simple diagonal horn structure. The radiation patterns were very similar to those obtained with a conventional diagonal horn. However, to obtain good patterns, the micromachined waveguide was modified by eliminating the outer wafers near the horn. The copolarised radiation patterns were not sensitive to the amount of undercut modelled for the isotropically etched surfaces. We also saw a significant reduction in the on-axis cross-polarisation response when the flared section had flat walls. This result could be used to design an improved waveguide-to-horn transition for conventionally manufactured diagonal horns. Furthermore, at 110GHz a large die area will be required for silicon inserts. Hence this technique will be better suited for higher frequencies where less area is needed.

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References

1 PETERSEN, K.E.: 'Silicon as a mechanical material', *Proc. IEEE*, 1982, **70**, pp. 420–457

2 YAP, M., TAI, Y.-C., MCGRATH, W.R., and WALKER, C.: 'Silicon micromachined waveguides for millimeter and submillimeter wavelengths'. Proc. 3rd Int. Symp. Space Terahertz Technology, Ann Arbor, MI, USA, 1992, pp. 316–323

3 KATEHI, L.P.B.: 'Novel transmission lines for the submillimeter-wave region', *Proc. IEEE*, 1992, **80**, pp. 1771–1787

4 LOVE, A.W.: 'The diagonal horn antenna', *Microw. J.*, 1962, **5**, pp. 117–122

5 JOHANSSON, J.F., and WHYBORN, N.D.: 'The diagonal horn as a submillimeter wave antenna', *IEEE Trans.*, 1992, **MTT-40**, pp. 795–800

6 WITHINGTON, S., and MURPHY, J.A.: 'Analysis of diagonal horns through Gaussian-Hermite modes', *IEEE Trans.*, 1992, **AP-40**, pp. 198–206

Magnetically scannable microstrip antenna employing a leaky gyromagnetic microstrip line

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Indexing terms: Microstrip antennas, Chiral materials, Strip lines

Rigorous full-wave spectral-domain analyses of a magnetically scannable gyromagnetic microstrip leaky-wave antenna are presented. Varying the DC magnetic bias field by ~6.5%, the maximum radiation angle of the leaky-wave antenna, measured from the horizon, shifts from zero to almost 90°.

Introduction: Ferrite-loaded microstrip patch antennas have beenm widely investigated [1 – 4], owing to their abilities for DC magnetic bias control of beam scanning, antenna pattern, radar cross-section, etc. In contrast to these patch antennas which radiate at the resonance modes, a new travelling-wave antenna is presented. The new antenna, as shown in the inset of Fig. 1, employs the concept of leaky-wave propagation of the first higher-order mode on gyromagnetic microstrip line. Recently, many such leaky-wave antennas integrated on isotropic dielectric substrates have been reported 5 – 7]. The aim of this Letter is to study the feasibility of the new scannable gyromagnetic leaky-wave antenna by employing the rigorous full-wave spectral domain approach (SDA) based on the dyadic Green impedance formulation.

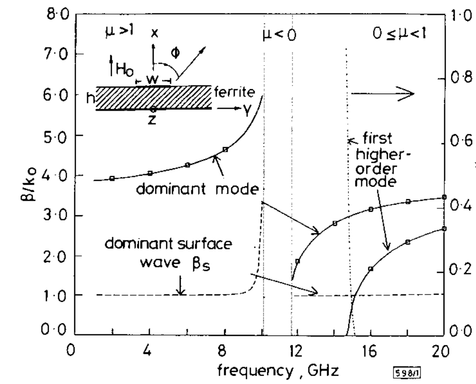

Fig. 1 *Dispersion characteristics of open gyromagnetic microstrip line*

Structure parameters are: ε_f = 15.2, M_s = 95.5kA/m, H_o/M_s = 3.0, h = 0.635mm, w = 3.175mm

□ data reported in [8]

Results of analyses: Before presenting the full-wave field-theory-based data of the leaky-wave antenna, the validity of our formulation employing the spectral-domain dyadic Green impedance function had been confirmed by obtaining very good agreements between our data and those published by Borburgh [8] for the bound modes. Fig. 1 plots the modal characteristics of the open gyromagnetic microstrip line with structure and material constants listed in the caption. The first higher-order mode becomes a leaky mode at ~15.2GHz when its propagation constant β is less than that of the first surface wave propagating along the magnetised ferrite substrate. Although the leaky-wave dispersion curves resemble those of the higher modes on isotropic microstrip line [9], the surface-wave leakage is a hybrid mode, not the usual TM mode in the isotropic case.

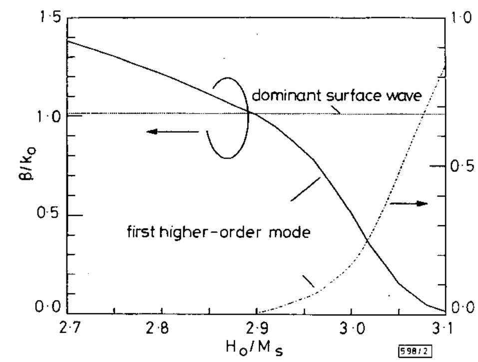

Fig. 2 *Bias-dependent leaky characteristics of first higher-order mode at 14.9GHz*

Fig. 2 shows the bias-dependent leaky-mode properties of the first higher-order mode at 14.9GHz. Notice that the normalised propagation constant β decreases from 1 to almost 0 by only varying the normalised DC magnetic bias field H_o/M_s from 2.9 to 3.1. This indicates that the maximum beam angle, measured from the z-axis and approximated by $\theta_m = \cos^{-1}(\beta/k_o)$, can be tuned from 0 to almost 90° by adding a smaller tunable magnetic field to a fixed magnetic bias field $H_o = 3M_s$. For millimetre-wave application, the fixed bias field may be replaced by the internal field of anisotropy of hexagonal ferrite. By extending the results given in Fig. 2, Fig. 3 shows that the beam angle θ_m on the z-x plane scans almost linearly up to 80° when H_o is changed by 6.5%. Under different DC magnetic bias conditions, the normalised radiation patterns are plotted in Fig. 4 by employing the Huygen magnetic current source. Since the magnetic currents on the two apertures underneath the edges of microstrip differ by a small amount, the direction of the main beam will slightly depart from the z-x plane. The gyromagnetic leaky-wave antenna is assumed to be five free-space wavelengths long and properly terminated. The maximum beam

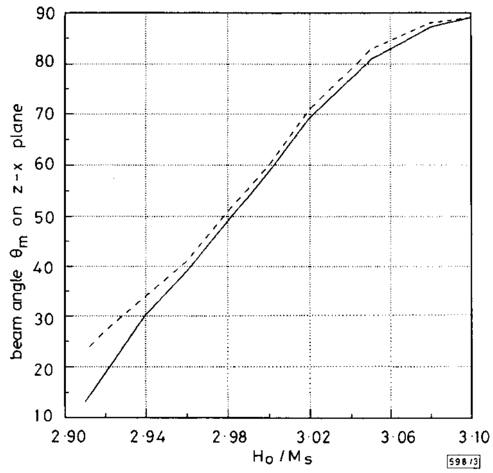

Fig. 3 *Bias-dependent beam angle θ_m on z-x plane*

angles on the z-x plane for various DC magnetic bias conditions are mapped to Fig. 3. The results show that the angle of maximum radiation agrees well with the approximate $\theta_m = \cos^{-1}(\beta/k_o)$ and the discrepancy at lower bias field is caused by the insufficient length of microstrip. Referring to Fig. 2, the attenuation constant α increases as the DC magnetic bias field increases, resulting in the observed widened beam width in Fig. 4.

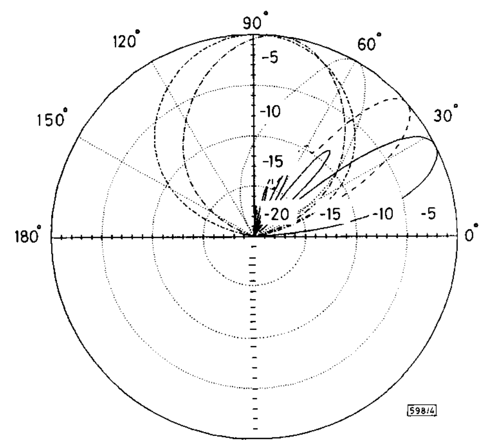

Fig. 4 *Theoretic bias-dependent radiation patterns on z-x plane*

The length of the microstrip line is assumed to be five free-space wavelengths at 14.9GHz and the terminal is matched.

——— $H_o/M_s = 2.92$
—··—·· $H_o/M_s = 2.96$
········· $H_o/M_s = 3.00$
—··—·· $H_o/M_s = 3.05$
— — — $H_o/M_s = 3.10$

Conclusion: A new gyromagnetic microstrip leaky-wave antenna capable of DC magnetic bias control of beam scanning is presented and validated by a rigorous spectral domain approach. The results show that the proposed antenna is a viable approach for beam scanning applications.

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References

1 YANG, H.Y., CASTANEDA, J.A., and ALEXOPOULOS, N.G.: 'The RCS of a microstrip patch on an arbitrarily biased ferrite substrate', *IEEE Trans.*, 1993, **AP-41**, pp. 1610–1614

2 POZAR, D.M.: 'Radiation and scattering characteristics of microstrip antennas on normally biased ferrite substrates', *IEEE Trans.*, 1992, **AP-40**, pp. 1084–1092

3 ROY, J.S., VAUDON, P., REINEIX, A., JECKO, F., and JECKO, B.: 'Circularly polarized far fields of an axially magnetized circular ferrite microstrip antenna', *Microw. Opt. Technol. Lett.*, 1992, **5**, pp. 228–230

4 HENDERSON, A., JAMES, J.R., and FRAY, A.: 'Magnetised microstrip antenna with pattern control', *Electron. Lett.*, 1988, **24**, pp. 45–47

5 TZUANG, C.K.C., CHOU, G.J., and LO, W.T.: 'A new quasi-planar leaky-wave antenna structure'. 19th Int. Infrared and Millimeter Waves Conf. Dig., Sendai, Japan, 1994, pp. 518–519

6 LIN, Y.D., SHEEN, J.W., and TZUANG, C.K.C.: 'Analysis and design of feeding structures for microstrip leaky wave antenna'. IEEE MTT-S Intl. Microwave Symp. Dig., Orlando, USA, 1995, pp. 149–152, Section TU3B

7 TZUANG, C.K.C., and CHOU, G.J.: 'An active microstrip leaky-wave antenna employing uniplanar oscillators'. 1995 European Microwave Conf., Bologna, Italy, 1995, Section B3.1

8 BORBURGH, J.: 'The behaviour of guided modes on the ferrite-filled microstrip line with the magnetization perpendicular to the ground plane', *Arch. Elek. Ubert.*, 1977, **31**, (2), pp. 73–77

9 OLINER, A.A., and LEE, K.S.: 'The nature of the leakage from higher modes on microstrip line'. IEEE MTT-S Int. Microwave Symp. Dig., 1986, pp. 57–60

Single-layer single-patch wideband microstrip antenna

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Indexing terms: Microstrip antennas, Antennas

A coaxially-fed single-layer single-patch wideband microstrip antenna in the form of a rectangular patch with a U-shaped slot is discussed. Measurements showed that this antenna can attain 10–40% impedance bandwidth without the need of adding parasitic patches in another layer or in the same layer.

Introduction: Microstrip antennas offer the advantages of thin profile, light weight, low cost, and conformability to a shaped surface and compatibility with integrated circuitry. In addition to military applications, they have become attractive candidates in a variety of commercial applications such as mobile satellite communications, the direct broadcast (DBS) system, global positioning system (GPS), remote sensing and hyperthermia. This is due in large measure to the extensive research aimed at improving the impedance bandwidth of microstrip antennas in the last several years.

The basic form of the microstrip antenna, consisting of a conducting patch printed on a grounded substrate, has an impedance bandwidth of 1–2%. One way of improving the bandwidth to 10–20% is to use parasitic patches, either in another layer [1] (stacked geometry) or in the same layer [2, 3] (coplanar geometry). However, the stacked geometry has the disadvantage of increasing the thickness of the antenna while the coplanar geometry has the disadvantage of increasing the lateral size of the antenna. It would therefore be of considerable interest if a single-layer single-patch wideband microstrip antenna could be developed. Such an antenna would better preserve the thin profile characteristics and would not introduce grating lobe problems when used in an array environment. In this article, we report the experimental results of a rectangular patch with a U-shaped slot which appears to have wide bandwidth characteristics.

Experimental results: The rectangular patch antenna with a U-shaped slot used in our experiment is shown in Fig. 1. The patch has dimensions 8.65" × 4.90". The dielectric medium between the patch and the ground plane is air. The patch is fed at the centre by a 50Ω coaxial probe, the outer and inner diameters of which are