Linear phase filter example: To test the performance of the proposed lossy integrator for the implementation of integrated current-mode wave-active filters, a fully differential 50MHz fourth-order 0.05° equiripple linear phase filter has been designed and simulated using typical 0.8μm digital BiCMOS process parameters with f_T = 10GHz at a bias current of 70μA for *npn* transistors [6]. The filter is commonly used in hard disk drive read channels. The wave active simulation of the filter is shown in Fig. 3, where the inverters normally required in single-ended structures are readily obtained from the fully differential structure. The characteristic port impedance is chosen to be 400Ω and a 2.5V power supply was used. The simulated group delay response of the filter is illustrated in Fig. 3 and closely matches the ideal response (broken line). Also, the circuit can be tuned to the desired cutoff frequency to compensate for process and temperature variations. The peaking in the response near the cutoff frequency is primarily owing to nondominant poles of the two-pairs. However, the effect of finite base currents can be completely compensated for by adjusting the bias current KI_0 (or I_1) in Fig. 1 for each two-pair. Furthermore, the same bias current can be used to partially compensate for the high frequency errors as discussed in [3]. At 10MHz, the simulated total harmonic distortion for the single-ended output is <1.27% for the peak input currents up to 90% of the bias current but significantly reduced to 0.2% for the differential outputs. The THD was obtained by performing a transient analysis of the circuit with a sinusoidal input followed by a Fourier decomposition of the output signal. Finally, the power consumption at the operating frequency is 3.65mW per pole.

Conclusions: A tunable current-mode lossy integrator suitable for current-mode wave-active filters has been presented. In addition to its low voltage requirements and simplicity, the presented circuit has high linearity and can operate at very high frequencies. Simulation results indicate the potential of the circuit for the implementation of high frequency high dynamic-range integrated continuous-time filters at low supply voltage and low power consumption.

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References

1 TINGLEFF, J., and TOUMAZOU, C.: 'Current mode continuous time wave active filters', *Electron. Lett.*, 1992, **28**, (5), pp. 463–465

2 TINGLEFF, J., and TOUMAZOU, C.: 'Low sensitivity simulation of LC lattice sections using the current mode wave active topology', *Electron. Lett.*, 1993, **29**, (4), pp. 396–398

3 TINGLEFF, J.: 'Current mode wave active filter: a topology for high frequency integrated filters'. PhD Thesis, Imperial College, United Kingdom, 1994

4 TOUMAZOU, C., LIDGEY, F.J., and HAIGH, D.G. (Eds.): 'Analogue IC design: The current-mode approach' (Peter Peregrinus, London, 1990)

5 FREY, D.R.: 'Log-domain filtering: An approach to current-mode filtering', *IEE Proc. G*, 1993, **140**, (6), pp. 406–416

6 EMBAI, S.H.K., BELLAOUAR, A., and ELMASRY, M.I.: 'Digital BiCMOS integrated circuit design' (Kluwer Academic Publishers, Boston, 1993)

Broadband compact horn feed for prime-focus reflectors

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Indexing terms: Horn antennas, Antenna feeds

A compact flare angle controlled corrugated horn antenna with a 60° half beamwidth is optimised by using a moment method for bodies of revolution. The horn has corrugations with simple rectangular cross-sections and is excited by a smooth wall circular waveguide. The resulting 15dB beamwidth varies by <18% and the crosspolar sidelobe levels are more than 26dB below the mainlobe, both over a 1.8:1 bandwidth. All results are confirmed by measurements. The horn is suited for broadband feeding of e.g. prime-focus reflectors in radio astronomy applications.

Introduction: Primary-fed reflectors are often used in broad band applications, such as radio telescopes. At microwave frequencies, the feed is often a choke horn, i.e. a waveguide opening with a couple of chokes or corrugations around it. The chokes equalise the radiation patterns in the E-plane and H-plane to improve the symmetry and reduce the crosspolar sidelobes [1]. However, the beamwidth of the choke horn decreases with increasing frequency. It is also important to keep the feed diameter small to reduce the weight and centre blockage of the reflector aperture. Thomas *et al.* presented a compact corrugated horn which gives good beam symmetry and low spillover over a relative bandwidth of 1.8:1 [2]. The variation of the 15dB beamwidth was ~40% over the 1.8:1 bandwidth. This performance is obtained by gradually flaring the horn out to 180° and exciting it by a waveguide with ring loaded corrugations.

We describe a horn with four simple rectangular corrugations which has only an 18% variation of the 15 dB beamwidth over the same 1.8:1 bandwidth. This is advantageous as the illumination taper of the reflector and therefore the aperture efficiency will be more constant with frequency. In addition, the horn is simple to manufacture. The optimisation has been achieved using the moment method for bodies of revolution [3]. The results are confirmed by measurements.

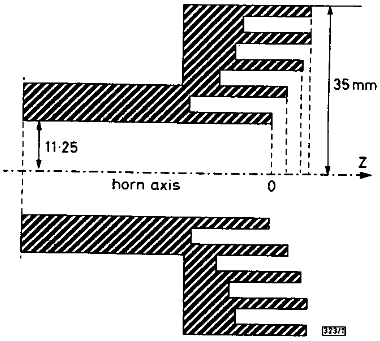

Fig. 1 *Cross-section of corrugated horn*

Design and feed performance: The horn consists of a circular waveguide which is excited by the dominant TE_{11} mode and connected to the corrugated section as shown in Fig. 1. To achieve constant beamwidth over a broad frequency band, the horn is designed to be flare angle controlled according to [4]. Coaxial corrugations are used to reduce the diffraction from the outer horn edge. They are also easier to machine and numerically optimise than other shapes. Since the feed is required to be small, analytical design tools are not accurate. Therefore, the design has been performed numerically by using a computer code for bodies of revolution [5] through a cut and try process. In the numerical model, an infinitesimal dipole located on the axis is used to excite the dominant TE_{11} mode in the waveguide, which is closed at the end opposite to the horn. The return loss is calculated from several maximum and minimum field values on the axis of the feeding waveguide between the dipole and the horn. The radiation fields are computed from the dipole current and the induced currents on all the metal surfaces. For each trial, the frequency was varied within the test bandwidth of 9 – 17GHz. Dozens of different geometries were analysed to reach the final design, with the dimensions given in Table 1 and Fig. 1.

Table 1: Dimensions of broadband horn where width of corrugations = 4.375mm, thickness of ridges between them = 1.25mm and depths in Table are measured from ridge closest to waveguide

Corrugation number (from throat to aperture)	Depth [mm]	z-location of top of ridges [mm] (Fig. 1)
1	9.375	1.250
2	7.500	2.500
3	7.500	3.125
4	7.500	3.125

The measurements are performed over the frequency band 9 - 17GHz. The radiation patterns at 12GHz are shown in Fig. 2.

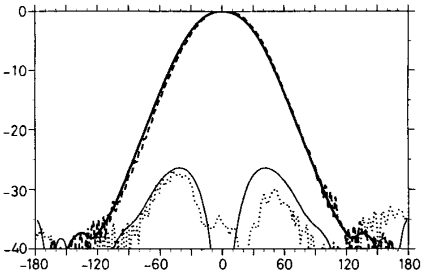

Fig. 2 *Copolar and crosspolar radiation patterns at 12GHz*
——— calculated CO
——— calculated XP
- - - - measured CO
·········· measured XP

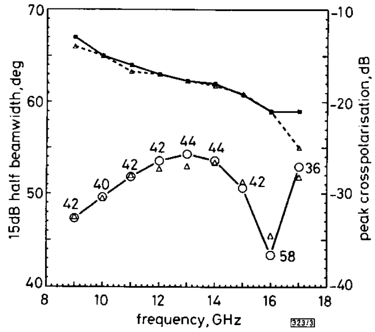

Fig. 3 *15dB half-beamwidths of copolar radiation patterns and level of first crosspolar sidelobe in 45° plane against frequency*
—■— computed BW
- - - - measured BW
○ computed CX
△ measured CX

The computed and measured copolar and crosspolar patterns in the $\phi = 45°$ plane are found to be in very good agreement with each other. Similar agreement is present at all frequencies. The 15 dB half beamwidth of the copolar pattern in the 45° plane is plotted against frequency in Fig. 3. It varies from 66 to 61° within the frequency range 9 – 15GHz, which indicates that the horn is working in a flare angle controlled mode. When the frequency is >15GHz, the measurements show a rapid variation in the beamwidth, which indicates that the radiation becomes more controlled by the aperture of the waveguide rather than the flare of the horn. The crosspolar sidelobes in the 45° plane are also plotted against frequency in Fig. 3. They are seen to be more than 26dB below the main beam over the whole band. The numbers written on the curve give the directions of the maxima of the first crosspolar sidelobe at each frequency. The low crosspolar sidelobes indicate good rotational symmetry of the radiation patterns and coinciding phase centres in the E-plane and H-plane.

The phase centre has been calculated from the radiation field as described in [6]. When feeding a reflector with a subtended angle of 65°, the best phase centre is located within $z = 7.0 \pm 1.7$mm over the frequency band 9 – 17GHz. The return loss was measured to be better than 20dB over the frequency band 10 – 17GHz without using any matching screws or irises, as shown in Fig. 4.

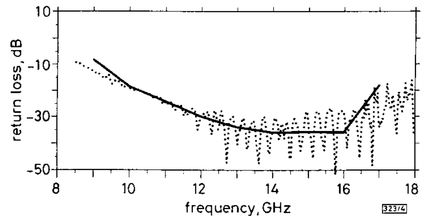

Fig. 4 *Measured and calculated return against frequency*
·········· measured
——— MM calculated

Conclusions: A simple compact corrugated horn has been designed. The horn has, over a bandwidth of 1.8:1, achieved small variations of the beamwidth and the phase centre locations, as well as crosspolar sidelobe levels <–26dB. In addition, the feed provides low spillover when used in a paraboloid. The feed can be applied to radio telescopes.

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References

1 OLVER, A.D., CLARRICOATS, P.J.B., KISHK, A.A., and SHAFAI, L.: 'Microwave horns and feeds' (IEEE Press, New York, 1994)

2 THOMAS, B.M., GREENE, K.J., and JAMES, G.L.: 'A wide-band prime-focus horn for low-noise receiver applications', *IEEE Trans.*, 1990, **AP-38**, (11), pp. 1898–1900

3 KISHK, A.A., and SHAFAI, G.L.: 'Different formulations for numerical solution of single or multi-bodies of revolution with mixed boundary conditions', *IEEE Trans.*, 1986, **AP-34**, pp. 666–673

4 KIDAL, P.-S.: 'Gaussian beam model for aperture-controlled and flare-angle-controlled corrugated horn antennas', *Proc. IEE*, 1988, **135**, (4), pp. 237–240

5 KISHK, A.A.: 'Scattering and radiation from multi-bodies of revolution using method of moments'. Manual Version 5.0, 1993

6 KIDAL, P.-S.: 'Combined E- and H-plane phase centres of antenna feeds', *IEEE Trans.*, 1983, **AP-31**, pp. 199–202