In conclusion, we have developed a simple configuration for a laser diode transmitter which produces laser properties crucial for air and space based remote sensing and/or free space optical communication. These include: narrow spectral width under large signal low data rate PN code or pulsed modulation, tunability and high output power. We believe these are the first experimental results reported for modulation of a fibre grating system. Our laser transmitter system is promising for applications requiring a narrow linewidth, constant wavelength source. We are investigating the mechanical engineering issues associated with fielding a robust system.

![Graph](image_url)  
**Fig. 2** Spectra of HP OSA for laser diode under 1 Mbit/s PN code modulation with an extinction ratio of 0.01 with and without optical feedback at 20°C.

Operating current = 70 mA; amount of feedback = 10%

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**Compact microwave elliptic function filter using novel microstrip meander open-loop resonators**

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**Indexing terms:** Microwave filters, Elliptic filters, Microstrip resonators

A new type of microwave elliptic function bandpass filter using microstrip meander open-loop resonators is proposed. It is shown that the new filter structure is small and allows nonadjacent electric and magnetic couplings to be realised and adjusted. A four-pole filter of this type has, for the first time, been designed and fabricated. The filter is very compact, occupying a circuit size of about a quarter-wavelength by a quarter-wavelength at a midband frequency of 1.47 GHz. Both the simulated and measured results are presented.

**Introduction:** Recently, expanding wireless, cellular and other mobile communication systems have presented new challenges to design and produce high quality miniature filters with low costs [1]. It would seem that planar filters which can be fabricated using printed-circuit technologies would be preferred whenever they are available and suitable because of smaller sizes and lower fabrication costs. Therefore, there has been a growing interest in developing new planar filter structures [2–5]. Some structures, which may allow cross-couplings between nonadjacent resonators to realise an elliptic function response, are more attractive to many communication systems where the bandpass filters are often required to have a flat group delay over a passband as well as sharp skirts (high frequency selectivity). One type of those structures is that of dual-mode microstrip filters. However, this type of filter may require a large circuit size for fabrication, especially at lower microwave frequency bands, such as L, S or C band, which are used by many satellite and mobile communication systems. Hence, it would be desirable either to miniaturise this type of filter [3] or to develop new types of planar elliptic function filters. In this Letter we report the recent development of a new type of compact microwave elliptic function filter which uses microstrip meander open-loop resonators. We show that the new filter is much more compact than the conventional microstrip dual-mode ring filter. In the new filter structure it is easy to identify and adjust the electric and magnetic couplings for nonadjacent resonators within a single plane. We also present for the first time the experimental results of the new filter. Thus, the feasibility of the proposed filter has been confirmed not only theoretically but also experimentally.

![Diagram](image_url)  
**Fig. 1** Proposed microwave elliptic function filter using microstrip meander open-loop resonators

New elliptic function filter: Fig. 1 shows the proposed filter structure for realising elliptic function response, constructed from four so-called microstrip meander open-loop resonators (though more resonators may be implemented). To illustrate how small the new filter is compared with the dual-mode microstrip filter using conventional ring resonators, Fig. 2 shows key resonator elements of both filters on the same scale. As can be seen the meander open-ring resonator is smaller than $\lambda_m/8$ by $\lambda_m/8$, where $\lambda_m$ is the guided wavelength at the midband frequency, whereas the dual-mode ring resonator requires a circuit size amounting to $\lambda_m/\pi$ by $\lambda_m/\pi$. To fabricate the proposed filter in Fig. 1, the required circuit size only amounts to $\lambda_m/4$ by $\lambda_m/4$. This size is even smaller than that required by a single dual-mode ring resonator. Since a four-pole dual-mode ring filter is composed of two dual-mode ring
resonators, the circuit size required to fabricate such a filter would amount to $\lambda_g/\pi$ by $\lambda_g/\pi$. Therefore, the proposed filter could save at least 50% circuit size as compared to the dual-mode ring filter. This size reduction can be significant, especially for those circuits and systems where the size reduction is important.

![Fig. 2 Key resonator elements drawn on the same scale](image)

It is obvious that any coupling in the proposed filter is that of the proximity coupling, which is basically through fringe fields. The nature and the extent of the fringe fields determine the nature and the strength of the coupling. At the centre frequency, each of the meander open-loop resonators has the maximum electric fringe field at the side with an open-gap and the maximum magnetic fringe field at the opposite side. Because the fringe field exhibits an exponentially decaying character outside the region [6], the electric crosscoupling can be obtained if the open sides of two nonadjacent resonators are proximately placed, whereas magnetic crosscoupling can be obtained if the sides with the maximum magnetic fringe field of the two nonadjacent resonators are proximately placed. For the cascade couplings, although the electric and magnetic fringe fields at the coupled sides may have comparative distributions, it can be shown that the magnetic coupling is dominant because the fringe electric field decays faster than the fringe magnetic field for a given extension. Thus it would seem that the required couplings for realisation of elliptic filters can be achieved using the proposed filter structure. This has also been verified by both the simulation and experiment.

![Fig. 3 Layout and simulated performance of a four-pole microwave elliptic function filter using microstrip meander open-loop resonators](image)

**Simulation and experiment:** To confirm and demonstrate the elliptic function response of the proposed filter, a filter of this type with a fraction bandwidth of 2% at a midband frequency 1.47GHz has been designed and fabricated on an RT/Duriod substrate having a thickness of 1.27mm and a relative dielectric constant of 2.2. Fig. 3 illustrates the layout and the simulated performance of the filter. The simulated performance was obtained using a full wave EM simulator [7]. As can be seen, the whole size of the filter is 20.0 by 18.75mm, which is $\lambda_g/4$ by $\lambda_g/4$ on the substrate, as expected. This size is quite compact for distributed parameter filters and demonstrates the compactness of the new filter structure. The filter transmission response exhibits two attenuation poles at finite frequencies, which is a typical characteristic of the elliptic function filters. The fabricated filter was measured on an HP 8510 network analyser and the measured performance is shown in Fig. 4. The midband insertion loss is -3.4dB, which is mainly due to the conductor loss and can be reduced using a superconductor. Again the measured group delay and the insertion loss demonstrate a typical elliptic function response.

![Fig. 4 Measured performance (insertion loss and group delay) of filter in Fig. 3](image)

**Conclusions:** We have proposed a new compact microwave elliptic function filter using microstrip meander open-loop resonators. It has been demonstrated that the new filter has a very compact size and could save at least 50% circuit size as compared with a conventional microstrip dual-mode ring filter having the same poles. We have designed and fabricated a bandpass filter of this type for the first time. The feasibility has been confirmed by both theoretical and experimental investigations. Both the good performance and the compactness of the proposed filter are encouraging for further development.

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