However, the experimental results in this work suggest that the decreasing value of α will have a compensating effect and that the disadvantages in linewidth terms of short lasers may not be so great (and conversely the advantages of long lasers).

Also shown in Table 1 are the results for a 1·3 μm BH laser and a 0·85 μm CSP laser, both 300 μm long. Comparable devices at 1·5 and 1·3 μm have similar values of α (6·4 cf. 6·6), whereas at 0·85 μm α is much smaller (2·8). The difference may be due to the larger contribution of free carriers to the refractive index in long-wavelength materials as measured by Turley.[12]

Conclusions: We have described a new simple method for determining the linewidth-broadening factor α which is based on easily and accurately measured device parameters. Results for 1·5 μm lasers show that α decreases with decreasing laser length. Devices of comparable length (300 μm) at 1·3 and 1·5 μm give similar values of α. However, a 0·85 μm CSP laser had a much lower value.

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M-TYPE ELECTRODE PLANAR GUIDED-WAVE BEAM SPLITTER

Indexing terms: Integrated optics, Electro-optical modulators, Beam splitters

A planar guided-waved beam splitter with an M-type electrode is proposed, analysed and demonstrated. The device was realised on a Ti-diffused $LiNbO_3$ planar waveguide and tested under a 6328 Å optical wave. It exhibited a deflection power 1·38 times higher than that of a zig-zag array beam splitter.

Among various electro-optical devices in integrated optics, there is a prism type of deflector[1] which can operate at a high speed[2] due to its simple electrodes and can provide deflection in more than one position.[3] When it is arranged in array configuration, enhancement on the beam positioned resolution can be obtained.[2] It has been realised on a channel waveguide to be a double-pole double-throw switch.[4] Further study on its electrode configuration has been done to give a more linear phase shift for this device.[5] Modified electrode configuration based on this device has also been proposed and demonstrated to be a beam splitter.[6]

In this letter, we propose and demonstrate a new type of modified electrode, M-type electrode, which operates with a similar principle to the prism electrode but also acts as a beam splitter. The electrode is shown in Fig. 1*a*, where the electrode is in the shape of an M. With the voltage V applied as shown, an effective equivalent electrode configuration is obtained in Fig. 1*b* where virtual electrodes with applied voltage $V/2$ are added. Owing to the arrangement of the tilting electrodes and the alternating applied voltages, there are effectively two sets of prism arrays with one array deflecting the optical beam into one direction and another array deflecting the optical beam into another direction. Hence, the device acts as a beam splitter. The corresponding modulated phase fronts are also shown in Fig. 1*c*.

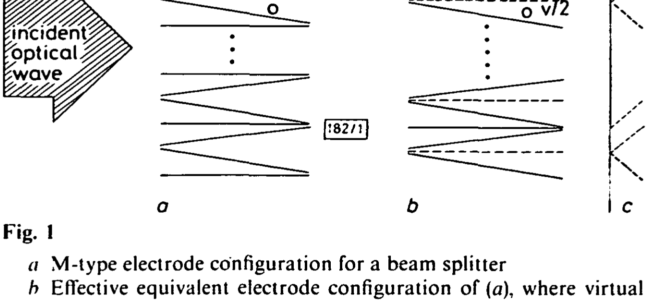

Fig. 1

a M-type electrode configuration for a beam splitter
b Effective equivalent electrode configuration of (*a*), where virtual electrodes of applied voltage $V/2$ are added
c Corresponding modulated wavefront of optical wave

For this type of beam splitter, the deflection power is 1·5 times that of the beam splitter with a zig-zag electrode. This can be easily seen from the Figure, since for this M-type electrode, the real horizontal electrodes are applied with a voltage V instead of $V/2$ as compared to those virtual electrodes in the zig-zag electrode. Theoretically, this can also be shown as the following. For a single element of the M-type beam deflector as shown in Fig. 2, the phase shift in terms of the incident beam height on the aperture A of the electrode can be obtained by integrating the induced electro-optical refractive-index change through the whole electrode length B, i.e.

$$\eta(z) = \frac{2\pi}{\lambda} \int_0^B \Delta n \, dx$$

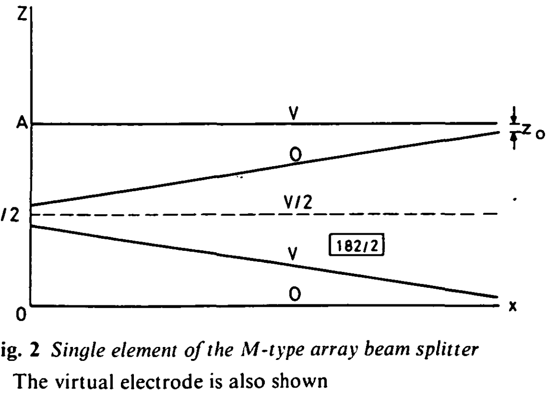

Fig. 2 *Single element of the M-type array beam splitter*
The virtual electrode is also shown

where λ is the wavelength of the optical beam, $\Delta n = n_e^3 \gamma_{33} E_z/2$, n_e and γ_{33} are the extraordinary index of refraction and the appropriate electro-optical constant of the $LiNbO_3$ crystal, respectively, and E_z is the electric field between electrodes due to the applied voltage. If Kaminow and Stulz's results[1] on E_z are used, $\eta(z)$ can be obtained to be

$$\eta(z) = \eta_0 \left[\frac{1}{2} \left(\frac{(A/2) - z - z_0}{z} \right)^{1/2} - \left(\frac{z - z_0}{(A/2) - z} \right)^{1/2} \right] \qquad \text{for } z_0 < z < (A/2) - z_0$$

or

$$= \eta_0 \left[- \left(\frac{A - z - z_0}{z - (A/2)} \right)^{1/2} + \frac{1}{2} \left(\frac{z - (A/2) - z_0}{A - z} \right)^{1/2} \right] \qquad \text{for } (A/2) + z_0 < z < A - z_0$$

where $\eta_0 = 2n_e^3 \gamma_{33} VB/\lambda A$. Comparing this expression with that of Reference 6 of the beam splitter with the zig-zag electrode, it is 1·5 times larger.

An experimental device of this M-type electrode array has been fabricated and tested. The device was fabricated on a Ti-diffused, Y-cut, X-propagation $LiNbO_3$ planar waveguide. The dimensions for this device were chosen to be $A = 110\ \mu m$, $B = 3300\ \mu m$, the width of the electrodes and the spacings between electrodes were both 10 μm and the number of elements $N = 10$. The device was tested by coupling a 6328 Å optical wave into the electrode waveguide region. Fig. 3 shows pictures of the output light spots of the device for applied voltages of 0, 15, 25 and 30 V. The pictures were taken at a distance of 60 cm away from the device. For the applied voltage of 15 V, the beam spot splits into two side spots while the central spot still exists. For the applied voltage increased to 25 V, the beam splits into four spots, while the central spot disappears. With the applied voltage increased further, the beam splits further away. For comparison, a zig-zag electrode array beam splitter of the same dimensions was fabricated on the same substrate and tested. When the deflection angles of the two devices were compared, those of the M-array beam splitter were 1·38 times larger than those of the zig-zag array beam splitter. This was 8% deviation from the theoretical value of 1·5. This deviation may be due to the finite length of electrodes, which was assumed to be zero during the theoretical derivation.

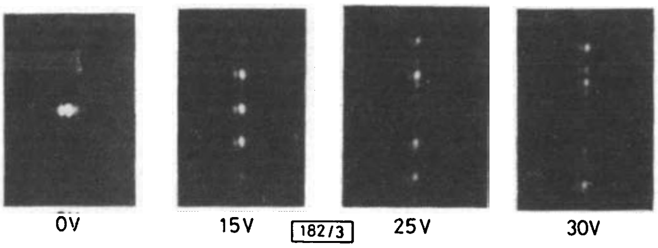

Fig. 3 *Output beam spots of experimental devices being applied voltages of 0, 15, 25 and 30 V, respectively*

With the increased applied voltage, the beam splits further away from the centre position

In conclusion, in this letter we have proposed and demonstrated a beam splitter with an M-type electrode. This device has a deflection power 1·5 times higher than that of the beam splitter with the zig-zag electrode.

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4–20 GHz MAGNETOSTATIC-WAVE DELAY-LINE OSCILLATOR

Indexing terms: Circuit theory and design, Magnetostatics, Oscillators, Delay lines

A single-mode 4–20 GHz tunable oscillator is described. The oscillator makes use of a narrowband magnetostatic-surface-wave delay line in a feedback loop of a solid-state amplifier. The output power from the oscillator was always > +15 dBm throughout the tuning range.

The use of magnetostatic-surface-wave (MSSW) delay lines in oscillator feedback loops has been demonstrated at S-band[1–3] and X-band.[4,5] To date, the highest frequency at which such an oscillator has been reported is 10 GHz.[5] In this letter, we describe a tunable MSSW-delay-line oscillator for the 4–20 GHz frequency range with output power of more than +15 dBm.

Fig. 1 is a schematic diagram of the experimental arrangement of the MSSW oscillator. The output from the MSSW delay line was fed to a microwave solid-state amplifier whose output was always > +20 dBm. A microwave directional coupler (2–26·5 GHz, $A = -16$ dB) was used to couple the oscillator output to an HP-8566A spectrum analyser. Oscillations occur at frequencies where the loop gain exceeds unity and the phase shift around the loop satisfies the condition

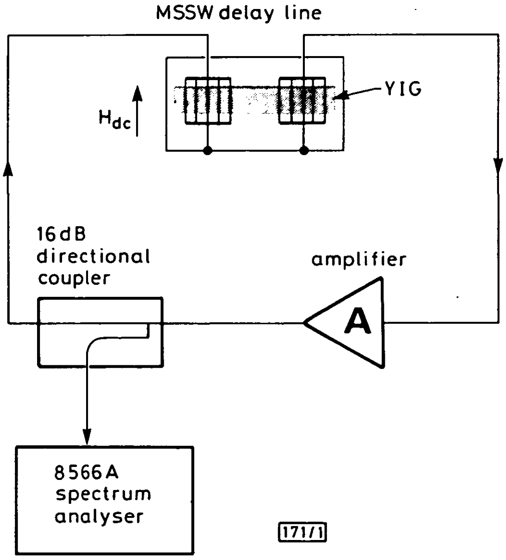

Fig. 1 *Block diagram of experimental arrangement*

$$\Phi_{DL} + \Phi_A + \Phi_C = 2\pi n \qquad (1)$$

where Φ_{DL}, Φ_A and Φ_C are the phase shifts associated with the MSSW delay line ($\Phi_{DL} = 2\pi f \tau_p$, where τ_p = phase delay), the amplifier and the cables, respectively, and n is an integer. If τ_c