less at higher wavelengths ($\lambda = 1{\cdot}3\ \mu$m), where it would be easier to achieve polarisation insensitivity.

It is interesting to note that for that particular device $V_\pi$ is of the order of 5 V for polarisation insensitivity to be compared to 2 V minimum $V_\pi$ drive voltage for TM waves. This means that in this case only a factor of 2 has to be paid to achieve polarisation independence. Fig. 3 shows the behaviour of the polarisation-insensitive modulator when driven by a sine wave. No static differential phase bias was shown between the TE and TM response curves. Transmission was lower for TM polarisation than for the TE one, probably due to the presence of an outdiffused waveguide in the sample which was realised in dry $O_2$ atmosphere.

In conclusion, we have experimentally confirmed theoretical predictions concerning the modulation efficiency in electro-optical integrated devices. In particular, a polarisation-insensitive amplitude modulator has been obtained with a command voltage of the order of 5 V.

The new schemes developed here can probably be applied to other low-drive-voltage electro-optical devices like polarisation-independent directional coupler switches for the $1{\cdot}3\ \mu$m region.

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# NEW FAMILY OF ACTIVE *RC* VARIABLE EQUALISERS

*Indexing term: Circuit theory and design*

A new family of active variable equalisers is introduced. The proposed variable equaliser transfer function is generated from Bode's classical transfer function using a new mathematical transformation. The new circuit uses a single operational amplifier and the required full range of variation is obtained by varying a single resistor $R_V$ from zero to $R_0$ (a reference resistance). The variable equaliser circuit requires a single shaping grounded impedance for realisation.

*Introduction:* Variable equalisers (VEs) with well defined properties were introduced by Bode,[1] and his principles are still applicable. Several active *RC* structures have been proposed which realise the transmission properties of the classical Bode VE.[2–4] The general transfer function of the Bode VE has the form

$$T(s) = \frac{1 + xH(s)}{x + H(d)} \tag{1}$$

The parameter $x$ is usually chosen to be equal to $R_V/R_0$, where $R_0$ is a suitable reference resistance and $R_V$ is a variable resistance. When $x$ varies from zero to infinity, $T(s)$ varies from $H(s)^{-1}$ to $H(s)$. This range $[0, \infty]$ is called the 'whole range' of variation. A flat response, $T(s) = 1$ is obtained when $x = 1$.

The Zyoute VE circuit[3] which is based on the transfer function in eqn. 1 is very attractive since it requires only a single operational amplifier (OA) and does not need an extra NIC[5] or a switch[6] to cover the whole range of variation, and it does not contain an extra differential amplifier.[7] The Zyoute VE however requires a floating variable resistance $R_V$ to vary over the range $0 \ldots + R_0 \ldots \infty$ to cover the whole range.[3]

In this paper a new transformation is proposed which results in a family of VE transfer functions. The proposed VE realisation retains all the advantages of the Zyoute VE,[3] besides the variable resistance $R_V$ varies only from 0 to $R_0$, to cover the whole range.

*New family of equalisers:* In this Section a new family of active variable equalisers is introduced. The family of equalisers is generated from the Bode VE using the transformation given by

$$x = \frac{Kb}{1 - b} \tag{2}$$

where $K$ is a real number greater than one.

Inserting eqn. 2 into eqn. 1 produces the transfer function

$$T(s) = \frac{(1 - b) + KbH(s)}{Kb + (1 - b)H(s)} \tag{3}$$

where $H(s)$ is the maximum equalisation shape, $T(s)$ is the variable equalisation shape, $b$ is the control parameter ($b = R_V/R_0$, the full range of the variable resistance $R_V$ is from 0 to $R_0$). When $b$ varies from 0 to 1, $T(s)$ varies from $H^{-1}(s)$ to $H(s)$. A flat response $T(s) = 1$ is obtained when $b = 1/(K + 1)$.

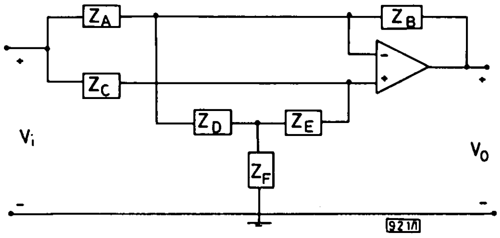


**Fig. 1** *Basic circuit*

*VE realisation:* Consider the network shown in Fig. 1, its transfer function is given by[3]

$$T(s) = \frac{Z_A Z_F(Z_D + Z_E) + Z_A Z_B Z_E + Z_D(Z_A Z_E - Z_B Z_C)}{Z_A Z_F(Z_D + Z_E) + Z_A Z_D(Z_E + Z_C)} \tag{4}$$

Let

$$Z_B Z_C = 2 Z_A Z_E \tag{5}$$

and

$$Z_B = Z_C \tag{6}$$

The transfer function reduces to

$$T(s) = \frac{\left(1 - \dfrac{Z_D}{Z_B}\right) + K\dfrac{Z_D}{Z_B}\dfrac{Z_F}{Z_F + Z_B}}{K\dfrac{Z_D}{Z_B} + \dfrac{Z_F}{Z_F + Z_B}\left(1 - \dfrac{Z_D}{Z_B}\right)} \tag{7}$$

where

$$K = 1 + \frac{Z_B}{Z_E} \tag{8}$$

Comparing eqns. 3 and 7 it is seen that

$$b = \frac{Z_D}{Z_B} \tag{9}$$

$$H(s) = \frac{Z_F}{Z_F + Z_B} \tag{10}$$

$Z_B$ is the reference resistance $= R_0$, $Z_D$ is the variable resistance $= R_V$ and $Z_F$ is the shaping impedance $= Z_0$.

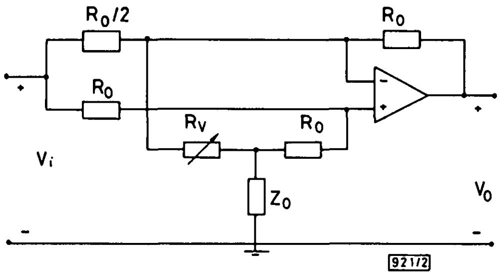


**Fig. 2** *Proposed variable equaliser with K = 2*

A family of equalisers can be obtained for different values of the parameter $K$. As an example, choose $K = 2$. In this case $Z_E = Z_B = R_0$ and the transfer function can be written as

$$T(s) = \frac{Z_0(R_0 + R_V) + R_0(R_0 - R_V)}{Z_0(R_0 + R_V) + 2R_0 R_V} \tag{11}$$

The VE circuit is shown in Fig. 2.
When $R_V = 0$,

$$T(s) = \frac{Z_0 + R_0}{Z_0} = \frac{1}{H(s)}$$

When $R_V = R_0$,

$$T(s) = \frac{Z_0}{Z_0 + R_0} = H(s)$$

and a flat response is obtained when $R_V = R_0/3$.

Other realisations* for different values of the parameter $K$ and experimental results are not included here to limit the length of the letter.


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# 120 km LIGHTWAVE TRANSMISSION EXPERIMENT AT 1 Gbit/s USING A NEW LONG-WAVELENGTH AVALANCHE PHOTODETECTOR


*Indexing terms: Optical fibres, Lasers and laser applications*



A transmission experiment was performed to study the high-speed potential of a long-distance gigabit lightwave system employing a single-frequency 1·5 μm laser and a new long wavelength III-V avalanche photodetector. A 120 km length of standard production single mode fibre was used in the test, in which a bit error rate of $2 \times 10^{-10}$ was achieved at 1 Gbit/s. This distance is the longest reported to date for rates higher than 500 Mbit/s, and the product of bit rate and distance (120 km Gbit/s) is the highest value achieved for any bit rate. The distance was limited by the 32·3 dB loss of the transmission path together with a total of 5·6 dB in power penalties associated with chirp broadening of the laser line.


*Introduction:* A number of recent optical transmission experiments have demonstrated the desirability of employing single-frequency injection lasers to overcome the problem of high dispersion at the wavelength of minimum fibre loss.[1–3] At least until coherent techniques begin to approach their theoretical potential,[4] it appears that systems employing intensity modulated single frequency lasers at 1·5 μm will continue to provide the longest transmission distances at any given bit rate. The high bit rate limits of such systems are studied in this letter. We take advantage of the high-speed performance of a new quaternary avalanche photodetector (APD)[5] as well as the demonstrated high-speed modulation ability and single-frequency nature of a 1·55 μm ridge guide cleaved-coupled-cavity ($C^3$) laser.[6,7] A previous experiment[8] at 1 Gbit/s employing a $C^3$ laser and a PINFET receiver realised a link distance of 101 km.

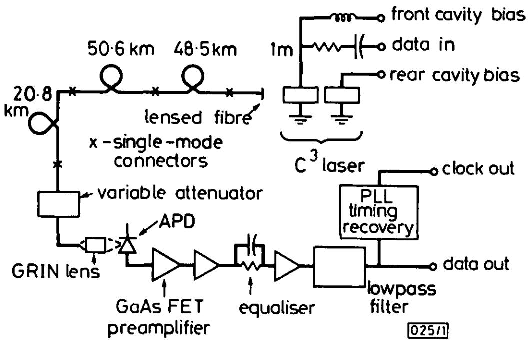


**Fig. 1** *Block diagram of 1 Gbit/s 120 km experiment described in the text*

*System:* Fig. 1 shows the component configuration for the experiment. The laser was maintained at 19°C with a thermoelectric cooler. (Performance was essentially unchanged for temperature changes of about ±2°C.) The laser was switched between two power levels, 5·6 mW and 1·5 mW, corresponding to the mark and space levels of a $2^{15} - 1$ bit pseudorandom nonreturn to zero bit stream. The transmitted eye pattern is shown in Fig. 2*a*. The main-to-side mode power ratio, as determined from the output of the back of the laser during modulation, was 5000:1.

Coupling of the laser light into the fibre was accomplished with 40% efficiency by means of a microlensed fibre pigtail. The fibre, with an 8 μm core and a depressed index cladding,[9] was made by Western Electric. It had a zero dispersion wavelength of 1·3 μm and a dispersion of 17·5 ps/km nm at 1·55 μm. The loss was 0·24 dB/km before splicing and 32·3 dB loss after splicing. A single-mode variable attenuator was used for the measurement of the error-rate curves shown in Fig. 3.

The fibre output was coupled using a graded index rod lens to a new type of APD incorporating an intermediate-bandgap InGaAsP grading layer between an InGaAs absorption layer and the InP multiplication layer.[5] The use of this intermediate layer improved the speed of response of the APD by a factor of about 20. At unity gain the APD dark current was 24 nA, and the quantum efficiency of the detector, which had no antireflective coating, was 68%. The detector was followed by