A New, Small-Sized Transmission Line Impedance Transformer, with Applications in High-Speed Optoelectronics

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Abstract— **A new, small-sized transmission line transformer (TLT) is described, which matches 50-Ω circuits to low input resistance components, as semiconductor lasers and PIN photodiodes. This TLT is formed by different coplanar waveguide configurations, and printed on a very high-dielectric constant substrate (ϵ_r = 80). This TLT considerably improves the temporal response of high-speed photodiodes as compared with the conventional coupling scheme.**

I. Introduction

IN HIGH-SPEED optoelectronics applications, such as optical communications, it is common to use components having low input resistance, typically in the range of 3 to 10 Ω, as semiconductor laser diodes and PIN photodiodes. This resistance, together with the residual capacitance of the component, often determines the system bandwidth, through the characteristic RC time. The component residual capacitance has been reduced as the fabrication processes progressed, increasing the operational speed. However, little has been done about the fact that laser diodes and high-speed photodiodes are normally coupled to 10 Ω circuits. Such arrangement, beside limiting the bandwidth of the component, makes it difficult to handle short electrical pulses in time scales of pico- or femtoseconds, as required for high-speed optoelectronics. Recently, a TLT was proposed [1], [2] to match the input resistance of such components to 50 Ω, allowing considerable improvement of the temporal response of semiconductor laser diodes and high-speed photodiodes, as compared with conventional coupling. The TLT reported in [1] and [2], a combination of microstrip, stripline and coplanar structures, was printed on a low dielectric constant substrate (alumina). However, its large dimensions (total length of 5 cm) made it difficult to integrate the TLT to components and circuits. It is well known that for high-dielectric constant materials, the wavelength at a particular frequency is significantly reduced. This makes it possible to construct smaller devices without increasing the reflection coefficient. Therefore, compatibility between the dimensions of the impedance transformer and those of the diodes can be achieved with transmission lines printed on very high-dielectric constant substrates.

Manuscript received June 12, 1992. This work was supported by TELEBRÁS (Brazilian Telecommunications Company).

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IEEE Log Number 9204286.

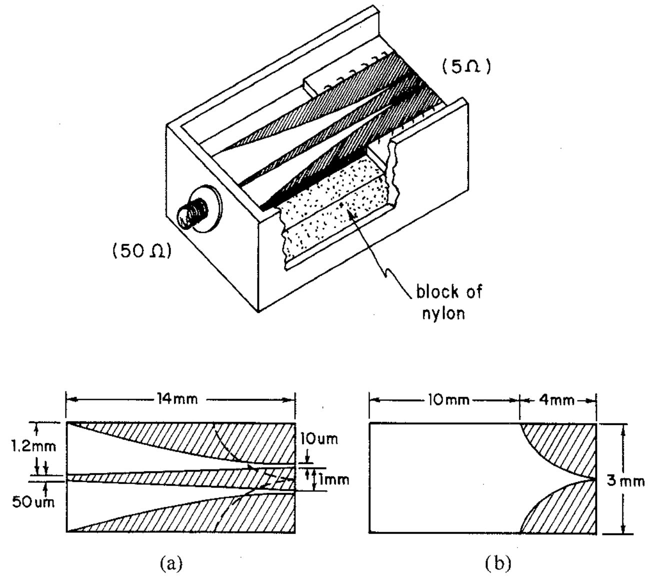

Fig. 1. Transmission line impedance transformer: (a) upper and (b) lower faces.

This letter describes a new TLT, combining different coplanar waveguide (CPW) configurations on a very high-dielectric constant substrate. This new TLT, whose electrical characteristics are equivalent to those of the one in [1], [2], has dimensions that are small enough to allow easy integration between 50-Ω circuits and optoelectronics devices. Experimental results demonstrate a significant improvement of the temporal response of a high-speed photodiode when the TLT is used.

II. The Transmission Line Impedance Transformer

Fig. 1 shows the configuration of the TLT, including all the dimensions, and illustrate details of the packaging. The TLT was printed on a 0.635-mm thick ceramic substrate of very high-dielectric constant (ϵ_r = 80), using the two sides of the substrate. At the input end, a standard 50-Ω CPW is used. The separation between the center strip and the semi-ground-planes is reduced along the structure in order to obtain a 5 Ω impedance at the output end. However, with the standard CPW configuration it is not possible to realize, with this substrate, the low-impedance

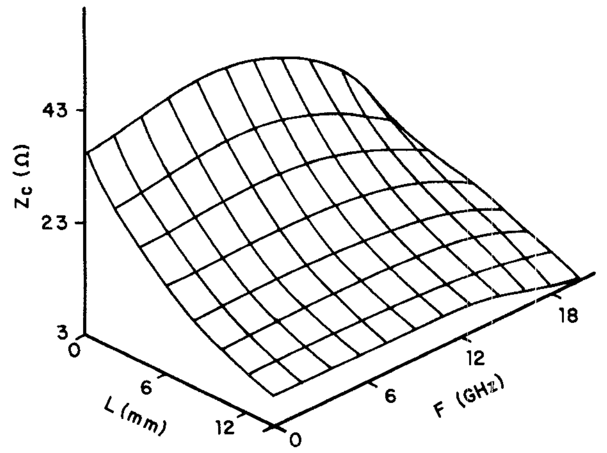

Fig. 2. Theoretical variation of the characteristic impedance with frequency along the TLT.

level required at the output, as the transversal dimensions would be unfeasible. In order to overcome this difficulty, two semi-ground-planes are introduced at the lower face at a certain distance from the input port, and their separation decreases continually, yielding a conductor-backed CPW at the output. As far as the authors are aware, this CPW-slotline configuration has not been considered before. More details about the propagation characteristics of the CPW-slotline will be described elsewhere. The TLT is a high-pass structure, and so all frequencies above its cutoff, which is determined by its length [3], are transmitted with low attenuation. The total length of the TLT was 14 mm, yielding a lower frequency cutoff of around 300 MHz.

The handling of very short electrical pulses requires accurate knowledge of the high frequency characteristics of the three CPW configurations used in the TLT (standard CPW, CPW-slotline, and conductor backed CPW). The well-known spectral domain approach (SDA), e.g., [4], was then chosen for the analysis of the CPW configurations, as it allows a full-wave analysis of non-TEM transmission lines. The SDA was also used to investigate the occurrence of higher order modes, and it was observed that they could be avoided up to 20 GHz, provided that the total width of the TLT was limited to less than 3.0 mm. Fig. 2 shows the variation of the characteristic impedance with frequency along the TLT, as calculated by the SDA. In this figure, the impedance, calculated as the ratio between the "voltage" across gap on the upper face and the average power, for each position along the TLT, ranges from a maximum value of 53 Ω to a minimum of 3 Ω. Such impedance variation was confirmed experimentally through time-domain reflectometry.

The microwave characterization of the TLT showed an insertion loss below 3 dB from 500 MHz up to 12 GHz, and a return loss better than 15 dB from 500 MHz up to 18 GHz, as illustrated in Fig. 3. It is worth observing that, over the frequency range from 0.5 to 20 GHz, the insertion loss per wavelength is smaller than 0.8 dB, which is quite satisfactory. The dielectric substrate contribution to this loss was not considered in the simulations, as no information, such as the material loss tangent, was available at the time. The

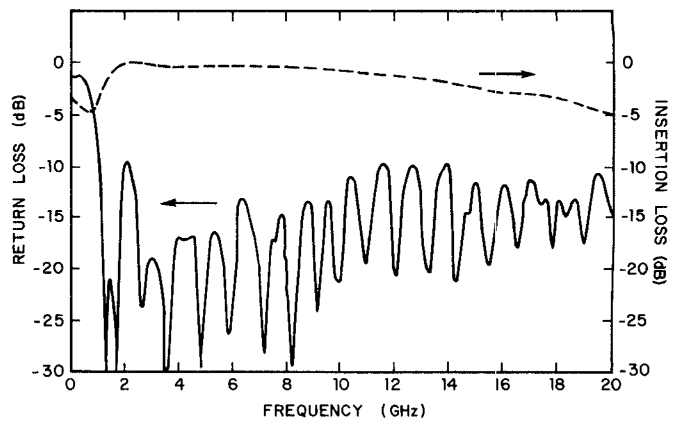

Fig. 3. Experimental curves for return and insertion loss variation with frequency.

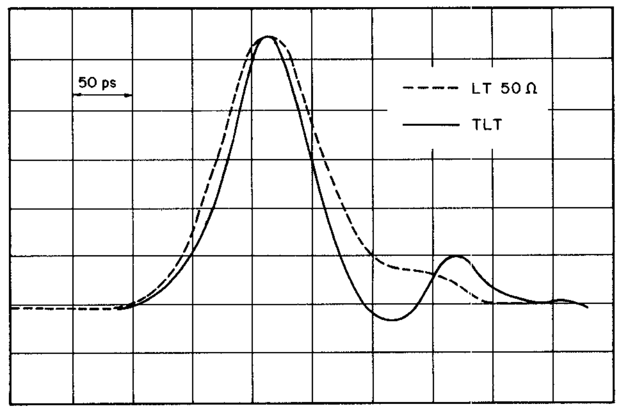

Fig. 4. Comparison of the response of a PIN photodiode to short optical pulses, when the diode is coupled through the TLT (solid curve) and through a conventional 50-Ω microstrip line (dashed curve).

overall insertion loss can be somewhat reduced by decreasing the length of the TLT, using, for example, a Chebyshev taper instead of the exponential one employed here [3].

III. Experimental Results

In order to verify experimentally the efficiency of the TLT in the coupling of photodiodes, a comparison was made between the responses of a InGaAs PIN photodiode when coupled to the TLT and when coupled to 50 Ω by the conventional scheme, for excitation, in both cases, by short optical pulses. The light source was a mode-locked semiconductor laser, producing ≈ 20-ps pulses (FWHM) at 1.3 μm wavelength, with 250-MHz repetition frequency. The PIN photodiode, with a capacitance of ≈ 1.6 pF, and series resistance of ≈ 18 Ω, was initially connected to the end of a 50-Ω microstrip transmission line on alumina substrate, and dc-biased to −20 V through a bias network. The detected laser pulses were sampled and displayed with a Tektronix S4 sampling head, and a 7704 Oscilloscope. Next, the PIN photodiode was coupled to the low-impedance port of the TLT. A comparison of the two oscilloscope traces shows that both the rise- and fall-times of the detected pulses are significantly shorter when the TLT is used, as illustrated in Fig. 4. The oscillation observed at the tail of the pulse when the TLT is used can be explained as follows: as the TLT is a high-pass structure, the frequencies below its cutoff are filtered out. However, computer simulations showed that they do not affect the shape of the short pulse propagating along the TLT. The exception is the light source repetition frequency: when filtered out (as is the case here), it gives rise to the oscillation observed at the tail of the pulse. This oscillation can then be avoided by increasing either the repetition frequency of the light source or the length of the TLT, at the expense of higher insertion loss.

In Fig. 4, the reduction observed in the fall-time (2.8 times) is more apparent than that of the rise-time (1.2 times), due to the limit imposed by the light pulse duration. It is interesting to note that, as anticipated from simple considerations about the RC product, the fall-time reduction obtained here is greater than that reported in [1] (1.7 times), as the present photodiode has a lower series resistance than that used in [1]. This result indicates that the lower the series resistance of the photodiode (and faster the rise-time), the more efficient the TLT will be, i.e., the greater the improvement obtained in bandwidth.

IV. Conclusion

A new and compact transmission line impedance transformer that improves the bandwidth of semiconductor laser systems was introduced. Its reduced dimensions allow it to be easily incorporated in the small packing of photodiodes and laser diodes. This TLT uses the new CPW-slotline configuration, which showed that low values of characteristic impedances could be obtained with feasible transversal dimensions on very high-dielectric constant substrates.

Acknowledgment

The authors would like to thank TELEBRÁS (Brazilian Telecommunications Company), for providing the photodiodes, and to TRANS-TECH, INC., for providing samples of the S8600 ceramic substrate.

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