2.B Counterpropagating Pulses for Ultrahigh-Frequency Electro-Optic Time-Domain Reflectometry

In recent years, the achievable-gain bandwidth product for solid-state devices has increased to the point where electronic time-domain reflectometers (TDR) and network analyzers are often unsuitable for device characterization. The bandwidth limitations of conventional instrumentation can be largely attributed to the electrical parasitics associated with probes, which require mechanical contact with the device to be tested. As a consequence, much recent research has been devoted to noncontact characterization based on picosecond optical pulses.[1-3] Prominent among this class of methods is electro-optic sampling, which typically employs a stable, high-repetition-rate (approximately 100-MHz), picosecond laser combined with conventional electronic-signal-processing methods.[3] This approach permits the direct observation of electrical signals on electro-optic substrates such as GaAs[4] or through noninvasive finger probing at virtually any location in a substrate-independent fashion.[5] (See the article, "A Substrate-Independent Noncontact Electro-Optic Probe Using Total Internal Reflection," in this issue.) Here we propose a new method of time-domain reflectometry based on the electro-optic sampling technique and the principle of counterpropagating pulses, and present experimental results of symmetrical pulse generation.

In general, the TDR consists of a step or impulse signal source and a feedthrough waveform acquisition instrument connected to the device under test (DUT), as shown in Fig. 32.7. An electrical waveform propagates from the pulse generator to the DUT, and the acquisition instrument detects the waveforms incident upon and reflected from the DUT input for subsequent analysis. It is desirable to locate the plane of observation of the sampling instrument at the DUT/transmission line interface to minimize distortion; however, the resulting temporal overlap of the incident and reflected waveforms makes it impossible to observe the DUT behavior. The observation plane must therefore be separated from the device input; several problems, however, that are especially severe for physically small, high-bandwidth DUT's then arise. For example, the measured waveforms differ from the true-

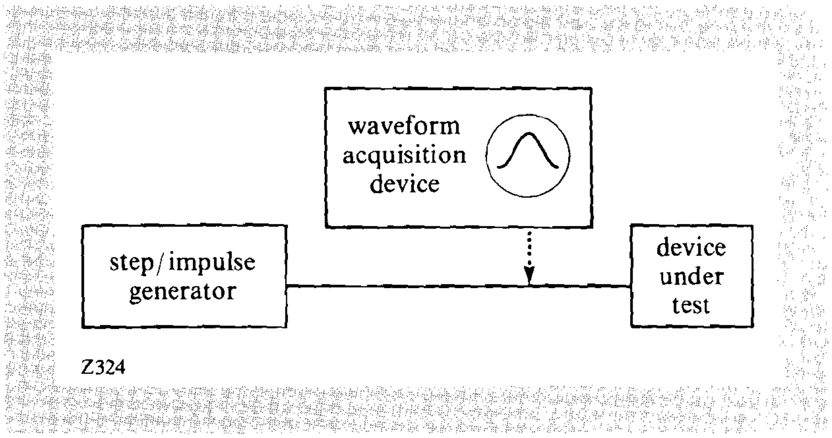

Fig. 32.7
Time-domain reflectometer.

incident and reflected waveforms due to dispersion and frequency-dependent attenuation caused by the section of transmission line between the DUT input and the waveform acquisition instrument. The effect of wafer probes, connectors, attenuators, or other waveform-distorting elements that lie in the signal path must also be de-embedded from the data. It is these problems we address with the symmetrical pulse propagation technique.

In one implementation of this concept, a coplanar waveguide and a photoconductive switch were fabricated, using a liftoff process on 1500 Å of thermally evaporated nickel-gold-germanium on a semi-insulating <100>-cut GaAs substrate. The lines were 3 cm in length, with the switch positioned 1 cm from one end of the waveguide, as pictured schematically in Fig. 32.8. A photomicrograph of the switch detail is shown in Fig. 32.9.

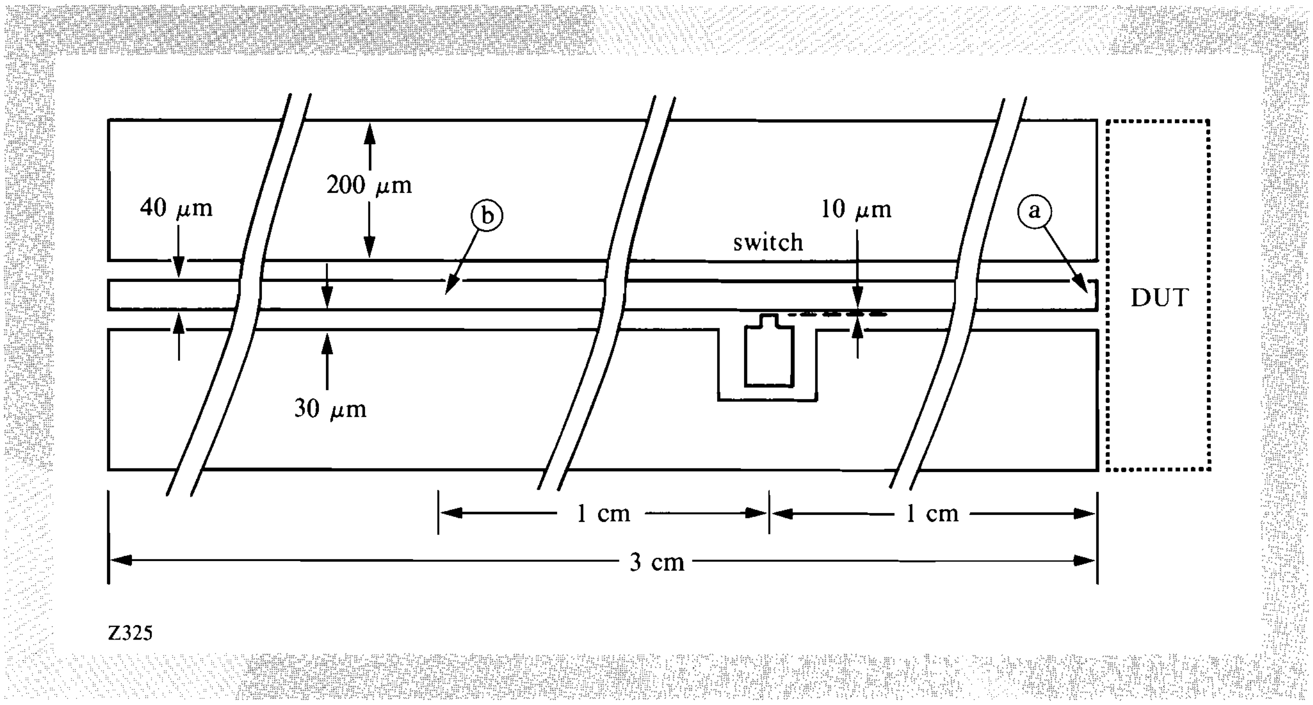

Fig. 32.8
Waveguide detail.

A compressed picosecond optical pulse from a frequency-doubled YAG laser (λ = 532 nm) was focused onto the 10-μm switch gap, which was biased with a 100-kHz sine wave. The resulting optically generated carriers in the gap produced an electrical transient on the central waveguide conductor that propagated away from the switch in both directions on the waveguide.

As the symmetrically propagating pulses travel on the waveguide, they undergo equal degrees of attenuation and dispersion per unit distance. Therefore, the waveform that arrives at point (b) in Fig. 32.8 will appear identical to the waveform arriving at point (a), and by electro-optically sampling the waveform at point (b), the waveform incident on the DUT is predicted. The reflected waveform is then obtained by subtracting the incident waveform from the waveform obtained at point (a).

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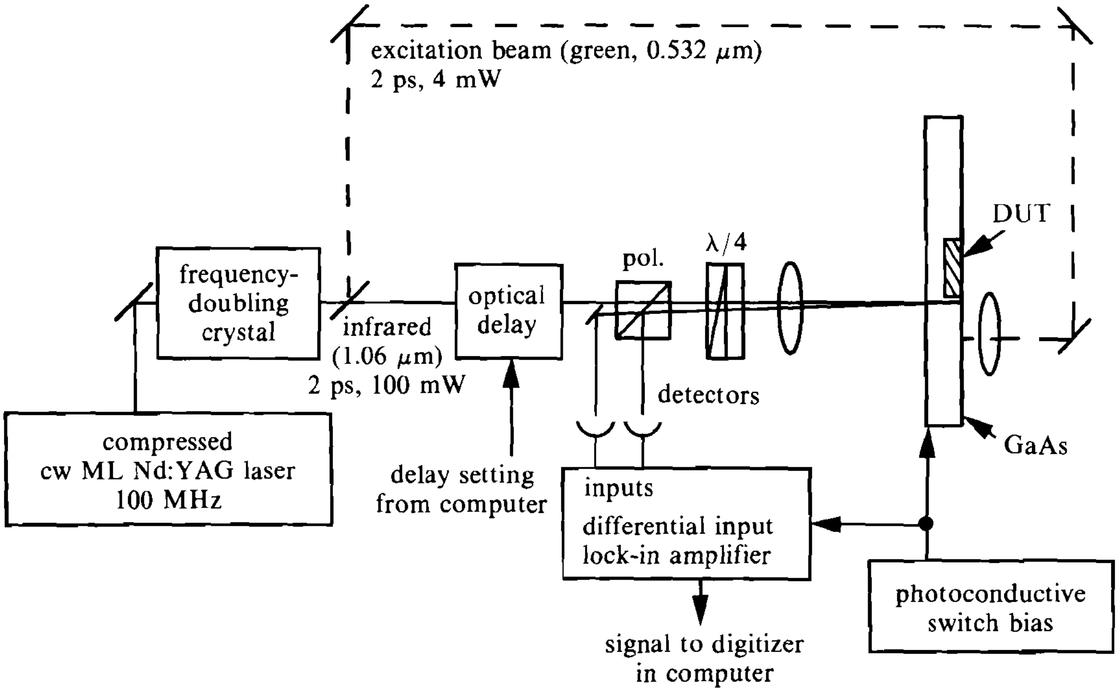
Fig. 32.9
Switch detail.

The electro-optic sampling was realized using a sub-bandgap (λ = 1.06 μm) laser pulse to probe the electric field emanating from the central conductor of the waveguide. The signal was then processed by a signal averager and lock-in amplifier. Since the excitation and sampling laser pulses originated from the same source, they were precisely synchronized, yielding jitter-free waveform acquisition.[3] A schematic of the electro-optic sampling system is shown in Fig. 32.10.

Fig. 32.10
Electro-optic sampling system.



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Given the near-ideal nature of the electro-optic sampling, the major source of error in this approach was anticipated to be due to nonuniform waveguide characteristics. To test this, we acquired the waveforms from our experimental setup at a distance of 7 mm on each side of the switch. As can be seen in Fig. 32.11, good agreement in the wave shapes was observed until the reflection from point (a) occurs at approximately 120 ps.

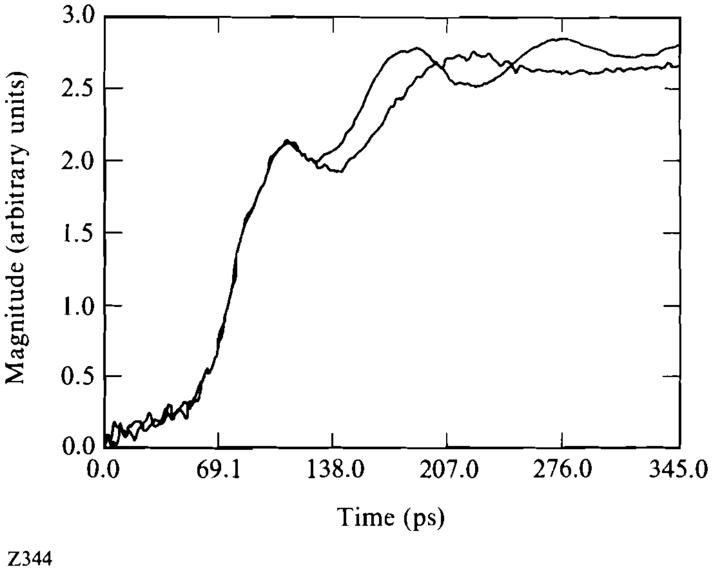

Fig. 32.11
Counterpropagating waveforms.

Essentially the same results were observed for an alternate implementation of the concept, using a 4-mm-long coplanar stripline consisting of two 50-μm-wide nickel-gold-germanium lines separated by 50 μm. The substrate was GaAs, and a 10-μm break in one line served as the photoconductive switch. Symmetrical waveforms with 4-ps rise times were obtained at a distance of 1.5 mm from the switch, demonstrating that symmetrical pulses with extremely high bandwidths may be obtained for high-frequency-device characterization.

These results indicate that waveguide propagation characteristics of sufficient uniformity for applying the counterpropagating-pulse approach to time-domain reflectometry are obtainable. In contrast to the conventional TDR, the potential advantages of a TDR based upon this approach can be enumerated as

1. Sampling is performed directly at the device/transmission line interface. As a result, de-embedding of the transmission line response is not required.

2. Device biasing may be applied on the end of the transmission line opposite the DUT, excluding wirebonds, if no circuit elements lie in the signal path. This feature allows waveform acquisition with a low degree of distortion. For GaAs devices,