4.B Picosecond Electro-Electron Optic Oscilloscope

The technique of electro-optic sampling[1-3] presently offers the only means by which an electrical waveform can be time resolved with subpicosecond resolution. With a sensitivity of ~1 mV and the capability of sampling in a contactless configuration, this technique has become a valuable tool for the characterization of ultrafast electronic components. The contactless mode of sampling can also be scaled up to allow sampling on a plane surface, permitting the evaluation of any number of discrete components within an integrated circuit. In spite of these attractive features, the electro-optic sampling technique has been adopted by only a few large laboratories, the major drawback being the requirement of a short-pulse laser system. The complexity of such a laser results in a sampling oscilloscope that is delicate, maintenance intensive, and expensive, precluding its development in industry and many universities.

Recently, we have developed a conceptually new picosecond sampling oscilloscope that maintains the salient features of the electro-optic sampler while eliminating the need for a short-pulse laser. The new oscilloscope, called the electro-electron optic oscilloscope, represents the converse approach to electro-optic sampling.

Principle of Operation

In both systems the process of sensing an E-field-induced change in birefringence with polarized light is the same. What has changed (Fig. 24.33) is the replacement of the short-pulse laser with a cw laser and the slow-response detector with a streak camera. A streak camera is comprised of an electron image converting tube that, via the photoelectric effect, converts an optical pulse to an electron pulse replica. This electron pulse can then be rapidly deflected, or streaked in a time-varying electric field. An electron pulse streaked in this manner has its time axis mapped along the direction of deflection onto a phosphor screen, where it can then be recorded. With this arrangement, the temporal resolution of the oscilloscope is determined not by the shortness of an optical pulse, but by the resolution of the streak camera. Presently, streak cameras with a few picoseconds' resolution are commercially available. As depicted in Fig. 24.33, by using a cw laser each electrical signal is first converted to an optical replica, then to an electron replica within the streak camera. Consequently, each electrical waveform is sampled in its entirety with every shot.

Experiment And Results

The experimental setup is shown in Fig. 24.34. The modulator is a Lasermetrics Pockels cell having a response time of ~40 ps. The Pockels cell and Soleil compensator are placed between crossed polarizers. A 1-mw HeNe laser is used as the cw probe. The device being characterized is an HP step recovery diode model 33002-A that is driven at 85 MHz along with the deflection plates of the synchroscan-type streak camera. In this configuration, a simple phase shift between the two sine waves is all that is required for synchronizing the diode to the streak camera.

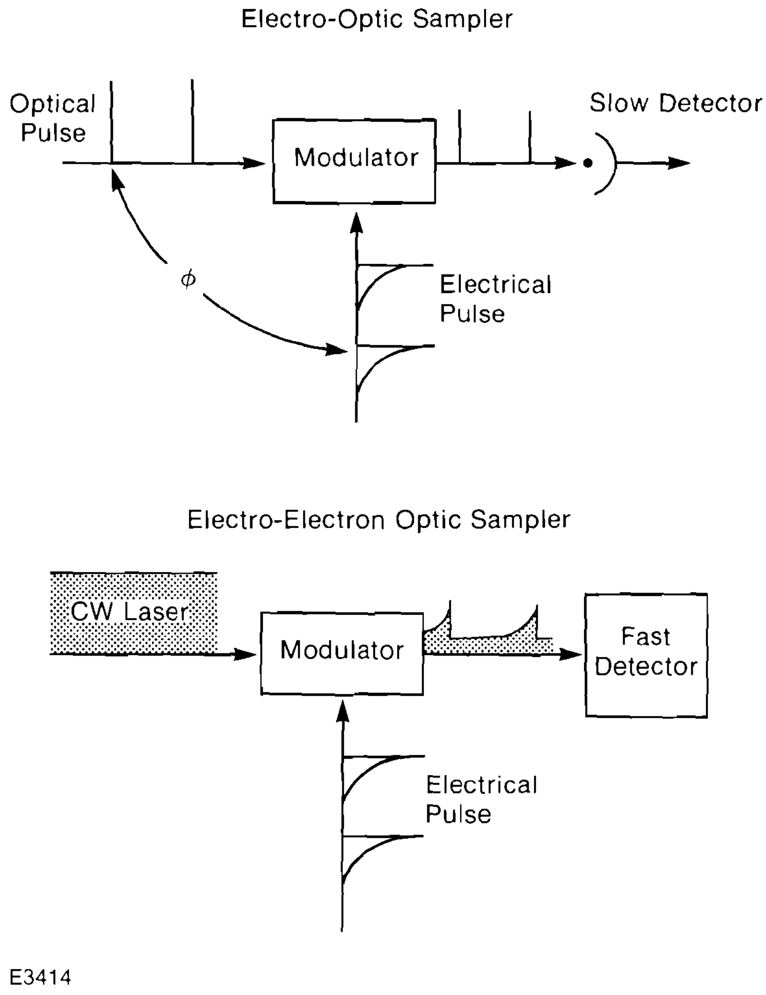

Fig. 24.33
Converse approaches to electro-optic sampling.

For the initial experiment, the compensator was adjusted to 50% transmission for maximum sensitivity of modulation, dT/dV. In order to operate at this point, it is necessary to attenuate the transmitted beam by five optical depths (OD). This assures us of an average current density from the photocathode safely below the damage threshold (~ 10 μA/cm^2). Attenuating the transmitted signal by 10^5, though, also attenuates the modulated signal by the same factor. As a consequence, no signal could be found even after several tens of seconds of integration time. However, we discovered that if we adjusted the optical compensator off the 50% transmission point down to a transmission factor of 10^{-5} and then removed the 5-OD optical attenuation, a signal large enough to be observed even in real time appeared on the streak camera monitor. An explanation for the enhancement of the modulated signal is offered from Figs. 24.35 and 24.36. In Fig. 24.35 we have

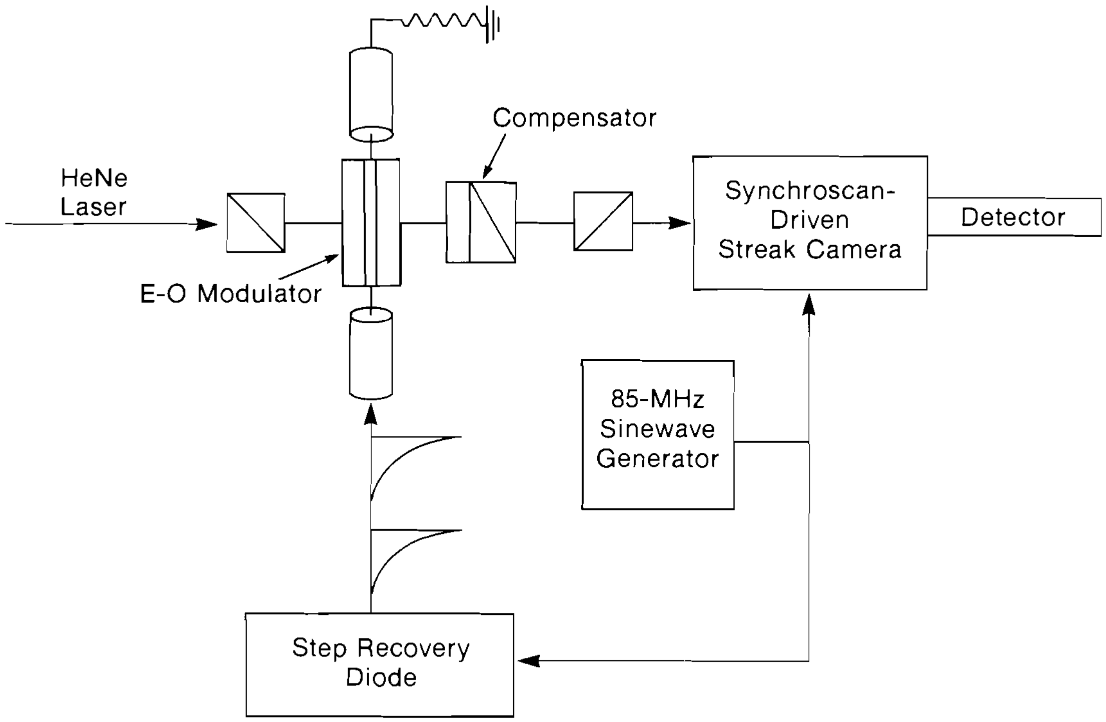

Fig. 24.34
Experimental layout.

plotted both the transmission function T for a modulator between crossed polarizers, as well as the corresponding sensitivity curve dT/dV. We see that the sensitivity indeed has its maximum at $V_\pi/2$, that is, at the 50% transmission point. However, when the transmitted background signal can only be a small portion of the incident signal, an enhancement in the depth of modulation *relative* to the background can nevertheless be achieved. By adjusting the compensator (or, equivalently, the dc bias voltage), the efficiency of modulation (dT/dV)/T goes as cot $[(\pi/2)\, V/V_\pi]$ (see Fig. 24.36). In this way, the number of modulated photons can be increased, in our case, by a factor of $\sqrt{10^5}$ over the conventional approach of biasing to 50% and then attenuating by 5 OD. Though each optical replica consists of just a few tens of photons, the synchroscan streak camera, upon accumulating 85×10^6 shots/s, reconstructs the waveform within seconds. It is important to bias slightly off the zero transmission point so that a signal possessing both polarities is not rectified. The issue of nonlinearity of response for the modulator is not a serious one since a maximum excursion of a few volts along a transmission curve whose V_π is 5000 V results in a deviation of less than 1% from a straight line. Figure 24.37 displays the signal of the step recovery diode. The response agrees well with a measurement made using a Tektronix sampling oscilloscope.

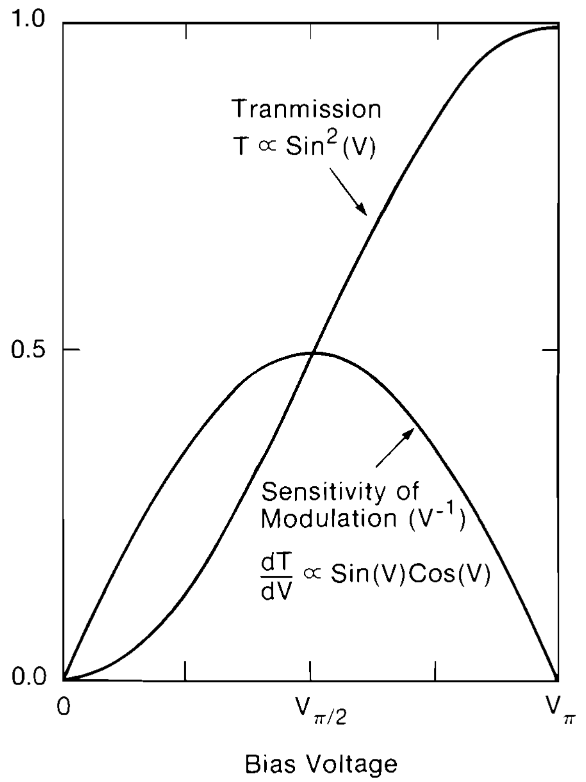

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Fig. 24.35
Transmission and sensitivity of modulation curves for an electro-optic modulator.

In conclusion, we have developed a novel picosecond oscilloscope that is based on the electro-optic effect but eliminates the need for a short-pulse laser system. The electro-electron optic oscilloscope maintains the attractive features found in the electro-optic sampler but is relatively simple to operate, less expensive, and portable. In addition, the sampling frequency of this oscilloscope can be adjusted to accommodate the optimal operating frequency of the circuit in question. Any cw laser having a wavelength between 250 nm and 1000 nm can be chosen as the probe. As an example, a semiconductor laser can be used, allowing the probing of GaAs—which happens also to be an electro-optic material. Finally, because the electro-electron optic sampler samples each waveform in its entirety, the system can potentially be used in single-shot mode.

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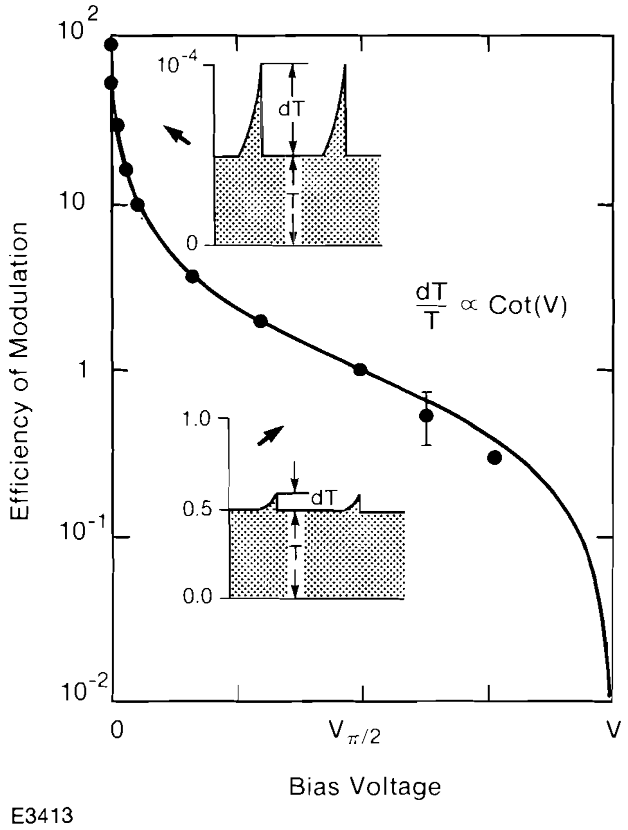

Fig. 24.36
Efficiency of modulation. Note difference in scales for the inserted transmission curves.

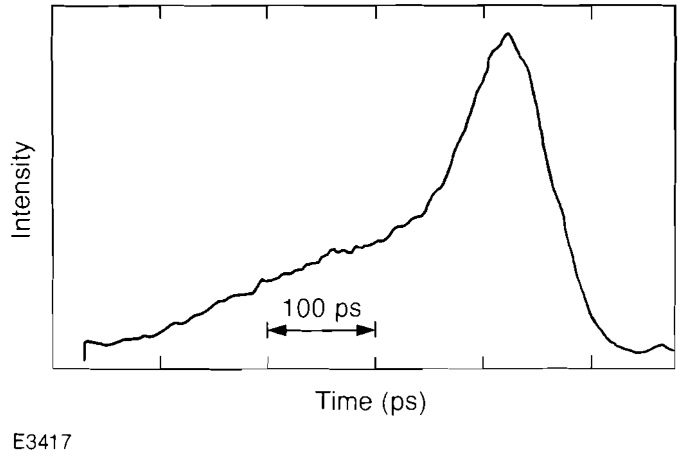

Fig. 24.37
Time-resolved response for step recovery diode.

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