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3.B Picosecond Sampling with Electron Pulses

Recent advances in picosecond photodetector and photoconductive switching technology have created the need for a measurement system capable of accurately characterizing small electrical signals with picosecond resolution. To date, the best temporal resolution has been achieved using the picosecond electro-optic sampling system[1,2] developed at LLE. This device is based on the use of an electrical signal having an unknown temporal profile to modulate the intensity of a short optical pulse by means of an electro-optic crystal. An optical pulse, of 100-fs duration, probes the change in birefringence of this crystal resulting from the electric field of the applied unknown electrical signal. This birefringence responds quickly (<100 fs) and linearly to the applied field. The optical probe pulse is short, compared with the typical duration of the unknown electrical signal (0.1 ps vs few ps), which allows for an accurate sampling of the signal's waveform to be taken. The most recent results from this system place the temporal resolution at 600 fs with a signal sensitivity of better than 50 μV. The electro-optic technique was reported in LLE Review, Volumes 11 and 13.[2]

At this time, we report on a new approach to signal sampling analogous to the electro-optic system. In this approach, electron pulses, rather than optical pulses, are used to interrogate the unknown electrical signal. This new technique, "electron-optic sampling," does not as yet allow as fine a time resolution as the electro-optic sampler. An important advantage of the electron-optic sampler over the electro-optic sampler, however, is that electrical signals in free space can now be investigated. Since electrons are charged particles sensitive to electric fields, a short electron pulse can act as a probe to monitor directly changes in the field.

The electron-optic sampler used in this work is illustrated in Fig. 35. A 100-fs optical pulse (at 610 nm) from a colliding-pulse mode-locked laser[4] is split in two with half the light directed between the electrodes of a GaAs:Cr photodetector biased to 30 Vdc. The other half of the pulse is frequency-doubled (to 305 nm) and directed onto the gold photocathode of the front end of a streak camera placed in vacuum (with the deflection plates removed), where the light pulse is converted into a sub-picosecond electron probe pulse.

The photogenerated electrical signal from the photodetector propagates in vacuum down a balanced-strip transmission line with no dielectric material between the plates. The electron pulse passes through the spacing between the plates of the transmission line assembly where the electric field from the electrical signal is established. When the electron pulse arrives in coincidence with the electric field, the electrons are deflected by an amount proportional to the electric field. This deflection results in the displacement of a spot on a phosphor screen placed in the path of the electron pulse. As in the electro-optic sampler, only a small segment of the total electrical signal is sampled at any one time. By changing the relative delay between this unknown signal and the electron pulse, a new portion of the signal can be sampled. In this manner, the full waveform of the unknown electrical signal can be mapped out.

There are several reasons why the front end of a streak camera tube is an ideal pulse source. Such a tube, in its usual mode of operation, converts short optical pulses into exact electron-pulse replicas, down to a single-picosecond time scale. The electrons are highly monoenergetic (one part in 10^4), and, in its present application, this tube gives picosecond or sub-picosecond electron pulses. The electrons are also easily imaged and capable of being pulsed at a rate of 100 MHz. Due to the large repetition rate, only a few electrons per pulse are necessary to give a significant signal. Using, on the average, less than one electron per pulse, no temporal broadening by space-charge effects can occur, and tight focusing is possible. In the future, this feature could make possible the use of photogenerated electrons as a possible source for time-resolved scanning electron microscopy. In addition, and most importantly, the electron pulses can be synchronized to within 1 ps of the original pulse.[3]

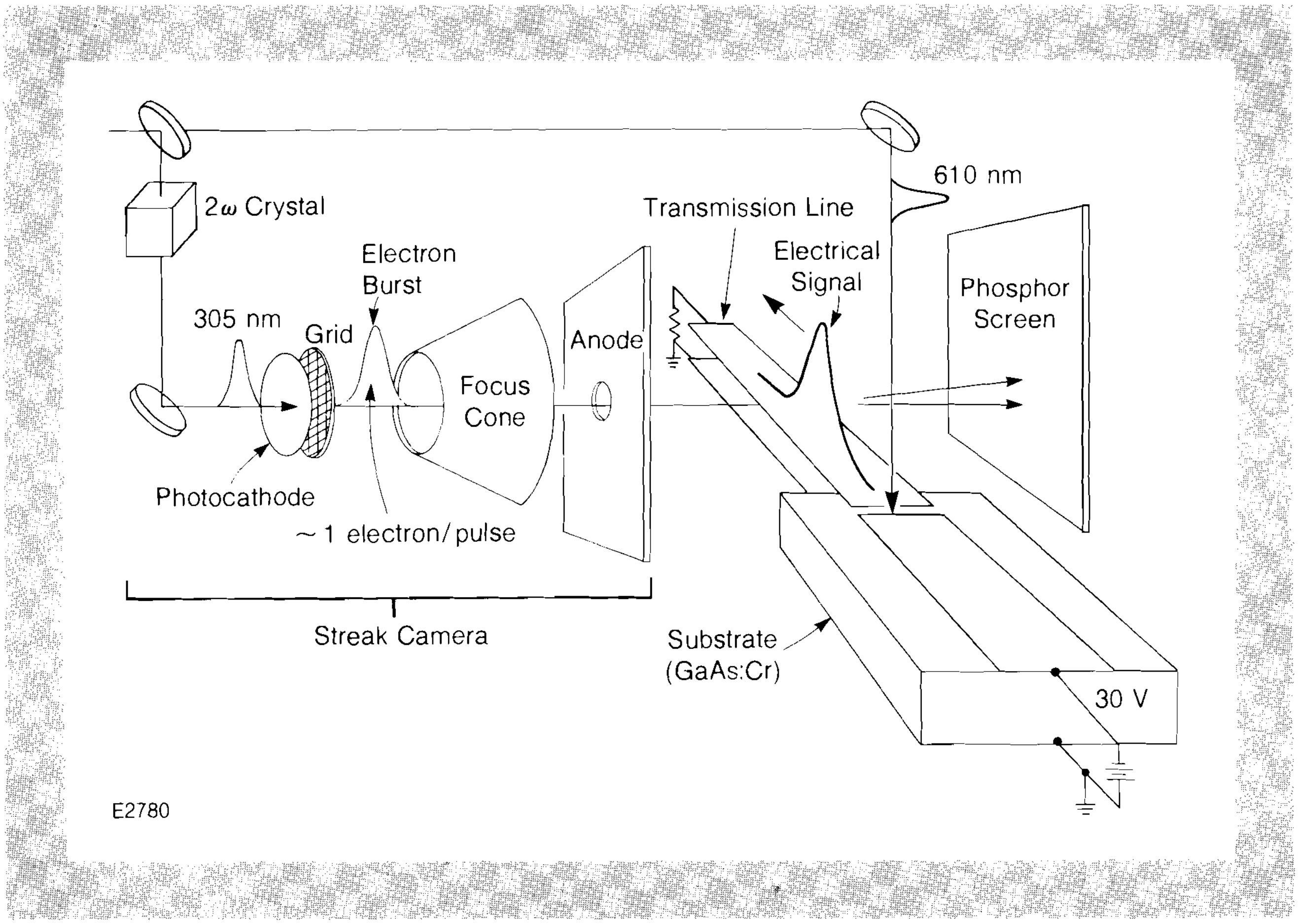

Fig. 35
Schematic diagram of the picosecond electron-optic sampler. A 100-fs optical pulse (at 610 nm) is split in two with half the light directed between the electrodes of a GaAs:Cr detector. The other half of the pulse is frequency-doubled (to 305 nm) and directed onto the gold photocathode of the front end of a streak camera. The electrical signal to be investigated propagates down the transmission line, establishing a traveling electric field between the two plates as it propagates. The field deflects the short electron pulse so that the spot on the phosphor screen is shifted by a small fraction of the spot diameter.

After passing between the transmission-line plates, the electrons are converted using a phosphor-screen/image-intensifier assembly back into a visible signal. The position of the deflected spot is read electronically. Displacements of less than one part in 10^3 of the spot diameter were measurable using a lock-in amplifier in conjunction with a signal averager. The result of this preliminary work is shown in Fig. 36. The 10-90% rise time is ~35 ps, which mainly corresponds to the electron transit time of the 20-keV electrons across the 2.5-mm deflection plate width. The maximum electron pulse deflection observed corresponds to a 1-V signal amplitude. The structure on the falling edge of the signal is the signal reflection due to the impedance mismatch at the point where the stripline leaves the substrate. Since the temporal resolution scales with the deflection plate width, the resolution of the system should be easily improved to the single-ps level by narrowing the deflection plates.

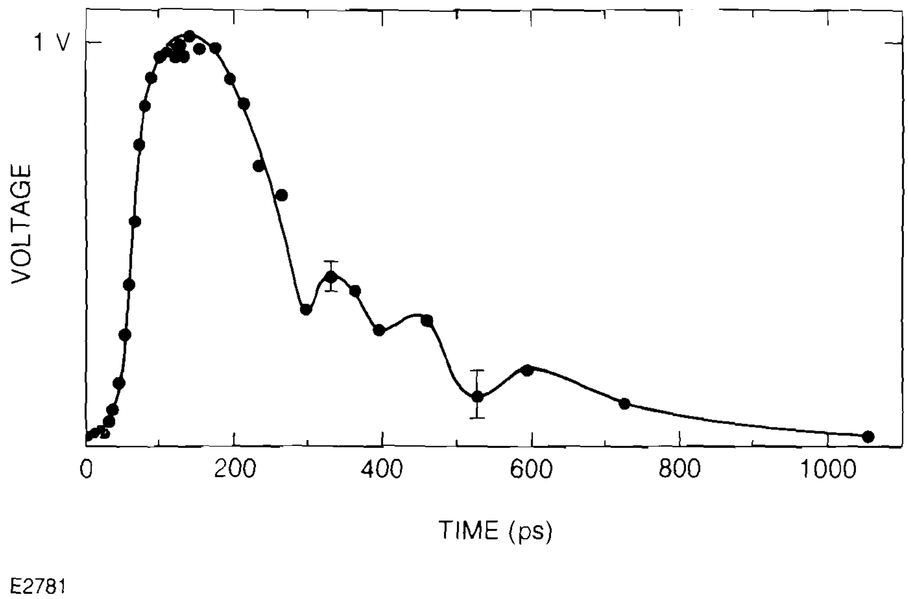

Fig. 36.
The rise time of the impulse response of the GaAs:Cr detector measured by the electron-optic sampler is ~35 ps. The maximum electron-pulse deflection observed corresponds to a signal amplitude of 1 V. The structure on the falling edge of the signal is due to the signal reflection off the impedance mismatch at the point where the stripline leaves the substrate.

The experiment described here restricts the electrical signal to a symmetric transmission line, but because the electron-optic sampler monitors the electric fields directly, it is possible to interrogate any electrical signal that radiates into free space. The electron-optic sampler will permit picosecond-scale sampling of electric fields radiating from radar antennas, the fringing fields of an integrated circuit, or simply the end of a coaxial cable.

Summary

The electron-optic sampler developed at LLE samples electrical signals directly by probing their electric fields with electrons. This method does not require crystals or any other device to be placed between the electric signal and the probe. In fact, free fields can be sampled. The temporal resolution for a signal of a few millivolts is approximately 35 ps, but a resolution of a few picoseconds appears possible in the near future.

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