# Section 3
# ADVANCED TECHNOLOGY DEVELOPMENTS

## 3.A Ultrafast Device Characterization — The Five-Picosecond Transistor

As switching speeds of microelectronic circuits increase, new problems arise in characterizing them. It is now typical for a new device to be faster than direct, conventional measurement techniques. Some insight can still be gained from indirect measurements.

One such technique is the ring oscillator. With this technique, 10, 20, or more devices are connected in a ring configuration, and the entire ring is made to oscillate at its maximum frequency. The individual device response is then taken to be the period of oscillation divided by the number of devices in the ring. The large number of devices tends to average out individual device characteristics. In addition, connections between the devices start affecting the overall response. As the individual device response becomes faster, these effects become more pronounced.

Another technique commonly employed is gain measurement in the frequency domain. Here a single device is used as an analog amplifier, and the gain, as a function of frequency, is measured. While this measurement is useful in analog applications of transistors, the relationship between frequency response and time-domain response is not exact. Here, too, the difficulties with increasing device speed become more pronounced. Generally, measurements can be made from dc to about 26 GHz using commercial connectors. Beyond this frequency, measurements are made in narrow frequency bands, using a separate apparatus for each band. In addition, each apparatus is optimized for operation in that particular frequency band. Eventually, however, the high-frequency response is linearly extrapolated from the highest measured frequencies.

Direct measurement can, however, be achieved through the electro-optic sampling technique. First developed at LLE in 1982,[1] this technique takes advantage of the advances made in ultrashort laser-pulse technology. The LLE system was a colliding-pulse mode-locked (CPM) laser, which routinely emits pulses of less than 100-fs FWHM. These short optical time intervals permit a direct measurement of electrical signals with rise times of a few hundred femtoseconds.[2]

Recently, this technique has been applied to the characterization of several new types of devices such as the two-dimensional electron gas field-effect transistor (TEGFET) and the metal semiconductor field-effect transistor (MESFET).[3] Although still tractable by the indirect techniques described above, their device rise times of 16 and 25 ps, respectively, represent switching speeds beyond the capacity of conventional direct measurement.

One device, however, resists even indirect attempts at characterization: the permeable-base transistor (PBT). Conceived at MIT Lincoln Laboratory in 1979,[3] the PBT presents unique problems in its manufacture. As shown in Fig. 26.20, a PBT is arranged similarly to a vacuum-tube triode, except that here the "grid" has submicrometer dimensions. By interrupting the GaAs growth process to fabricate the grating, contaminants are introduced, which keep yields low. As of this writing, only

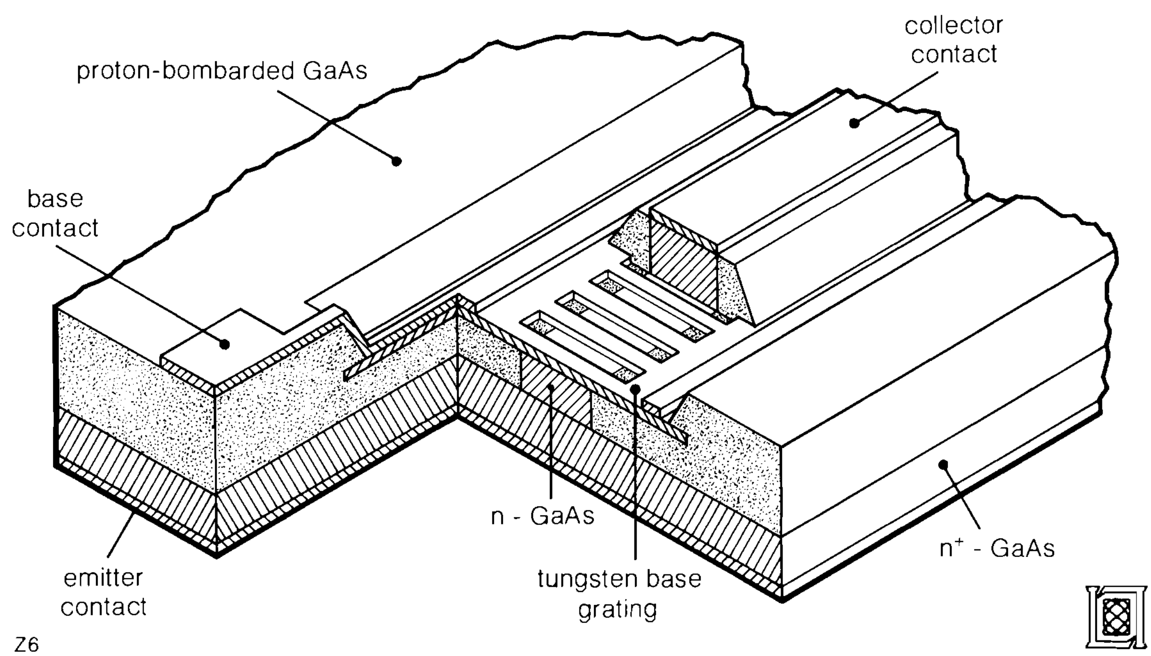


*Fig. 26.20*
*Geometry of the permeable-base transistor (PBT).*

single devices have been fabricated. With only single, discrete devices available, ring oscillators cannot be fabricated. In addition, the analog measurements have proved very difficult because of the very high gain of the PBT. The device is now known to oscillate at maximum frequencies above 200 Ghz.[4] An example of the frequency versus gain characteristics for several wafers of PBT's is shown in Fig. 26.21. The very nonlinear response is due to the interaction between the device and the experimental apparatus. Curve HiP2 was truncated before the onset of fixture resonances. The speed of this device results from advances in fabrication techniques that allow for extremely small dimensions in both the horizontal and vertical directions. These advances have led to a device that until now remained completely uncharacterized in the time domain.

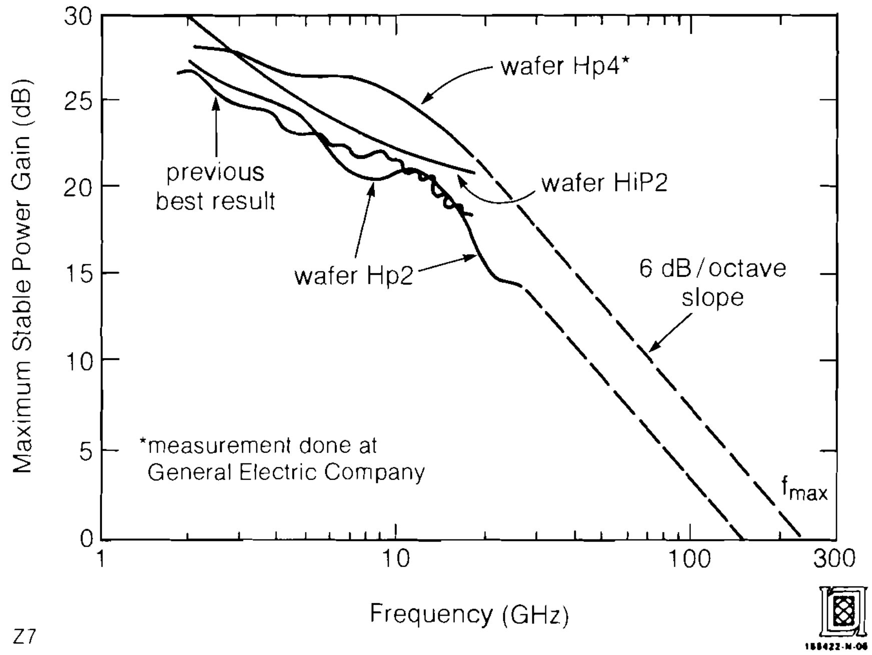


*Fig. 26.21*
*Frequency versus gain measurements for various PBT wafers. The PBT tested was from wafer Hp4.*

For electro-optic characterization, the PBT was built into the sampling geometry shown in Fig. 26.22. This geometry permits dc biasing as well as high-speed operation. The CPM-laser-based sampling system measured the rise time, as shown in Fig. 26.23. Electromagnetic radiation from the input connection was thought to cause the negative prepulse. This feature did not scale in amplitude with PBT gain. It has also been present in earlier measurements on TEGFET and MESFET devices. The gain of the PBT is shown, as a function of applied voltage, in Fig. 26.24.

This measurement identifies, to the best of our knowledge, the currently fastest three-terminal room-temperature device. It also represents a benchmark measurement, since from now on faster devices can only be measured effectively by electro-optic techniques.

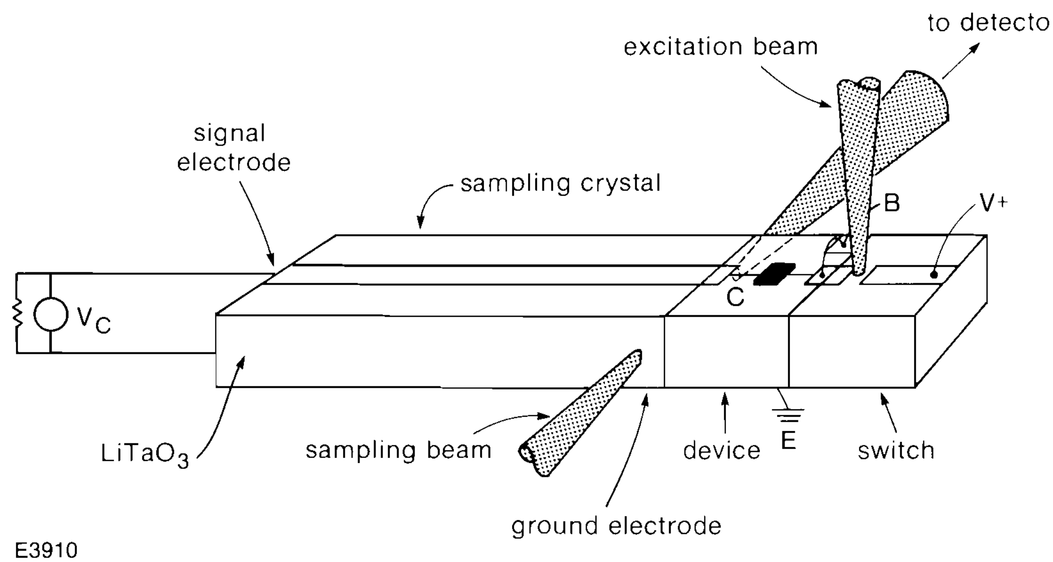


*Fig. 26.22*
*Sampling geometry for PBT characterization. Looping wire bonds were used for bias leads to prevent loading of high-speed signal paths.*

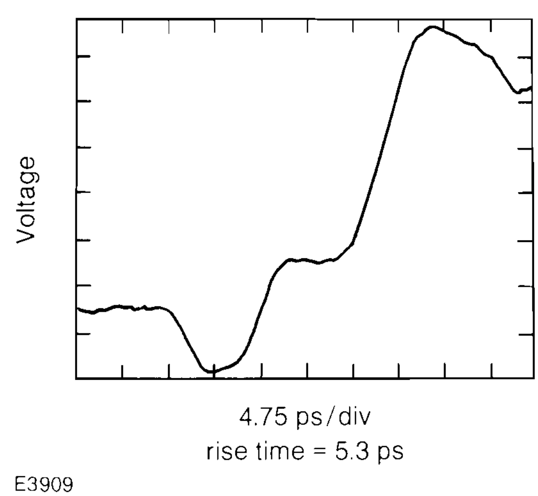


*Fig. 26.23*
*Step response of PBT as measured by the electro-optic sampling system.*

## ACKNOWLEDGMENT

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