In conclusion, an integrated tapped delay line structure consisting of a coplanar waveguide transmission line with Schottky diode peak detector taps has been fabricated. The structure was driven with two pulse compressor circuits producing two 20 pS pulse trains. The relative phases of the two inputs were determined from the position along the structure of the collision event as captured by the hold capacitors. Shifts of 1 pS in the trigger input signal were easily detectable during steady state testing of the structure. Improvements in the current resolution should be possible with better pulse compression circuits yielding greater slew rates for input pulses and reduced dispersion due to tap discontinuities by further distribution of the taps along the line. Finally, when coupled with external processing circuitry the CPPD should be capable of picosecond resolution detection of trigger events in one-shot or in steady state.

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ELECTRO-OPTIC SAMPLING OF OPTOELECTRONICALLY PHASE-LOCKED 10·0 GHz MICROWAVE SIGNALS USING SEMICONDUCTOR LASER DIODES

Indexing terms: Optical measurement, Lasers and laser applications, Photoconducting devices, Phase-locked loops, Electro-optics, Semiconductor lasers

10·0 GHz microwave signals optoelectronically phase locked by a laser-diode-based GaAs : Cr photoconductive harmonic mixer ($\lambda = 0{\cdot}81\,\mu$m) have been measured noninvasively using the electro-optic sampling technique with a gain-switched InGaAsP laser diode ($\lambda = 1{\cdot}3\,\mu$m).

The electro-optic sampling (EOS) technique[1,2] has been shown to be a very powerful tool for measurement of electrical waveforms noninvasively at internal nodes of discrete electronic devices and integrated circuits. Compact laser-diode-based EOS systems have also been demonstrated by several groups recently.[3–5] In these systems, it is essential that phase coherence or time synchronisation is maintained between the optical probe pulses and the continuous wave (CW) microwave waveform to be measured. Recently, Li *et al.*[6] demonstrated optical phase locking of microwave signals up to 1·3 GHz by intermixing microwave signals with the harmonics of the optical probe pulse using the electro-optic effect in GaAs microstrip circuits. The signals were then displayed using the photoconductive sampling technique.[7,8] This novel technique is potentially useful for diagnostics of millimetre wave integrated circuits (MMICs) up to 100 GHz at the wafer level. In a previous Letter,* we demonstrated optoelectronic phase locking of microwave signals up to 12·01 GHz using a laser-diode-based GaAs : Cr photoconductive harmonic mixer. In this Letter, we report for the first time electro-optic sampling of 10·0 GHz optoelectronically phase-locked microwave signals using semiconductor laser diodes.

Our experimental apparatus is shown in Fig. 1. It consists of an optoelectronic phase-locked loop (OEPLL) and an

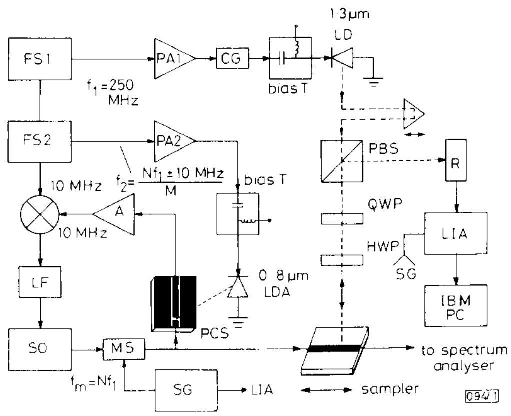

Fig. 1 *Experimental setup*

FS: frequency synthesiser
PA: power amplifier
LF: loop filter
SO: sweep oscillator
CG: comb generator
LD: laser diode
LDA: laser diode array
PCS: photoconductive switch
PBS: polarisng beam splitter
QWP: quarter-wave plate
HWP: half-wave plate
R: receiver
LIA: lock-in amplifier

electro-optic sampling system. Two electronically phase-locked synthesisers were used to gain switch a laser diode array (LDA, Spectra Diode Laboratories, model SLD-2410, $\lambda = 0{\cdot}81\,\mu$m) at f_2 and an InGaAsP laser diode (LD, Toshiba, model TOLD-300, $\lambda = 1{\cdot}3\,\mu$m) at f_1, respectively. In the OEPLL, a free running signal at f_m from a microwave sweep oscillator (HP8620C), simulating the monolithic device, was used to bias a GaAs : Cr switch with $10\,\mu$m gap and intermixed with the appropriate harmonic component of the electrical pulses generated by 100 ps optical pulses from the LDA illuminating the switch. The signal at the output port of the switch was amplified by a low-noise 26 dB-gain amplifier and mixed with the 10 MHz reference signal of the frequency synthesiser (HP8657A) at f_2. The detected error signal was used to phase lock the sweep oscillator which operates as a voltage-controlled oscillator (VCO) via a loop filter. In the present experiment, $f_1 = 250$ MHz, $f_m = Nf_1$, and $f_2 = (Nf_1 \pm 10\,\text{MHz})/M$, where M, N are integers. Fig. 1 is the instrument-limited spectrum of the 10·0 GHz optoelectronically phase-locked signal, exhibiting minimal sidebands.

This signal was either amplitude modulated or chopped with a microwave switch at 1·0 kHz and sent to the EOS also shown in Fig. 2. We used the standard reflection-mode probing geometry. A train of 30 ps optical pulses from the gain-switched and phase-locked 1·3 μm LD was sent through a polarising beam splitter (PBS), a quarter-wave plate (QWP)

* WU, H.-H., CHANG, C.-S., and PAN, C.-L.: 'Optical phase-locking of microwave signals up to 12 GHz by laser-diode-based GaAs : Cr photoconductive harmonic mixer', submitted to *Electron. Lett.*, 1991

and a half-wave plate (HWP) and focused on the ground plane of a GaAs microstrip transmission line used as the

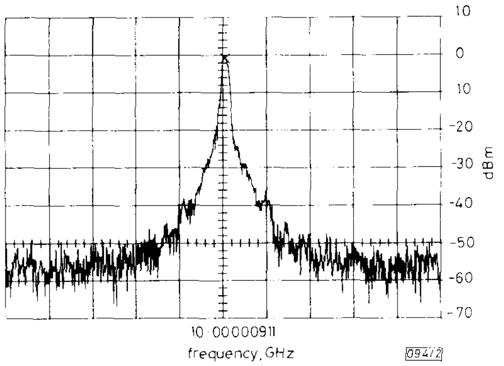

Fig. 2 *Spectrum of 10·0 GHz optoelectronically phase-locked signal*
Resolution BW = 100 Hz
Frequency span = 500 Hz/division
Amplitude scale = 10 dB/division

sampler. The microwave signal changes the polarisation of the reflected probe beam which passes back through the lens and the waveplates. The probe pulses were then directed by the beamsplitter to a Ge photodiode and processed by a lock-in amplifier. Several cycles of the 10·0 GHz signal were observed as the optical probe pulses were scanned across the microwave waveform by employing an optical delay line. This is shown in Fig. 3. It is worth noting that the microwave signal

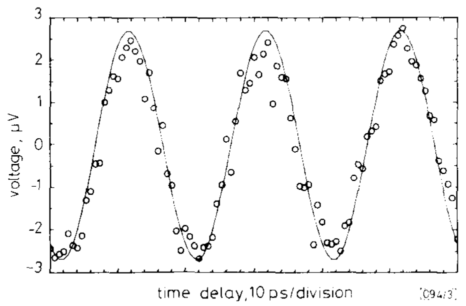

Fig. 3 *10·0 GHz microwave signal probed by electro-optic sampling*
○ experimental data
——— 10·0 GHz sinusoid

can be synchronously probed electro-optically by the 1·3 μm LD without offset, i.e. $f_m = Nf_1$, in our scheme.

In summary, we have demonstrated electro-optic sampling of 10·0 GHz optoelectronically phase-locked microwave signals using semiconductor laser diodes. One potential application of this technique is for the characterisation of MMICs at the wafer level.

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INEXACT MATCH ASSOCIATIVE MEMORY CELL

Indexing terms: Memories, Parallel processing

A new associative memory cell is described and analysed using SPICE3d1. The CMOS cell uses current summation to compute, in parallel, Hamming distances between the search key and each word in the memory. For 32 bit words, SPICE simulations of a 2 μm process show a delay of 4 ns/bit for Hamming distances less than three.

Introduction: The first uses of associative memories were in system architectures to improve the translation table lookup process in the cache memory.[1] The improvement is the result of the parallelisation of an exact match of a search key to all words stored in the translation buffer memory. An exact match, B bits in length, can be expressed as

$$match = \prod_{i=1}^{B} \overline{S_i \oplus W_i}$$

where S_i is the value of the ith bit of the search key, W_i is the value of the ith bit of the word stored in the associative memory and $\oplus$ is the exclusive-OR operator. Many associative memories evaluate the contribution of each bit to the above product (*match*) by using a six transistor static memory and a pass transistor exclusive OR. The output of the exclusive OR controls an input to a B input NOR gate. This cell is shown in Fig. 1. The area labelled NOR in Fig. 1 is not the entire B input NOR. In the memory, the output of the NOR gate (*match*) extends along the word axis of the memory and is terminated with either a clocked (dynamic gate) or resistive load (ratioed gate). If for example, a ratioed pullup completes the logic for *match*, *match* = 1 indicates that all B bits of the search key and the memory word are identical; this is an exact match. If one or more bits in the search key differ with the memory word, *match* will equal logic 0. In a memory of M words, the search key can be compared to all the words in the memory simultaneously because every word in the memory will have its own *match* line. The two simple circuit techniques outlined provide two types of parallelism: bit parallelism from the extended NOR and word parallelism from the multiplicity of *match* lines. When compared to RAM, these orthogonal parallisations are the sources of improvement for the lookup process in cache memory design. Cache design and other