MICROWAVE APPLICATIONS OF A LASER-DIODE-BASED PHOTOCONDUCTIVE HARMONIC MIXER

Ci-Ling Pan, Hsiao-Hua Wu, and C.-S. Chang

Institute of Electro-optical Engineering, National Chiao Tung University
Hsinchu, Taiwan 300, Republic of china

Abstract

We report two microwave applications of a laser-diode-based photoconductive harmonic mixer: (1)Time synchronization and relative phase of two microwave oscillators at 10 GHz to the optical pulse train at 500 MHz; (2)Measurement of the waveform of an optoelectronically phase-locked 12.01 GHz microwave signal as well as the waveform and spectrum of picosecond electrical pulses generated by a step recovery diode via a low-frequency replica.

Introduction

With the recent advances in high speed optoelectronics, the application of lightwave technology to microwave and millimeter wave system has attracted much attention. A number of applications has been demonstrated, e.g., optically controlled microwave devices and circuits [1], waveform and spectrum measurements by electro-optic and photoconductive sampling [2-4]. In addition, the distribution of microwave signals through high speed fiber-optic links is also quite important [5]. In many of these applications, time synchronization between the optical probe pulses and the microwave signal or of a number of microwave oscillators to the same reference frequency is necessary. Optical phase locking of microwave signals using the electro-optic (EO) harmonic mixing technique [6] and display of the phase-locked signal by photoconductive sampling via a low-frequency replica [7] have recently been reported. Recently, we have demonstrated optoelectronic phase-locking of microwave signals up to 18 GHz [8] and electro-optic sampling of the optoelectronically phase-locked microwave signal up to 10 GHz by a laser-diode-based GaAs:Cr photoconductive harmonic mixer. In this work, we report the extension of this technique to the synchronization of microwave oscillators for distributed architectures and display of the microwave waveform and spectrum measurement via a low-frequency replica.

Experimental Methods

Our experimental setup for the synchronization of two microwave oscillators is shown in figure 1. A gain-switched laser diode driven by the master oscillator was used to generate 30ps optical pulses at 500 MHz. A beam splitter was used to divide the optical beam and an optical delay line was inserted in one of the splitted beams for adjustment of the relative phase between these two optical paths. A pair of GaAs:Cr photoconductive switches were biased by the target oscillators and used to intermix the harmonic components of the optically generated electrical pulses with the microwave signals to be phase-locked. The output of the photoconductive switch at the intermediate frequency (IF) was amplified, fed to a phase detector, through a loop filter, and used as the error signal to control the free-running target oscillators which operate as voltage-controlled oscillators (VCO). The phase locked frequency ,f_m, of the microwave oscillator was given by $f_m = N f_o \pm f_r$,where N is an integer, f_o is the repetition frequency of the optical pulse train, f_r is the 10 MHz reference signal fed to the phase detector.

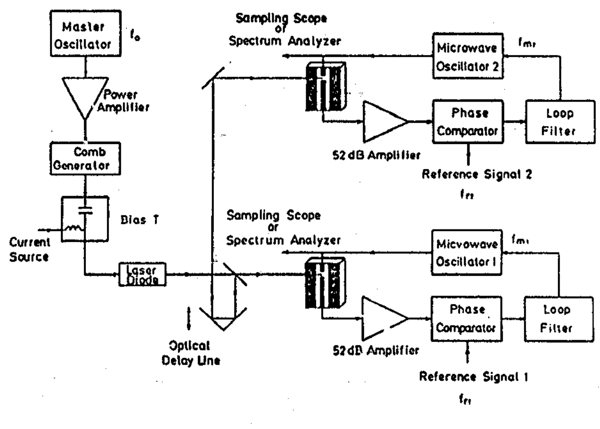

Fig.1 Experimental arrangement for optoelectronic synchronization of two microwave oscillators.

IF2

In the second experiment, the optoelectronically phase-locked VCO at f_{RF} was used to bias another GaAs:Cr photoconductive harmonic mixer which functioned as a sampler. The sampled output at the intermediate frequency (IF) consists of sum and difference of multiples of f_{RF} and f_{LO}, $f_{IF}(M,N) = Mf_{RF} \pm Nf_{LO}$, where M, N are integers. The waveform or spectrum of the baseband of $f_{IF}(M,N)$ reproduces that of the microwave signal but with a time enlargement factor $f_{RF}/\Delta f$. The number of sampling points, $L=f_{LO}/\Delta f$. The baseband signal was lowpass filtered, amplified and displayed on a conventional real-time oscilloscope or a spectrum analyzer.

Optoelectronic synchronization of microwave signals

Figure 2 shows the waveforms of the two optoelectronically phase-locked signals at 10.01 GHz from the two microwave oscillators. Figure 3 shows the same phase-locked microwave signals which were tuned out of phase by the optical delay line. Microwave signals with an arbitrary offset in frequency can be phase-locked to the repetition frequency of the optical pulse train by adjusting one of the reference frequencies for the oscillators. As an example, for an offset in frequency of 10 kHz, i.e., f_r= 10 MHz and 10.01 MHz for the two oscillators, two spectrally pure lines at 10.0000247 GHz and 10.0000347 GHz were observed. This is shown in Figure 4. It can be seen that the phase noise is quite low in our scheme.

Waveform and Spectrum Measurement via a Low-frequency Replica

In the first experiment, we have measured an optoelectronically phase-locked 12.01GHz microwave signal. The waveform directly displayed on a sampling oscilloscope (Tek7854) is shown in Fig.5 (upper trace). The down-converted 10MHz baseband IF signal displayed with real-time plug-ins on the same oscilloscope is shown in Fig.5 (lower trace). The waveform of the lower trace reproduced that of the upper trace but with 1201-fold enlargement in time. The number of sampling points per period of the measured waveform was 50. In the second experiment, we demonstrated the capability of replicating a fast electrical signal and its harmonic spectrum. A 499MHz sinusoid electronically phase-locked to the activating laser pulse train (at 498.9MHz) was amplified and used to drive a step recovery diode (SRD) which generated ≈ 100ps-wide electrical pulses. The output of the SRD as measured directly by a sampling oscilloscope is shown in Fig.6 (upper trace). The replicated waveform (with 4990-fold enlargement in time) is also shown in Fig.6 (lower trace). The number of sampling points per period is 4989 in this case. This is a factor of 624 improvement over the previous work, which used a main frame laser system [7]. This is only possible because of higher and readily adjustable repetition rate of the gain-switched laser used in this work. The replicated spectrum of the output of the SRD is shown in Fig.7.

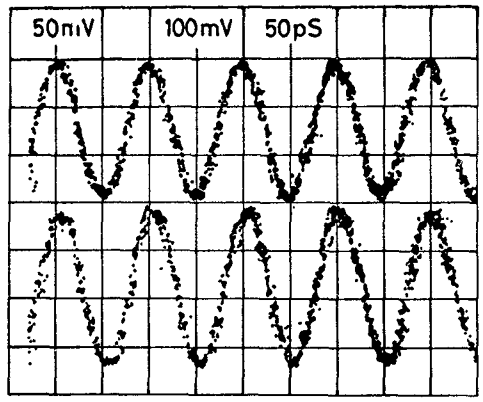

Fig.2 Waveform of two 10-GHz phase-locked oscillators tuned in phase.

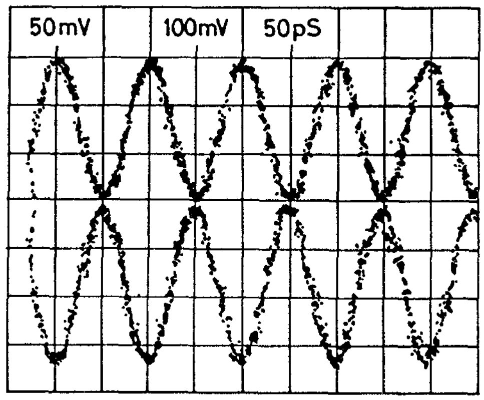

Fig.3 Waveform of two 10-GHz phase-locked oscillators tuned out of phase.

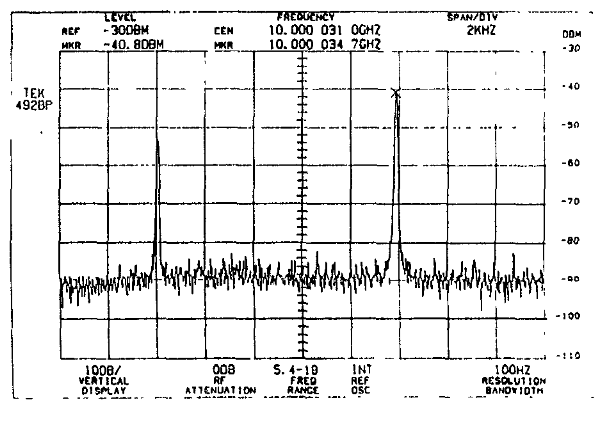

Fig.4 Spectra of two 10-GHz phase-locked oscillators with a frequency offset of 10 kHz (resolution bandwidth 100 Hz, vertical scale 10 dB/div and horizontal scale 2 kHz/div).

CONCLUSIONS

We have demonstrated two applications of a compact laser-diode-based photoconductive harmonic mixer.One of the unique features of our approach is that the photoconductor functions not only as a optical receiver but also as an electronic harmonic mixer. In the first experiment, two 10-GHz microwave oscillators have been phase-locked together. The relative phase between the phase-locked signals can be continuously tuned over a whole cycle by an optical delay line. Phase-locking of the two oscillators with a frequency offset of 10 kHz was also demonstrated. Extension of this technique to phase-locking of a number of oscillators should be straightforward. In another set of experiments, the waveform of optoelectronically phase-locked 12.01 GHz microwave signal as well as waveform and spectrum of picosecond electrical pulses generated by a step recovery diode measured by this technique are presented. In comparison with previous electro-optical sampling or photoconductive sampling experiments using main-frame lasers, the principal advantages of the present system are: (1) compactness (2) a large number of sampling points (3) waveform and spectrum can be displayed on any convenient time scale or frequency range.

ACKNOWLEDGEMENT

This work was supported in part by the National Science Council of the Republic of China under grant NSC80-0417-E-009-05

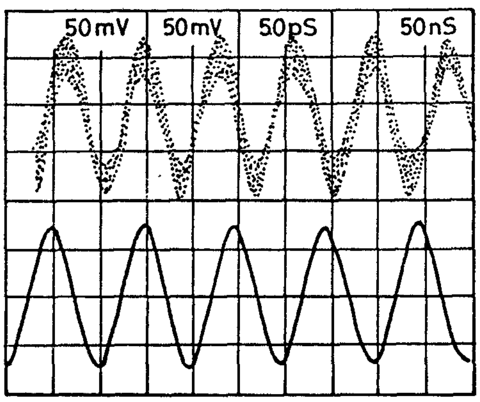

Fig.5 Optoelectronically phase-locked 12.01GHz microwave signal measured by a sampling oscilloscope (upper trace, vertical scale: 50mV/div, horizontal scale: 50ps/div) and the present technique (lower trace, vertical scale: 50mV/div, horizontal scale: 50ns/div).

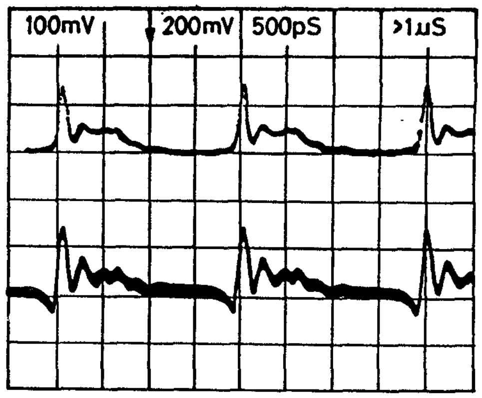

Fig.6 The output waveform of a SRD at 499MHz measured by a sampling oscilloscope (upper trace, vertical scale: 100mV/div, horizontal scale: 500ps/div) and the present technique (lower trace, vertical scale: 200mV/div, horizontal scale: >1μs/div).

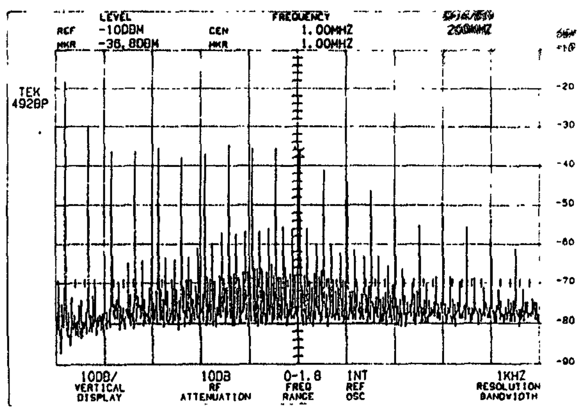

Fig.7 The spectrum of the output of a SRD at 499MHz measured by the present technique.

REFERENCES

1. A.J.Seeds and A.A.DeSalles, "Optical Control of Microwave Semiconductor Devices," IEEE Trans. Microwave Theory.Tech., vol.MTT-38, pp.577-585, May, 1990, and references therein.

2. H.-L.A.Hung, P.Polak-Dingels, K.J.Webb, T.Smith, H.C.Huang, and C.H.Lee, "Millimeter-wave monolithic integrated circuit characterization by a picosecond optoelectronic technique," *IEEE Trans. Microwave Theory Tech.*, vol.MTT-37, pp.1223-1230, Aug. 1989.

3. M.J.W.Rodwell, M.Riaziat, K.J.Weingarten, B.A.Auld, and D.M.Bloom, "Internal microwave propagation and distortion characteristics of travelling-wave amplifiers studied by electro-optic sampling," *IEEE Trans. Microwave Theory Tech.*, vol.MTT-34, pp.1356-1362, Dec. 1986.

4. J.A.Valdmanis, "Electro-optic measurement techniques for picosecond materials, devices and integrated circuits," in *Measurements of high speed signal in solid state devices, Semiconductors and Semimetals*, vol.28, pp.136-219, R.B.Marcus, Ed., New York: Academic Press, 1990.

5. S.Daryoush, "Optical synchronization of millimeter-wave oscillators for distributed architectures," IEEE Trans. Microwave Theory Tech., vol. MTT-38, pp. 467-476, May 1990, and references therein.

6. M. G. Li, E. V. Chauchard, C. H. Lee,"Intermixing optical and microwave signals in GaAs microstrip circuits for phase-locking applications," IEEE Trans. Microwave Theory Tech., vol. MTT-38, pp.1924-1931, Dec. 1990.

7. H-L.A.Hung, M.G.Li, S-L.L.Huang, and C.H.Lee, "Characterization of microwave integrated circuits using an optical phase-locking and sampling system," in *IEEE Int. Microwave Symp. Dig.*, pp.507-510, June, 1991.

8. H.-H.Wu, C.-S.Chang, and C.-L.Pan, " Optoelectronic phase-locking of microwave signals up to 18 GHz by a laser-diode-based GaAs:Cr photoconductive harmonic mixer," *IEEE Microwave Guided Wave Lett.*, vol.2, pp.11-13, Jan. 1992.

9. H.-H.Wu, C.-S.Chang, and C.-L.Pan, "Electro-optic sampling of optoelectronically phase-locked 10.0 GHz microwave signals using semiconductor laser diodes," *Electron. Lett.*, vol.27, pp.1622-1623, Aug. 1991.