Optoelectronic Phase-Locking of Microwave Signals up to 18 GHz by a Laser-Diode-Based GaAs:Cr Photoconductive Harmonic Mixer

Hsiao-Hua Wu, Chen-Shiung Chang, and Ci-Ling Pan

Abstract—**A GaAs:Cr photoconductive switch activated by 30-ps optical pulses from a gain-switched laser diode (λ = 0.79 μm) was used as a harmonic mixer to optoelectronically phase-lock microwave signals up to 18.01 GHz. The conversion loss of the harmonic mixer was 70 dB at 16.01 GHz. The phase noise degradation of the phase-locked 16.01-GHz signal at 5-kHz offset measured with respect to the 1.0-GHz synthesizer signal for driving the laser diode was 30 dB.**

I. Introduction

THE use of either ultrafast photoconductive (PC) [1]–[3] or electrooptic (EO) [4]–[6] sampling techniques to characterize the performance of discrete microwave devices and monolithic microwave integrated circuits (MMIC's) has been an active area of research recently. For measurement of CW microwave signals, phase coherence or time synchronization between the signal and the optical probe pulses is mandatory. Previous workers have often used a microwave frequency synthesizer as the signal source and synchronizing the mode-locker driver of the laser to it. Alternatively, two phase-locked microwave synthesizers can be used to drive the laser and inject microwave signals into the device under test synchronously.

Recently, Li *et al.* [7], [8] demonstrated optical phase locking of microwave signals up to 14.928 GHz by intermixing microwave signals with the harmonics of the optical probe pulse using the electrooptic effect in GaAs microstrip circuits. This technique can potentially be used to phase-lock an MMIC oscillator at frequencies up to 100 GHz at the wafer level. It is interesting to investigate the feasibility of replacing the main-frame mode-locked laser used by previous workers with a diode laser, which is compact, has high repetition rate and exhibits minimum timing jitter [9]. Furthermore, other types of optically pumped mixers are available [10]. In particular, photoconductive mixers have previously been reported in GaAs up to 4.5 GHz [11] and InP materials up to 0.1 GHz [12]. These mixers should exhibit a sensitivity equal to or higher than that of the electrooptic harmonic mixer. They are also compatible with the aforementioned wide-band sampling techniques and can be integrated with MMIC's. In this letter, we demonstrate for the first time optoelectronic phase-locking of microwave signals up to 18.01 GHz with a laser-diode-based GaAs:Cr photoconductive harmonic mixer.

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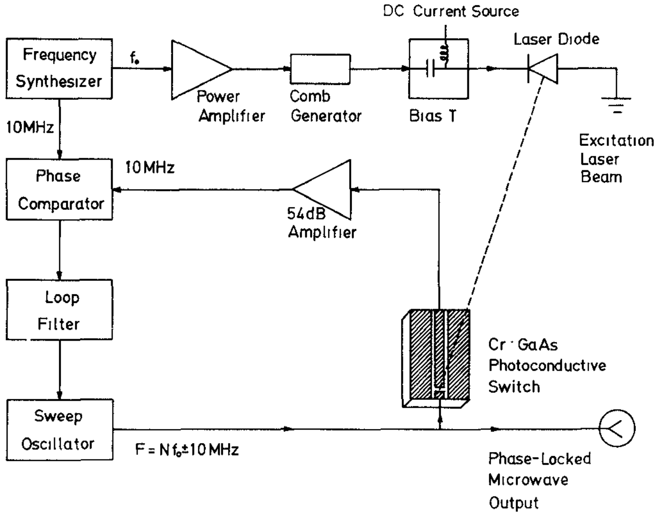

Fig. 1. Schematics of the experimental set up for optoelectronic phase-locking of the microwave signal using the laser-diode-based photoconductive harmonic mixer.

II. Experimental Methods

A schematic diagram of our experimental set up is shown in Fig. 1. The light source for the work reported here was a gain-switched lase diode (Mitsubishi, model ML-4102, λ = 790 nm) drived by a comb generator (HP33005C) at $f_0 = 1000$ MHz and generating 30 ps pulses. The photoconductive switch consists of a straight 10-μm gap in a 50 Ω coplanar waveguide transmission line fabricated on the GaAs:Cr substrate. With dc bias of 10 volts and illuminated by 30-ps optical pulses at an average power of 1.3 mW, the photoconductive response of the switch was 60 mV and the pulse width was 100 ps as observed on a sampling oscilloscope (Tektronix 7854 w/S-4 sampling head). The power of the fundamental and 16th harmonic of the generated electrical pulses as measured by the spectrum analyzer (Tektronix 492BP) were, respectively, –32 dBm and –64 dBm. In the phase-locking experiment, the free running microwave signal at a power level of 20 dBm from a microwave sweep oscillator (HP8350C) was used to bias the GaAs:Cr switch and intermixed with the appropriate harmonic component of the optically-generated

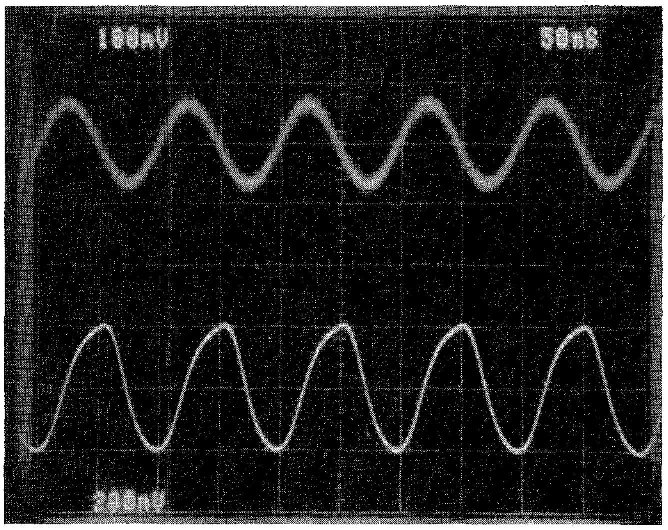

Fig. 2. 16.01 GHz optoelectronically phase-locked signal as monitored on the oscilloscope (upper trace: 10-MHz intermixed signal after two stages of amplification (54-dB gain). lower trace: 10-MHz reference signal from the frequency synthesizer).

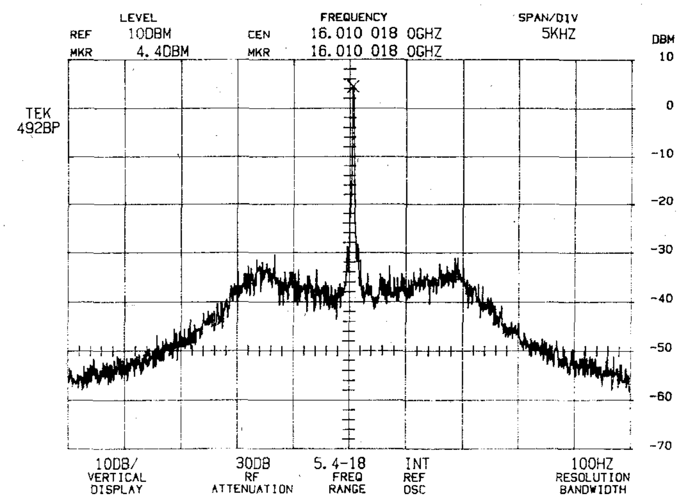

Fig. 3. Spectrum of the 16.01 GHz optoelectronically phase-locked signal (resolution BW = 100 Hz, frequency span = 5 kHz/div., vertical scale = 10 dB/div).

electrical pulse. The signal at the output port of the switch was then amplified by two stages of low-noise amplifiers with a combined gain of 54 dB and mixed with the 10-MHz reference signal of the microwave synthesizer (HP8657A) driving the laser diode. The resultant error signal was used to phase-lock the free-running microwave oscillator that operates as a voltage-controlled oscillator (VCO) via a loop filter. In our experiment, the expected phase-locked frequency of the VCO should be $F = (Nf_0 \pm 10)$ MHz, where N is an integer.

III. Results and Discussion

The conversion loss of the photoconductive harmonic mixer from microwave to the intermediate frequency (10 MHz) were measured to be 34 dB at 2 GHz, 70 dB at 16 GHz, and 84 dB at 18 GHz, respectively. When the phase lock condition was achieved, two clean 10-MHz signals from the output of the amplifiers and the synthesizer, respectively, could be observed on a monitoring oscilloscope triggered by one of these signals. This is shown in Fig. 2, for $F = 16.01$ GHz ($N = 16$). The slightly distorted sinusoid in the lower trace is intrinsic to the synthesizer used. At this time, the output spectrum of the microwave oscillator as observed on the spectrum analyzer became more stable and narrower. Fig. 3 illustrates typical phase-locking result at 16.01 GHz. The sideband of the spectrum of the phase-locked signal are primarily due to the phase noise within the phase-locked loop and timing jitter of the laser. The latter is expected to be small for laser diodes [9]. The spectrum of phase-locked microwave signal have been observed from 2 to 18 GHz. The phase noise degradation of the phase-locked signal at 5 kHz offset measured with respect to the 1.0 GHz synthesizer signal for driving the laser diode were 20 dB at 2 GHz, and 42 dB at 18 GHz, respectively.

IV. Conclusion

In summary, we have demonstrated optoelectronic phase-locking of microwave signals up to 18.01 GHz using a compact laser-diode-based GaAs:Cr photoconductive harmonic mixer. The upper bound for frequency of the phase-locked signal in this work was limited by the response of the photoconductive switch and laser pulse width. Picosecond GaAs-based photoconductive switches have been recently reported [13]. Subpicosecond pulses can also be generated from a mode-locked semiconductor laser [14]. It can, thus, be expected that the present optoelectronic phase-locking technique will be an attractive scheme for achieving phase lock of millimeter-wave signals at the wafer level.

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