CHARACTERIZATION OF MICROWAVE INTEGRATED CIRCUITS USING AN OPTICAL PHASE-LOCKING AND SAMPLING SYSTEM

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Abstract

Using an optical technique, phase-locked microwave signals of up to 15 GHz from voltage-controlled oscillators (VCOs) have been achieved. Combining this technique with a photoconductive switch, a new microwave waveform sampling system that displays the characteristics of oscillators and amplifiers has been demonstrated. The approach has potential applications for optically phase-locked microwave subsystems and monolithic integrated circuit characterizations.

INTRODUCTION

Time-domain waveform measurements and displays are useful in the characterizations of microwave components, especially nonlinear circuits such as oscillators, power amplifiers, and mixers. The current sampling scope using Josephson devices is limited to a bandwidth of 70 GHz and requires cryogenic cooling (1). Using optical techniques, characterizations to higher frequencies in the millimeter waves can be realized. Measuring the characteristics of microwave and millimeter-wave integrated circuits using picosecond pulses as the input signal has been demonstrated (2), (3). Other approaches using optical/microwave source synchronized systems have also been reported (4); however, in applying such a technique to achieve a microwave input signal to characterize circuits, the time synchronization between the microwave signal and the modulated laser source is crucial for producing a jitter-free waveform. A complex scheme with multiple frequency synthesizers is required. Other methods that will maintain the coherence between microwave oscillation and laser pulses include indirect optical locking of a millimeter-wave IMPATT oscillator (5) and optical mixing of an injection-locked laser diode (6).

Recently, a new phase-locking technique for a microwave oscillator with laser pulses that uses the intermixing of microwave and picosecond optical signals via electro-optic (E-O) effects was demonstrated (7). This paper reports new results by extending the phase-lock scheme to higher frequencies. In addition, the technique has been combined with the use of a photoconductive switch to display a replica of the output waveform from microwave circuits. Potential applications include the characterization, and optical phase-locking of GaAs MMIC VCOs and the measurement of other (linear and nonlinear) microwave or millimeter-wave integrated circuits.

ANALYSIS AND EXPERIMENT

Sampling is a well-known method to characterize high-frequency repetitive waveforms through the study of lower frequency signals. Figure 1 illustrates the sampling scheme in a time domain. The narrow optic pulse train gates the input microwave signal, producing an output proportional

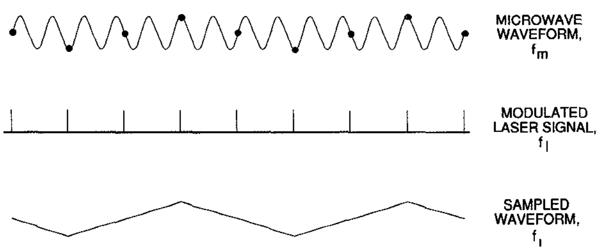

Figure 1. Sampling Scheme

to the input value at that particular instant in time. The microwave signal frequency satisfies the following conditions:

$$f_m = Nf_l \pm f_i$$

or

$$= (NM \pm 1) f_i$$

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where f_m is the microwave frequency, f_l the laser modulation frequency, f_i the intermediate frequency (IF), and N is an integer. M (f_l/f_i) represents the number of sampling points per period, which might not be an integer. With sufficient mapping points M, the IF waveform should be similar to that of the microwave but with a time enlargement factor of $\pm(NM \pm 1)$.

A schematic of the optically phase-locked loop (PLL) system is shown in Figure 2. The optical source is a mode-locked Nd:YLF laser with a modulation frequency of f_l. The output is compressed by a fiber pulse compressor, resulting in a full-width-at-half-maximum (FWHM) pulse duration of 3 picoseconds at a wavelength of 1.06 µm. The microwave signal generated by the VCO source passes through the GaAs microstrip circuit. The resulting electric field close to the microstrip line modulates the multiple reflected optical beam in the GaAs substrate from the E-O intermixing effect (7). The modulated light is then demodulated using a polarizer and a photodetector (EG & G YAG 100). The detected signal is filtered, amplified, and then mixed with the reference signal derived from the same driver of the acoustic-optical modulator used to mode-lock the laser. The resultant difference in frequency between the reference signal and the detected signal is converted and supplied to the VCO as a voltage difference through the loop filter.

MEASURED RESULTS

Using a signal generator such as one from the HP86200 series as the VCO in the PLL, optically phase-locked microwave signals at 1.3, 2.4, and 15 GHz have been achieved. Figure 3 shows the phase-locked microwave spectrum at 15.06 GHz. In the PLL, the laser modulation frequency was 76 MHz, and the intermediate frequency was 9.5 MHz. Optically phased-locking an MMIC MESFET VCO is currently being studied. Because signal detection using E-O sampling does not require a microwave launcher contact

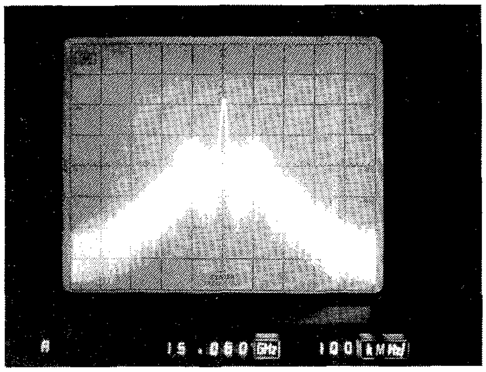

Figure 3. Spectrum of 15-GHz Oscillation

and needs only low-frequency probes, the present phase-locking technique can potentially be applied to optically phase-lock a series of MMIC VCOs to frequencies in the millimeter-wave region.

The PLL can also be used to measure the waveform of a microwave component, such as an amplifier operating at saturation. Figure 4 shows the experimental setup for such an application. In the PLL, a one-stage divider circuit (which divides by four) or a two-stage divider circuit (which divides first by four and then by two) was used to generate f_i at 9.5 MHz or 4.75 MHz, respectively, depending on the microwave frequency. The phase-locked micro-

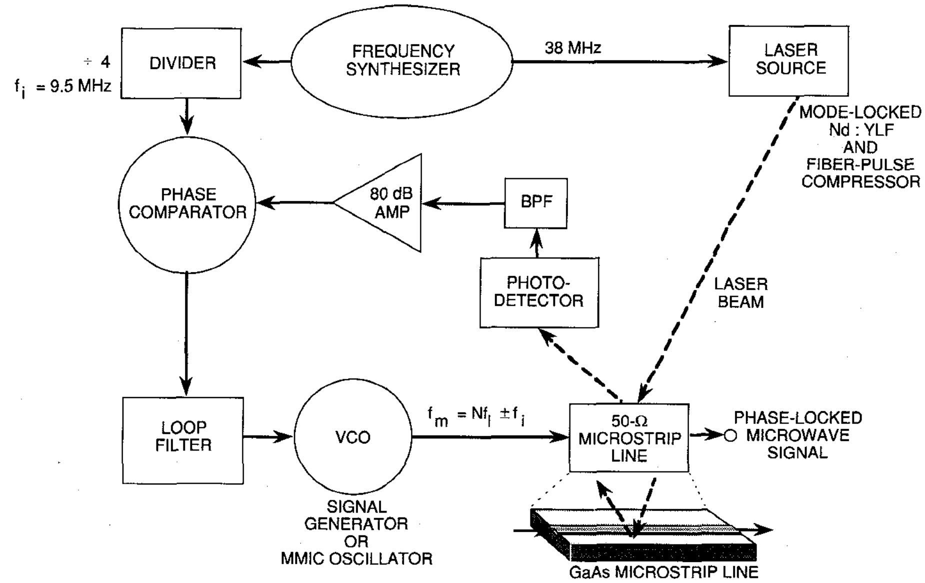

Figure 2. Schematic of Optically Controlled Phase-Locked Loop

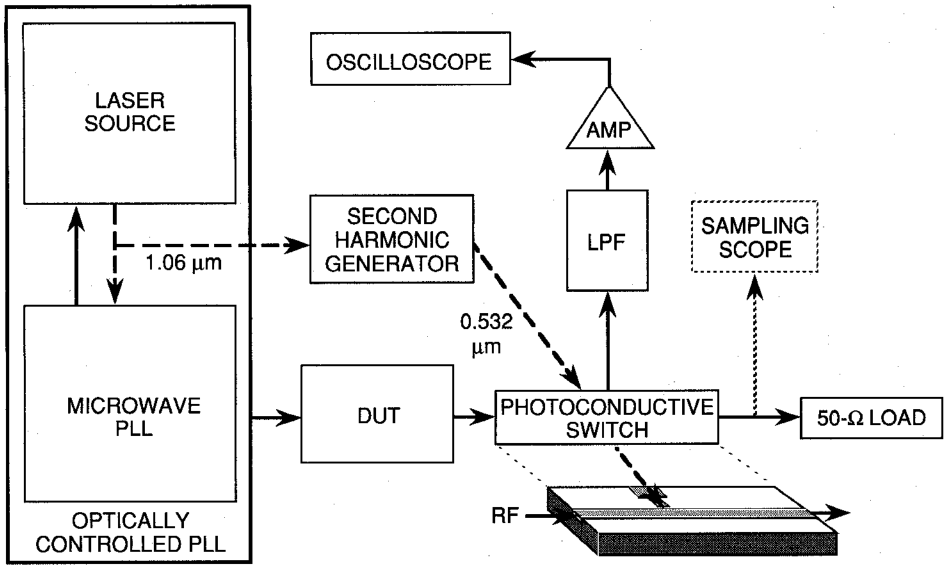

Figure 4. Schematic of Optic Sampling System

wave signal is fed to the device under test (DUT), and the output waveform is detected through the photoconductive sampler (an O^+ implanted GaAs photoconductive switch). The sampled output signals are f_i and its harmonics, which are then passed through the low-pass filter.

The waveform can subsequently be displayed on a conventional oscilloscope. For optimal replication of the microwave waveform, the value of $M = f_1/f_i$ should be as large as possible; the minimum value for f_i should be above the noiseband of the laser. If the oscilloscope is externally triggered by the reference signal (which is either 9.5 MHz or 4.75 MHz in the examples presented here) from the divider circuit in the PLL and the 0.532 µm sampling beam is optically delayed, the displayed waveform on the oscilloscope will shift horizontally. The displayed waveform repeats itself when the optical delay is equal to the period of the operating microwave frequency of the DUT. Thus, the wavelength and frequency of the measured microwave signal, as well as the waveform shape, can be determined.

When the DUT is simply a transmission line, the displayed output waveform is that of the phase-locked microwave signal. Figure 5 shows the exact replica of the detected sinusoidal waveform of a 2.4-GHz signal when an HP86222B was used as the VCO in the PLL. Another example is given in Figure 6, where the waveforms were obtained from an amplifier (DUT) driven into saturation by the VCO in the PLL at 536 MHz. The sampled waveform obtained optically is given in Figure 6a, and that from a conventional sampling scope measured at the end of the microstrip line in a photoconductive switch circuit is indicated in Figure 6b.

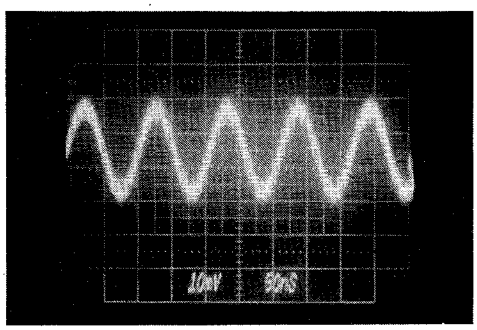

Figure 5. Displayed Waveform of a Low-Frequency Replica of a 2.4-GHz Oscillation

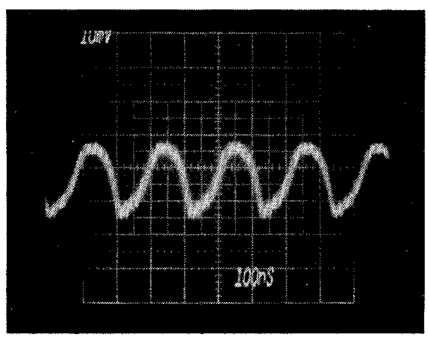

Figure 6a. Measured Waveform of the Output of a Large Signal Amplifier (Optical Method)

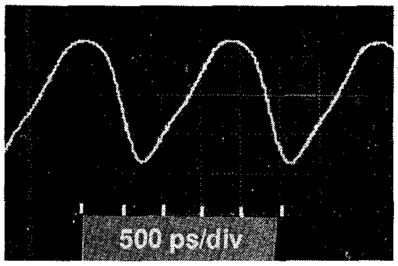

Figure 6b. Measured Waveform of the Output of a Large Signal Amplifier (Sampling Scope Method)

CONCLUSIONS

By using a new phase-locked scheme that uses optical-microwave intermixing and E-O effects, the characteristics of a VCO in a PLL can be determined. Combining the phase-locked scheme with photoconductor sampling, replicas of microwave circuit waveforms can be displayed with a conventional time-domain oscilloscope. This combined sampling technique has potential applications in the optical phase-locking of microwave/millimeter-wave systems and the characterization of nonlinear circuits such as oscillators and large signal amplifiers.

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