INTERNATIONAL TOPICAL MEETING ON

MICROWAVE PHOTONICS MWP 2000

11-13 September 2000

St. John's College, Oxford, UK

Organised by:
Institution of Electrical Engineers

Co-sponsored by:
IEEE Lasers and Electro-optics Society
IEEE Microwave Theory and Techniques Society

We wish to thank the following for their contribution to the success of this conference:

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High Frequency and Broadband Signal Measurements by Ultrafast Opto-Microwave Intermixing and Sampling

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Abstract

Low frequency replication (600 kHz to 18 MHz) of a high frequency waveform (1 GHz to 30 GHz) was achieved using a photoconductive-based optical-microwave (OM) sampler. This OM sampler performs better than a 20 GHz digitizing sampling oscilloscope and is also superior to the standard pump and probe systems with orders of magnitude improvement in data acquisition rate.

I. Introduction

As electronic signals move to higher frequencies and wider bandwidths, there is need for new methods of measuring these high-frequency/high-speed (tens of GHz) and/or high bit rate (tens of GBs/s) signals[1-3]. In this work, critical technical issues associated with the design of a rugged, compact, "real-time" sampling system using photoconductive switches as the test signal generator and sampler were investigated. The design concept is based upon an optoelectronic equivalent time sampling principle and optical-microwave signal mixing. It involves first phase locking of the periodic input signal to be measured to the periodic optical pulses from a mode-locked laser and subsequent sampling of the locked signal by the optical pulses. A photoconductive (PC) switch is used for the optical-microwave mixer and another photoconductor for the sampler. The optical pulses we use were provided by 100 fs pulses from a Ti-Sapphire laser. The optical-microwave intermixing process generates a low-frequency replica of the high-frequency input signal. The ratio of the repetition rate of the input signal to its low-frequency replica is the time expansion factor. The repetition rate of the low-frequency signal provides the offset frequency for the equivalent time sampling. Since there is no electro-mechanical moving parts required to acquire a waveform, the sampling is done at a fast rate, and acquisition times of 10 ms or less are possible. The success of this technique depends critically on the stability and reliability of the optical microwave phase locked loop (OMPLL) which locks the phase of the signal generator to the optical pulses.

2. Experimental set up

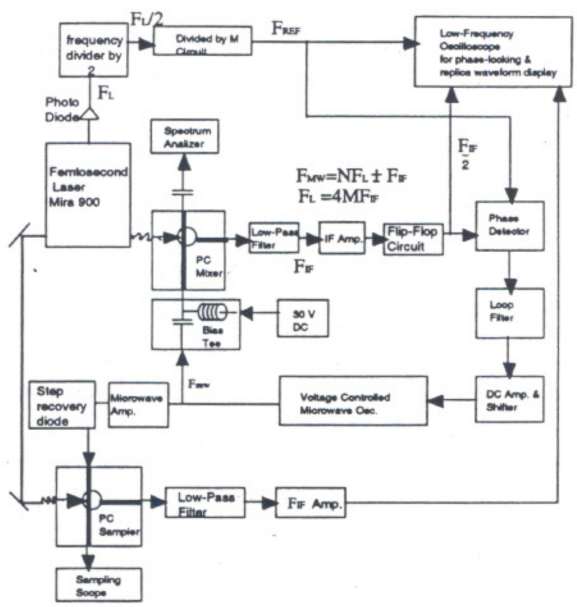


Figure 1. OM sampling system

Figure 1 is the schematic diagram of the OM sampling system. The 100 fs 800 nm laser beam is split into two beams, one for OM phase locking (OMPL) and the other for waveform sampling. One beam of the laser beams illuminates the GaAs PC mixer (which is used in phase locking the laser and the microwave or pulse source). The laser signal and microwave output are mixed in the PC mixer and the resultant intermixed signal is then amplified through a high gain intermediate frequency (IF, 600 kHz) amplifier. Then the IF signal is sent through a flip-flop circuit and its phase is compared to a reference signal which is obtained by frequency dividing the output from the laser photo detector. The resulting error signal is then delivered through a loop filter to tune the voltage controlled oscillator (VCO). When OM phase-locking is established, a clear trace around the center frequency of the microwave oscillator will appear and the frequency bandwidth will decrease by two orders of magnitude. Only after phase locking has been established should the high frequency waveform sampling be carried on.

3. Phase locking loop (PLL)

A PLL basically is a feed back system, that synchronizes an oscillator in phase and frequency to an incoming signal. The phase detector measures the phase difference between the input and output signals and produces an error signal proportional to the measured phase difference. The error signal will drive the VCO, changing its frequency so as to minimize the phase difference between the input and output signals. The frequency of the output signal will be identical to that of the input signal and will follow every change of the latter.

There are two type of phase detectors, one is solely phase sensitive, another is frequency sensitive. The later one is sensitive to phase noise, requires signals with a signal to noise ratio of >30 dB, and requires signals with fast transitions (sharp edges). In our case, the Fif is from a PC switch which provides a weak signal with high level noise. Consequently, we use a phase sensitive detetector in the PLL. To ensure good phase locking, a flip-flop circuit must be used. This makes the OMPLL system very stable.

4. Optical sampling and the replica of the microwave waveform

The working principle of waveform time replica is illustrated in Figure 2.

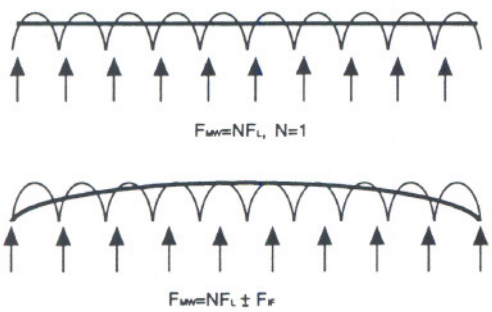
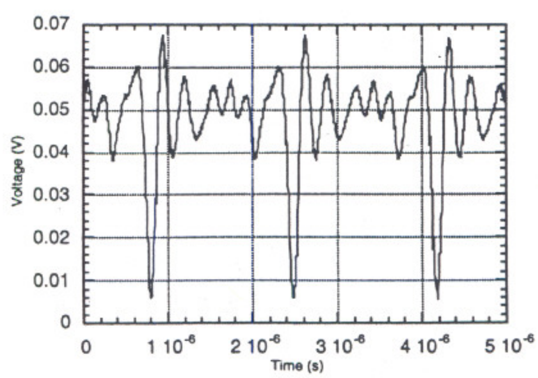


Figure 2. Principle of the time replica

The upper graph shows that the laser pulse will sample the same position of the microwave signal if there is no offset frequency between F_{mw}, the microwave frequency, and NF_l, the multiple laser frequency (N is the multiplier). The sampled output (thick line) will be a flat line. However, if an offset frequency, F_{if}, exists, different mode-locked laser pulse will be sampled at different phases (or delays) on the microwave signal, as shown in the lower graph of Figure 2. The time scale of the OM sampled waveform will be expanded by a factor of $1/F_{if}$ relative to actual time.

In our experiment, the F_{if} was selected to be 600 kHz. The phase locked microwave signal was then used to drive a step recovery diode (SRD) in order to generate high frequency and broadband signals for validating OM sampling systems. The waveform was measured with both a HP 54750A digitizing 20 GHz bandwidth sampling scope and with the present OM sampling system. The results from Figure 3 indicated that excellent agreement was achieved and that OM sampling exhibits a higher bandwidth. The time enlargement factor was 2000 for the waveforms shown in fig. 3. The width of the OM-sampler-measured pulse is approximately 7 ps, which has a bandwidth exceeding the bandwidth of the 20 GHz sampling scope.

The spectrum of the SRD output signal and that of the replica were also measured. The maximum harmonics of the signal from the SRD extend beyond 30 GHz which is beyond the bandwidth of the 20 GHz HP digitizing sampling scope. The low-frequency (OM-sampled) replica, on the other hand, had its harmonics extending only to 18 MHz, which is well within the bandwidth of the 20 GHz sampling scope and most digitizing waveform recorders. It is clear that information above 20 GHz is lost using the 20 GHz sampling oscilloscope ~~while~~ whereas its OM-sampled replica preserves all information. The experimental details and results will be reported.



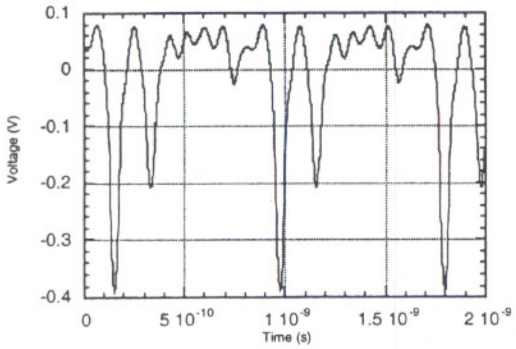


Figure 3. OM sampled replica waveform(top) & scope

sampled microwave waveform (bottom)

Figure 4 shows the working principles for high frequency microwave sampling in the frequency domain. The upper graph shows the spectrum of the envelop of the mode-locked laser pulse train and the broadband high frequency microwave signal before intermixing. After intermixing, various sum and difference frequencies are generated, as shown in the lower graph. Any of these sum or difference frequencies from the intermixed signal could be used to perform OM phase locking. However, we have experimentally determined that the F_{if} provides the most stable phase locking. The F_{if} is defined as the frequency of the lowest OM intermixed signal which is the beating frequency between the Nth harmonic of the laser pulse train and the fundamental frequency of the microwave signal. After intermixing, a broadband low frequency replica of the broadband high frequency microwave signal is produced, which is shown on the left-hand side in the bottom panel of figure 4.

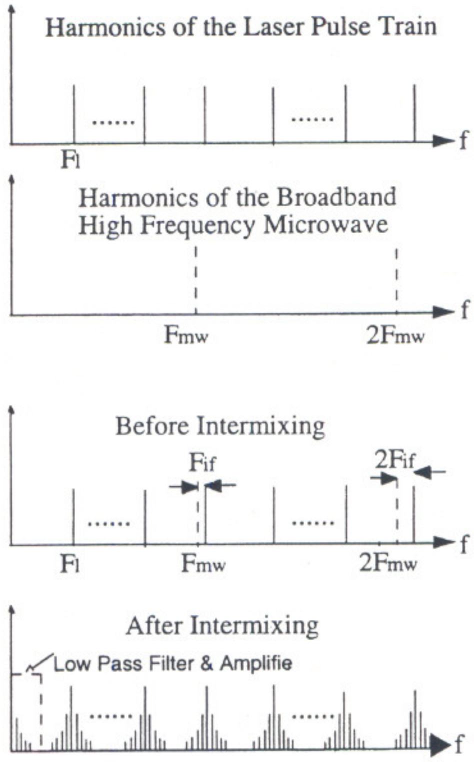


Fig. 4 Working principle for broadband high frequency microwave sampling

5. Conclusion

A flip-flop circuit was used to achieve a stable OMPLL. The flip-flop circuit greatly improved the operational stability and reliability of OMPLL relative to other circuits tried.

Low frequency replication of a high frequency waveform (1 GHz to 30 GHz) was achieved. Results show that the OM sampling system performs better than a 20 GHz digitizing sampling oscilloscope and is also superior to the standard pump and probe systems with orders of magnitude improvement in data acquisition rate.

References

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