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Improved Methods for Frequency Measurement of Short Radar Pulses

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***Abstract*— A method for measuring the frequency of short radar pulses is presented. In our experiment, two frequency synthesizers were used as a signal source, a double balanced mixer as a phase detector and a fast sampling oscilloscope (1 Gs/s) was used for data acquisition/display. Therefore our method is relative in nature.**

Since this method is based on waveform measurements, also even shorter pulses and their frequency deviations can be measured or at least detected and evaluated. In our test setup, 18 ns pulses can be produced. A waveform of such short pulses cannot be measured using a conventional oscilloscope, but a dedicated high-speed sampling device.

I. Introduction

Last year, in EFTF 2006, we presented a setup for measuring short-term instabilities of controlled oscillators. With a quite simple system, good results were attained. We could measure relative frequency changes of 1.6 Hz with 10 000 s^{-1} sampling rate [1]. Methods presented in this paper are a follow-up to the previous work.

In some modern pulsed radars the pulse length is short; often even less than 100 ns. Frequency changes during the pulse are thus difficult to detect using conventional methods or measurement devices. Regardless of the pulse width, meaningful Doppler processing calls for precise frequency definition. This may be required even for a single pulse, in case heavily agile waveforms are used in electronic warfare (EW) situations [2], [3].

II. Measurement setup

A. Frequency measurements

In our experiment, two frequency synthesizers were used as a signal source. A real radar was available, but it was not used at this stage, because to verify the measurement method, the pulse shape had to be almost ideal with fast rise and fall times. Block diagram of the measurement setup is presented in Figure 1. Later in this text, synthesizers are called synthesizer #1 and #2, #1 is the upper synthesizer (HP 8341B) in the block diagram.

Signals from synthesizers were fed to the RF and LO ports of a double balanced mixer. An attenuator and a low-pass filter was connected to the IF-port of the mixer. The attenuator is needed to ensure proper impedance matching between the mixer and the filter, which is needed to remove unwanted mixing products.

The output voltage of an ideal mixer is

$$A_1 \sin(\omega_1 t) \cdot A_2 \sin(\omega_2 t) = \frac{A_1 A_2}{2}\left[\cos[(\omega_1 - \omega_2)t] - \cos[(\omega_1 + \omega_2)t]\right], \qquad (1)$$

where A_1 and A_2 are amplitudes and ω_1 and ω_2 are angular frequencies of input signals. In this application, input signals are almost of the same frequency, so the output signal has one low frequency component, while other frequencies are equal to or higher than the carrier frequency, and thus they can be easily filtered out.

To eliminate the effect of the instability of the time base, reference output of the synthesizer #1 was connected to the reference input of the synthesizer #2. Since only relative frequency changes can be measured using this method, the quality of the time base does not have serious effect on the results. Synthesizer #1 is, however, equipped with high-quality ovenized crystal oscillator.

A pulse generator was used to modulate the synthesizer #1, and a fast sampling oscilloscope (1 Gs/s) was used for data acquisition and display. Different triggering configurations were used, but usually the oscilloscope was triggered by the signal used for pulse modulation.

Modulation domain analyzer is also a practical tool for frequency measurements of pulsed radar signals. Typically this kind of devices do not have as good resolution as our setup, but if the measured signal is downmixed using an external mixer and oscillator (or synthesizer), the measuring performance can be improved. Frequency resolution is comparable to our setup, but sampling interval will be too long, 100 ns [4].

Frequency counters, on the other hand, are really accurate, but usually they can not be used to measure short pulsed signals even if they happen to have an external gate facility. Typical microwave counter has too long measurement time even when the lowest resolution is used.

B. Waveform measurements

Since the output voltage or power of the mixer depends on the amplitude of the input signals, the waveform of the measured pulse must be known. Usually a spectrum analyzer

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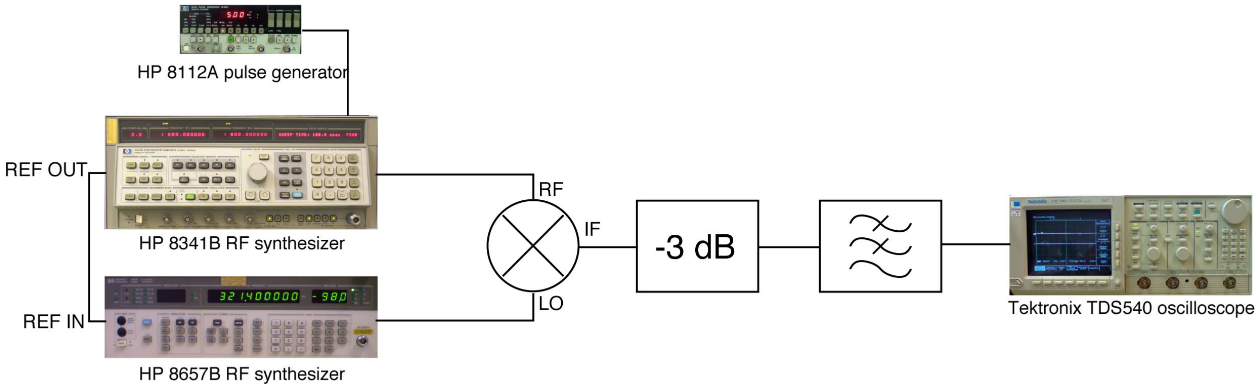

Fig. 1. Block diagram of the frequency measurement setup. Two synthesizers were used as a signal source. If a real radar is used, it replaces the upper synthesizer (synthesizer #1) and the pulse generator. Both synthesizers use the same time base. Synhesizer #1 is pulse modulated by pulse generator. Signals from the synthesizers are mixed, and mixing product filtered using low pass filter. Attenuator is used to ensure proper impedance matching between the filter and the mixer. Finally signal is measured using fast sampling oscilloscope.

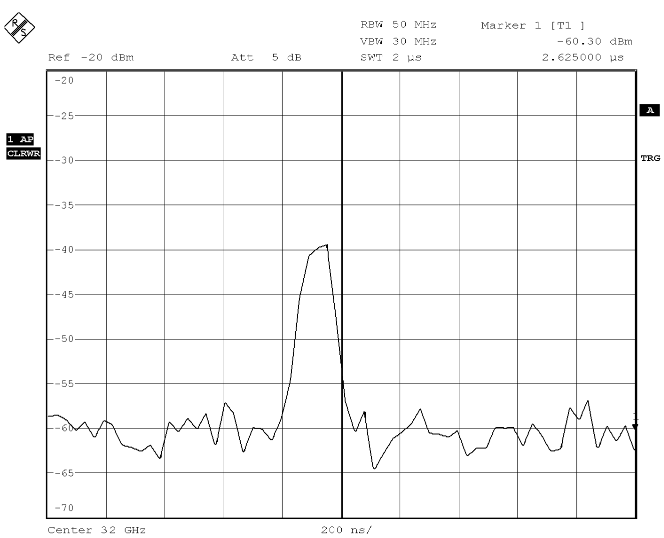

Fig. 2. A 200 ns pulse measured using a high-end spectrum analyzer with 50 MHz resolution bandwidth. Pulse shape can not be determined, and the actual peak power of the pulse was even 10 dBm higher than the indicated power.

or a detector diode and oscilloscope could be used, but with short pulses some special instrumentation is needed.

A spectrum analyzer, even with a really wide resolution bandwidth (e.g. 50 MHz), is not fast enough (see Figure 2), and detector diodes have typically stray capacitance which causes inaccuracy in pulse shape definition.

We have developed a dedicated measuring receiver to solve this problem. It is designed for microwave region, so it has a WR28 599U waveguide interface. The receiver itself consists of a waveguide-to-coax adapter, high-quality detector diode, a video amplifier and a low pass filter. Block diagram of the receiver and the whole measurement setup can be seen in Figure 3.

Device under test (DUT) is typically a radar or a plain transmitter. Since output power of a radar may be really high, an adjustable attenuator is used to set the power to suitable region. Attenuator is adjusted by micrometer screw, and it is calibrated for the operating frequency. Measuring receiver is also calibrated. A sampling oscilloscope is used for data acquisition.

For evaluation purposes we have used a semiconductor based, voltage controlled microwave oscillator in 30 GHz region.

III. Results

A. Frequency measurements

To verify the operation of the setup, we used 2.06 GHz center frequency. The synthesizer #1 was pulse modulated with 40 μs pulse repetition frequency (PRF) and 200 ns pulse length. One drawback in our setup is, that pulse generator can not be triggered using synthesizer #2. Therefore pulses are not synchronized with phase of the synthesizers and triggering the oscilloscope is tricky.

With this setup, we were able to detect a momentary frequency difference of 200 kHz with 2.06 GHz center frequency. Since the performance of the setup depends only on the pulse length and frequency difference, similar results can be expected also with higher frequencies.

The main motivation of this research is to detect and evaluate frequency changes. Therefore methods to calculate the absolute instability of the frequency are not presented here.

The frequency change caused by Doppler effect is

$$\Delta f = \frac{fv}{c} = \frac{v}{\lambda}, \quad (2)$$

where Δf is frequency change, f is center frequency or carrier frequency, v is velocity of the target, c is the speed of light and λ is wavelength. Doppler frequencies typcally range from 10 Hz to 10 kHz, depending on the application, carrier frequency and target. This is far beyond the capabilities of our setup, but especially in EW situations, quite peculiar waveforms may be used.

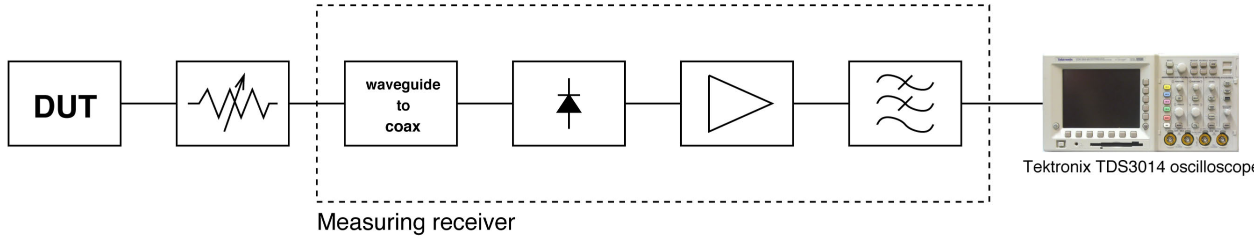

Fig. 3. Block diagram of the waveform measurement setup. A dedicated measuring receiver, which consists of a waveguide-to-coax adapter, detector diode, video amplifier and a low-pass filter, is used. Device under test (DUT) is typically a radar or a plain, pulse modulated oscillator. A calibrated, adjustable attenuator may be used, if the power level is too high. The measuring receiver is designed for microwave region, so it has waveguide interface. An oscilloscope is used for data acquisition/display.

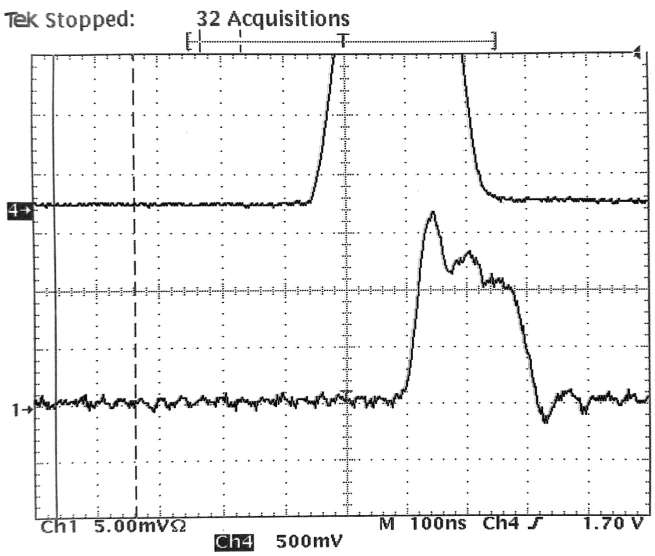

Fig. 4. The 200 ns pulse measured using setup presented in Figure 1. Frequencies of the two mixed signals differ slightly, which causes the inclination of the peak of the pulse. Ripple is caused by the low pass filter used in the system. In this measurement, frequency difference of the signals was 200 kHz, while the center frequency was 2.06 GHz. Lower frequency differences can not be reliably detected.

Pulse compression, or chirping, is used to increase the resolution of the pulsed Doppler radar [5], [6]. During the pulse, carrier frequency is swept linearly. Chirp frequency modulation rate varies a lot depending on application, but for example in remote sensing, RADARSAT satellite's synthetic aperture radar it is 0.70 MHz/μs when the fine resolution mode is used. Chirp duration is 43 μs. [7]

One measurement result is presented in Figure 4. In this case oscilloscope was triggered using the modulating pulse, which is the upper waveform in the figure. The other waveform is the simulated radar pulse, whose frequency differs 200 kHz from the carrier frequency. The shape of the pulse differs remarkably from the original square wave; the top is inclined. The ripple is caused by the low-pass filter.

At this stage, chirped pulses were not tested.

B. *Waveform measurements*

To evaluate the performance of the built measuring receiver, the attenuator and the receiver itself were calibrated. HP 8341B RF synthesizer was used as a signal source, and the throughput of the attenuator was measured using HP 437B RF power meter. The output voltage of the measuring receiver was measured using HP 3458A multimeter. All used equipment have been recently calibrated, so the results are traceable to the primary standards.

Characteristics of voltage controlled semiconductor oscillators vary individually, so the pulse modulator must be designed specifically for each oscillator, if fast rise and fall times are desired. Performance of the modulator-oscillator combination used here was tuned for short, square-shaped pulses. It must be noted, that in this oscillator, the control voltage adjusts the output power, not the frequency.

In Figure 5, the operation of the measuring receiver and test oscillator are demonstrated. The uppermost waveform is the signal used for pulse modulation, and the waveform in the middle is the output power of the microwave oscillator measured using the presented setup. Lowest signal is used for triggering the oscilloscope.

The pulse length is ca. 100 ns, and rise time is 37 ns. Fall time is really short. Difference in the rise and fall times is caused by the electrical design of the pulse modulator. With some tuning of the modulator, power fluctuation of the pulse is very low.

Figure 6 presents the capability of the setup. By using fast discrete components and carefully tuning the oscillator, even 18 ns pulses can be produced and also measured reliably.

IV. Conclusion

A setup for measuring the frequency of short radar pulses was presented. With this system, frequency difference of 200 kHz can be reliably detected, when the carrier frequency is 2.06 GHz. Our setup outperforms spectrum analyzers and frequency counters in this field.

If this frequency measurement setup is used, also the waveform of the pulse must be known, because it has a significant effect on the output signal of the mixer.

The demonstrated waveform measurement setup consists of a test transmitter, measuring receiver and a fast sampling

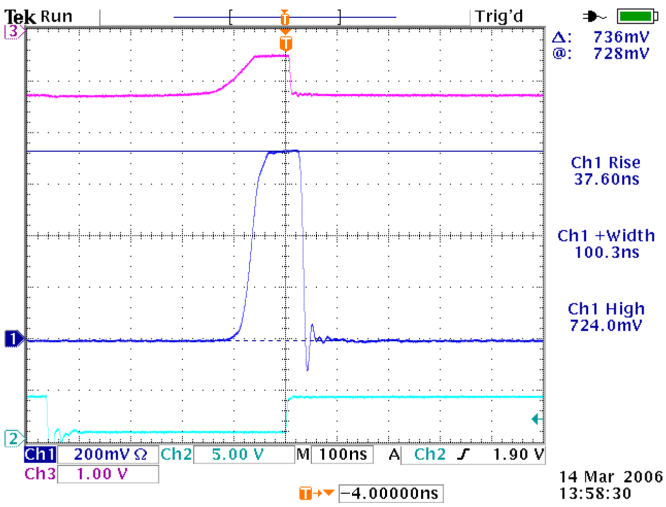

Fig. 5. A 100 ns pulse measured using the system presented in the Figure 3. The uppermost waveform is the signal used to modulate the oscillator, and the middle signal is the output power of the oscillator. Rise and fall times are quite fast, and pulse shape is almost ideal square wave.

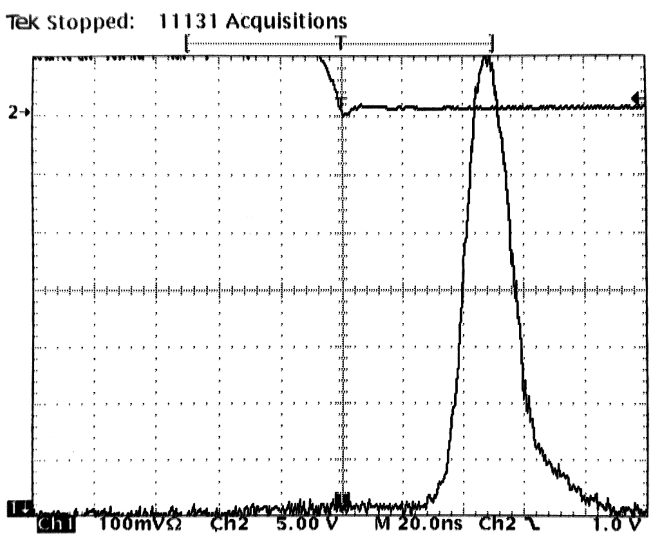

Fig. 6. An 18 ns pulse measured using our setup. Pulses this narrow can be detected with spectrum analyzer, but pulse shape cannot be analyzed. Fast rise and fall times are achieved by careful tuning of the pulse modulator/transmitter-combination.

oscilloscope. Transmitter and receiver are designed for 30 GHz region, and they have waveguide interfaces. The system is calibrated and the measurement results are traceable to the primary standards.

Our test transmitter is pulse modulated, and pulse length is adjustable. In test measurements the pulse length was usually 100 ns ... 200 ns, but also short, even 18 ns pulses can be produced. According to our results, waveform and peak power measurement results of such short pulses are reliable.

In the future, methods to calculate the absolute momentary frequency will be further looked for.

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