CLOCK DISTRIBUTION IN SLR STATIONS

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Presentation at the 11th International Workshop on Laser Ranging, September 21 – 25, 1998
in Deggendorf, Germany

1. Introduction

A design and analysis technique for distributing the 10 MHz clock signal in a SLR station is presented; the design is using noise reduction techniques [5] and an edge sharpening technique in order to improve the cycle-to-cycle jitter [6] of the 10 MHz sine wave which affects the ranging precision.

2. Design Implementation

Most of the SLR stations in the world measure with off-the-shelf time interval counters (like HP5370B from Hewlett Packard or SR620 from Stanford Research Systems) to measure the laser runtime relative to their 10 MHz source. They use the asynchronous event (like laser return) as a start to the time interval counter and the next edge of the 10 MHz source as a common stop.
The 10 MHz source has a very good long-term stability. But because of its sinusoidial shape, the short-term jitter can be improved by sharpening the risetime and falltime. By applying noise reduction techniques (like filtering) and edge sharpening, the performance in terms of cycle-to-cycle jitter has improved [6]. A high Q quartz filter with Q = 2,000 at 10 MHz centre frequency is reducing the noise bandwidth down to [4]:

$$\left(f_{U3dB} - f_{L3dB}\right)\cdot\frac{\pi}{2} = 7.854\cdot kHz$$

A good filter design for reducing noise bandwidth is described in [6]. The following block diagram shows the design of the clock distributor built for a SLR station. It has been in succsessful and continuous operation at a station since June 1998.

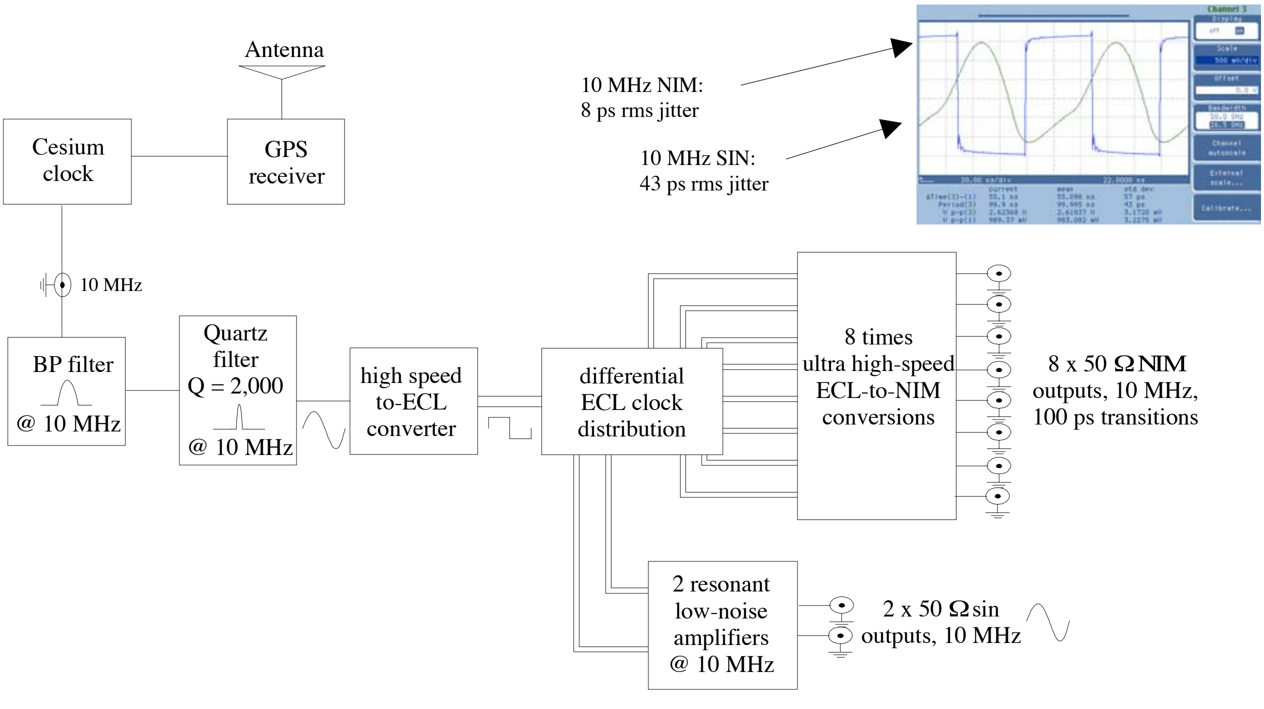


Figure 1: Block diagram of the clock distributor and timing measurement of the outputs

The rms jitter of 43 ps of the 10 MHz sine wave is the same measured value from the output of the cesium clock as well as from the output of the clock distributor device.

The key is to produce very fast output transitions ($t_r \cong t_f \cong 100$ ps) out of the 10 MHz sinusoid in order to minimize the trigger uncertainty of the time interval counters, by not adding any spurious outputs, ie significant noise in the circuit design. These transitions correspond to an equivalent 3-dB bandwidth of approximately 3.5 GHz, considering the response of a simple low-pass filter [7]:

$$t_r := 100 \cdot ps$$

$$BW_{3dB} := \frac{0.35}{t_r} \qquad\qquad BW_{3dB} = 3.5 \circ GHz$$

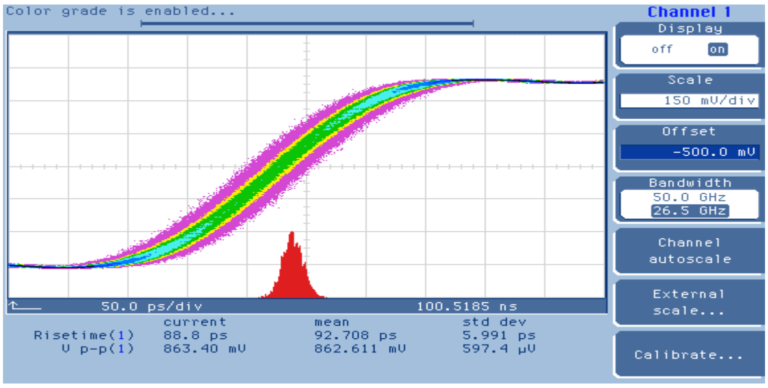
This technique together with noise reduction techniques are reducing the jitter, ie are improving the precision of the time interval measurements [6]. A difficult measurement problem occurs when attempting to make timing measurements such as time interval, in the presence of jitter. Jitter is a common problem in high-speed digital circuits such as those used in satellite laser ranging systems. Traditional measurement algorithms produce highly unstable results in the presence of jitter. Signal averaging being applied in most modern time interval counters to reduce the effects of jitter and yield stable measurement results. However, applying averaging to a signal with jitter has the effect of low-pass filtering the signal, degrading its rise time. The more jitter in the signal, the more the rise time is degraded according to the following expression [8]:

$$t_r := 90 \cdot ps$$

$$Ji_{pp} := \frac{\sqrt{\ln(2)}}{2 \cdot \pi \cdot \frac{0.35}{t_r}} \qquad\qquad Ji_{pp} = 34 \circ ps$$

$$Ji_{rms} := \frac{Ji_{pp}}{6} \qquad\qquad Ji_{rms} = 5.7 \circ ps$$

The following measurement shows the rise time of the clock distributor, taken with a high bandwidth digitizing sampling oscilloscope, and the measurement for the standard deviation which is equivalent to the rms jitter. The measured result of about 6 ps is verifying the calculation above.



```
Scale      150 mV/div
Offset     -500.0 mV
Bandwidth  50.0 GHz
           26.5 GHz

      50.0 ps/div                       100.5185 ns
                current       mean          std dev
  Risetime(1)   88.8 ps       92.708 ps     5.991 ps
     V p-p(1)   863.40 mV     862.611 mV    597.4 µV
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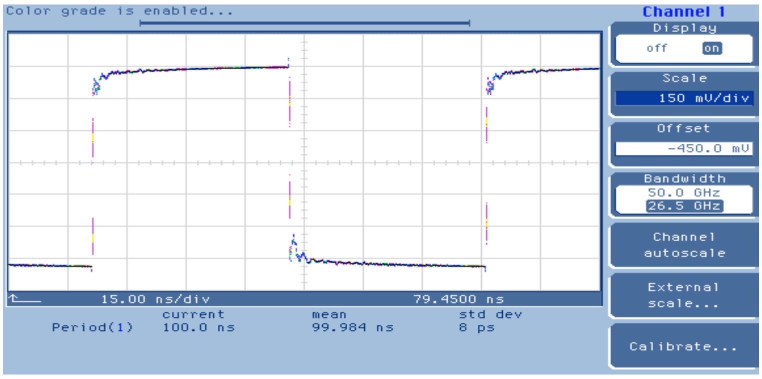
Figure 2: Typical NIM output with a risetime of 90 ps and a jitter of 6 ps is minimizing trigger uncertainties of triggered Δt counters

The test results show clearly that the jitter of the fast NIM outputs is much better than the jitter of the sinusoid outputs (8 ps compared to 43 ps). This is mainly due to its fast transitions of about 100 picoseconds.
The jitter on the period measurement (8 ps) can be calculated by the quadratic sum of the jitter on the rise time (6 ps) and the jitter on the fall time (5.5 ps):

$$\sqrt{(6 \cdot ps)^2 + (5.5 \cdot ps)^2} = 8.1 \circ ps$$

The calculated value shall be confirmed by the measurement, shown in figure 3.



```
Scale      150 mV/div
Offset     -450.0 mV
Bandwidth  50.0 GHz
           26.5 GHz

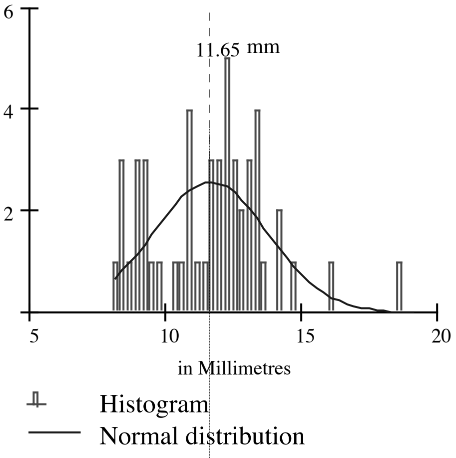
      15.00 ns/div                      79.4500 ns
                current       mean          std dev
  Period(1)     100.0 ns      99.984 ns     8 ps
```

Figure 3: Period measurement on the 10 MHz NIM output: 8 ps rms

3. Data Analysis

The following analysis shows the rms values of a set of calibration data (rms values for a measured range to a target on the telescope) of a SLR station without the clock distributor (refered to $data_1$) and after installing the clock distributor (refered to $data_2$). The data are taken from a ranging system; this implies that all components like laser, telescope, atmosphere, retro-reflector, timing system, detectors are included. The software program MathCAD was used for analyzing the data.

3.1 Analysis of rms values of the calibration data before installing the 10 MHz clock distributor:

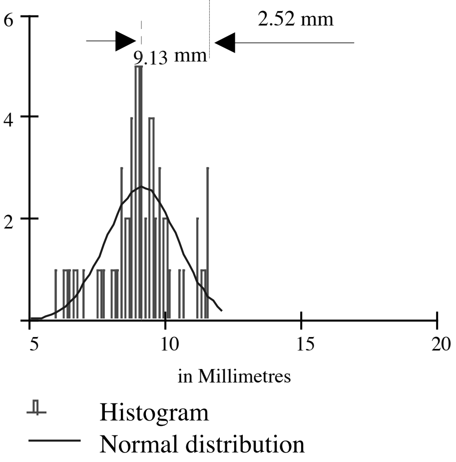


$\mathrm{meanRMS}(data_1) = 11.651$ mm

$\mathrm{SD}(data_1) = 2.133$ mm

Figure 4 a: Ranging data analysis of rms values without clock distributor

3.2 Analysis of rms values of the calibration data after installing the 10 MHz clock distributor:



$\mathrm{meanRMS}(data_2) = 9.13$ mm

$\mathrm{SD}(data_2) = 1.323$ mm

Figure 4 b: Ranging data analysis of rms values with clock distributor

The standard deviation $\mathrm{SD}(data_2)$ of the analyzed rms values („standard deviation of the standard deviation“) for the measured range has improved by 38 per cent, whereas the mean value $\mathrm{meanRMS}(data_2)$ of that calculated standard deviation for the range has improved by 21 per cent, after operating a SLR station with the 10 MHz clock distributor. Basically, the ranging precision has improved.

4. Specification Summary

8 NIM outputs:

Termination	50 Ω
Voltage level	0 V to –0.8 V
Duty cycle	50 %
Rise time, 20 % to 80 %, typ.	95 ps
Fall time, 20 % to 80 %, typ.	115 ps
Standard deviation on rise time	6.0 ps
Standard deviation on fall time	5.5 ps
Standard deviation on period measurement	8 ps
Standard deviation on Δt measurement between 2 different NIM outputs	10 ps

2 sine wave outputs:

Termination	50 Ω
Voltage level	$2.6\ V_{pp} \cong 0.9\ V_{rms}$
Standard deviation on period measurement	43 ps
Standard deviation on Δt measurement between NIM output and sine wave output	57 ps

Specification on 10 MHz input:

Termination	50 Ω
Voltage level	$0.5\ V_{rms}$ to $1.0\ V_{rms}$

Power supply:

+6 Volt	80 mA
–6 Volt	650 mA

The frequency distributor is available with user defined output channels and input frequency. It is installed in a standard NIM module for a Camac Crate and we are able to send a demonstration module to any station which is interested in testing and/or using an excellent frequency distributor.

5. References

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