The New Phase-calibration System of the Geodetic Observatory Wettzell

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Abstract In order to reduce systematic errors in VLBI operations, the one-way delays of the system are captured by injecting a narrow pulse train into the detection chain through an input coupler located near the front-end of the receiver chain. Such a pulse train generates calibration tones in the observation bandwidth, which are equally spaced by the repetition rate of the pulse train. In geodetic VLBI, tones with 1 MHz spacing are used. The tones propagate through the entire detection chain and are recorded along with the observed signal. They are extracted in post processing and are used for keeping track of the VLBI receiver delays. We are presenting the design and construction of the phase calibration unit, which will be used in the new 13.2-m Twin Radio Telescopes Wettzell (TTW) at the Geodetic Observatory Wettzell. It is also planned to be installed in the 20-m Radio Telescope Wettzell (RTW) as well. The design was inspired by A. E. E. Rogers' and B. Corey's phase calibration system. The new phase calibration operates either from 5, 10, or 100 MHz input frequencies and allows programming of the repetition rate of the output pulses. Together with the phase calibration tone generator, a low jitter programmable pulse generator was included. The pulse generator can be used for the additional timing of system delay aspects and therefore supports new approaches for the determination of systematic errors within the VLBI receiver chain.

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1 Introduction

The VLBI technique is very dependent on phase stability measurements with respect to the reference frequency which is, in many cases, a hydrogen maser. To fulfill extreme phase stability measurements of the astronomical radio sources in the receiving chain (local oscillators, filter, cables, etc.), a test signal is injected near the VLBI input receiver. The use of such a signal allows monitoring of phase variations of the open loop detection system over the observation time by comparing received signals to a stable calibration tone locally generated in the detection bandwidth. For such a system, one of the most important things is to monitor the cable delay carrying the reference frequency for generating calibrations tones at the beginning of the receiver chain.

The currently implemented pcal system at the 20-m Wettzell Radio Telescope uses the cable delay measurement system, which is based on the mixing of a reference signal from an H Maser with the divided signal from the same source. Such a signal is then sent up to the phase calibration unit, where the signal is reflected back. After the reflection, the signal carries the phase modulation which is proportional to the cable length. In the VLBI room, there is a high resolution phase comparator comparing phase of the reflected signal with the H Maser reference. Thanks to the time expansion in phase comparator (2.5 ps of cable length is equal to 1 us phase difference), the phase can be measured using a common counter with high resolution [1]. The

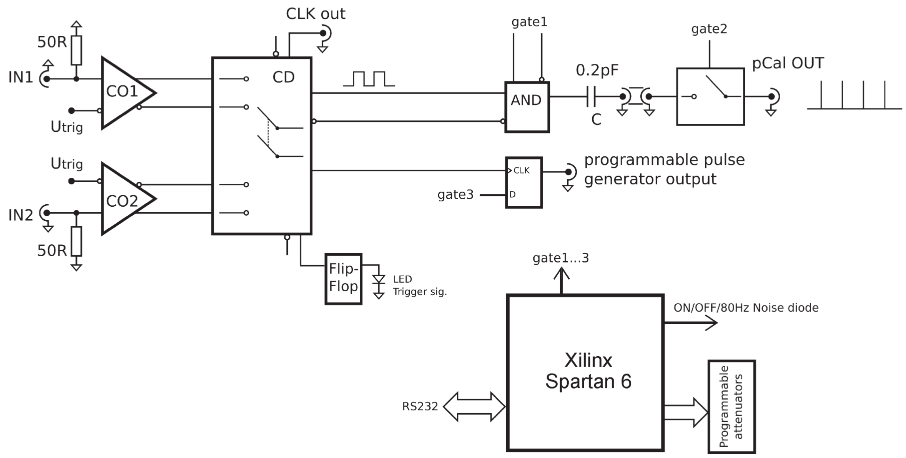

Fig. 1 Block diagram of the pcal unit.

approach described in this paper is based on TWTT using two Event Timing (ET) devices [2].

2 New Phase-calibration System Design

At the Geodetic Observatory Wettzell we have developed the new pcal system. The narrow pulses are formed by small capacitance at the output of the fast logic AND gate from the Hittite Microwave. The negative pulses are filtered out using the microwave switch HMC-C019. The entire end-stage of the circuitry was inspired by A. E. E. Roger's and B. Corey's phase calibration system [3]. In our pcal system, we have chosen another approach in the gating output stage to divide input frequency. We are buffering input frequency with common clock buffer circuitry and distributing this frequency in to the FPGA. In the FPGA we are generating synchronous gate signals with input reference. Those gate signals are used for dividing the input frequency by any integer N and for cutting out the negative pulses in the output pulse train. Figure 1 shows the block diagram, and Figure 2 is a photograph of the pcal system. The advantage of using the frequency divider implemented in the FPGA is that the user can connect any frequency in the range of 1 MHz up to 100 MHz to the input of the pcal system.

We have measured the output pulse shape using a 50 GHz Tetkronix sampling oscilloscope, shown in Figure 3. The pulse amplitude is 80 mV, and the rise and fall times of the pulse are better than 20 ps.

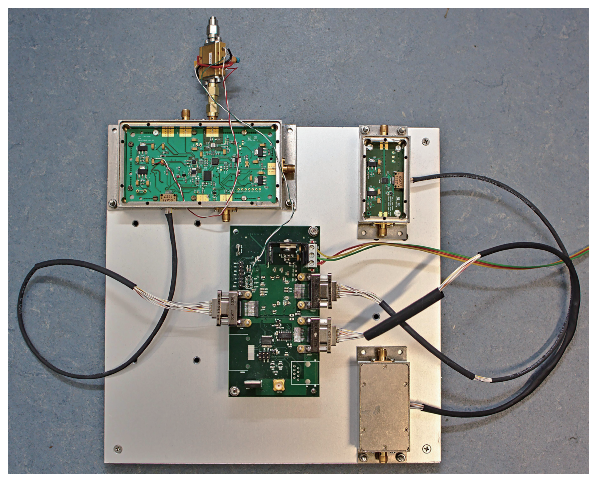

Fig. 2 Photograph of the pcal unit.

Thanks to modern low temperature dependent components, the delay temperature dependency is $+0.3$ ps/K for input frequency 100 MHz, and for 5 and 10 MHz, the temperature coefficient was measured to be -1 ps/K and -0.2 ps/K. The temperature dependancy for the input frequency of 100 MHz is shown in Figure 4. In addition to a standard generation of the pcal tones, the programmable low jitter pulse generator was implemented. This output can provide timing information suitable for triggering another devices like event timers. The programmable pulse generator was used for measuring cable delay temperature dependency and choosing suitable temperature stable cables for the new Twin Telescopes Wettzell.

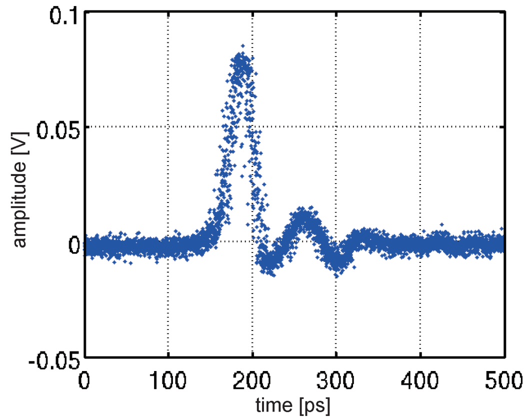

Fig. 3 Pulse shape of the output of the pcal, measured with a sampling oscilloscope.

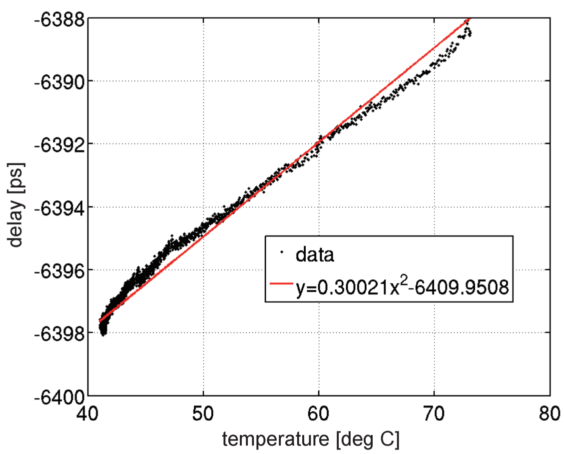

Fig. 4 The pcal unit timing delay temperature dependency.

The output power was measured using the Rohde and Schwartz spectrum analyzer. The output power varies within 2 dB in bands from 2 GHz up to 12 GHz slightly below −80 dBm, which is shown in Figure 5.

The new pcal system allows the measurement of the electrical cable delay of the reference frequency. The method is shown in Figure 6. The function of cable delay measurement is being developed. The reference frequency is power split in the VLBI control room. One part of reference frequency is sent to the VLBI antenna, where pcal tones and the pulse train suitable for triggering the event timer are generated. The second part of the reference frequency is used for triggering the event timer in VLBI control room. The two event timing devices are interconnected with another

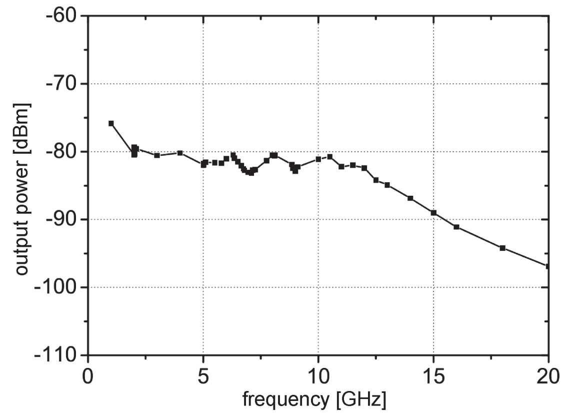

Fig. 5 The pcal output power level with tone spacing of 5 MHz.

cable. The built-in programmable pulse generators inside the event timers are activated alternately, and the generated pulse is sent through the interconnecting cable to the second event timing device, where the Time of Arrival (ToA) is measured. At the same time, this pulse ToA is measured by the event timer, which generated the pulse. This technique implements a two way measurement principle and is used to set the zero difference between both event timers [4]. After that measurement the event timers are switched to a second input, where pulse trains from a reference frequency are connected. The difference of the ToAs measured at the second input is directly proportional to the cable delay. The biggest advantage of such a method lies in the fact that the cable delay is measured at the output of pcal unit.

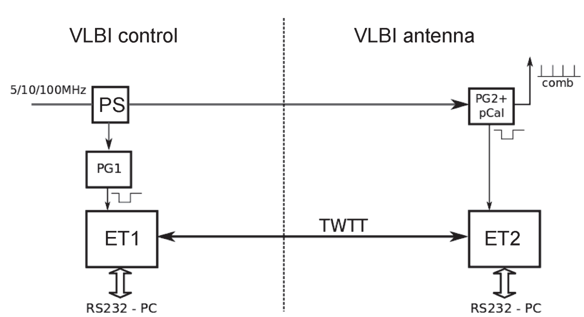

Fig. 6 Concept of the VLBI cable delay measurement.

Figure 7 shows an example of the cable delay measurement technique implementing two event timers with the two way technique. The cable delay was compared with an old measurement technique. The figure shows the dependency of the independent cable delays on azimuth and elevation (red—cable delay measured using the two way technique with event timers, green—cable delay of the new pcal system, and blue—currently implemented pcal cable delay technique). There is a large difference between the old and the new systems of a maximum of 10 ps. Unfortunately, due to limited experimental time, it was not possible to analyze where the difference is coming from.

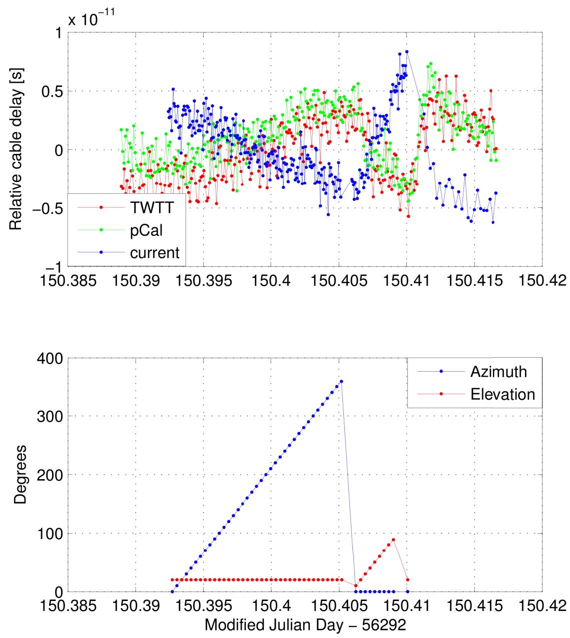

Fig. 7 Different VLBI cable delays' azimuth and elevation dependency.

3 Conclusions

We have designed and constructed the new pcal system generating any integer N pcal tone spacing from the reference frequency. The tones' output power is $\sim$ 80 dBm in band spacing from 2 up to 12 GHz. The device has a very low temperature coefficient +0.3 ps/K for an input frequency of 100 MHz. In addition, the pcal has a built-in programmable pulse generator, which can generate pulses suitable for triggering external devices such as event timers or time interval counters. This output can be used for cable delay measurement or another timing application.

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