TEMPERATURE AND HUMIDITY DRIFT CHARACTERIZATION OF PASSIVE RF COMPONENTS FOR A TWO-TONE CALIBRATION METHOD

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Abstract

Femtosecond-level synchronization is required for various systems in modern accelerators especially in fourth generation light sources. In those high precision synchronization systems the phase detection accuracy is crucial. However, synchronization to a low noise electrical source is corrupted by a phase detection error originating in the electrical components and connections due to thermal and humidity-related drifts. In future, we plan to implement calibration methods to mitigate these drifts. Those methods require a calibration signal injection, called second tone, into the system. Intrinsically, the injection circuit remains uncalibrated therefore it needs to be drift-free. We performed drift characterization of a set of RF components, which could serve for implementation of a signal injection circuit, namely selected types of couplers and splitters. We describe the measurement setup and discuss the challenges associated with this kind of measurement. Finally, we provide a qualitative and quantitative evaluation of the measurements results.

MOTIVATION

A two-tone calibration method bases on an additional signal injection to the electronics circuits, which should get calibrated; in our case it is a phase detector for synchronization of a laser. Because the second signal properties are known, a drift arising in phase detector circuit can be measured. On this base a drift for an effective signal (being a subject of detection) can be estimated. Naturally, the second signal should be distinguishable from the effective one, therefore slightly apart in frequency. From the other hand, it should also be close enough to allow for comparison of the phase change between the two. A thorough analysis for a proper frequency choice has been presented in [1] and in essence shows, that the smaller the offset, the better calibration. More detailed description or another view on the method can also be found for example in [2, 3].

The injection of a calibration signal requires auxiliary hardware, which consist of at least a small section, where the effective and the calibration signal would not share the same path. An example would be a passive RF combiner, where its two arms are separate for each signal. Consequently, this piece of a circuit remains uncalibrated and introduces an error. In this paper, measurements of drift between two inputs of a combiner are presented, which allow for a rough comparison of different selected components.

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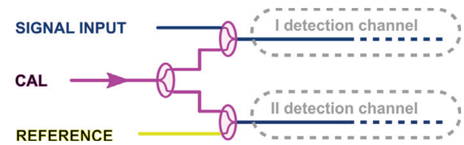

Figure 1: Phase calibration scheme.

APPLICATION

In our case, the method will be used in a bit more complex setup, where additionally a complete second channel is introduced, injected with a reference signal. As the reference is intrinsically drift-free, it allows, that the drifts of the circuits can also be observed at the original frequency, possibly further improving the drift calibration. The drawback of this additional calibration method is, that the circuits are made equal, but are not very same; there are natural differences between them. These include for example PCB traces lengths inaccuracies or ambient temperature differences. The errors can be reduced by a proper PCB routing and placing both channels close to each other, but they can never be completely removed. Therefore both methods could be seen as supplementary to each other. However, the injection circuit in case of combined methods becomes bigger. Effectively, it has a structure depicted in Fig. 1. The splitters/combiners shown here can be as well implemented by couplers; the most important is, that the arrangement remains symmetrical.

In this configuration, the effective phase difference between the laser and the reference $\Delta\phi_{Eff}$ (which is present at the entrance of a phase detection module, that is yet devoid of parasitic drifts from the detector circuits) is defined by a following equation [1]:

$$\Delta\phi_{Eff} = \Delta\phi_{EffMeas} - A * \Delta\phi_{CalMeas}$$

where:
$\Delta\phi_{EffMeas}$ – phase difference measured by a phase detector between the input signal at the first channel and the reference at the second channel
$\Delta\phi_{CalMeas}$ – phase difference measured by a phase detector between both channels at the calibration signal
$A = \frac{f_{Eff}}{f_{Cal}}$ – coefficient to translate the drift at the calibration frequency into phase difference at the frequency of the measured signal

Besides phase stability, another crucial requirement for the injection circuit components to assure a decent level of calibration, is good isolation. This allows to avoid refer-

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ence signal leaking into the information channel or crosstalk between the calibration signals - both would distort the measurement. For same reasons, special care has to be taken for proper matching to avoid reflections. It might be inevitable to use ancillary attenuators, but they introduce more drifts and aggravate SNR. If the part does not provide proper isolation due to its design, then the required attenuator has to be accordingly bigger.

Besides above listed general requirements, there are also few attributes to consider regarding the specific application. Usually, the synchronization of pulsed lasers takes effect at one of the higher harmonics of the repetition rate to improve accuracy. But the base harmonic of the laser should also be detected to define the right RF-bucket, so that there is no ambiguity and the locking occurs at the correct phase/timing. This means, that the laser synchronization takes place in 2 steps: first coarse synchronization at the base harmonic (without any drift correction) followed by the fine synchronization at the higher harmonic. This is then also a subject for calibration, and its frequency should conform with the reference. If the external laser signal splitting to get both signals should be avoided, a combiner for the main input (1st detection channel in Fig.1) has to transmit both base and higher laser harmonic. To keep the symmetry, the combiner at the 2nd channel should be the same. In consequence, the part should be dual-band or wideband. Wideband leaves the detector more flexible, as different lasers with different base repetition rates can be handled. Another important factor not to be forgotten is the size of the components. The best is, if they can be integrated on a PCB.

Considering all requirements listed above, the following parts have been selected and measured:

1. CBR16-0006 Marki Microwave 200 kHz - 6 GHz coupler. It is very wideband, but its form factor does not fit onto PCB. Nevertheless, it is small enough to consider it as an external part to the board, giving not too much mechanical stress when hanging on the PCB connectors. Its isolation is 38 dB by 16 dB coupling.

2. Resistive splitter. Very wideband, simple and small, but shows nearly no isolation. Therefore it has been measured also in the version equipped with 30 dB attenuators, which corresponds to a relative good isolation of a Wilkinson splitter. For test purpose, the part has been designed and fabricated on a RO4003 laminate, of good thermal and humidity stability. The resistors have been selected to have low (in the range of 15-25) ppm/°C value, which promises low temperature drift. The attenuators have been implemented on the same PCB; the 30dB attenuator again with the same low ppm/°C values, the 0 dB attenuator has been made out of 100 ppm/°C 0 Ohm resistors.

3. S 802-4-1.900-M02 MECA Wilkinson splitter. According to the previous tests that is the lowest drift splitter we know. Therefore it is a good reference to other measurements.

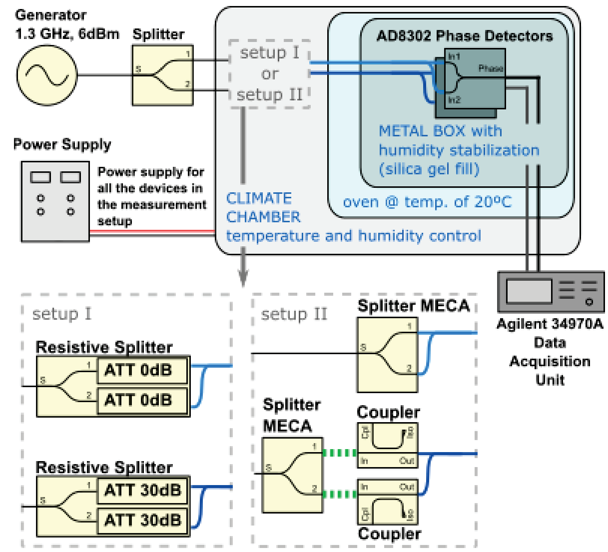

Figure 2: Measurement setup schematic.

MEASUREMENT SETUP

The measurement setup is illustrated in Fig. 2. First bunch of components characterized, called 'Setup I', included resistive splitters in version with and without attenuators. The second set of parts, described as 'Setup II', were MECA splitters and couplers. The detectors have been placed in a humidity stabilized box. The box with the phase stable cables connecting DUTs with the phase detectors, all together, have been enclosed in an oven, which allows for temperature regulation. The equipment did not allow, in terms of available space, for a measurement of more than 3 DUTs at once, that is why they were divided into two groups. The measurement required, for its precision, very low drift cables of exact lengths. These include:

- 2 cables of same lengths, short and low drift, for connection between MECA splitter and the couplers (marked in green in 'Setup II'). Here a Teledyne Phase Master190E of length 13 cm has been used.

- 4 cables of Teledyne Phase Master 160, A64 type. Each of 50 cm length, which allowed, very tightly, to connect the phase detectors box and the measured components, which were placed outside the stabilized area, but within the climate chamber to experience controlled environmental change.

In the section that follows, the measurements conducted in this setup will be presented.

MEASUREMENT RESULTS

The temperature drift has been measured with the temperature profile depicted in Fig. 3 (and in Fig. 6) by dashed green line. The temperature has been changed from 17°C to 25°C in steps of 2°C, and back to 17°C. After each step the stable conditions were left for 8 hours. There are 2 more temperature readings: from the box with phase detectors

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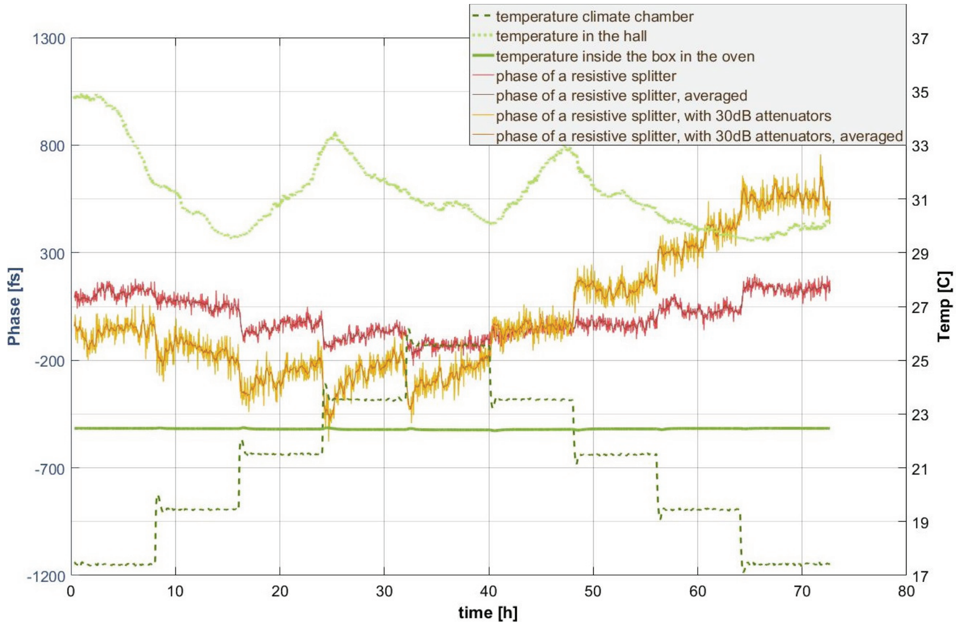

Figure 3: Setup I. Phase difference measured at 1.3 GHz between the outputs, and environmental temperature vs. time.

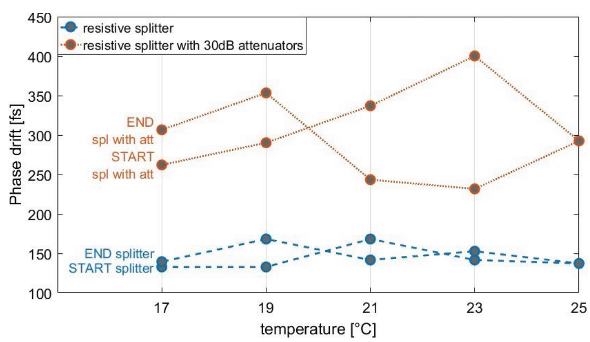

Figure 4: Setup I. Peak-peak drifts within each step.

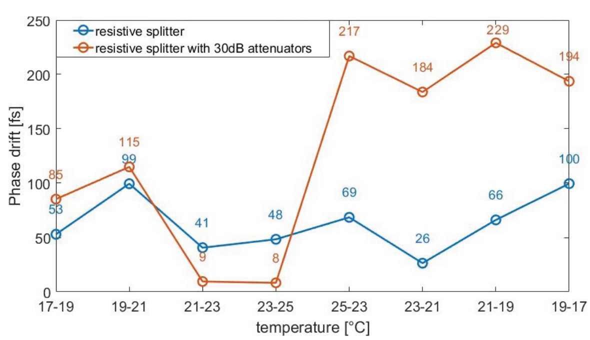

Figure 5: Setup I. Drift per 2°C steps (between mean values of each step).

and from outside the climate chamber, in the hall where it is located. While doing preceding measurements, the phase detectors were placed in the free air outside climate chamber and the hall temperature fluctuation had a great effect on the measurements results. Here can be observed, that the influence, if exists, is marginal, so that no correlated effect is present. The figures 3 - 5 show different measurements from 'Setup I', i.e. the setup with resistive splitters. It can already be observed, that the phase fluctuations within each step, i.e. where the conditions are kept constant and the phase ideally would not change, is much smaller for the resistive splitter without attenuators. This is more clearly shown in Fig. 4. Here, there are usually 2 values for each temperature - one when the temperature was rising and one when falling. The less hysteresis visible, the more reliable the measurement, proving the correlation of the drift only to the induced environmental conditions. The measurement proves, that the peak-to-peak fluctuations for the resistive splitter with the 30 dB attenuators are bigger, approximately by a factor of 2. It also reveals, that apparently another effect of unknown origin contributes to the measurement of the splitter with 30 dB attenuators. This was definitely not the humidity around the splitters or the phase detectors, which readings were also followed, but not shown in the figures for clarity. The drifts had no correlation with humidity, besides the measurement of the resistive splitter. Unfortunately, there the dependence was also not very clear and coefficient determination impossible; no phase jump was present when making a humidity step. Only the phase drift direction changed according to humidity steps direction (humidity rising or falling) and the phase drifted by about 300 fs per 20 % humidity change (in both directions the same). This measurement has been done for step lengths of 12 hours and probably even longer periods were needed to see any convincing correlations.

The temperature coefficient, so the phase change corresponding to the temperature change, is depicted in Fig. 5. The already mentioned effect is also manifested here, as a strong asymmetry of the plot. It lowers the drift when the temperature is rising and increases, when the temperature goes down. The most representative would be probably the value between 'flat' steps of the yellow plot in Fig. 3,

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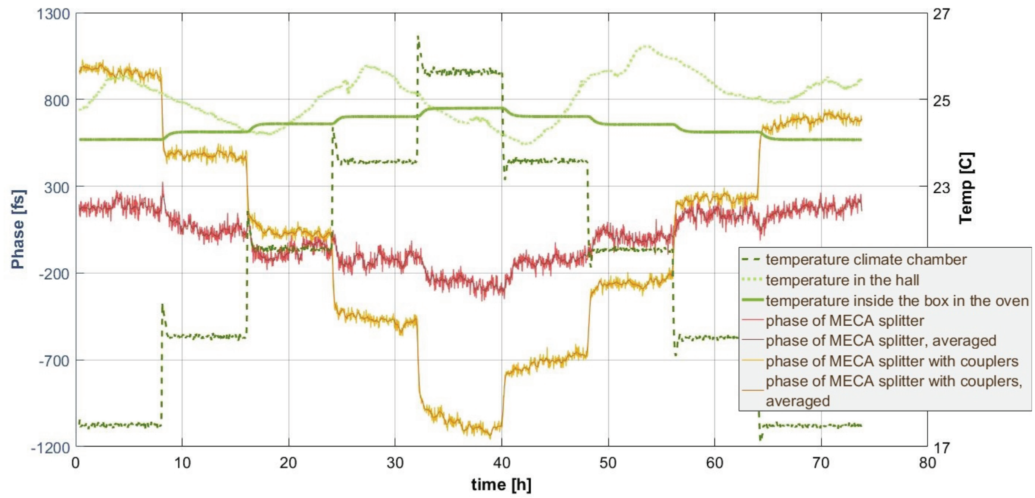

Figure 6: Setup II. Phase difference measured at 1.3 GHz between the outputs, and environmental temperature vs. time.

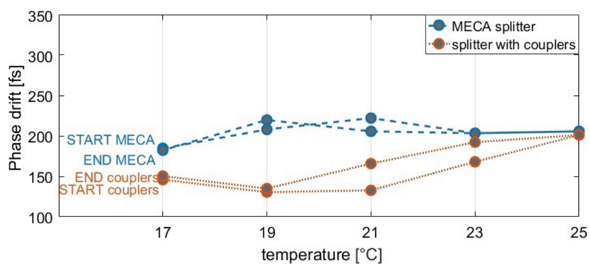

Figure 7: Setup II. Peak-peak drifts within each step.

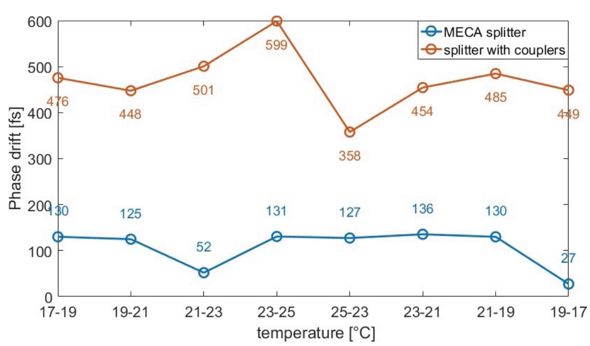

Figure 8: Setup II. Drift per 2°C steps (between mean values of each step).

which is a step from 23 °C to 21 °C. The readings is around 180 fs/2 °C giving the coefficient of 90 fs/°C. The coefficient for the splitter with 0 dB attenuators is about 30 fs/°C (calculated from the mean of the values shown in the plot).

Figures 6-8 show the same measurements for Setup II. The splitter with couplers reveals slightly lower peak-to-peak drift within each step than the splitter alone. In turn, it is much more sensitive to temperature. The coefficient is 240 fs/°C in comparison to the 50 fs/°C of the MECA splitter alone.

Conclusions and Outlook

Temperature coefficients of all the parts are relatively high taking in the account the required precision of our phase detector, which should be on the level of tens of femtoseconds. On the other hand, the measurement setup contributes to the drift and an integrated version of the measured components should reveal better performance. Surprisingly, the best component is the self-made resistive splitter, which shows 140 fs pk-to-pk drifts within 8 hours in stable conditions, and 30 fs/°C temperature coefficient, so both even better than for a low drift MECA splitter with an additional advantage of being closed in a housing (which could act as a low pass filter for any temperature effects) . The limitation of the resistive splitter is a necessary attenuator, which makes the phase inaccuracy between the outputs distinctly bigger. One of the solutions relaxing the requirements would be a selection of a very high isolation splitter for a calibration signal. As it does not have to be wideband, the design of this part could be concentrated more on the isolation attribute.

The commercial couplers occured to be very drifty and together with their inconvenient form factor, it yields to exclusion from this project.

REFERENCES

[1] S. Jablonski, "A Fiber-Optic System Using a Continuous-Wave Laser for Providing Phase-Stable Radio-Frequency Signals to Remote Locations", Ph.D. thesis, Warsaw University of Technology, 2016.

[2] G. Huang et al., "Signal processing for high precision phase measurements", Proc. BIW10, TUPSM082.

[3] E. Janas et al., "MTCA.4 phase detector for femtosecondprecision laser synchronization", Proc. FEL2015, TUP045.

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