# RECENT PROGRESS ON THE TECHNICAL REALIZATION OF THE BUNCH PHASE TIMING SYSTEM BUTIS

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*Abstract*

A high precision phase synchronous clock distribution system is mandatory for generating local RF reference signals in an accelerator complex. The dedicated Bunch Phase Timing System (BuTiS) at GSI performs this function. The accuracy of the realized installation under rough ambient conditions is presented. Procedures for calibration and standardization aspects of system modules are pointed out. Hardware as well as software interfaces of the system are described. The interfacing between GPS and BuTiS is explained.


## INSTALLATION AND SETUP

### *System Layout and Overview*

BuTiS is the dedicated time synchronization system for the FAIR project [1] [2]. The requirement to generate 1° phase synchronous RF-signals of 10MHz leads to a system of sub nanosecond precision within an area of 1000m in diameter. The optical network for BuTiS was developed in 2009 [3] and is well tested. A special focus is now set to the electrical generation of the local clock signals to reach the BuTiS design goal of a relative time synchronization of 100ps for the duration of the experimental cycle over the whole FAIR campus. A comparison to point out this challenge: the 100ps equivalent electrical length is 2cm for all signal lines and connectors of the BuTiS distribution. The precision of time is in the same magnitude like the time deviation (caused by gravitational time dilation) of two exact clocks installed at 10m difference sea-level after one day of observation.

In Fig. 1 the system layout of the star shaped distribution system is shown. The output signals of the BuTiS center reference generator, optionally locked to a low noise low jitter GPS signal, are modulating two DWDM laser sources using Mach-Zehnder amplitude modulators. (Two wavelengths and one for spare from the 100GHz ITU* grid are used: $\lambda_i$=1549.32, 1550.12, 1551.72 nm.) The optical signals were multiplexed, all together optically amplified (EDFA), then split and fed into one of the twelve BuTiS single mode fiber lines. One BuTiS line comprises an Optical Add Drop Multiplexer (OADM) used to feed in an optical channel for the path length measuring signal ($\lambda_M$=1548.52), a length of around 500m fiber optical cable (FOC), a Fiber Bragg Grating (FBG) that reflects the measurement signal (other channels pass through the FBG) and the BuTiS receiver unit. The BuTiS receiver unit performs optical to electrical conversion as well as channel demultiplexing. The BuTiS local reference synthesizer is used for delay correction. One additional BuTiS receiver unit residing in the BuTiS center operates as 'local reference monitor'.

The central measuring unit uses optical up and down conversion of a vector network analyzer (VNA) measurement signal. For a path length measurement, the

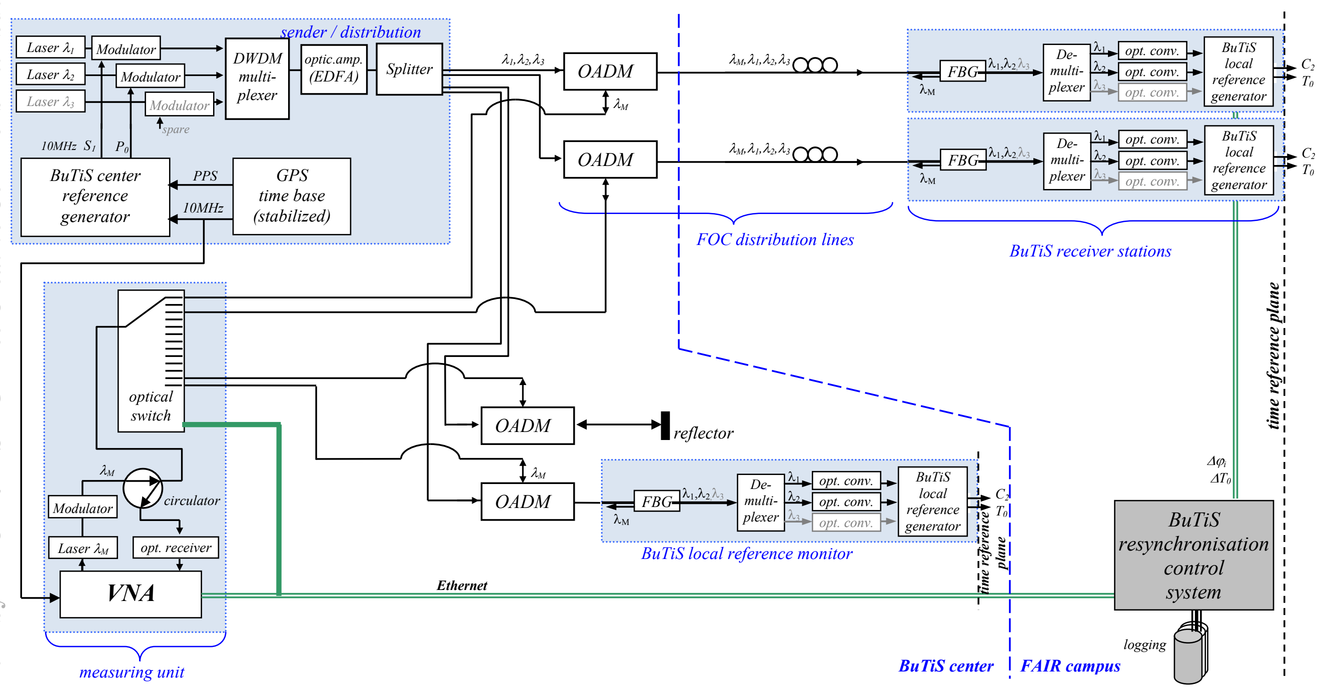


Figure 1: BuTiS full system layout.

* International Telecommunication Union

stimulation signal is routed via an optical switch to the OADM of the dedicated BuTiS line and reflects at the FBG. The signal coming back is separated from the FOC by an optical circulator. After electrical down conversion the signal is fed into the in VNA input. The linear phase response is minimized inside the VNA and delivers the total path length.

From the BuTiS center, still situated in the laboratory, two 12-fold loose fiber tube optical cables were installed. One cable leads to the SIS cavity supply area and the other to the ESR cavity supply area. On these two paths long-term observations of the group delays had been done. (The definite location of the BuTiS center within the FAIR complex will be situated closer the accelerator and shortens the FOC signal path to about 500m.)

### Stability Measurements

With the installed cables (Huber&Suhner Masterline multi-fiber loose tubes, jelly filled, with 12 fibers) observations of the signal group delay were done. The result is shown in Fig.2. A clear correlation of the signal delay and the outdoor temperature is found. As expected the maximum change of the mean group delay on the installed cable is much less than measured in the climatic test chamber *(39ps* $km^{-1}$ $K^{-1}$*)*. The estimated variation over the whole year is smaller than *±1ns*.

Summarizing the measurements pointed out that the variation of the group delay of the 1km FOC is within the expectation of the theoretical considerations [4] including a huge safety margin.

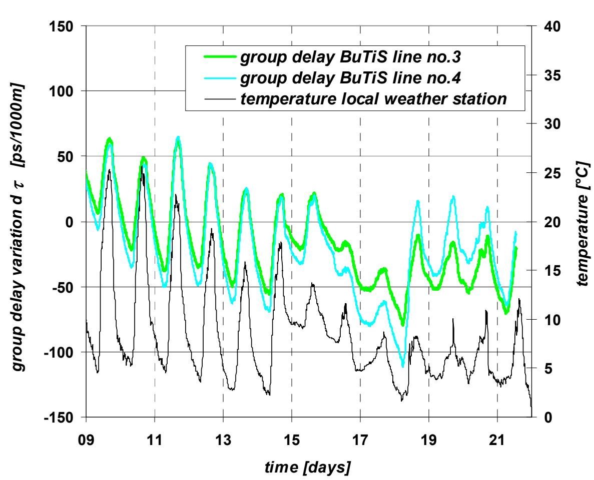


Figure 2: Group delay variation of the 1km FOC installation versus time (double passage measurement October 2010).

### Delays Between Fiber Optical Lines

In addition to these measurements under normal operation conditions, thermal stress tests of an FOC cable reel inside a climatic test chamber were done. The group delay $\tau$ had not changed faster than *1ns/km* per hour for a temperature step $\Delta T$ of *20°C*. The speed of signal delay change is less then 0.3ps per second.

A second result of very importance is the tracking of the group delay for all 12 fibers within the jelly filled tube of the cable. The results indicate that fiber to fiber group delay differences are almost two orders of magnitude smaller than the absolute group delay variation over temperature. This close matching is emphasized in (Fig.3).

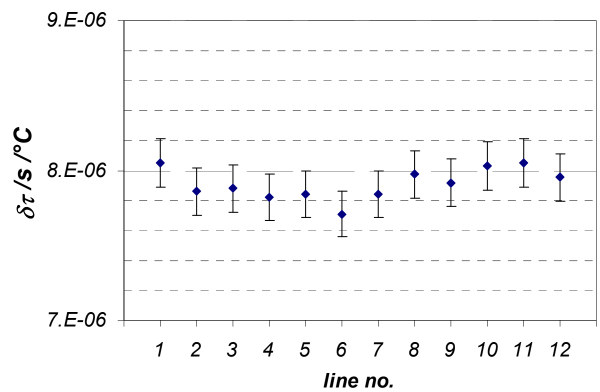


Figure 3: Difference of temperature coefficients of different fibers in a loose tube jelly filled FOC.

### BuTiS Local Clock Synchronization

The BuTiS local reference generator gets the $P_0$ pulse and the 10MHz $S_1$ phase reference signal from the BuTiS distribution system. It locally generates two delay compensated clock signals: the $C_2$ 200MHz sinusoidal time/phase reference and an identifier pulse $T_0$ every 10µs to tag one positive edge of the $C_2$ signal. The delay of the identifier pulse $T_0$ in relation to the incoming $P_0$ identifier pulse can be set remotely in steps of 5ns. The rising edge of the $T_0$ pulse output is synchronized with the negative zero crossing of the 200MHz output. Secondary a 10MHz frequency reference signal is available.

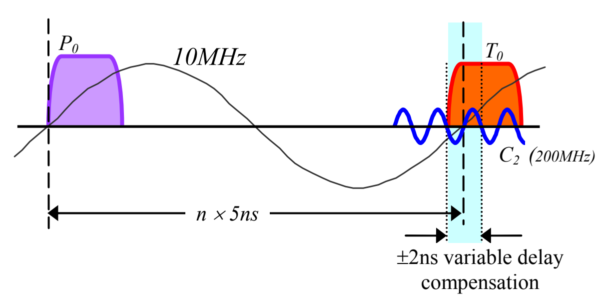


Figure 3: BuTiS local time regeneration.

The 200MHz $C_2$ is generated by phase locking a Direct Digital Synthesizer (DDS) to the incoming 10MHz $S_1$ reference. The phase can be shifted ±360 degrees in steps of half a degree corresponding to 7ps time steps. Phase shifting occurs without jumps. In case of input signal interruption the intrinsic stability of the internal time base allows the BuTiS local reference generator running in a so called fly-wheel mode lasting for minutes.

### *White-Rabbit Cooperation*

The White Rabbit CERN Control and Timing Network [5] will be used for FAIR accelerator control. It is planned to synchronize this control Network to the BuTiS 10kHz ($T_0$) clock. All time stamps, commands or control system events are referenced to $T_0$ pulses (10µs). They are triggered at the next $T_0$ pulse in the local device. Using the correlation of the $C_2$ clock, the sub nanosecond precision provided by the BuTiS is guaranteed.

### *The Resynchronization Process*

The interval of 10µs between two $T_0$ identifier pulses guarantees that the event command sent during this period has arrived completely at the destination device. It is ready for execution in one of the 2000 following periods of the 200MHz time reference signal. The time granularity for these event triggers is 5ns. For higher trigger resolution the low jitter clock $C_2$ can easily be frequency multiplied.

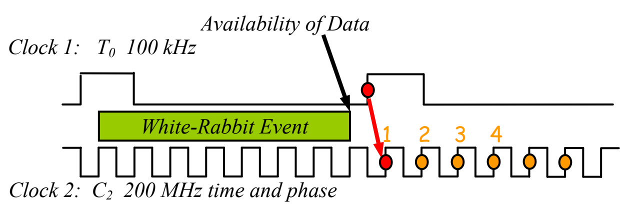


Figure 4: BuTiS method of resynchronization

## STANDARDIZATION

All FOC of the BuTiS lines were lengthened to an electrical delay of modulo 5ns ±1ns (1m ±20cm). To preserve interchangeability of components the electrical delays are kept in a database.

Table 2: Standard Delays of BuTiS Devices

| | |
|---|---|
| UTC to BuTiS master $P_0$ | ±25ns |
| BuTiS Center optical distribution | ~50ns (±0.5ns) |
| BuTiS FOC distribution line | ~2.5µs modulo 5ns (±0.5ns) |
| BuTiS local reference gen. programmable delay $C_2$ | 0s (±7ps) ±2.5ns |
| BuTiS local reference gen. programmable delay $T_0$ | 0… 8191×5ns (0…40µs) |
| BuTiS receiver unit | ~50ns similar to 'local reference monitor' |

Delay calibration of the measuring path will be done by a reflector mounted directly at the start of each distribution line. In combination with individual calibration values of the receiving units contained in the data base, the actual total distribution delays will be recovered.

## INTERFACES

### *Clock Distribution*

The interface between the BuTiS endpoints and the electronic components is a versatile clock distribution module able to compensate different delays (from 1ns to some ps) caused by the connection cables or the connected electrical components themselves. Alternative clock frequencies derived from the 200MHz signal can be provided. The module is based on an AD9516 from analog devices.

### *Control Software*

The measurements in the climatic test chamber are well founded arguments to use Ethernet to control the BuTiS local reference generators. The group delay variation (*<3ps/s*) is slow in comparison to the latency of a local Ethernet.

For Ethernet communication with BuTiS sub devices SCPI standard is used and for every device a dedicated .net user control exists. The control program is also a .net application and writes all measurement data and the BuTiS control system status on a local file. This file will be copied on a server. Access to this data from accelerator control system and Maintenance & Diagnostics system [6] will be regulated by group policies.

## OUTLOOK

Since the forward path delay of a loose fiber bundle is measured, due to the tight fiber to fiber delay tracking, the BuTiS back channel gets a versatile tool to measure local signals in correlation to BuTiS center time reference.

## REFERENCES

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