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THE SYNCHRONIZATION SYSTEM OF THE THOMX ACCELERATOR*

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Abstract

The ThomX compact light source uses a 50 MeV ring to produce X-rays by Compton scattering. For historical reasons the linac and the ring could not operate at harmonic frequencies of each other. A heterodyne synchronization system has been designed for this accelerator. This synchronization is based on mixing the two RF frequencies to produce an heterodyne trigger signal and that is then distributed to the users. Bench tests of the system has demonstrated a jitter of less than 2 ps rms between the two clocks. We describe here this synchronization system.

INTRODUCTION

ThomX is a compact light source. It has been described in details in [1, 2]. It is made of a photo-injector, a linac that accelerates the electrons up to 50 MeV, and a ring in which the electrons are kept for about 20 ms. In the ring the electrons interact with a laser stacked in a Fabry-Perot cavity to produce X-rays. After about 20 ms the electrons are extracted and sent to a dump. A drawing of ThomX can be seen in Fig. 1.

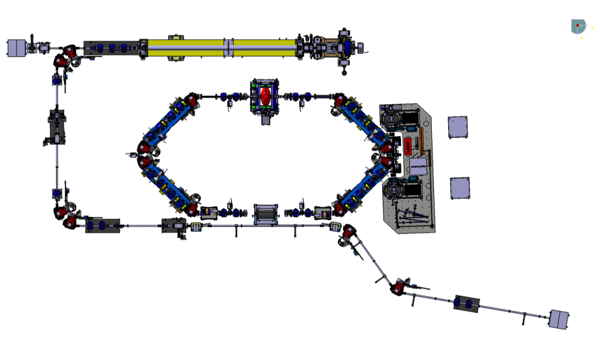

Figure 1: The ThomX compact Compton source. The linac can be seen at the top of the image, the ring in the middle et the Fabry-Perot cavity is on the right.

This document describes how the timing synchronisation signals are decided, generated and distributed to all the components of the accelerator.

HETERODYNE SYNCHRONISATION

One of the key constraint that was set by the RF group at the onset of the project was that the linac frequency and the Ring frequency had to be independent. The linac RF frequency had to be strictly[1] at 2998.50 MHz whereas the ring frequency had to be around 500 MHz and had to follow the seasonal ring expansion and contraction.

This constraint has required us to consider an heterodyne synchronisation to look for common zeros between the two frequencies (as shown in Fig. 2).

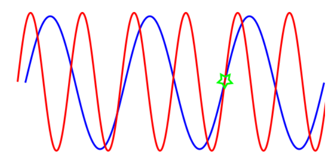

Figure 2: In heterodyne mixing a beating is looked for between two unrelated frequencies so that a common zero crossing can be found.

This can be achieved using a mixer that mixes the two RF frequencies to extract the beat modes when one of the two frequencies crosses zero (high frequency component of the signal) and when the two frequencies cross zero simultaneously (low frequency component). A low pass filter is then used to keep only the low frequency component and then a zero-crossing detector is used to find only the low frequency zero crossings (corresponding to the two frequencies having a simultaneous zero). It is important to note that the common zero crossing condition is true only at the location of the mixer as anywhere else this may not be true due to different cable length. However what matters is not to have exactly the common zero crossing but a fixed phase relation between the two frequencies (this fixed phase relation can then be adjusted by using a phase shifter). As we always want to operate at the same phase of the mains and of the laser (which has yet another frequency), the zero crossing detectors is latched by a signal generated from the laser and the mains. A simplified version of the circuit used is shown on Fig. 3.

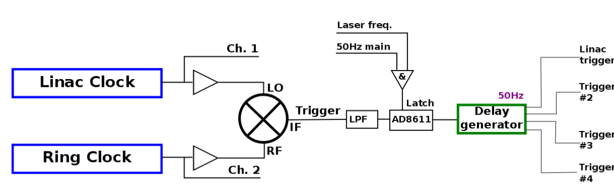

Figure 3: A simple schematic of the circuit used for zero crossing detection.

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[1] More recent developments with the RF group make that this constraint may be lifted.

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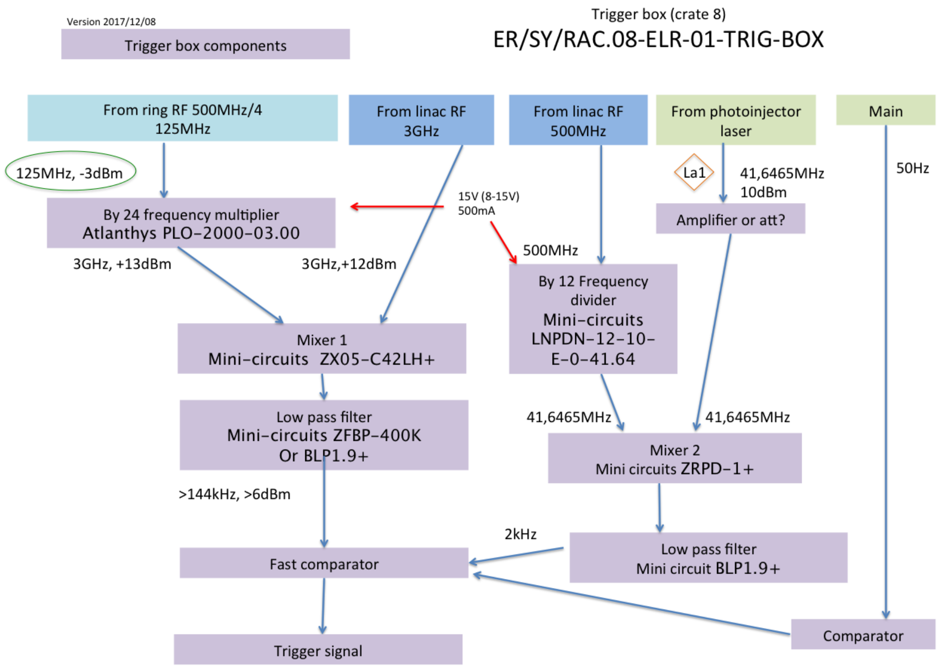

Figure 4: The frequency manipulation to find the heterodyne trigger signal.

It should be noted that this heterodyne scheme has already been tested successfully for the ESCULAP [3] project at LAL and has been documented in [4] where a jitter of about 1.3 ps rms between the two clocks had been reported.

The mixing of the frequencies and their manipulation to generate this heterodyne trigger signal is shown in Fig. 4. It should be noted that to perform the RF signal comparison with the lowest possible noise the ring RF frequency is multiplied so that it is comparable to the linac frequency. For product availability reasons this was only possible by first doing a division by 4 and then a multiplication by 24.

RF SIGNAL DISTRIBUTION

To ensure a high quality RF signal the linac clock synthesizer is a Rohde & Schwartz SMA100A with a frequency range going up to 6 GHz. The ring RF clock synthesizer is an HP NB 5181B MXG with a frequency range going up to 3 GHz.

The linac RF synthesizers has enhanced phase noise performance with an SSB phase noise better than −127 dBc/Hz at 3 GHz at 20 kHz offset. the ring synthesizer has also a low phase noise option with an SSB phase noise at 500 MHz better than −143 dBc/Hz at 20 kHz offset. To allow longitudinal feedback it also has a frequency modulation option.

The RF signal distribution is shown in Fig. 5.

One of its main features is that several frequency dividers are use to convert frequencies to sub-harmonics. Some users also asked for a TTL signal at the ring frequency so a sine to TTL converter from Wenzel (signal translator LNST) is used and then the TTL signal is distributed.

This scheme has now been tested in details. One of the most important source of noise in this scheme is the frequency dividers used to go from the source frequencies to the sub-harmonic frequencies required by the users. Figure 6 shows the phase noise measured at the source and after different frequency dividers. The noise is significantly higher but still acceptable.

In Fig. 5 each red square corresponds to a point where a measurement was done during the tests. As an example the measurements done at point L5 are shown in Fig. 7.

TIMING SIGNAL DISTRIBUTION

Once the trigger signal is generated it will be distributed to all the accelerator components requiring it. A very low jitter delay generator was necessary. Our jitter specification was that the jitter had to be less than 50 ps + 10^{-7} × delay. This corresponds to the performances of the best delay generators available on the market. After a call for tender the product selected was a customized[2] version of the Greenfield GFT1020. The jitter induced by this device in the signal distribution has not yet been measured.

OUTLOOK

The ThomX compact Compton source is due to start at the end of 2018 or the beginning of 2019. Most of the components of the synchronisation system have been tested and have been confirmed to be within the specifications.

The authors would like to acknowledge the contribution of Mohammed Karim Khaldi and Naomi Chmielewski from Univ. Paris-Sud to these measurements.

[2] The standard product is not capable of triggering on an external clock which was a key requirement for us, so we had to ask for this customization.

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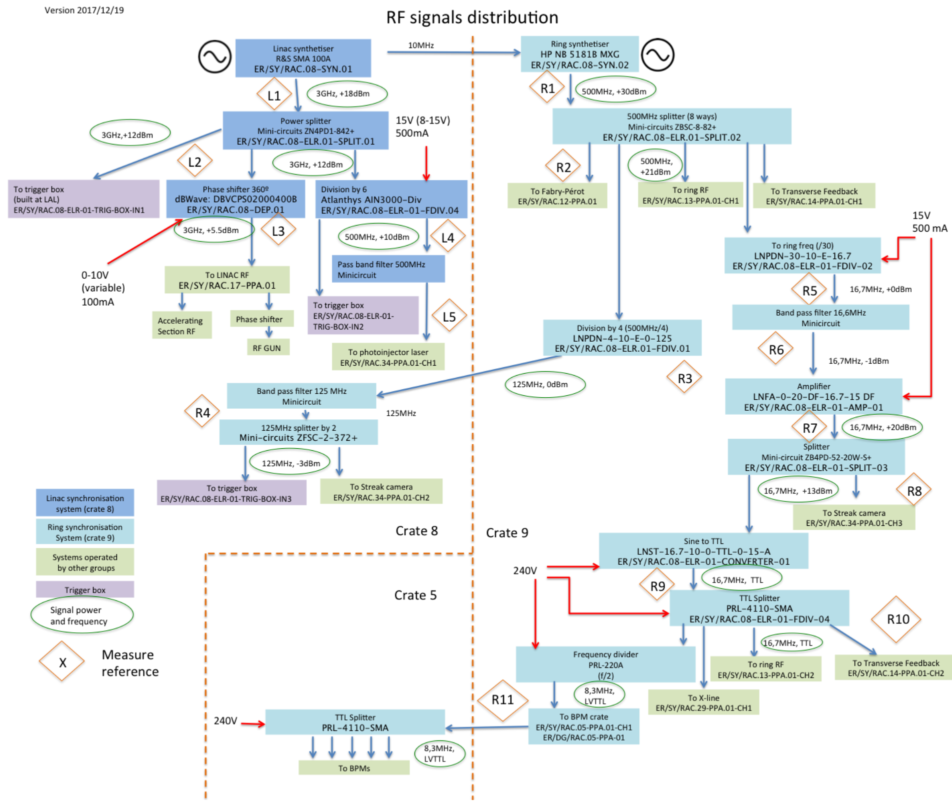

Figure 5: The RF distribution scheme.

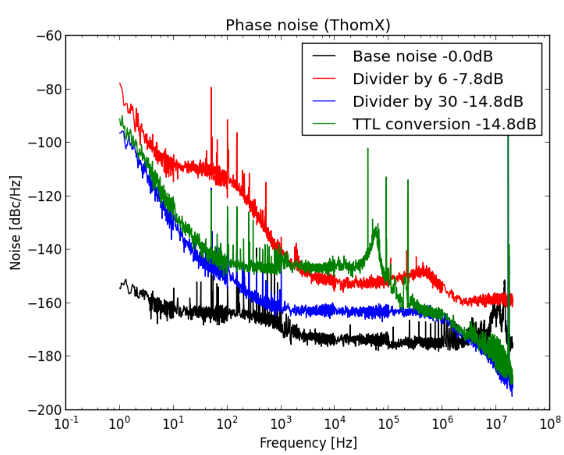

Figure 6: (Very preliminary) Phase noise measurement at different point of the RF distribution scheme and corrected in amplitude so that they can be compared at an equivalent carrier frequency of 100 MHz. The black curve corresponds to the phase noise of the 500 MHz Ring synthesizer measured on position R1 of Fig. 5. The red line to position L4 (after the division by 6 in the Linac RF chain), the blue line to position R5 (after division by 30 of the ring frequency) and the green line to position R9 (after conversion to TTL).

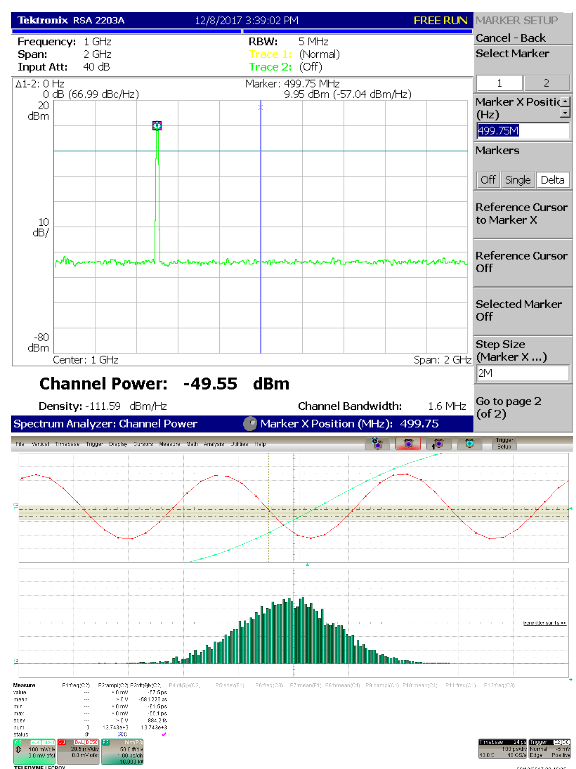

Figure 7: Measurements of the spectral purity (top) and the jitter (bottom) at point R5 of Fig. 5.

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