LISA INJECTOR OPTIMIZATION BY STRIPLINE SIGNAL SPECTRAL ANALYSIS

M. Castellano, M. Ferrario, M. Minestrini, P. Patteri, F. Tazzioli, INFN - LNF; L. Catani,
S. Tazzari, INFN - TOV; G. Cavallari, CERN - SL.

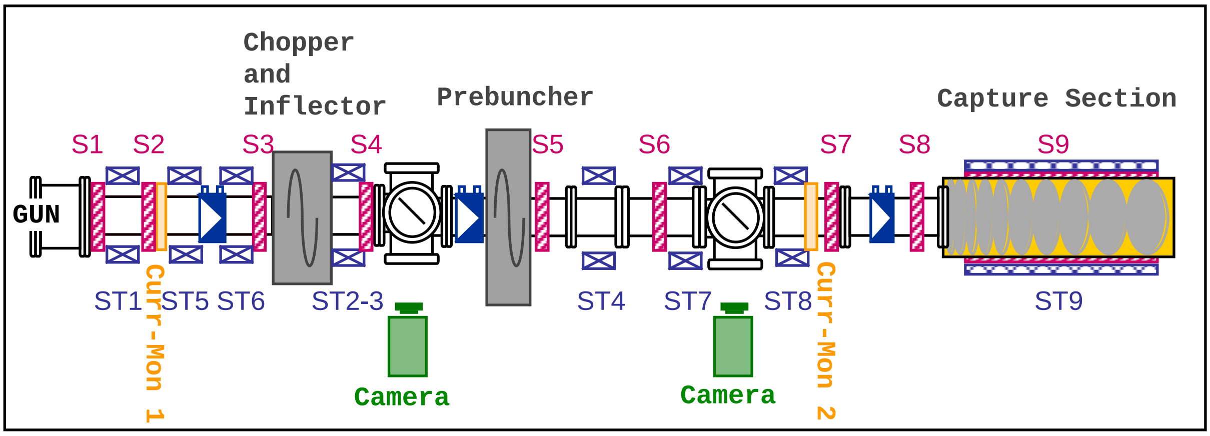

Figure: 1 Sketch of the LISA Injector. ST: Steering Coil, S: Solenoid.

Abstract

The performance of the LISA injector and the time structure of the beam have been checked by means of a quasi-on-line analysis of the line spectra of stripline signals. Preliminary measurements showed a dominant line in the spectrum at 2.5 GHz, indicating that the bunch entering the capture section was too long, occupying more than one adjacent RF bucket. This results in a non uniform acceleration and beam losses in the subsequent 500 MHz linac. A careful tuning of the injector parameters has since been done looking at the line spectra behavior. Beam spectra computations and measurements are illustrated.

1 INTRODUCTION

The LISA accelerator consists of a normalconducting injector followed by a superconducting linac [1].

In the injector a thermionic gun provides a 100 KeV continuous beam several msec long at 1-10 Hz repetition rate which is transformed by a 50+500 MHz chopping system and a 500 MHz pre-buncher in a train of bunches 8 ps long of 2 mA average current with 50 MHz repetition rate. Focusing solenoids, steering coils, collimators and diagnostic elements are distributed along the line as sketched in Fig.1. A β-graded 2.5 GHz capture section drives the beam up to 1.1 MeV. The beam is then injected into the linac where four 500 MHz SC accelerating cavities of the DESY-HERA type accelerate the beam up to 20 MeV.

The 50 MHz subharmonic chopper (inflector) consists of a pair of deflecting electrodes with a superimposed DC bias voltage. The chopper is a RF cavity operating in the TE_{102} deflecting mode at the main linac frequency 500 MHz. They work in combination with a collimator . The chopping action is performed by subtracting the combined effect of the 50 and 500 MHz sine waves from that of a bias voltage on one of the electrodes of the Inflector, so that the beam is allowed to cross the collimator on the crest of the wave, see Fig. 2.

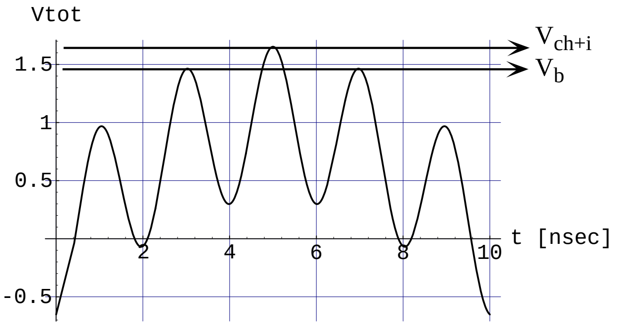

Figure: 2 Combined effect of the 50 and 500 MHz sine waves during the chopping action. V_{ch+i} : total voltage of Inflector and Chopper, V_b : Bias voltage.

The resulting beam at the entrance of the pre-buncher should be a train of 500 ps bunches with 50 MHz repetition rate and at the entrance of the capture section each bunch should be less than 100 ps long. The desired average current is 2 mA.

The rather complicated beam modulation performed by the injector is very sensitive to the voltage and phase setting of chopping and bunching cavities. An undesirable modulation of the beam at 2.5 GHz performed by the capture section results in acceleration off-crest and eventually beam losses in the main 500 MHz linac; while a 500 MHz modulation performed by the chopper is acceptable for acceleration but not for some applications (FEL).

The beam time structure, Fig. 3, has been checked by recording the frequency spectrum of the voltage induced by the accelerated beam on a stripline detector downstream of the capture section. Even if a stripline is not the proper diagnostic tool for beam time structure analysis, as for example broad band resistive monitors, nevertheless much information can be extracted from it, if the structure of the induced signal spectrum is properly taken into account.

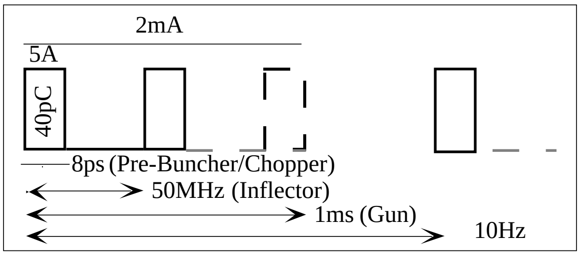

Figure: 3 Designed LISA beam time structure.

2 EXPECTED BEAM SPECTRA

Our striplines consist of four electrodes, 15 cm long, forming a transmission line of 50 Ω characteristic impedance with the vacuum pipe. The electrode is terminated at one end via a coaxial vacuum feedthrough into a matched resistive load and at the other end is short circuited. The voltage at the load resistor appears as a doublet of pulses of opposing polarity, the second one reflected by the shorted circuit end, reproducing the longitudinal time distribution of the beam current and separated in time by an interval b=2L/c, where L is the length of the strip and c the light velocity [2].

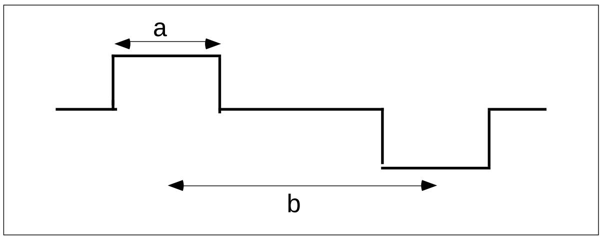

Figure: 4 Induced signal time structure of a single bunch .

Considering for sake of simplicity square signals as represented in Fig. 4, the amplitudes components A_n of the spectrum are given by :

$$|A_n| \div \frac{\sin(n\omega_o a / 2)}{n\omega_o a / 2}\sin(n\omega_o b / 2) \qquad (1)$$

where a is the bunch length, b is the time delay of the reflected signal and n the harmonic index of the fundamental repetition frequency 50 MHz

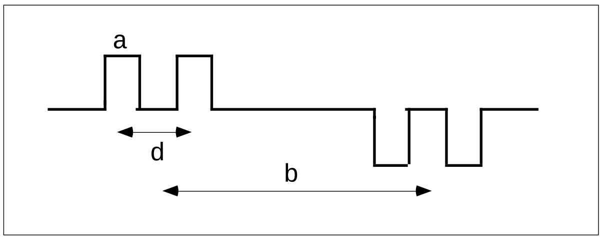

Figure: 5 Induced signal time structure of a bunch doublet.

If the injector parameters are not properly set, one may have a more complicated time structure. For example an excessively long bunch entering the capture section is captured on more than one rf bucket, resulting in a pair of doublets separated by an RF period d=0.4 ns (2500 MHz), as shown in Fig 5. In the latter case the amplitudes of the spectra components are given by:

$$|A_n| \div \frac{\sin(n\omega_o a / 2)}{n\omega_o a / 2}\sin(n\omega_o b / 2)\cos(n\omega_o d / 2) \qquad (2)$$

If the parameters are properly set one observes strong line sidebands at the inflector 50 MHz frequency around the multiples of the 500 MHz fundamental frequency under the envelopes showed in Fig. 6. The first case corresponds to the ideal performance of the injector parameters, see eq. (1) with a=10ps and b=1ns. The second one corresponds to a fair performance of the injector, when more than one 500 MHz crest crosses the bias voltage line, see Fig. 2, and a burst of bunches 2 ns apart passes the collimator, see eq. (2) with a=10ps, b=1ns and d=2ns. The width of the envelope is narrowed, and tends to a pure 500 MHz line with its multiples in the limiting case when the inflector voltage is set to zero. The last and worst case corresponds to an incorrectly pre-bunched beam at the entrance of the capture section with a bunch length longer than the cavity acceptance of 100ps, see eq. (2) with a=50ps, b=1ns and d=0.4ns.

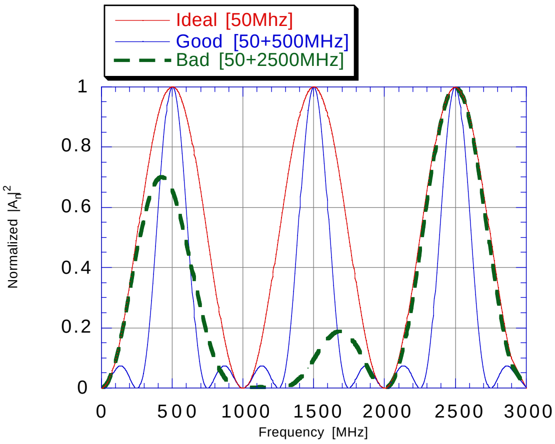

Figure: 6 Normalized $|A_n|^2$ envelopes versus frequency.

An indication of the correctness of the bunch micro-structure is readily obtained from the ratios of the amplitudes of the 500 MHz, 3rd and 5th harmonic [3].

3 EXPERIMENTAL SETUP

The beam induced signal in the stripline is picked up from one of the four electrodes and transmitted by a low attenuation cable 20 m long to a spectrum analyzer HP70206A. The frequency span was limited to 3 GHz because at higher frequencies a strong signal attenuation occurs. Due to the pulsed structure of the 1 msec beam with a repetition rate of 1 Hz, the spectrum analyzer has been set in a Max Hold configuration for at least 15 minutes for each measurement, in order to record a sufficient number of lines. The resolution bandwidth was 300 KHz. The major causes of error are the beam current and position fluctuations. The first parameter is monitored by a current toroidal transformer that showed stable beam current within 5% during each measurement. We tried to compensate transverse beam displacements by summing up the signal of the four electrodes with a set of combiners. There was no change in the spectral distribution but only loss of sensitivity due to the insertion of the combiners, thus indicating that the transverse position of the beam was stable.

4 MEASURED SPECTRA

The power spectra reported in this section have been compensated for the cable attenuation and normalized to the maximum measured value. In order to get more insight on the performance of each injector component we first measured the spectra produced by pure 500 MHz modulation on the beam performed by the chopper without pre-buncher and inflector.

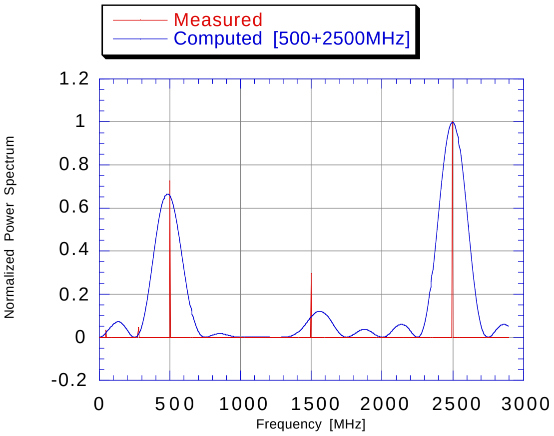

Figure: 7 Spectrum produced by 500 MHz modulation on the beam performed by the Chopper only.

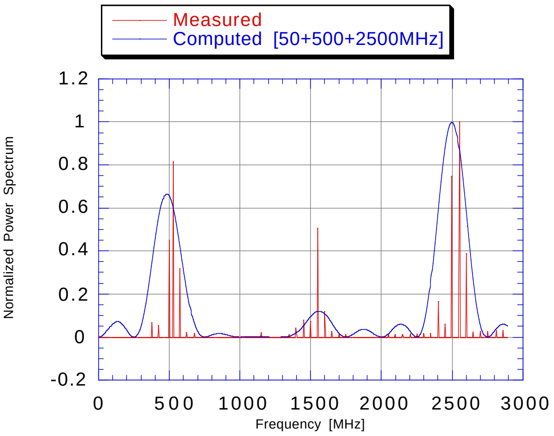

Figure: 8 Spectrum produced by a 50+500 MHz modulation on the beam performed by Chopper and Inflector.

As shown in Fig. 7, we detected a three line spectrum with the 500 MHz line and its multiples 1500 and 2500 MHz. The ratio of the amplitudes of the 500 and 2500 MHz components indicate also a strong modulation at 2500 MHz as expected because we inject a train of 1ns long bunches into the capture section . We then introduced the 50 MHz inflector modulation, resulting in the appearance of the 50 MHz sidebands around the previous 500 MHz multiples, as shown in Fig. 8.

We then introduced the 500 MHz pre-buncher voltage, resulting in the reduction of the 2500 MHz line amplitude as expected for the desired short bunch. The width of the sidebands as shown in Fig. 9, corresponds to an impure 50 MHz modulation. We had to accept this compromise to have a current of 2 mA.

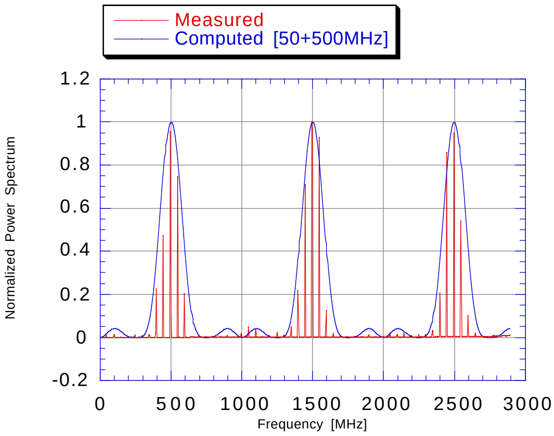

Figure: 9 Spectrum produced by the full Injector.

5 CONCLUSION

These preliminary results shows that an analysis of the stripline spectra can be useful for beam time structure optimization. Further improvements are under way in order to get some rough information on the bunch length looking at the ratio of the 500 and 2500 MHz lines .A stripline for TESLA Test Facility [4] will soon be tested on the LISA injector, and will be also used to detect the time structure of the beam.

REFERENCES

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