THE CEBAF MASTER OSCILLATOR AND DISTRIBUTION REMODELING*

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Abstract

Jefferson Lab's CEBAF accelerator operation requires various frequency references to be distributed along the site. Three signals: 10 MHz, 70 MHz and 499 MHz are synthesized in the Machine Control Center (MCC) while 1427 MHz and 429 MHz are derived from 499 MHz and 70 MHz signals in four separate locations. We are replacing our obsolete 10 MHz, 70 MHz and 499 MHz sources with new sources that will incorporate a GPS receiver to discipline a 10 MHz reference. In addition the MO (Master Oscillator) system will be redundant (duplicate MO) and a third signal source will be used as a system diagnostic. Moreover, the 12 GeV Energy Upgrade for CEBAF accelerator will be adding 80 new RF systems. To support them the distribution of 1427 MHz and 70 MHz signals has to be extended and be able to deliver enough LO (Local Oscillator) and IF (Intermediate Frequency) power to 320 old and 80 new RF systems. This paper discusses the new MO and the drive line extension.

INRODUCTION

Figure 1 shows a block diagram of the proposed system. A commercial 10 MHz GPS receiver will feed two 10 MHz and 70 MHz generators. Our intent is to purchase custom made units from an oscillator manufacturer. The addition of the 10 MHz reference is needed to meet our phase noise (jitter) specification at the intermediate frequency (IF), 70 MHz, and the cavity frequency of 499/1497 MHz. The 70 MHz will be phase locked to the 10 MHz reference. The 499 MHz source will be a commercial signal generator (Agilent, Rhode Schwarz, etc.). It will be frequency locked to the 10 MHz reference. By using a commercial signal source we can take advantage of the frequency modulation input and adjust the frequency for the path length variations. In addition the 10 MHz will be distributed from the GPS through a distribution amplifier to the Injector, North Linac, W1 and the South Linac service buildings, as it is now. In the service building the 499 MHz is multiplied by

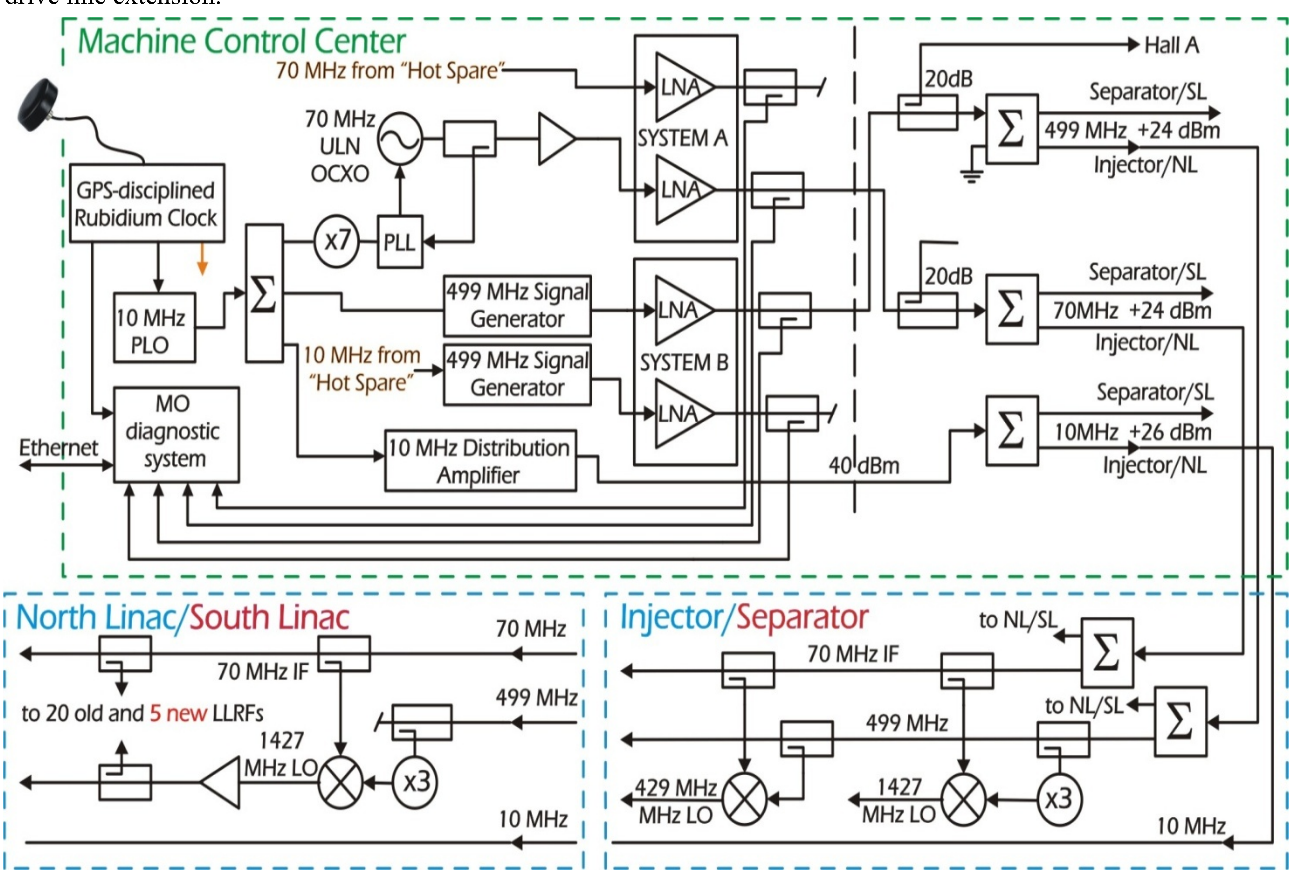

Figure 1: Block diagram of the MO system.

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three to generate the RF cavity frequency of 1497 MHz. In addition, a "Local oscillator" or LO signal is generated by mixing the RF signal with the 70 MHz or IF. This gives us 1427 MHz which is then amplified and distributed down the service building. These frequencies are recombined at the LLRF controllers to drive the superconducting cavities.

Path Length Adjustment

In order to accommodate the 12 GeV upgrade it is necessary to allow for path length changes via frequency adjustment. In the past a system of magnetic doglegs has been used to adjust for this variation throughout the year [1]. Using frequency eliminates the need for a "new" magnetic path length scheme, saving a substantial sum of money. The signal sources that we are investigating have a "dc" input to modulate frequency. The modulation range can be adjusted anywhere from approximately 10Hz/volt up to 100 kHz/volt. The system uses a precision 16 bit DAC to adjust the signal source frequency and will be automated through EPICS.

MO Diagnostic

A weak spot for CEBAF operations has been the lack of an adequate master oscillator monitor. While the MO is not a habitual offender of accelerator down time, when it does fail it can be difficult to trouble shoot. We present a design to be incorporated in the upgrade MO system to monitor and track all frequencies.

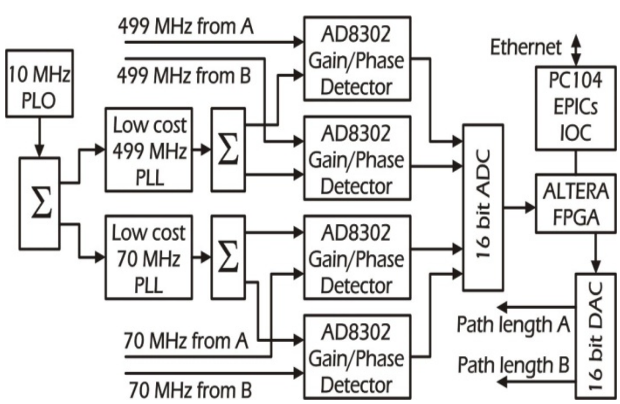

Figure 2: MO diagnostic block diagram.

The design uses readily available phase and amplitude IC's to track any phase, frequency or amplitude drifts or excursions. As Figure shows, the two fully functional MO chains (A and B) are continuously monitored using AD8302s which precisely monitor phase and magnitude differences between two signals. Any phase drift, error, an amplitude jump or a frequency excursion can be determined using the process of elimination from all six RF signals including the two diagnostic phase-locked loops (PLL). Sixteen bit instrumentation ADCs will be receiving the information from these ICs. The chassis will also provide the DAC signals to drive the path length frequency adjustment. In addition, internal diagnostics in the 10/70 MHz oscillator and 499 MHz signal source are monitored in the diagnostic chassis. To do this, an inexpensive FPGA will interface between the ADCs/DACs and a PC104 module. The PC104 will act as an EPICs IOC running the real time operating system RTEMS.

DRIVE LINE EXTENSION

1427 MHz LO signal is distributed along the linac through the 1-5/8" rigid line equipped with the temperature control system [2]. The line temperature regulator is designed to maintain 50° Celsius +/- 0.2° C over an ambient temperature variation of +/- 10° C. Each linac will have about 250m drive line and the total phase sensitivity for the temperature change is 8° phase/1°C [3]. This setup should maintain slow phase drift due to the

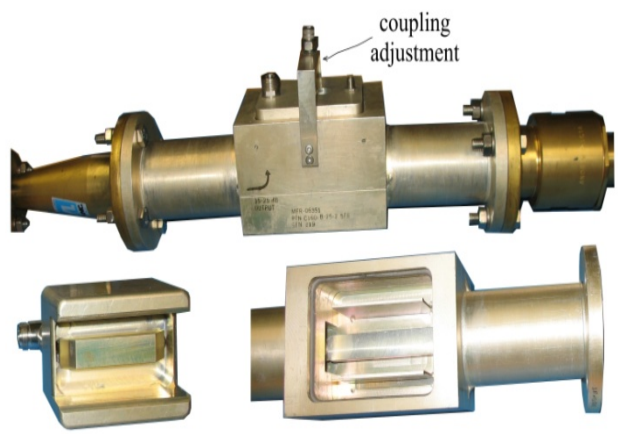

Figure 3: 1427 MHz directional coupler.

ambient temperature change below 3°. The 70 MHz signal is distributed via Superflex 3/8" cable attached to the rigid line so the temperature of the line is controlled with the same system. 10 MHz signal propagation will utilize RG8/U. While this signal is used for external synchronization of variety of instruments, the signal phase stability is not as critical. We are planning to use similar types of cables for all lines in the 10 new zones.

Each zone is equipped with the 1427 MHz CEBAF style directional coupler (see Figure 3) and 70/10 MHz commercial couplers with fixed coupling factor. The coupling factor of the CEBAF style device can be manually adjusted from -27 dB to -10 dB. This coupling range, as well as 500 W of initial power of the LO signal is necessary to provide +30 dBm LO signal to old zones and +32 dBm LO signal to 10 new zones after measured rigid line and coupler insertion losses.

PHASE NOISE REQUIREMENTS AND EXPECTED PERFORMANCE

We intend to use commercial "off the shelf" signal generators for the new system, which allow as to use the frequency modulation option. The disadvantage of this approach is the poorer phase noise performance in comparison with a custom designed narrow bandwidth unit. When evaluating a 499 MHz signal generator it is important to keep in mind that this oscillator contributes to the uncorrectable error in the cavity field, moreover the beam energy spread requirement is directly tied to the phase stability in the accelerating cavities. For the CEBAF accelerator the relative beam energy spread $\frac{\sigma E}{E}$ has to be smaller than 2.5×10^{-5}. This value is a result of combination of the finite bunch length and cavity amplitude and phase error fluctuations. It was shown that for bunch length of ~300fs phase error should not exceed 0.5° RMS for uncorrelated disturbances and 0.25° RMS for correlated errors, with the assumption that a third of the energy spread originates from the phase noise [4] [5]. Given that between cavities the MO is a correlated noise source, it makes sense to use the correlated requirement. Table 1 shows integrated RMS values of the noises of the described oscillators for the frequency bandwidth from 10 Hz to 100 kHz. We can assume that energy fluctuations due to the phase drift slower than 10 Hz are compensated by the CEBAF Fast Feedback System, a beam based feedback system designed to correct the beam position and the beam energy near the target of the nuclear physics experiment in the frequency band from 0 to 80 Hz [6].

Table 1: Signals noise specification

Source	RMS phase noise	RMS time jitter
10 MHz PLO	80 µdeg	22 fs
70 MHz ULN OCXO	670 µdeg	27 fs
499 MHz (Agilent)	37 mdeg	200 fs

The noise of 1427 MHz LO, a multiplied and mixed product of 499 MHz and 70 MHz, is dominated by the noise from the 499 MHz source so we expect to have 120 mdeg of noise or 230fs of the time jitter. Things get better because by connecting external reference of 10 MHz from our ultra low noise PLO we expect an improvement of Agilent noise performance by at least by a factor of 2 down to 60mdeg/115fs. Moreover, the MO noise contributes to cavity filed noise only within control loop bandwidth BW_{CTRL}. For the control gain $G_{CTRL}=120$ and cavity bandwidth CAV_{BW}=46 Hz ,

$$BW_{CTRL} = G_{CTRL} \times CAV_{BW} = 5500Hz$$

For this bandwidth MO noise contribution is reduced by roughly another 20% and should not exceed 50mdeg/100fs. To be complete we must add in noise contributions due to amplification. Effects of amplification on phase noise are typically small. They can be estimated by adding a flicker noise (1/f) contribution to the spectral density along with the amplifier's noise figure. Figure 4 shows an example of the minimal noise degradation due to the amplification for the Agilent 4428B signal generator and Mini-Circuits amplifier ZFL-200 (NF=7).

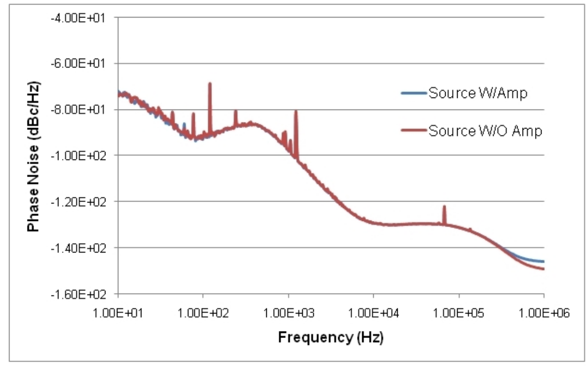

Figure 4: Phase noise plots with and without amplifier.

SUMMARY

A short overview of the reference signals distribution system has been presented with the emphasis on the signal noise performance. We estimated that the new 1427 MHz LO signal will have a phase stability better than 0.1°/ 200 fs RMS and total phase sensitivity for the temperature change is 8° per 1°C. New MO diagnostics with the real time operating system capability have been proposed. The reference system is GPS disciplined, thus the 10 MHz signal fulfills the Stratum I level of stability [7].

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