# REFERENCE SIGNAL DISTRIBUTION FOR BEAM POSITION AND PHASE MONITORS AT LANSCE*

R. C. McCrady, H. A. Watkins, Los Alamos National Laboratory, Los Alamos, NM 87545 U.S.A.

*Abstract*

The new beam position and phase monitors at LANSCE measure the phase of the beam relative to a reference signal from the master reference oscillator. The distribution of the reference signal along the 800m-long linac is subject to thermal effects, and phase drifts of the reference signal are observed to be greater than 15 degrees. We are investigating stabilization schemes, one of which involves distributing two RF signals of different frequencies. By observing the phase difference between the two signals, the phase drift of the reference signal can be deduced. Initial tests indicate that the reference can be stabilized to within 0.5 degrees using this scheme. In this paper we will present the principles of operation of this stabilization scheme and results from tests of the system.

## INTRODUCTION

Deployment of instrumentation for beam position and phase monitors (BPPMs) is imminent at LANSCE, and a 201.25 MHz reference signal is necessary at each of the instrumentation chassis for the phase measurement. Measurement of the beam phase provides time-of-flight information for the tune-up process, as well as diagnostic data for troubleshooting accelerator systems.

The short-term stability requirements for the reference are stringent in order to enable the tune-up process, but long-term stability requirements are fairly relaxed, at about ±1°.

The instrumentation systems are distributed throughout the ~1 km-long klystron gallery, so thermal effects on the reference distribution medium are significant; variations of almost 20° have been observed in tests over the course of a few days, mostly following the diurnal temperature cycles. While this magnitude of variation is not a show-stopper for the system, greater stability would facilitate the use of the phase measurements for long-term monitoring and for troubleshooting.

The original plan for the system had the reference signal tapped off of a thermally-stabilized transmission line that serves as the distribution medium for the accelerator klystrons; this is illustrated in Figure 1. The signal would then have been routed along the same path as the signals from the BPPM electrodes to the instrumentation chassis. This would compensate for thermal effects, as the beam signals and the reference would be subjected to the same environment. This part of the project has been delayed indefinitely, so we are seeking an economical alternative solution.

In an effort to leverage existing infrastructure, we have been exploring the possibility of distributing the reference signal on spare fibres in some recently-installed fibre-optic bundles. In addition to being an economical solution, our experience with analog fibre-optic links gave us confidence that the reference signal could be distributed over long distances with low attenuation, and we were hopeful that we could implement a stabilization scheme. One such scheme is presented in the following sections.

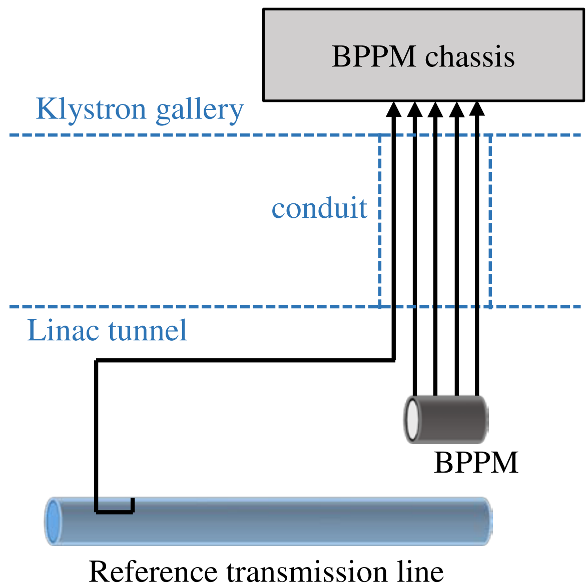


Figure 1: The original plan for distribution of the 201.25MHz reference signal.

## THE BPPM SYSTEM

The transducers for the BPPMs are four-electrode, shorted-striplines about 4.8 cm long. These aren't ideally tuned for the 201.25 MHz beam-bunch frequency, as they were designed to replace existing phase-only, single-electrode transducers without modification of the beam pipes.

Coaxial cables transmit the beam-induced signals from the beam tunnel to the instrumentation chassis in the klystron gallery.

The instrumentation has 5 inputs ports, one for each electrode and another for the 201.25 MHz reference signal that serves as a fiducial for the beam phase measurement. Because the input hardware is an off-the-shelf, general-purpose card, additional input ports are available. The significance of this is discussed below.

## DISTRIBUTION ON OPTICAL FIBRE

To test the idea of distributing the 201.25 MHz reference signal on optical fibre, we identified a pair of spare fibres in an existing fibre bundle to use in a loop-back

*Work supported by the United States Department of Energy under contract DE-AC52-06NA2596.

ISBN 978-3-95450-176-2

measurement, as illustrated in Figure 2. The total signal path length for the test was about 2 km. The network analyser used to generate the test signal and to measure the phase of the return signal was stabilized with a GPS-derived 10 MHz reference.

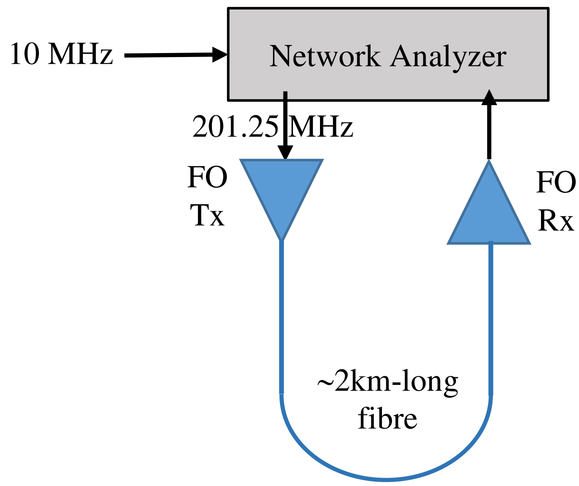


Figure 2: Schematic diagram of the loopback setup for testing the phase stability of the reference signal distributed on a fibre-optic link.

The 201.25MHz RF signal generated by the network analyser was fed into a Miteq LBL-10M3G analog fibre-optic link (FOL) transmitter, which sent the signal on the ~2km fibre path, and the FOL receiver fed the RF signal on coaxial cable back into the network analyser for the phase measurement.

The phase of the received signal relative to the transmitted signal is shown in Figure 3. A variation of >15° was seen over the course of the test period of a few days.

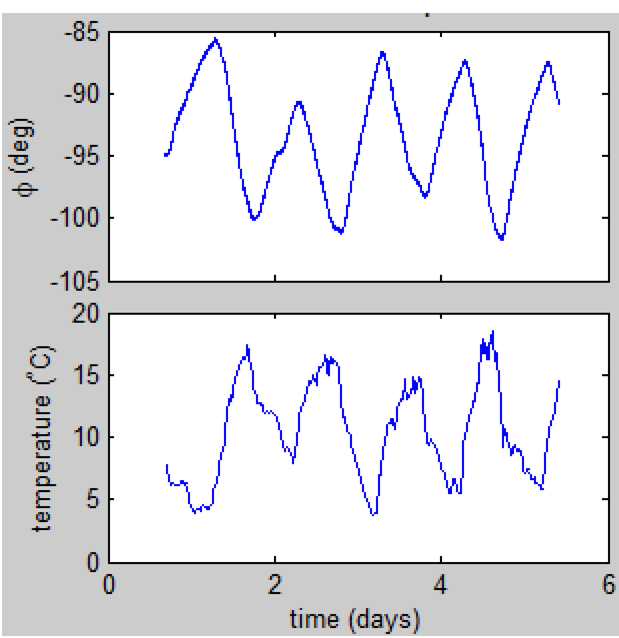


Figure 3: Results of the loopback test.

The shorter (several minute) stability of the signal phase would enable the Δt linac tune-up process, but we were motivated to find a way to stabilize the phase to enable greater use of the phase measurements.

Because the reference distribution was not part of the original scope of the BPPM project, an economical solution is highly desired.

## STABILIZATION SCHEME

The stabilization scheme described here works as follows: Both 201.25MHz and 805MHz reference signals are transmitted to a BPPM chassis. Assuming the changes in group delay are the same for the two signals, the changes in phase of the 805MHz will be four times those of the 201.25MHz signal. By monitoring both signals at the BPPM chassis, the change in phase of the 201.25MHz signal can be deduced and corrected.

The individual changes to the phases of the 201.25MHz and 805MHz can't be measured, but the phase of one relative to the other can. The phase of the 805MHz signal will change four times as much as the 201.25MHz:

$$\Delta\phi_{805} = 4 \times \Delta\phi_{201}$$
$$\theta \equiv \Delta\phi_{805} - \Delta\phi_{201} = 3 \times \Delta\phi_{201}$$

The change in the relative phase between the two signals is 3 times the change in phase of the 201.25MHz signal. This is illustrated in Figure 4.

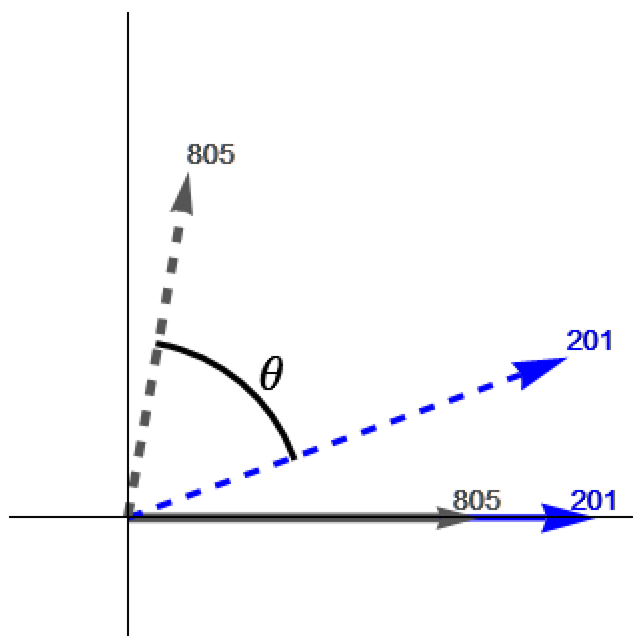


Figure 4: Phasor diagram illustrating the stabilization scheme. The original phasors are shown as solid arrows, and the phase-shifted phasors, at some hypothetical later time, are shown as dashed arrows. The quantity that can be measured is the relative phase of the two signals, θ. In this example, the 201.25MHz signal has shifted by 20° and the 805MHz has shifted by 4 times that amount, 80°. The phase between them is 60°, which is 3 times the shift of the 201.25MHz signal.



ISBN 978-3-95450-176-2

This stabilization scheme relies on identical group delays for the two signals. On coaxial cable this would probably not be the case, however on the fibre-optic link the signals are transmitted as light of a single wavelength; the group velocity doesn't depend on the signal frequency.

To test the feasibility of this correction scheme we set up a single 4-port network analyser to transmit and receive both 201.25MHz and 805MHz signals on two FOLs, with all the fibres within a single bundle to ensure that they were subjected to nearly identical environments. (See Figure 5.)

The result of this test is shown in Figure 6. The corrected 201.25MHz reference signal varies by about 1° over the few-day test.

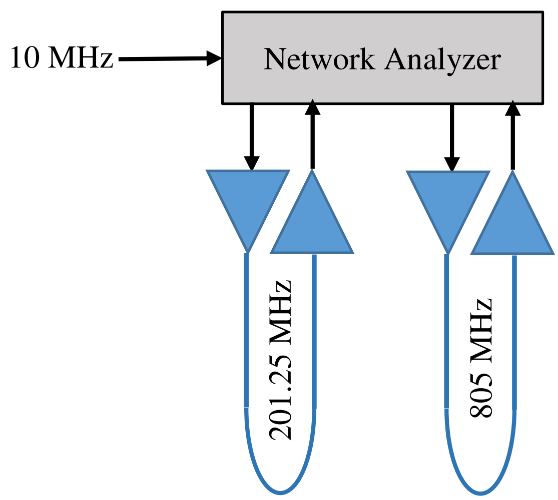


Figure 5: The loopback test setup for the dual frequency test.

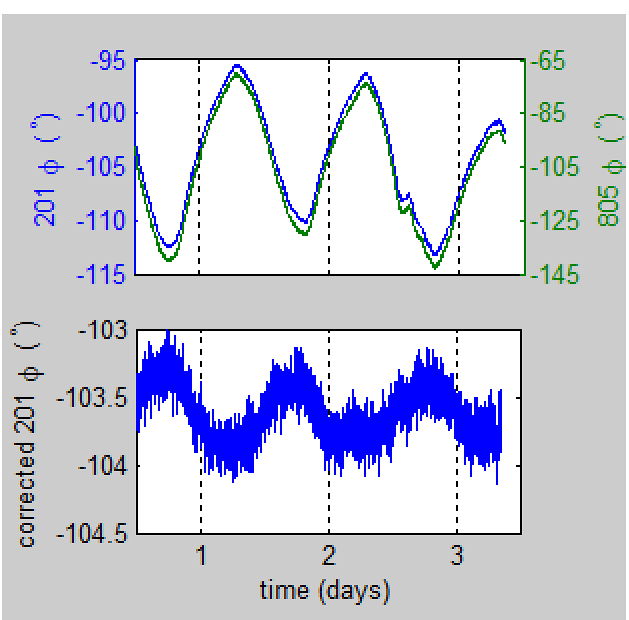


Figure 6: Results of the dual-frequency loopback test. The top plot shows the phases of the two signals, and the bottom plot shows the 201.25MHz phase corrected as described in the text.

## PHASE MEASUREMENT

We are considering a couple of techniques for measuring the relative phase of the two signals. The challenge lies in the fact that they are of two different frequencies. One possibility is to use a diode-based frequency multiplier to convert the 201.25MHz signal to 805MHz. This requires several external analog components including the multiplier, filter, and a splitter (because the 201.25MHz signal must be sampled also.)

Another possibility is to sample both signals; the extra ADC input ports on the BPPM processor mentioned above could accommodate the additional signal. A copy of the 201.25MHz signal can then be digitally converted to 805MHz as shown in the following equations:

$$\cos(4wi) = 8\cos^4(wi) - 8\cos^2(wi) + 1$$

Where $w$ is the phase advance per sample interval and $i$ is the sample index number. By defining $\cos(wi)$ to be the 201.25MHz reference samples, it can be up-converted to 805MHz to allow a phase measurement.

The RF signals into the BPPM system are sampled at 240Msamples/sec; this is below the Nyquist frequency for both reference signals. Numerical simulations of the process indicate that the technique works well even with such under-sampling.

This digital up-conversion and the subsequent phase measurement require several arithmetic blocks in the FPGA-based signal processing unit, and few FPGA resources are available beyond those required for the BPPM functionality; we are evaluating whether this can be accommodated.

## SUMMARY

We've described a scheme for stabilizing a reference signal for a beam phase measurement that involves distributing a harmonic of the reference signal and observing the change in phase between the reference and its harmonic. A correction for the reference can be deduced from this relative phase measurement. We are currently evaluating how to implement this correction scheme.

## ACKNOWLEDGEMENT

We thank Dan Young for help with the fibre-optic infrastructure at LANSCE, and Phil Torrez, Lawrence Castellano, and Mark Prokop for providing access to the signals from the master reference oscillator.

ISBN 978-3-95450-176-2