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# Spectrum Analysis of LL Noise Under Synchronization

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Subject Spectrum Analysis of PLL "Noise" Under Synchronization

## OBSERVATIONS AND CONCLUSION

Purpose: To identify the frequencies present in the residual phase/frequency modulation of the beam after it is locked to an external low noise reference oscillator.

Procedure: An FFT program using 1024 points was implemented on the PDP-10 along with a suitable graphic display. The digitized signal for this program is obtained from a LeCroy 2256 transient waveform recorder. It provides 1024 eight-bit resolution voltage samples at a rate up to 20 MHz. For this run the nominal sampling rate was 20 KHz.

The AGS was operated at about 28 GeV with a 200 msec flat top on time comb "D". Intensity was $1.7 \times 10^{12}$ and the beam was dumped inside of the machine at the end of the flat top. The old Gauss clock constant momentum servo loop was employed to provide a reproducible momentum from cycle to cycle.

Observations: The principal signal that was analyzed with the digitizer and FFT program was the output of the FM discriminator. Its input is generated by mixing the filtered bunch signal from a sum PUE, or the rf signal obtained from a capacity divider on one of the accelerating gaps, with a signal generator set at ≈ 455 KC above the nominal accelerating frequency. The discriminator has a bandwidth of ≈ ± 400~ for low values of the modulation index.

Eight samples of this signal were taken with the PLL closed and the bunch signal as the variable input and all exhibited essentially the same spectrum. There were two almost equal lines at 300 and 360 cycles with much smaller lines at 60, 240 and 420. Only the height of the 60~ line relative to the other lines varied much from sample to sample. Two of the samples (total sample time ≈ 50 msec in all cases) were taken with the bunch shape damper loop open. One then observed an additional line at 340~ which is twice the phase oscillation frequency at 28 GeV and $V_{rf}$ ≈ 250 kV. A separate spectrum of the peak detected signal from a wide band PUE showed a single line at 340 Hz with the damper off.

One additional discriminator signal was analyzed with the bunch signal as input. This was with the synchronization loop open on the flat top and the normal radial correction loop operating. In addition to the two lines at 300 and 360~ larger lines were present at 60~ and 120~ with much smaller lines at 180, 240 and 420. This is to be expected since the two loops have different frequency responses. Finally, the output of the rf voltage pickoff at station CD was used as the variable signal and the discriminator output with synchronization was analyzed. The spectrum showed a strong line at 360~ with equal lines at 300 and 420 of about half the peak line.

Three other signals were also analyzed; the main tuning current that biases all ten cavities; three of the vernier tuning loop current signals that correct for errors in the main tuning current which is program derived; and finally the output from a single turn on the back leg of one of the ring magnets.

The latter signal contained lines at 360 and 720 with a small amount at 1440 and a large line at 60~ which is due to ground loops.

The main tuning current spectrum showed a large line at 300~ with lines at 120 and 240 and still smaller lines at 180, 360, 540, 60 and 420. The vernier current signals all showed principal lines at 300 and 360 with the latter always larger. There was always a line at 60~ of larger amplitude than the other lines but here again one suspects pickup in the monitor channels. Lines of smaller amplitude than the 300~ line were present at 240, 420 and 600~.

Results and Discussion: Using a scope photograph of the discriminator output and its known calibration, one can compute the amplitude of the lines in the spectrum for the case with the synchronization loop closed and operating near maximum gain. The lines at 300 and 360~ being equal contribute a $\Delta f \approx 0.62$ Hz each while the remainder contribute about 0.47 Hz for a total peak swing of $\approx$ 1.7 Hz. This results in a $\Delta P/p = \pm 78 \times 1.7 \div 4.45 \times 10^6 = \pm 3 \times 10^{-5}$ of which each of the principal lines contributes $\pm 1.1 \times 10^{-5}$.

The study indicates that the principal driving term for the 300 and 360~ modulations is the ripple in the main tuning current. However, because of the interaction of the vernier loops and the synchronization loops this question needs further study. It is planned to remeasure the spectra of the main tuning current, all ten vernier currents and the discriminator output with the rf pickoff from the four stations so instrumented, without beam but at constant frequency (4.45 MHz). This data will then be repeated with beam and the radial loop in operation. From these observations, plus possible changes in the main tuning current supply, it is hoped to be able to reduce the observed modulations so that they contribute at most $\pm 10^{-5}$ in $\Delta P/p$ variations.