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Main Ring Bunch Length Monitor

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Abstract

Hardware to measure the Main Ring beam bunch length was installed in January of 1991. The system measures bunch length by comparing relative strengths of 53Mhz and 159Mhz components of signal from a beam detector. The output signal is proportional to bunch length, is scaled in nanosec., and has become a very useful diagnostic tool. Hardware design and operational performance are presented.

Introduction

The principle of operation for the Main Ring bunch length monitor (BLMON), motivation for it's design, choice of detector, and circuit components are given in detail elsewhere[2,3], and will be presented here only briefly. Electronics developed initially for BLMON early in 1990 produced unexpected noise on the output and exhibited useful operation over a small range of beam intensity. The emphasis of this paper is on a basic description of the electronics, improvements made to the original design and test procedures, and resulting performance.[4]

Measurement Principle

If N beam bunches with Gaussian longitudinal charge distribution pass through an ideal detector and are spaced by fixed time intervals, a signal V(t) is produced which is a function of σ_t, the rms. bunch length in time units, s, the detector sensitivity, I_n, the individual bunch currents, and $T_0=\tau_{rf}$, the bunch to bunch time spacing. Taking the Fourier transform of V(t) gives $V(\omega)$, and allows evaluating the peak height of $V(\omega)$ at harmonics of T_0. These harmonics dominate the beam signal spectrum. In the bunch length region of interest, the signal strengths at harmonics of $\omega_0=2\pi/T_0$ are:

$$V(m\omega_0) = 2V_{DC} \quad e^{-\left[\frac{2\pi^2 m^2 \sigma_t^2}{T_0^2}\right]}, \text{ and}$$

$$V_{DC} = \frac{s}{4\sqrt{2\pi}} \sum I_n$$

V_{DC} is the DC response produced by the beam. Solving the equation for σ_t/T_0 at frequencies m=1 and m=λ, and subtracting $V(\lambda\omega_0)$-$V(\omega_0)$ gives the normalized bunch length as a function of the ratio of two harmonic signal strengths:

EQN 1 $$\frac{\sigma_t}{T_0} = \sqrt{\frac{-1}{2\pi^2\left(\lambda^2-1\right)} \mathrm{Ln}\left[\frac{V(\lambda\omega_0)}{V(\omega_0)}\right]}$$

In the Main Ring accelerator, T_0 is nearly constant and the 95% interval of the beam distribution, referred to as the full bunch length $4\sigma_t$, is the quantity of interest.

A quarter wavelength coaxial stripline detector located in the Main Ring at E48 has resonances at (2n+1) F_{rf}. Signals from the upstream and downstream ends of the stripline are combined to allow detecting the beam current from both proton and antiproton beams. Detector output signals at the 53Mhz fundamental RF frequency and at the 159Mhz third harmonic give good sensitivity for detection of bunch lengths in the 1-12 nsec range of the Main Ring beam. These two frequencies are chosen for processing by BLMON electronics, which uses EQN 1 with λ=3.

BLMON Electronics Description

Figure 1 is a block diagram of the hardware. The beam RF input signal passes through a 7-bit digitally programmed attenuator with 127db range in 1db steps. For test purposes, the attenuator can be controlled locally. For normal operation, the attenuator is controlled remotely by system parameters named M:BUNAnn, where "nn" designates one of the seven Main Ring accelerator cycle type Tclk reset events. Each of the cycle types can have unique beam type (proton or antiproton), bunch intensity, and fill factor. Early in the appropriate Main Ring beam cycle, the correct M:BUNAnn parameter automatically switches into the attenuator control input and centers the input signal amplitude in the operating range of the BLMON hardware.

The attenuated beam input is then split into two channels. Trilithic Inc. tubular band pass filters with center frequencies of 53 and 159 MHz select the frequencies for processing by the first harmonic and third harmonic channels. The filters have matched bandwidths of 1Mhz to achieve comparable transient responses. Slight differences in the insertion loss of the filters and transmission loss of cabling is compensated for with a fixed attenuator at the input to the filter of the first harmonic channel.

Two stages of heterodyne receivers are used to detect each beam signal frequency component. The receivers offer good sensitivity and dynamic range. Intermediate frequencies (IF) of 10.7Mhz and 455Khz are used since commercial filters at these frequencies are readily available. Local oscillator (LO) RF signals used for down conversion to 10.7Mhz and 455Khz are derived from a Main Ring low level RF (LLRF) system input signal. The LLRF signal sweeps in frequency from 52.813Mhz to 53.103Mhz as the beam accelerates and remains synchronized with the beam RF input. The LLRF 53Mhz is mixed with a 10.7Mhz crystal oscillator output, band pass filtered at Fc=42.3Mhz, band reject filtered at Fc=10.7Mhz, and amplified to produce an LO signal near 42.3Mhz that correctly tracks the beam input first harmonic. The 42.3Mhz LO signal is mixed (1st mixer in figure 1) with the beam signal in a Mini Circuit Laboratories SRA-1 double balanced mixer to produce an output at 10.7Mhz with amplitude proportional to the strenght of the 53Mhz component of the beam signal.

In the 159Mhz receiver channel, the LLRF input drives a frequency tripler consisting of power splitters, SRA-1 mixers, RF amplifiers, and filters. The 159Mhz output is mixed with the 10.7Mhz crystal oscillator signal to produce an LO signal near 148.3Mhz. This LO signal mixes with the beam 159Mhz signal component to give a 10.7Mhz output with amplitude proportional to the strength of the 159Mhz component of the beam signal.

Subsequent processing of 10.7Mhz signals is identical for both frequency channels. Murata SFE 10.7 MA-Z band pass ceramic filters and RF amps drive the 10.7Mhz into the 2nd mixer stage RF input. A 10.245Mhz LO signal from a crystal oscillator down converts the 10.7Mhz to 455Khz. This IF signal is amplified and filtered by a Murata CFW 4558B ceramic filter with 22Khz bandwidth, and drives an operational amplifier and line driver.

The amplitudes of the 455Khz IF signals are proportional to the beam input signal strengths at the RF frequency first and third harmonics. A 455Khz coherent detector splits each 455Khz input into two signals, amplifies and limits one, and mixes this limited signal with the other in a MCL SRA-3 mixer. The outputs are filtered and amplified in an AD518 operational amplifier with offset and gain adjustments. The coherent detector outputs are labeled V_1 and V_3 in figure 1. They are available for local monitoring, and are read back by the host computer system as parameters M:BLM53 and M:BLM159. These signals are viewed when M:BUNAnn parameters are adjusted to place the input signal amplitude within the operating range of the electronics.

V_1 and V_3 also input to the normalizer circuit. Each voltage drives a Burr-Brown Corp. 4127 logarithmic amplifier. Log amp. outputs are subtracted by an operational amplifier and drive an AD534 four-quadrant multiplier in square root mode to produce the output voltage proportional to the beam bunch length as given by EQN 1. The output is scaled in the host computer database to convert the output to nanosec., and is named M:BLMON.

System Improvements

Bench tests of original hardware revealed noise on the BLMON output near 1.3Khz that was approximately equivalent to 2nsec. p/p bunch length modulation. The test procedure used the combined outputs of two crystal oscillators at 53 and 159Mhz to simulate a beam input signal. The 53Mhz oscillator also provided a LLRF input for generating LO signals. Since the two free running oscillator output frequencies were never exactly in the ratio of 3.00, this procedure introduced close in IM product sidebands at the offending frequency, especially on the 148.3Mhz LO source signal. These sidebands were well within the bandwidths of the filters intended to reject mixing products. The noise was easily eliminated by revising the test procedure to use only the 53Mhz crystal oscillator. It is a fifth overtone oscillator and its output is rich in harmonics. The harmonic at 159Mhz was selected with a bandpass filter, amplified to an appropriate level, and combined with the 53Mhz to provide a new test beam signal input. Like the actual beam signal, the test signal 159 and 53 Mhz frequencies were then exactly a ratio of 3, and the output noise was completely eliminated.

After finding and replacing a significant number of broken electronic parts, the useful dynamic range of beam signal was only 14db. The output of an MWA-130 amplifier between the first and second mixer stages in the third harmonic channel showed a noise floor about 12db above that expected. At small beam signal levels, this noise dominated the coherent detector input. Grounding and power bypassing at the amp. were improved to achieve the expected output.

A signal at 455Khz and approximately -35dbm was measured at the coherent detector inputs even with no beam input. This signal would initially appear and then persist after once applying a beam input, and reduced the range of coherent detector linear operation. Fast edges of 455Khz in the coherent detector limiter circuit initiated the noise, which then regenerated itself as input signal through power supply coupling. Bypass capacitors at the 15 volt power inputs were increased at four places in the limiter and the unwanted signal was reduced to -74dbm.

IM products from mixing stages in the LO signal generator hardware also limited the dynamic range of BLMON. Trilithic tubular filters at 42 and 148Mhz with 5 and 10Mhz bandwidths respectively were installed on the outputs of these stages.

A precision voltage source was used to check and tune normalizer board log. amp. scaling and dynamic range. V_1 and V_3 stages were matched, and gave proper operation over 4 decades of input range.

Conclusion

Much of the design and construction work for the BLMON system was completed by 1990, but the hardware operation fell quite short of the expected performance for unknown reasons. Investigation of the system resulted in substantial improvements in test procedures and operation with regard to accuracy and dynamic range. Comparisons of the M:BLMON output with calculated bunch lengths and those observed from wide band resistive wall monitors show close agreement. Remote control of the BLMON system attenuator and remote viewing of signals proportional to 53 and 159Mhz beam signal strength facilitate adjustment for the variety of Main Ring accelerating cycles.

Acknowledgments

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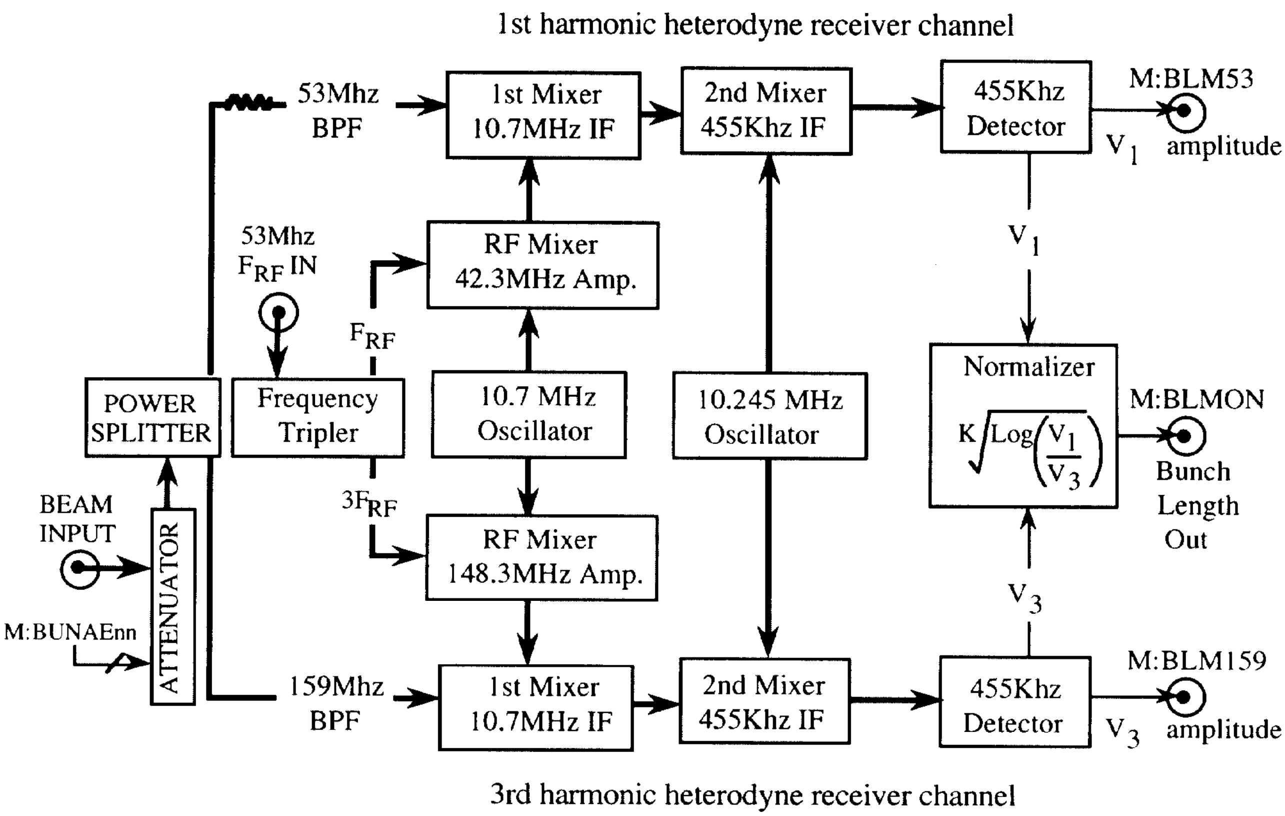

Figure 1: Bunch Length Monitor Block Diagram

Performance Summary

LLRF 53Mhz Input Level	+2 dbm
Beam Input Dynamic Range	40 db
Maximum 53/159Mhz Beam Input	-16 dbm
BLMON Frequency Response (-3db)	6 Khz
BLMON Accuracy (over 40db range)	+/- 2%

References

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