2.5 MHZ FEEDFORWARD BEAM LOADING COMPENSATION IN THE FERMILAB MAIN INJECTOR *

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Abstract

There are five 2.5 MHz ferrite cavities (h = 28) in the Main Injector with an R/Q of 500 that are presently used for coalescing for the Tevatron. For use with the Fermilab Recycler, feedforward (FF) beam loading compensation (BLC) is required on these cavities because they will be required to operate at a net of 2 kV. Under current Recycler beam conditions, the beam-induced voltage is of this order. Recently a system using a digital bucket delay module operating at 53 MHz (h = 588) was used to produce a one-turn-delay feedforward signal. This signal was then combined with the low level RF signal to the 2.5 MHz cavities to cancel the beam induced voltage. During current operation we have shown consistently to operate with over a 20 dB reduction in beam loading.

HARDWARE

The purpose of the hardware (Fig. 1) is to take the Main Injector resistive wall current monitor and delay it by one turn and combine it with the 2.5 MHz low level rf fan-out sent to the cavities. In digitizing at 53 MHz (VCO), we are sampling at 21 times the fundamental mode of the cavities with the Digital Bucket Delay. The signals of interest are the fundamental and the 90 kHz spaced transient mode lines, so a 10.7 MHz and 5 MHz low pass filter are used to remove the unwanted upper frequency response of the resistive wall current monitor. The Digital Bucket Delay consists of an A/D converter, a FIFO, and a D/A converter that all operate off of the VCO frequency. The A/D and D/A are both 14-bit and operate between ± 1 volt. With the FIFO, the signal is delayed by an integer numbers of rf cycles. The Main Injector harmonic number is 588 and taking into account cable delays and component positions we use the FIFO to delay the signal 536 buckets. A Mini-Circuits ZFSC-8-6 8 way-0° splitter was used to fan-out the signal to each of the five 2.5 MHz cavities. This signal was then combined with the low level RF (Fig. 2) just after the fundamental feedback [1] splitter/combiner using a Mini-Circuits ZFRSC-2050 2 way splitter/combiner. Presently the fan-out is only setup to act on proton transfers to the Recycler. A new fan-out is in the works to take into account Pbars spinning in the opposite direction and the position of the resistive wall current monitor in reference to the cavities.

OPERATION

The present mode of operation is to take a multi-batch injection of protons from the Booster into the Main Injector and create four 100E9 2.5 MHz proton bunches. These four bunches are then transferred from the Main Injector at 8 GeV with 2 kV of 2.514 MHz RF to match the Recycler. Reducing beam loading on the latter bunches is critical for an efficient transfer.

In all cases, fundamental feedback BLC is operating on each individual cavity with a gain of 5.

RESULTS

In Figure 3, the red trace shows the vector summation of the five 2.5 MHz cavities using the vlog output from an Analog Devices AD8309 Logarithmic Amplifier. The green trace is four batches of Protons being injected from Booster. Since the cavities have not been turned on at this point one can see the beam induced voltage on the cavities. At about 2.5 seconds the FF BLC was turned on for one second and the red trace goes down by a factor of 8 until the cavity is turned on to 2.2 kV. The 2.2 kV part of the trace is flat until FF BLC is turned off and then one can see the effects of beam loading take over again. In normal operations, the FF BLC is left on during the entire length of a proton injection into the Recycler ($2D cycle.) Figure 4 shows a plot from a HP 89441A Vector Signal Analyzer (VSA) at 2 seconds in the cycle. The blue trace is beam-induced voltage on cavity number five's gap monitor. The green trace is with FF BLC applied.

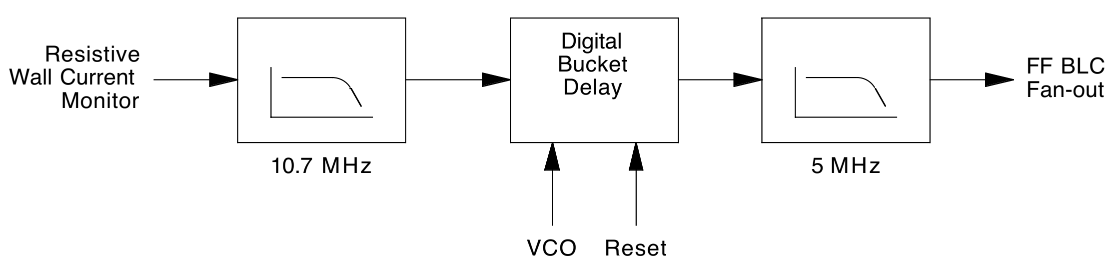

Figure 1: Block Diagram of Feedforward Beam Loading Compensation

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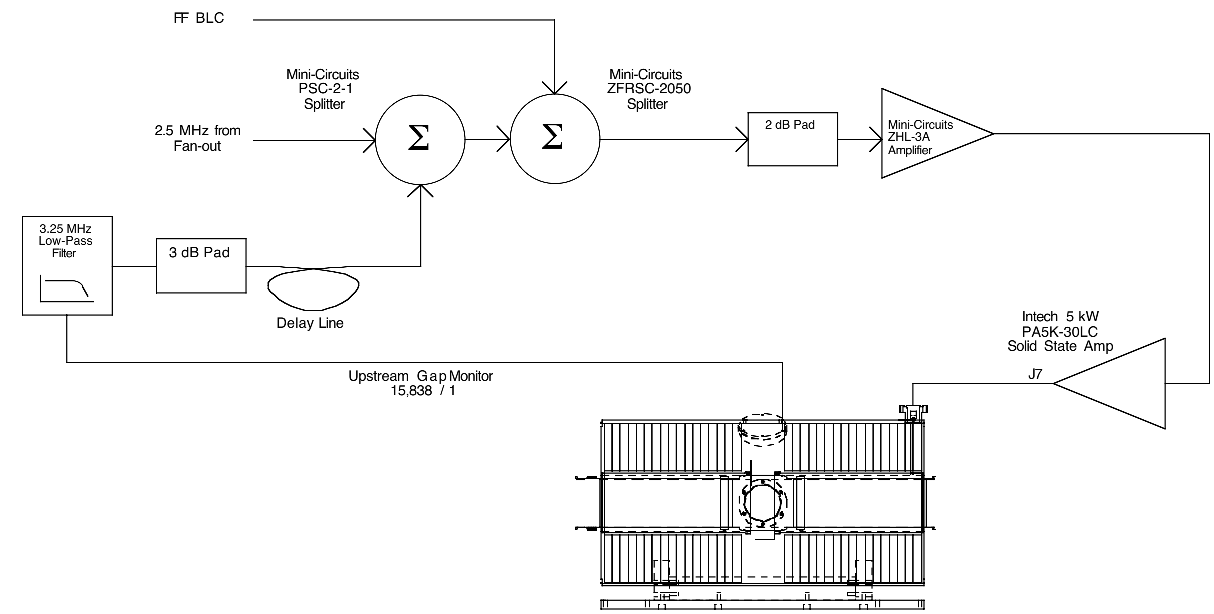

Figure 2: 2.5 MHz Coalescing Station Block Diagram

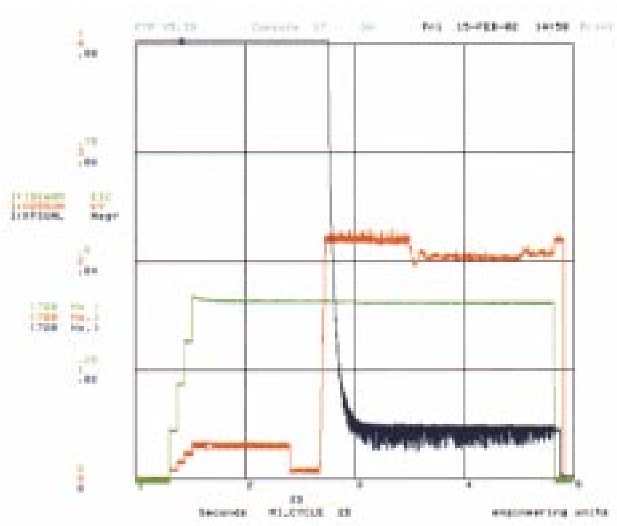

Figure 3: FF BLC on for a portion of a $2D cycle.

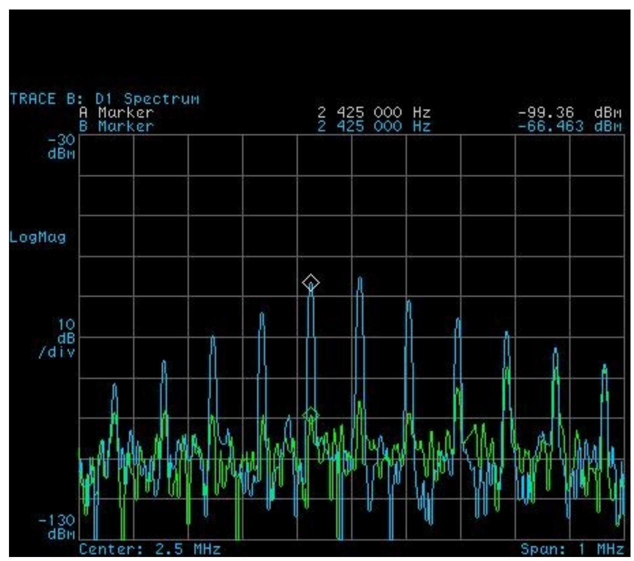

Figure 4: VSA plot of the gap monitor on Cavity #5

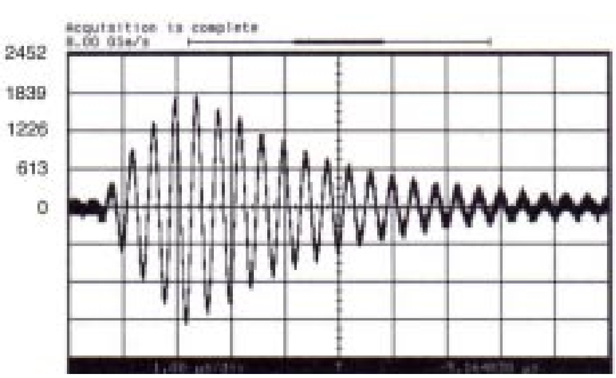

Figure 5: FF BLC off

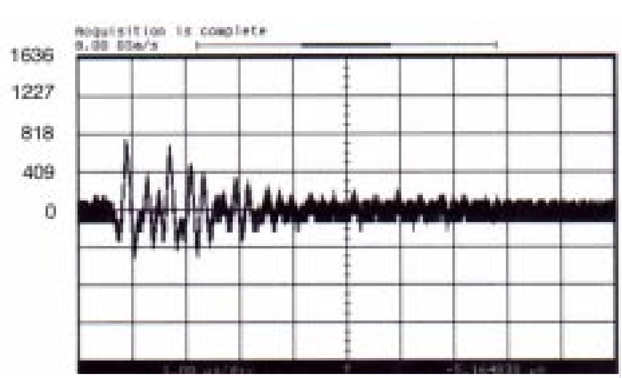

Figure 6: FF BLC on

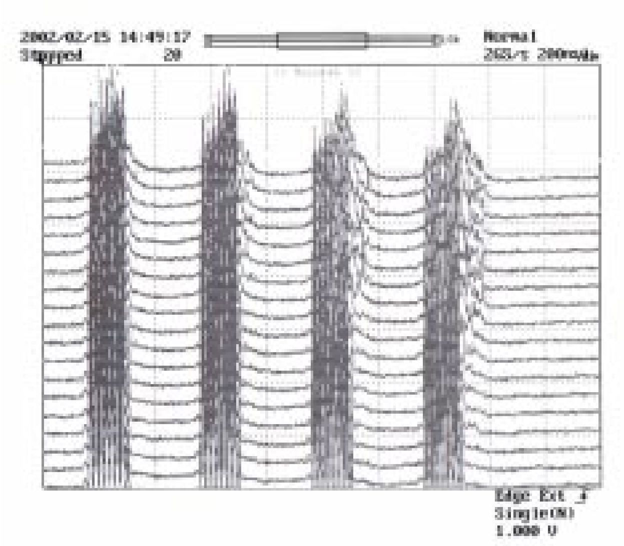

Figure 7: FF BLC off

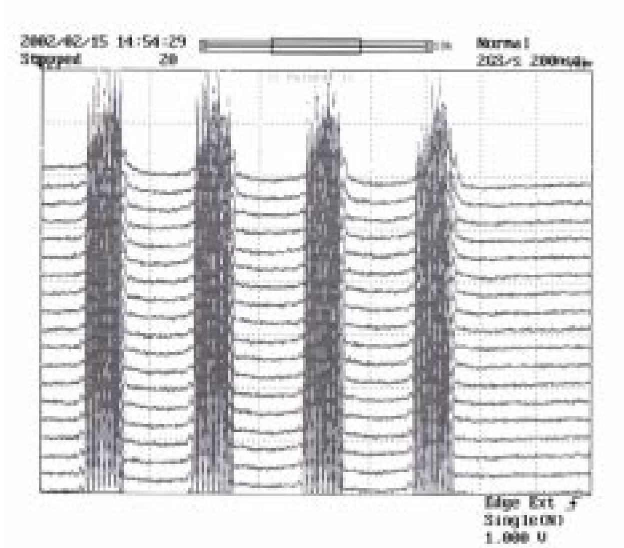

Figure 8: FF BLC on

Almost 30 dB of reduction is seen on the first lower transient beam loading line of Figure 4.

Figure 5 shows the vector summation of beam induced voltage on the five 2.5 MHz cavities from four 100E9 proton bunches. The time domain plot is for a single turn when no induced voltage is applied at 2 seconds on a $2D cycle. Note that almost 1840 volts is shown of beam loading. Figure 6 is under the same conditions as Figure 5, but with the FF BLC turned on. The reduction in beam loading voltage is very apparent. Figure 7 shows a mountain range of each of the four 100E9 proton bunches on a $2D cycle. Each of the bunches following the first are beginning to get wider on the left hand side from beam loading. In Figure 8, FF BLC is turned on and each of the bunches keep their original width. This allows for an efficient multi-bunch transfer to Recycler without any alignment errors.

CONCLUSIONS

Feedforward BLC has greatly reduced the amount of beam loading on the five 2.5 MHz Ferrite Loaded Cavities. The compensation system has been operational for over a year now and overall stability has been excellent.

REFERENCES

[1] J. Dey, J. Steimel, "Improving the Linearity of Ferrite Loaded Cavities Using Feedback," 2001 PAC, p. 873, Chicago, June 2001.