A TRANSVERSE TUNE MONITOR FOR THE FERMILAB MAIN RING

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ABSTRACT

The transverse tunes of the beam change during the acceleration ramp of the Main Ring. Resonant capacitive pickups were constructed to monitor these tune variations. The detectors were also designed to measure the amplitudes of the beam Schottky signals. Details of the technical design and results of measured beam signal are presented.

I. DESIGN PRINCIPLES

RF frequency drift due to acceleration		
kinetic energy [GeV]	revolution frequency [Hz]	RF frequency [MHz]
8	47417	52.78
150	47746	53.14

Table 1: The frequency changes during the energy ramping for Main Ring.

The operation parameters for Main Ring(MR) are depicted in Table 1. The harmonic number is 1113 for MR. The MR clock signal will be used to mix down the measured beam signal. The clock frequency corresponds to the n=159 rotation harmonic line. The detector response has to cover the range of frequency change of n=159 betatron sideband due to energy ramping. The fractional tune of the MR is 0.4. We chose to track the positive sideband of the n=159 harmonic line, which is 7.558 MHz at 8 GeV and 7.611 MHz at 150 GeV respectively. To enhance the signal to noise ratio, a resonant type of detector was chosen. The 3 dB frequency of detector response was chosen to be 7.558 and 7.611 MHz. The design parameters were set by the above considerations and depicted in Table 2.

f_{center}	7.59 MHz
Q_{load}	125
Q_{unload}	250

Table 2: The required parameters for Main Ring tune monitor.

A. *Mechanical design and circuit modeling*

The layout of the mechanical design[1] is depicted in Figure 1. A diagonally-cut cyclidrical pickup was chosen for its linear response to the beam displacement. The radius of pickup electrode is denoted by b, and the electrode length is denoted by ℓ. The configuration depicted in Figure 1 can be modeled by an electrical circuit as shown in Figure 2. C_p is the coupling capacitance between two electrode plates, C_g is the coupling capacitance between the electrode plate and the vacuum pipe. R_s is the shunt resistance due to the resistive loss of a practical inductor $R_s=Q_\ell \omega L$, Q_ℓ =the quality factor of inductor, L=inductance, ω=angualr frequency.

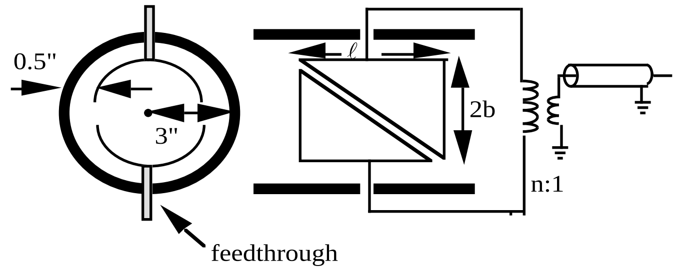


Figure 1: The mechanical layout of MR tune monitor with externally loaded coaxial cable.

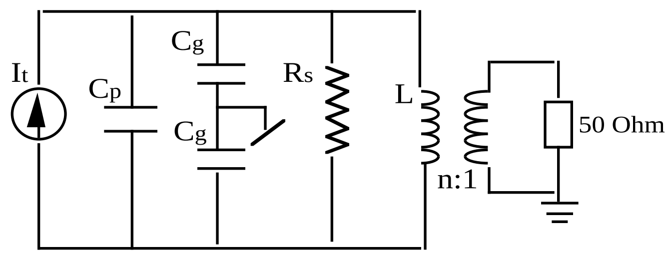
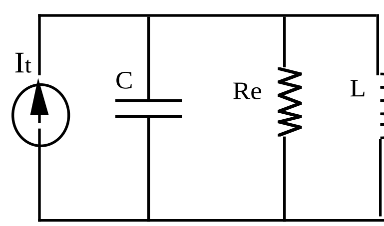


Figure 2: The equivalent circuit model of MR tune monitor.

The circuit shown in Figure 2 can be reduced to an RCL parallel circuit as shown in Figure 3.



$$\frac{1}{R_e} = \frac{1}{\omega Q_\ell L} + \frac{1}{50n^2}$$

Figure 3: The equivalent circuit of MR tune monitor, $C=C_p + C_g/2$.

To get the maximum output power from the detector, we need to match the load resistance, i.e. $R_e=Q_\ell \omega L/2$. For a RCL parallel circuit, the Q factor of the circuit is given by $Q=R/\omega L$. Therefore, the loaded Q factor of equivalent circuit with matched external load is $Q_\ell/2$. From Table 2 we conclude that the minimum inductor Q factor has to be larger than 250.

B. *Signal analysis in frequency domain*

Suppose the particle beam travels along the accelerator with a closed orbit error δy. The beam image current flows along the vacuum pipe. It will have to cross the gap between the vacuum pipe and pickup electrodes when the beam arrives at the upstream and downstream ends of detector. For a

* Operated by Universities Research Association Inc., under contract with the U.S. Department of Energy.

diagonally-cut cyclindrical pickup the induced wall currents flow onto the upstream ends of two electrode plates are[2]:

$$I_{T1} = \frac{-I_b(\omega)}{2}\left(1 + \frac{\delta y}{b}\right),\ I_{B1} = \frac{-I_b(\omega)}{2}\left(1 - \frac{\delta y}{b}\right)$$

The induced wall currents flow onto the downstream ends of two electrode plates are:

$$I_{T2} = -I_{T1}e^{-j\omega\ell/\upsilon},\ I_{B2} = -I_{B1}e^{-j\omega\ell/\upsilon}$$

Hence, the total current flows into the equivalent curcuit is:

$$\begin{aligned} I_t(\omega) &= I_{T1} - I_{B1} + I_{T2} - I_{B2} \\ &\approx -\frac{I_b(\omega)\cdot\delta y}{b}\cdot\frac{j\omega\ell}{\upsilon}\ \left(\text{when}\ \ \frac{\omega\ell}{\upsilon} << 1\right) \end{aligned}$$

The whole detector system is represented by Figure 3. The impedance of the whole system is:

$$Z(\omega) = \frac{j\omega L}{\frac{2}{\omega_0}(\omega_0 - \omega) + \frac{j}{Q_{load}}} \approx \frac{j\omega_0^2 L}{2(\omega_0 - \omega) + j\frac{\omega_0}{Q_{load}}}$$

The voltage across the primary inductor is given by:

$$|V(\omega)| = \frac{\ell\delta y I_b(\omega)}{b\upsilon C}\sqrt{\frac{Q_{load}^2}{1 + (Q_{load}/Q_\ell)^2}}$$

Therefore, the voltage across the secondary inductor is[2]:

$$\begin{aligned} |V_{out}| &= \frac{1}{n}|I_t(\omega)Z(\omega)| \\ &= \frac{\ell\delta y I_b(\omega)}{b\upsilon}\sqrt{\frac{R_0\omega_0 Q_\ell}{C}\frac{Q_{load}}{Q_\ell}(1 - \frac{Q_{load}}{Q_\ell})} \end{aligned}$$

The detector sensitivity is then given by:

$$S_\perp(\omega) = \frac{|V_{out}|}{\delta y I_b(\omega)} = \frac{\ell}{b\upsilon}\sqrt{\frac{R_0\omega_0 Q_\ell}{C}\frac{Q_{load}}{Q_\ell}(1 - \frac{Q_{load}}{Q_\ell})}$$

where ω_0 is the resonant angular frequency, R_0 is cable impedance 50 ohm, υ is the speed of particle beam and Q_{load} is the loaded Q factor of the equivalent circuit in Figure 3.

C. *Receiver design*

The signal processing scheme is described in Figure 4. To make the design simple, we want to utilize the available MR clock signal brocasting around the accelerator. Therefore, the frequency of local oscillator was chosen to be the one of MR reference clock. The distance from the location of detector to the main control room is about 500 fts. Heliax cables were used to minimize the resistive loss and frequency dispersion. Since the MR is running at bunched beam mode, we need to block out the large rf rotation harmonic lines due to beam bunching in order to prevent them from saturating the preamplifier. Because we also want to observe the Schottky signal, which we expect to be very small, a passive lowpass filter with 10 MHz bandwidth was built to minimize the insertion loss and block out the unwanted high frequency signals. Then the signal is divided into two outputs. One is reserved for study purpose, the other is mixed down to the baseband frequency then sent to the main control room. It will be used by the operation crews to monitor the transverse tune of MR and to calibrate the chromaticity values used by the control system.

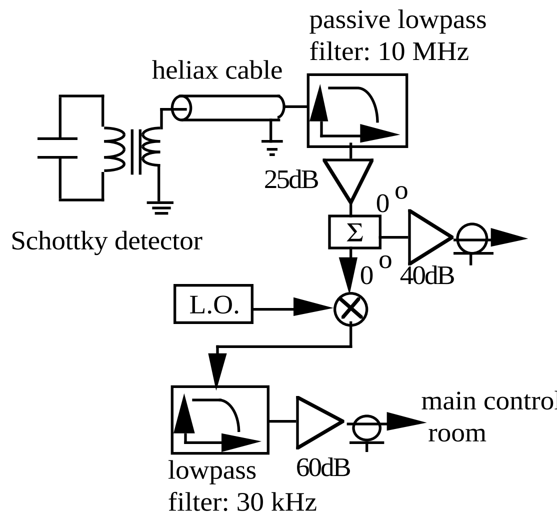


Figure 4: The block diagram of receiver design.

II. BEAM MEASUREMENTS

A. *Calibration*

The detector sensitivity was measured with both bench and beam measurements. The bench tests were done with the streched-wire method. The results of the bench measurements are depicted in Figure 5 and 6. The beam measurements were done with the prototype by using bunched beam, depicted in Figure 7. Because of the good agreement between the bench test and beam measurements, no calibration with beam was done for the final model.

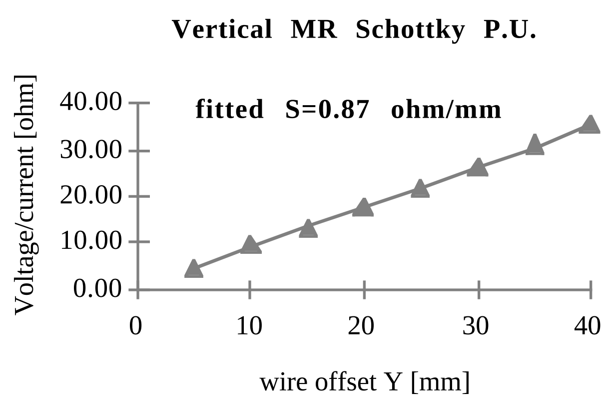


Figure 5: The result of bench calibration for vertical detector.

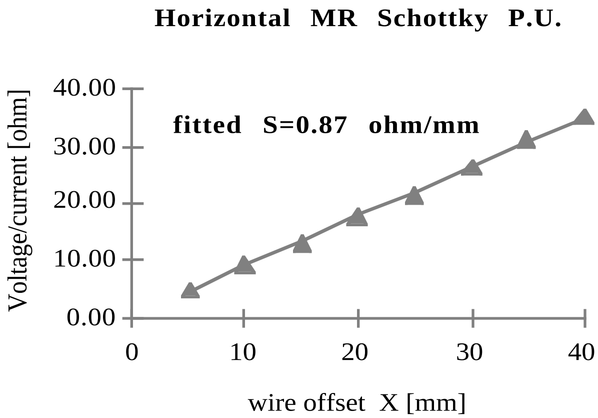


Figure 6: The result of bench calibration for horizontal detector.

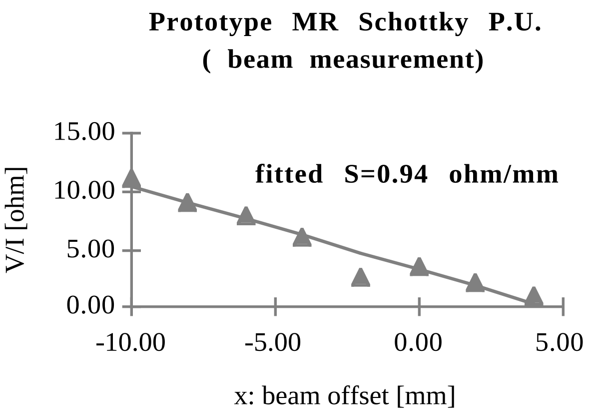


Figure 7: The result of calibration with bunched beam.

B. *Beam signal measurements*

Bunched beam signals measured right after injection are depicted in Figure 8 and 9. The debunched beam signal was also measured as depicted in Figure 10. The beam size derived from measured debunched beam signal was compared with flying wire profile monitor[3]. The conclusion is that the measured signal is not Schottky signal but coherent signal. The Schottky signal is buried by signal driven by coherent beam motion. Also the detector sensitivity is not high enough to observe the Schottky signal. At least a factor of 10 increase in the detector sensitivity is needed in order to observe the Schottky beam signal.

III. ACKNOWLEDGEMENT

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IV. REFERENCES

[1] Mechanical department/ accelerator division, Fermi drawing number 0450-ME-260541 and 0450-MD-260498.
[2] R. Siemann, Fermi EXP-155.
[3] A. Hahn, private communication.

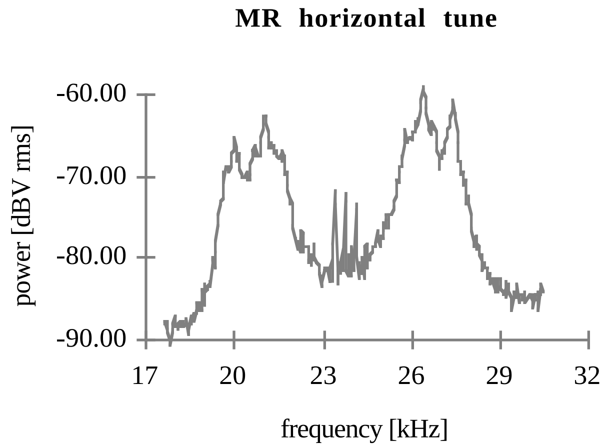

Figure 8: The measured bunched beam signal right after injection.

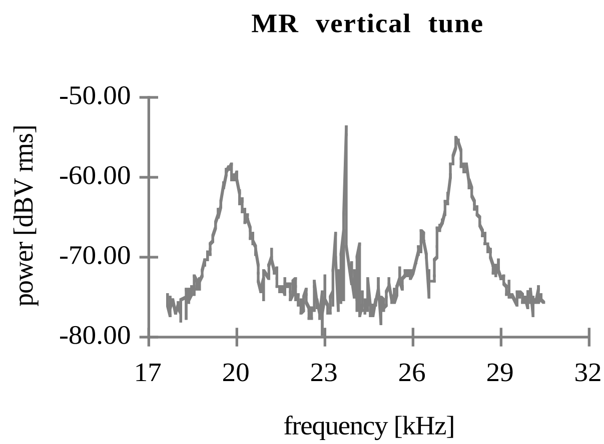

Figure 9: The measured bunched beam signal right after injection.

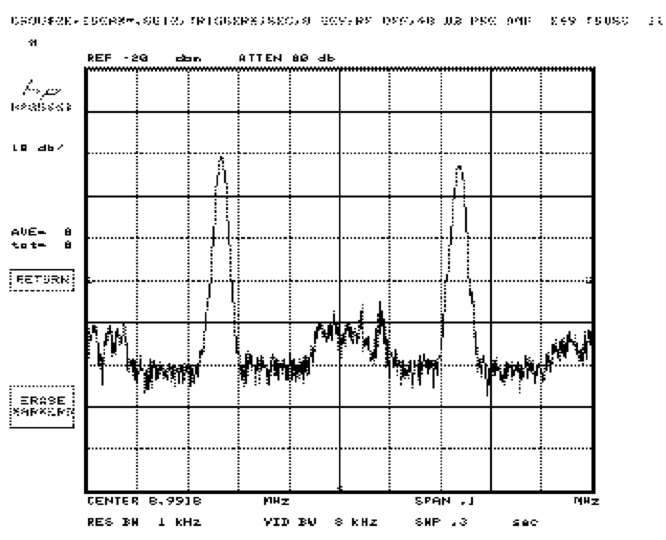

Figure 10: Debunched beam signal measured at the injection energy of MR.