AC COUPLING STUDIES AND CIRCUIT MODEL FOR LOSS MONITOR RING*

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Abstract

As a follow-up study to the initial design of FRIB Loss Monitor Ring (previously named Halo Monitor Ring [1]), we present recent results of coupling studies between the FRIB CW beam and the Loss Monitor Ring (LMR). While a ~33 kHz low-pass filter was proposed to attenuate high-frequency AC-coupled signals [1,2], the LMR current signal may still contain low frequency signals induced by the un-intercepted beam, for example, by the 50µs beam notch that repeats every 10ms. We use CST Microwave Studio to simulate the AC response of a Gaussian source signal and benchmarked it to analytical model. A circuit model for beam-notch-induced AC signal is deduced and should put a ~33pA (peak) bipolar pulse on the LMR at 100Hz repetition rate. Although its amplitude falls into our tolerable region, we could consider an extended background integration to eliminate this effect.

INTRODUCTION

Loss Monitor Ring (LMR), or previously called Halo Monitor Ring, is described in Ref [1, 2] as a metal ring with carefully specified aperture designed to intercept ions that are likely to be lost further downstream. While the to-be-lost particles hit and stop in the ring, most of the beam passes through it. Therefore three dominating signals are generated: primary current by the impacting ions, secondary emission current by the escaped electrons, and AC-coupled current induced by the beam. The former two signals are low frequency signals, which we want to measure as beam losses [2]. Therefore we need to eliminate the AC-coupled signal and ensure it is insignificant in our data acquision.

Considering FRIB CW beam structure, it can be generally layered as mini pulses and macro bunches: The mini pulses have a 100 Hz repetition rate and 50µs pulse spacing, which is required by the AC beam current monitor; the macro bunches, inside the mini pulse, have a repetition rate of 80.5 MHz with variable pulse spacing. To attenuate the macro-bunch induced signal that is in MHz range, we can use a ~33 kHz low pass filter to attenuate it [2]. However, the 50µs notch of mini pulse could induce some fake data in low frequency range that we want to estimate and find solutions.

Since the CST computation of µsec excitation is extreme long, we first simulated a nano-seconds Gaussian pulse in CST Microwave Studio and benchmarked the result with our analytical models. The validated model will then be applied to calculate the 50µs notch induced signal. According to the estimation, the induced signal is not critical but could put some fake background samples. Integration for an extended time period might help and we are investigating other schemes to release the concern.

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EM SIMULATION FOR AC-COUPLING

There are generally two ways to simulate the AC-coupled signal: CST Microwave analysis that simulates an excitation signal through the capacitive pick-up; or Particle Studio that simulates a Gaussian bunch through the ring. Since we are interested in low frequency response rather than MHz range, nonrelativistic bunch is not our concern. Therefore we use CST Microwave Studio to help build the circuit model for LMR.

Geometry Modelling of LMR

Figure 1 shows an example of the basic LMR design [2]. The niobium ring, which intercepts lost particles, is sandwiched by two copper plates, one for electric field shielding and the other one attached on the wall to remove heat. The mounting and shielding rings are electrically connected to the chamber. Ceramic or sapphire washes are used to electrically isolate the Niobium ring while thermally connecting it to the chamber through the mounting ring.

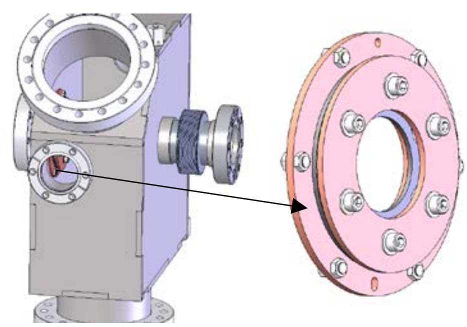

Figure 1: Basic mechanical design of LMR.

We modeled the basic LMR geometry in CST, as shown in Figure 2. The diagnostics box was simplified to a rectangular box and the bolts were smaller than the holes on niobium ring for electric isolation. Ceramic washers were attached on both sides of the niobium ring, as good dielectric material with reasonable thermal conductivity. A wire was set across the box with 220Ω approximate characteristic impedances at both ends.

EM Simulation

To measure the induced AC signal, we located a discrete ports (50Ω) from niobium intercept to grounded

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plate, as shown in Figure 2. The source signal is the default Gaussian excitation in Microwave Studio, specified for frequency range 1.5 GHz. And we assume all the washers to be 96% Alumina (ceramic) with ε_r=9.4.

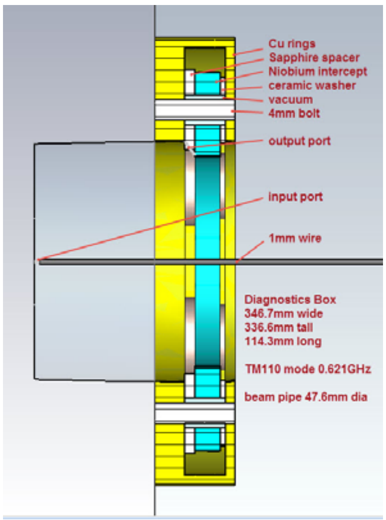

Figure 2: Cross-section view of LMR model in CST.

For convenience in labelling, we named the source port that drives source signal to be port 1, and the output port that connects Niobium ring to ground to be port 2. Figure 3 shows the voltage simulated at port 2, in logarithmic unit.

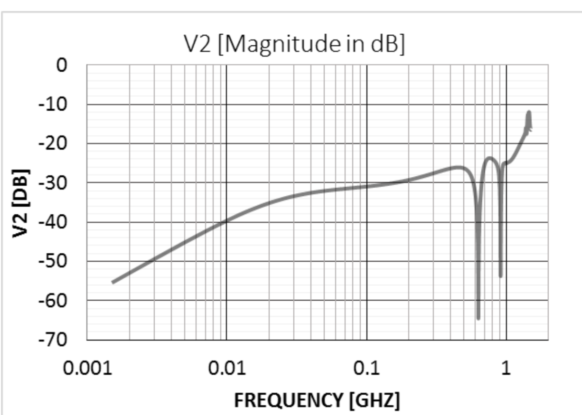

Figure 3: Simulated output voltage V_2 in the frequency domain, full bandwidth. The result is normalized to the source signal.

According to the diagnostics box dimension in Figure 2, the first fundamental mode of the box is TM110 with cut-off frequency 0.621 GHz, while the corner frequency for 50Ω 150pf RC circuit is only 0.021 GHz. Therefore the oscillations close to 1GHz should be caused by the box. At the same time, attachment of LMR perturbs the fundamental mode and brings in a little frequency shift, as shown in Figure 4.

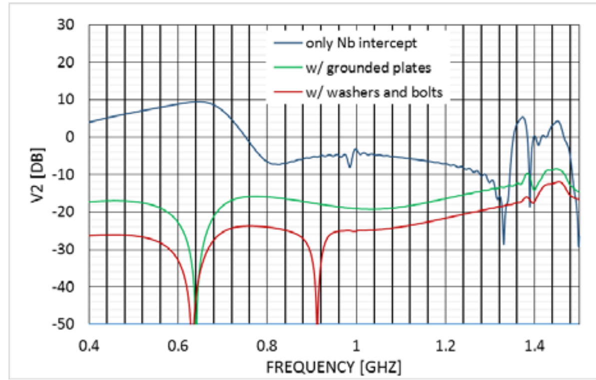

Figure 4: Comparison of output voltages with different structures of LMR. Different colours correspond to a) only niobium intercept, b) adding grounded copper plates, c) adding washers and bolts.

Analytical Model Benchmarking

As implied in Figure 3, in lower frequencies, the LMR could be taken as linear electrical network system, or simply a capacitive pick up ring, which could be described as Figure 5.

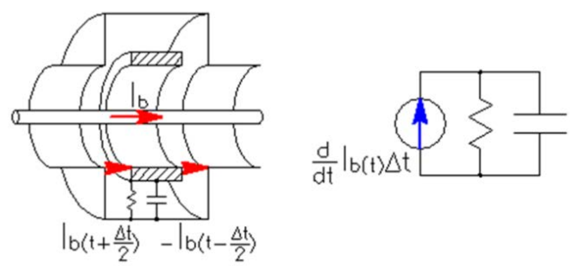

Figure 5: Model for capacitive pick-up.

Therefore the calculation of output voltage V_{ring} in the model becomes straight-forward:

$$V_{ring} = 2R_{ring} I_{wire} \sin\frac{\omega l_{eff}}{2c}\left(1+\frac{1}{\beta}\right) \tag{1}$$

where

$$R_{ring} = \frac{R}{1+j\omega RC}. \tag{2}$$

For the simulated LMR structure, R is set to be 50Ω, C is estimated to be ~150 pf and β=1. The actual length of the niobium ring is 5mm, but the effective length is longer. We adjust the effective length l_{eff} in the expression of V_{ring} to match the simulation in low frequencies. Figure 6 shows a perfect match between the calculated V_{ring} (dash line) and simulated V_2 (solid trace), where we assumed the effective ring length is 8.5mm.

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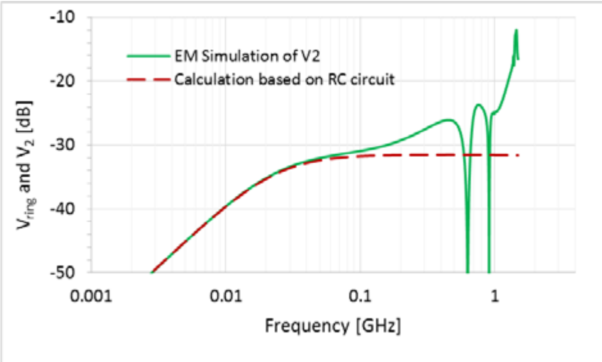

Figure 6: Calculated V_{ring} (dash line) matches simulated V_2 (solid line), by assuming the effective length l=8.5mm in the analytical model. Complete LMR structure is presented.

We did the same calculation & matching for the cases in Figure 4: niobium ring only and with copper plates. The estimated capacitances are 3 pf and 40 pf respectively. Figure 7 and 8 shows the matching result with effective length l=21mm and 8.5mm respectively. Also implied from Figure 6 to Figure 8, we could observe the necessity of a good shielding for LMR, which greatly reduces the effective LMR length by confining the field locally.

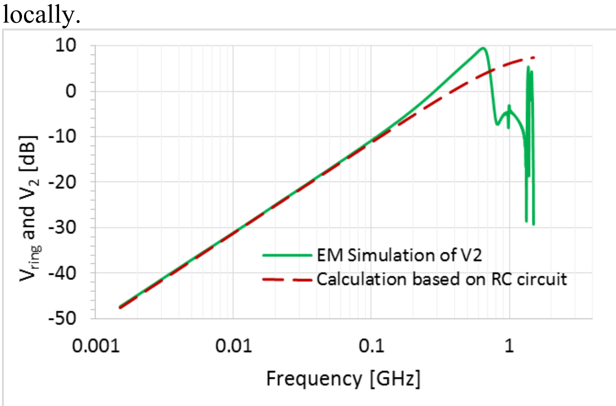

Figure 7: Calculated V_{ring} (dash line) matches simulated V_2 (solid line), by assuming the effective length l=21mm in the analytical model. Only Niobium ring is presented.

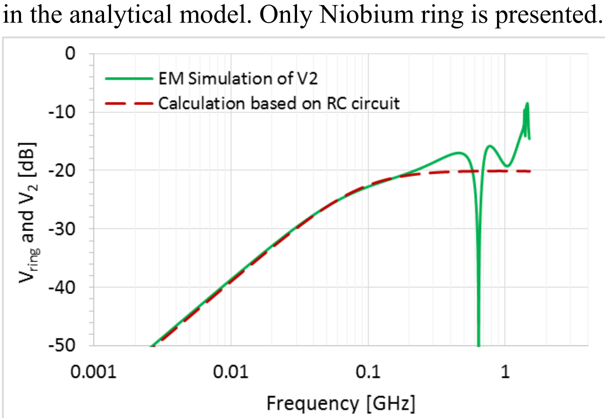

Figure 8: Calculated V_{ring} (dash line) matches simulated V_2 (solid line), by assuming the effective length l=8.5mm in the analytical model. Partial LMR structure (without washers and bolts) is presented.

LMR AC Signal Estimation

As we benchmarked the analytical model, we can use Equation 3 to estimate the induced current for the 50µs notch.

$$I_{notch}(\omega) = 2 I_{avg} \frac{\Delta t_{Notch}}{T} \frac{\sin\left(\frac{\omega \Delta t_{Notch}}{2}\right)}{\frac{\omega \Delta t_{Notch}}{2}}$$

$$\frac{I_{ring}}{I_{beam}} = 2 \sin \frac{\omega l}{2c}\left(1+\frac{1}{\beta}\right) \approx \frac{\omega l}{c}\left(1+\frac{1}{\beta}\right) \tag{3}$$

$$I_{ring} = \frac{1}{2} \frac{I_{ring}}{I_{beam}} I_{notch}$$

We plug in parameters β=0.033 and l=8.5mm into Equations (3). The average current at LS1 is 0.35mA. The Iring/Inotch could be think as a high pass filter, which has a bandwidth of 6.4 kHz. Combined with the 33 kHz loss pass filter that we plan to use, the final induced current will be ~33pA, as shown in Figure 9.

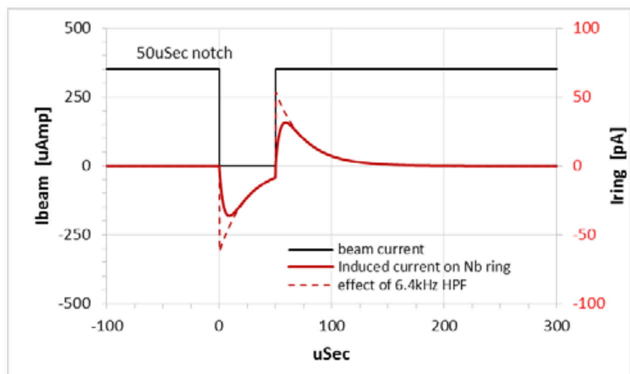

Figure 9: Induced beam current in time domain (red trace), as the effect of a 6.4 kHz high pass filter and 33 kHz loss pass filter.

CONCLUSION

As a follow-up study of LMR, we considered the effect of AC-coupling by FRIB mini pulse structure, which has a 50µs notch at 100Hz. Since it is too time-consuming to directly simulate the AC response for µs pulse in CST, we instead simulated a nano-second Gaussian excitation signal. Analytical model was benchmarked with the Gaussian excitation and effective ring length is obtained for different LMR structures. With the validated analytical model, we calculated the induced current for a 50µs rectangular pulse and it gives ~33pA induced current for 0.35mA average beam current at LS1. Compared with LMR desired detection limit 100pA ± 50pA, it is still tolerable. It, however, brings some fake background when we take the samples in the notch for background subtraction. Integration in an extended time could help.

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