Tuned Beam Position Detector for the Fermilab Switchyard

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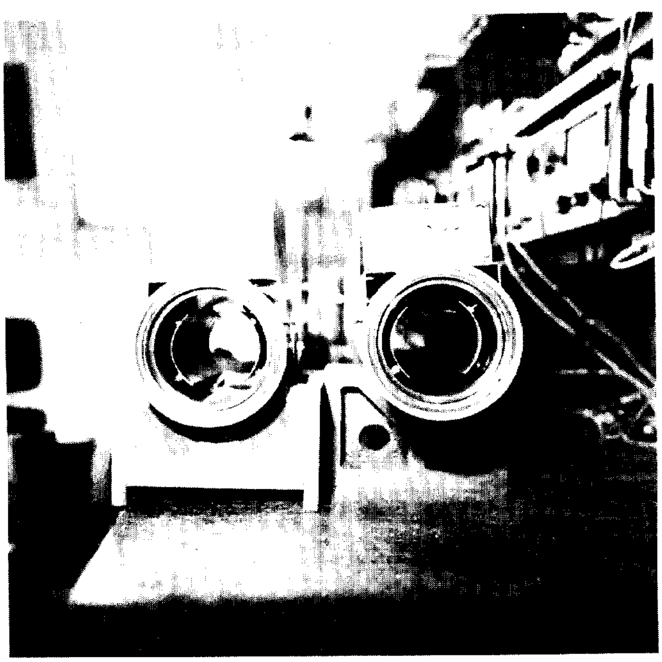
Abstract

Stripline beam position detectors, similar to those in the Fermilab Energy Doubler[1], have been designed to operate in the Fermilab Switchyard, with instantaneous extracted beam intensities smaller by a factor of 10^7 than present in the accelerator. The detectors are tuned to resonance at the RF frequency of 53.1 MHz., with a resulting increase of detector shunt impedance from 50 Ω to 9.5 KΩ and a Q of around 190. Beam position determination of 0.1 mm has been achieved for beam intensities as small as 10^3 protons per RF bucket.

Introduction

A particle beam may be considered a constant-current generator for this discussion. The signal power delivered to a position detector can therefore be increased by raising the detector shunt impedance for the Fourier components of beam current that are chosen. The switchyard beam is bunched at the Tevatron extraction frequency of 53.104 MHz and contains components of n x 53.104 for all n up $\geq$ 20. It was decided, however, to tune the detector for the n=1 Fourier component and ignore the rest for simplicity. We are therefore dealing with a free space wavelength of 6 meters, much longer than the detector, and we may consider the detector plates to the first order as lumped capacitances. Our task therefore was to design shielded inductors to resonate with the plate capacitances, and match the resulting impedance for maximum signal power transfer to the 50 Ω coax cable output. There is a pair of detector plates, facing each other inside the beam pipe, and we quickly discovered that the plate-to-plate capacitance is enough to invalidate the simple notion of tuning each plate with a separate inductor. A third tuned circuit proved necessary to "tune out" the large plate-to-plate coupling. We termed this the "notch" circuit.



Detector Description

Figure 1 shows end view for the short beam detector on the left (~7" plate length) and the long detector on the right (1 meter plate length). The detector body, or beam pipe, is schedule 40 304 stainless pipe of 4.056" I.D. The curved detector plates are copper, supported off the pipe bore by G-10 spacers. Figure 2 is the lumped-constant equivalent of detector plates within the pipe.

For inductors in the 1 meter detector, we used shorted coax hardline $\leq \lambda/4$ long. For inductors in the short detectors (needing much more inductance but in limited space) we used carefully supported copper single-layer solenoids.

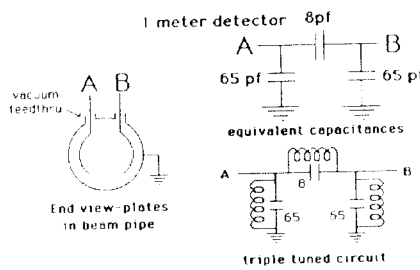


Fig.2- Lumped constant equivalent

Problem Listing

We attacked the following:

1. Obtaining the highest Q.
2. Decoupling the plate-to-plate capacitance.
3. Shielding for maximum effectiveness from external RF fields.
4. Trimmer tunability for final tuning at installation.
5. Providing inputs for calibration signals via a -100 db coupler.
6. Calculating the precise beam position transfer function of the pickup per se. NOTE: The stretched wire measurement technique[2] is inapplicable to the tuned detectors (they are high impedance) because the stretched wire, 393 Ω Zo, detunes the detectors by > 3 MHz.

Non Problems

We found no problem with:

7. Air-to-vacuum frequency shift. It behaves as predicted for air of K = 1.000590 and we tune it out.

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8. Temperature coefficient of tuning, and sensitivity to vibration. We measured both items, but the switchyard environment is sufficiently constant temperature and quiet there is no problem.
9. Deleterious effects on beam. The beam makes a single pass and its current is weak, therefore the detector is totally transparent. In a synchrotron, this tuned detector could cause trouble. See, e.g. Ng[3].
10. Detector bandwidth and time constant. The detector alone (not counting the readout circuitry) has a loaded Q ~190, therefore the bandwidth Fo/Q > 200 Kilohertz, and the time constant

$$t \doteq \frac{2Q}{W} = 1 \text{ microsecond.}$$

Thus the envelope of the detector signal will track beam position changes if they occur during beam spill.

Concerning item (6) we have approximate position transfer functions for the detector and are working on improving them. A precise analytic description for the position transfer function has not been done yet, but should be possible.

Hardware Effort

In this section of the report, we will describe the techniques we used in solving the problems that presented themselves.

To solve 1), we changed the detectors original vacuum feedthrus, which were lossy, to another type with copper center conductor, and for each detector, selected the optimum conductor proportions available for the inductors, in order to minimize loss. There were physical constraints on overall dimensions, because the detectors must fit sometimes confined spaces, but we attempted an optimum compromise. Trimmers and calibration signal ΔC capacitors were tested and selected for low loss; we found only certain types acceptable.

Item 2) was solved by the third tuned circuit, to be further described. We term it the "notch mode circuit" because the energy transmission from plate to plate is minimized by tuning this circuit to resonance at 53.104 MHz, resulting in a transmission null or "notch".

For shielding, item 3), we found both clamp joints and spring fingers not totally effective. Therefore, we went to all-soldered or welded joints. We learned how to pre-set coils so they would be the the correct inductance after lids were soldered in place. It is necessary to maintain > 140 dB shielding, a condition which we tested by radiating 1/2 watt of RF from a dipole antenna near the detector. We reworked any detector that leaked and picked up a signal above the spectrum analyser noise floor.

Small screw-adjustable trimmers took care of item 4. The trimmers give a 350 KHz trimming range.

For item 5), we developed small, fixed, well-shielded ΔC capacitors by soldering .125 hardline in brass blocks and setting a center conductor gap to give the required 100 db down signal. The calculated capacitance of the three-terminal capacitor so formed) is 9.4×10^{-16} f. We called these small capacitors "antenna blocks" because they feed a small calibrate signal into the detector plate system.

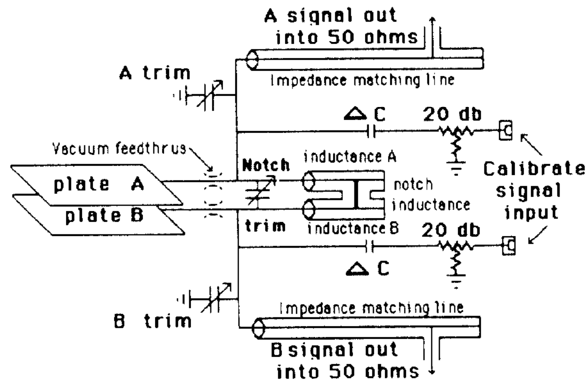


Fig. 3- Schematic of 1 Meter Detector

Circuit

Figure 3 is the circuit of the 1 Meter Tuned Detector. Figure 4 is the circuit of the short detector. The short detector uses coils rather than stub inductances. In both detectors, the impedance

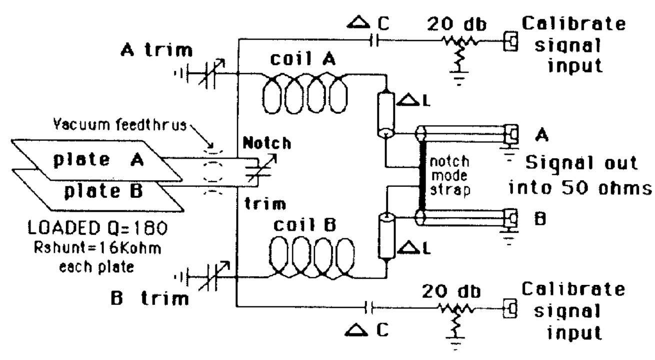
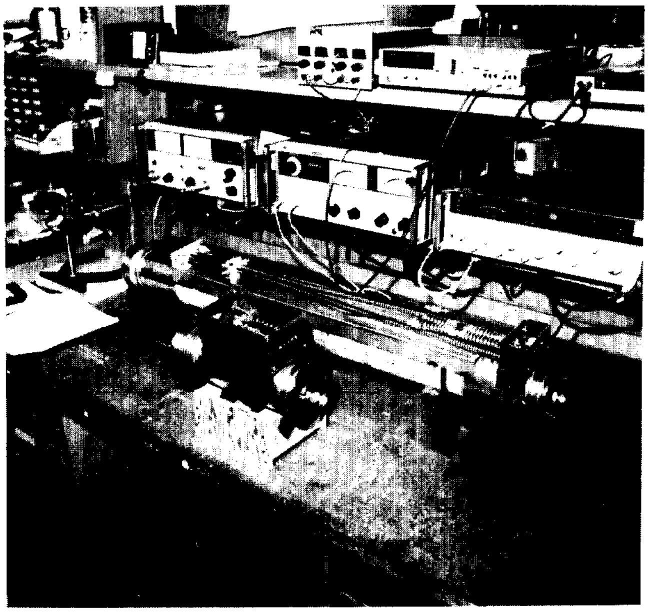


Fig.4 - Schematic of Short Detector

matching is set for maximum power transfer, i.e. the 50Ω load impedance is reflected to the detector plates as a resistive impedance equal to the unloaded detector shunt impedance. Stated another way, the loaded Q of the detector is one-half the unloaded Q. Because the detectors are most useful when connected into the system, we commonly state the loaded Q rather than the unloaded Q! (Were we selling detectors, we would advertise the unloaded Q).

Figure 5 shows a side view of the two detector types, during the tuning phase.



Utilizing the Detectors

Fifty eight 1 meter detectors and 12 short detectors were made. They are coupled to readout[4] and automated control systems[5] to perform their function in the Fermilab Switchyard.

Acknowledgements

We wish to thank Eric McEwen and Al Wagner for their skill and dedication in the RF detector construction and calibration.

References

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