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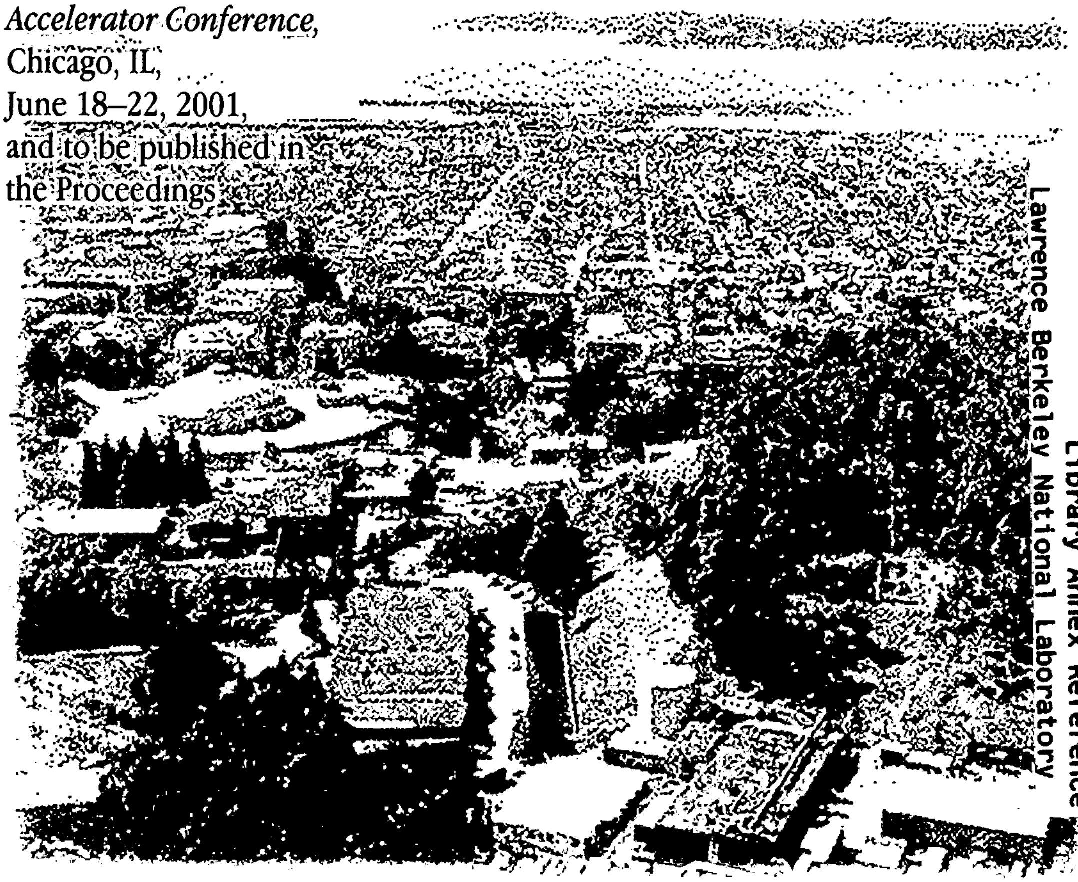

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ELECTRICAL DESIGN CONSIDERATIONS FOR A 40MHZ GAS IONIZATION CHAMBER*

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Abstract

The front IR quadrupole absorbers (TAS) and the IR neutral particle absorbers (TAN) in the high luminosity insertions of the Large Hadron Collider (LHC) each absorb approximately 1.8 TeV of forward collision products on average per pp interaction (~235W at design luminosity $10^{34}cm^{-2}s^{-1}$). This secondary particle flux can be exploited to provide a useful storage ring operations tool for optimization of luminosity. A novel segmented, multi-gap, pressurized gas ionization chambers is being developed for sampling the energy deposited near the maxima of the hadronic/ electromagnetic showers in these absorbers. The ionization chamber must be capable of resolving individual bunch crossings at 40MHz. The ionization chamber is segmented into quadrants; each quadrant consists of sixty $(40x40)mm^2$ Cu plates 1.0mm thick, with 0.5mm gaps. The 0.5mm gap width has been chosen so that the time for the ionization electrons to drift across the gap, is short enough to produce at the out put of the shaping amplifier, a signal that returns to the base line is less than the 25ns bunch spacing of the LHC. From noise considerations in the presence of a cable the stack of plates are connected electrically 10 in parallel, 6 in series to achieve an equivalent detector capacitance C_d~50pF. This type connection forms an electrode inductive L_e and electrode capacitive C_e network that must be optimized to transfer charge from the chamber to the sensing amplifier. This paper describes the design of the collection electrodes optimized for 40 MHz operation.

1 INTRODUCTION

The front IR quadrupole absorbers (TAS) and the IR neutral particle absorbers (TAN) in the high luminosity insertions of the Large Hadron Collider (LHC) each absorb approximately 1.8 TeV of forward collision products on average per pp interaction (~235W at design luminosity $10^{34}cm^{-2}s^{-1}$). This secondary particle flux can be exploited to provide a useful storage ring operations tool for optimization of luminosity. A novel segmented, multi-gap, pressurized gas ionization chambers is being developed for sampling the energy deposited near the maxima of the hadronic/ electromagnetic showers in these absorbers. The ionization chamber must be capable of resolving individual bunch crossings at 40MHz. The ionization chamber is segmented into quadrants; each quadrant consists of sixty $(40x40)mm^2$ Cu plates 1.0mm thick, with 0.5mm gaps. The 0.5mm gap width has been chosen so that time the for the ionization electrons to drift across the gap, is short enough to produce at the out put of the shaping amplifier, a signal that returns to the base line is less than the 25ns bunch spacing of the LHC. The high radiation environment that exists where the detector is to be located (> 100GRad over 10 years) forces the amplifiers to be connected with a cable a minimum of 3 meters away from the detector. From noise considerations in the presence of a cable, the stack of plates is connected electrically 10 in parallel, 6 in series to achieve an equivalent detector capacitance C_d~50pF. This type connection forms an electrode inductance L_e and electrode capacitance C_e network that must be optimized to transfer charge from the chamber to the sensing amplifier. The connection to the amplifier is a 3-meter radiation hard coaxial transmission line with a characteristic impedance of 50Ohm. The cable is connected into an active termination generated by the preamplifier. This type of termination (cold resistance) reduces the thermal noise that otherwise would be generated by a passive 50Ohm termination resistor. If the cable were correctly matched, the transmission line as seen by the detector, would be purely resistive with no inductive and capacitive component. With a correctly matched cable the inductive L_e and capacitive C_e portion of the connections exist only at the detector. The inductive and capacitive components associated with the detector must be kept as small as possible in order to move any resonance associated with the detector well above the 40MHz operating frequency of the amplifier. The measured capacitance value of the detector used in the first beam test showed a gap capacitance of 64pF and a 10 parallel connection of 640pF (typical). The measured equivalent capacitance for the complete detector was ~100pF. A frequency sweep of the detector showed a resonance at 33MHz. From these values the detector inductance was determined to be ~230nH. Figure 1 shows a detector quadrant.

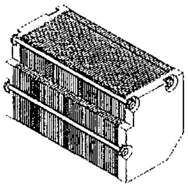

Figure 1. Detector quadrant consisting of 60, 0.5mm gaps and an area of $(40x40)mm^2$. This provides an equivalent 30mm gas length at 1 ATM.

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2 CHAMBER CONNECTIONS

2.1 Gap Connections

To provide fast charge collection and for signal to noise considerations in the presence of a cable, the detector is configured with 60 gaps 0.5mm gaps connected 10 in parallel and 6 series connections [1]. This connection provides an equivalent detector capacitance of 50pF as seen by the amplifier. Figure 2 shows the connection circuit of the individual gaps. The detector capacitance $C_d = (N_p/N_s)C_{gap}$ is the capacitance of a single gap multiplied by the number of gaps in parallel (N_p) and divided by the number in series (N_s). The total number of gaps is then $N_{gap} = (N_p{*}N_s)$.

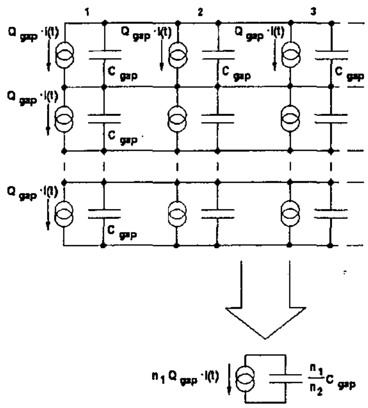

Figure 2. The detector gap connection forming an equivalent detector capacitance of 50pF as seen by the amplifier.

The signal to noise ratio is determined by Equation 1 and is proportional to the number of gaps, and the square of the liberated charge in the gap. It is inversely proportional to the capacitance of the gap (C_{gap}) and the square of the ballistic factor (σ ~ 2.8) that describes the reduction in signal due to clipping. This is the ratio of the electron charge transfer time (~ 20ns), to the shaping time (τ ~ 2ns) of the amplifier [1].

$$\left(\frac{S}{N}\right)^2 = \frac{N_{gap} Q_{gap}^2}{2kTC_{gap}\left(\frac{a_1 a_3}{\beta}\right)^{1/2} * \sigma^2} \qquad (1)$$

The plates are biased with stacked batteries that provide a potential difference between each gap of 50 volts or greater. The induced current that is measured at the amplifier has a contribution from only the electrons. The positive ions are considered DC because of their slow drift velocity when compared to the electron drift velocity. The induced charge is passed through the actively terminated transmission line to the amplifier.

2.2 Active Termination

The active "cold termination" is adjusted to approximately 50Ohms. The frequency response of the termination is made by implementing a high frequency bipolar transistor (Siemens BFP 540) and paralleled by 4 to reduce the base spreading resistance R_{bb}' [1]. This device has a larger transition frequency and a slightly smaller base spreading resistance when compared to the transistor employed in the previous amplifier version that used the NEC 856 [1]. The impedance of the "cold resistance" termination as a function of frequency is shown in figure 3. The figure shows that in the frequency range of interest, from a few MHz to more than 50MHz the impedance can be considered resistive and departs from the targeted 50Ohm value by less than 2% in this range. The slight slope in the frequency behavior has been attributed to a partially mismatched pole-zero cancellation in the preamplifier loop at lower frequencies. Effort aiming at removing this mismatch is presently underway.

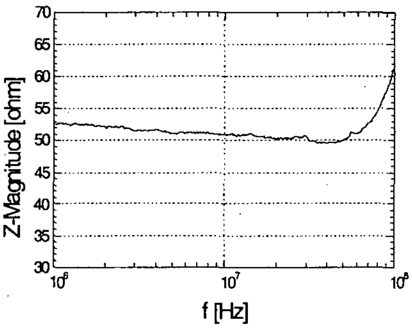

Figure 3. Impedance of the "cold resistance" termination as function of frequency.

2.3 Return Current Path

The return current of the properly matched transmission line is connected to the return of the battery ground reference of the detector. An estimate of the detector inductance can be made by considering the current path through the detector plates, their connections and the termination. Figure 4A shows how the current is formed in the column. The current originates when the hadronic/electromagnetic shower passing through the gas volume produces ionization electrons in each gap. The electrons form a column with an approximate diameter of 10mm. The physical chamber length is 91mm and the gas length is 30mm. The detector is symmetric about the center and therefore the bias circuitry exists only on one half the length of the detector. This reduces the physical length to an electrical length of 45mm. The chamber is design in a symmetric fashion to avoid having a capacitance variation on each end of the detector. In this configuration the high voltage is in the center and ground is located at each end. In this way, the housing of the detector is at the same voltage potential as the endplates of the detector. This also eliminates any stray end capacitance that would be present in an asymmetrical design.

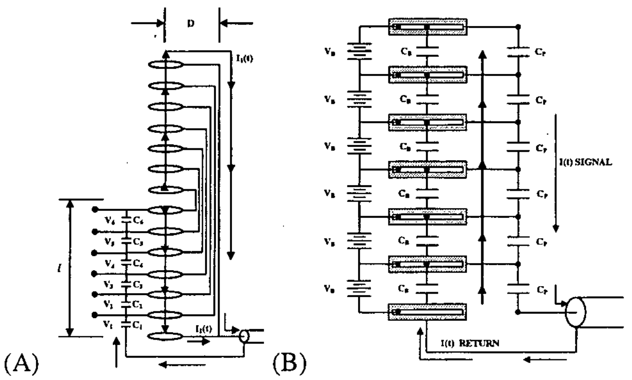

Figure 4 A&B. A) Schematic representation of the bias connection used for the first beam test. The chamber is symmetric so the current flows out from the center in both directions. B) Shows the schematic representation of the equivalent circuit for the new bias connection. Here the return current returns from the coaxial cable shield through the low inductive bias capacitors. The current is distributed over the entire width of the detector (40mm).

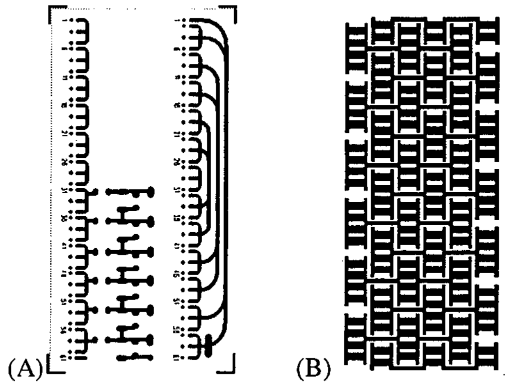

Figure 5 A&B. A) The bias connection board used for the first beam test. B) The new bias connection board to be used in the new chamber design. The type of connection allows the current to flow along the entire bias plane avoiding a loop type of connection.

2.4 Inductance Calculation

An estimate of the detector inductance for one conductor can be made by the approximation that the column of electrons is one of two parallel wires and the bias plate connection is the other wire[2]. The inductance is then given by equation 2. The design used for the first beam test we have l = 45mm, d_1 = 10mm, d_2 = 0. 3mm and D = 25mm. Taking into account that the current is flowing on the surface of the conductor at the operational frequencies of 40MHz, the inductance contribution from each conductors is L = 60nH with 4 conductors in series the value sums to 240nH plus stays.

$$L = \mu_0 l\left[\cosh^{-1}\left(\frac{D}{d_1}\right) + \cosh^{-1}\left(\frac{D}{d_2}\right)\right] \text{ Henry,} \qquad (2)$$

If you compare this value to a capacitive loaded coaxial line as shown in figure 6 you see that the minimum inductance that can be achieved for each parallel connection with $\boldsymbol{a}$ = 5mm, $\boldsymbol{b}$ = 25mm and $\boldsymbol{l}$ = 2.5mm, is L= 1.4nH and 6 connections yields ~8.5nH.

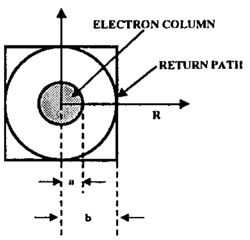

Figure 6 Cross section of a coaxial configuration superimposed with the rectangular cross section of the detector. The outer conductor is the return current path and the inner conductor represents the column of electrons generated by the electromagnetic shower. The chamber inductance should be ~4 times the coaxial inductance.

2.5 Chamber Inductance

The coaxial inductance value of ~8.5 nH represents the best inductance that can be expected from this detector configuration. To approximate this type of configuration in the detector, a wide return current path can be implemented to provide a reduced inductance in the chamber connection. With only one plane (the bias plane) in the current return path the minimum detector inductance should be 4 times the coaxial value or 34 nH. Figures 4B&5B shows the implementation when the complete width of the detector has been implemented as the return path for the current.

The first order resonance for the detector is described in equation 5 with the assumption that the series resistance is small. With a detector capacitance of ~50pF and a detector inductance of ~34nH the theoretical resonance value is ~122MHz. This value is a factor of three higher than the 40MHz operation frequency and should not be seen by the amplifier.

$$2\pi f_{res} = \frac{1}{\sqrt{LC}} \qquad (5)$$

3 CONCLUSIONS

Calculations show that a detector can be made with a fundamental resonance of greater than the amplifier bandwidth of 40MHz. The construction of a detector with an equivalent detector capacitance of 50pF and a loop inductance less than 300nH is constructed and will be tested before the next beam in September of 2001. Once the minimal loop inductance has been achieved the further shifting of the resonance can be achieved by decreasing the equivalent detector capacitance below 50pF.

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