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Electrical properties of carbon fiber support systems

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Abstract

Carbon fiber support structures have become common elements of detector designs for high energy physics experiments. Carbon fiber has many mechanical advantages but it is also characterized by high conductivity, particularly at high frequency, with associated design issues. This paper discusses the elements required for sound electrical performance of silicon detectors employing carbon fiber support elements. Tests on carbon fiber structures are presented indicating that carbon fiber must be regarded as a conductor for the frequency region of 10–100 MHz. The general principles of grounding configurations involving carbon fiber structures will be discussed. To illustrate the design requirements, measurements performed with a silicon detector on a carbon fiber support structure at small radius are presented. A grounding scheme employing copper–kapton mesh circuits is described and shown to provide adequate and robust detector performance.

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1. Introduction

Nowadays carbon fiber is a ubiquitous structural material used in a wide range of applications due to its high modulus and low mass. It offers great flexibility in terms of tuning thermal and mechanical properties through the orientation and number of lay-ups of the fibers. Carbon fiber support structures have also become common elements of detector designs for high energy physics experiments and are especially prevalent in the design of silicon vertex detectors. Early examples of the use of carbon fiber in external

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support structures are the DELPHI silicon detector [1], and the space frames for the BaBar [2] and CDF ISL silicon detectors [3]. In current designs, carbon fiber is integrated in the design of silicon detector modules, like the readout modules for the silicon tracker for the CMS experiment [4]. An example of a detector with a fully integrated carbon fiber support structure is the Layer 00 detector for the CDF collaboration at the Fermilab Tevatron collider [5].

While the use of carbon fiber solves a variety of mechanical problems, it presents a challenging set of electrical concerns. Highly conductive carbon fiber surfaces produce an undesirable capacitance relative to sensors, electronics and cables and can compromise the detector performance due to significant coherent noise pickup [6]. Well-designed coupling and grounding schemes are essential for producing low-noise environments for these detectors.

Here we describe the electrical characteristics of carbon fiber as applicable to a silicon tracker at small radius with an integrated carbon fiber support structure. Measurements are performed on a prototype of a detector that has been proposed for the DØ experiment at the Fermilab Tevatron collider, called the Layer Zero (LØ) detector [7]. In the next section the electrical characteristics of carbon fiber will be described. The carbon fiber test pieces were made using carbon fiber epoxy resin prepregs using K139, obtained from Bryte [8], and K13C, obtained from YLA [9]. The carbon fiber in both products was manufactured by Mitsubishi. K139 uses 110 Msi modulus fiber with a thermal conductivity of 210 W/mK, with a fiber aerial weight (FAW) of 55 g/m^2. K13C has a modulus of 130 Msi, with a significantly higher thermal conductivity of 620 W/mK and a FAW of 69 g/m^2 [10]. For both prepregs, the resin fraction is about 35% by weight, or roughly 50% by volume before curing.

Based on the results of the electrical tests of the carbon fiber, methods will be outlined that address the electrical requirements for the construction of support structures for silicon detectors. The design addresses all potential noise sources. Tests aimed at minimizing coherent noise contributions with a full-scale silicon detector, populated with a limited number of readout modules will be described. The paper concludes with a suggested set of design rules which need to be respected in the construction of silicon detectors with integrated carbon fiber supports.

2. Electrical conductivity of carbon fiber

Carbon fiber with ultra-high modulus ($\sim$1000 GPa) also has low resistivity (100 Ωcm) [10]. These materials are characterized by particularly high conductivity at high frequency with associated design issues. A series of tests were carried out to verify the conductivity of carbon fiber.

The first study performed was a measurement of capacitor impedance. Two parallel plate capacitors were built using 6 in. $\times$ 6 in. bare FR4 cores, with $\varepsilon_r = 4$, approximately 0.27 in. thick. The first capacitor, used for baseline measurements, had two tinned copper electrodes laminated to either side of the FR4 dielectric. Each electrode is approximately 0.075 in. thick. The second capacitor has a single tinned copper electrode attached to one side of the FR4 dielectric and a single carbon fiber electrode attached to the other side. The carbon fiber electrode was four plies of K139 fiber with a 4-layer $[0^\circ/90^\circ]_s$ lay-up, approximately 0.04 in. thick. Contact with the two electrodes of the capacitor under measurement was established using two 20AWG stranded wires connected to the two contacts of a BNC connector. For the capacitor electrode side, the strands were separated and splayed to maximize contact and taped to the electrode with a specific area of copper tape. Prior to the attachment of the probe, the contact area on the electrode was burnished with mildly abrasive polishing material (Scotch-Brite) and cleaned with ethyl alcohol. After taping the probe to the electrode, the tape was worked with a blunt tool to maximize contact to the strands of the probe and to force air from under the copper tape to the outside edge to maximize contact to the electrode. Past experience has shown that not taking care at this stage in the test preparation would result in inconsistent measurements. The size of the copper tape used to make contact with