BaBar Note #348

Design of the BaBar Position Monitoring Systems for the SVT and Drift Chamber

Pat Burchat, David Kirkby
Stanford University

May 28, 1997

Abstract

This document describes the design of a 32-channel position-monitoring system for the BaBar silicon vertex tracker (SVT) and drift chamber that meets the requirements described in BaBar Note #302. The system is based on commercially available capacitive sensors and signal conditioning electronics. In this note, we justify the choice of sensor and describe the design of the readout system, the mechanical mounting of the sensors, and the power and signal distribution. We also give specifications of the interfaces of this system with the BaBar detector control system, and budgets and schedules.

Contents

1 Introduction

The BaBar detector will be instrumented with two position-monitoring systems for the tracking detectors.[1] A system of six sensors in the forward direction and six sensors in the backward direction will monitor the gap, nominally about 8 mm, between the sensors, mounted to each B1 magnet, and the outer end of each of the two carbon-fiber silicon-vertex-tracker (SVT) support cones. In the backward direction, two additional sensors will monitor the relative z positions of the cone and B1 magnet at the same location. A second system of sixteen sensors will monitor the relative z and ϕ positions and the gap between the sensors, mounted to the inner cylinder of the drift chamber, and the outer surface of the support tube. The senosr mounts are being designed so that the nominal gap is approximately 8 mm.[2] The sensors will be located just outside the endplates at each end of the drift chamber.

The requirements for the position monitoring systems are described and justified in BaBar Note #302[1]. We summarize the requirements here. The primary requirement of the SVT system is to monitor relative motions of the B1 magnets and the SVT, in order to ensure that no load is applied to the SVT. This system should be operational during mounting and unmounting of the SVT on the B1 magnets, during installation of the SVT in the support tube, during transportation of the support tube from the assembly lab to the interaction region, during installation and removal of the support tube from the detector, and when the support tube is inside the detector. Therefore, a requirement of the monitoring system is that it have a portable readout system which can be used during installation of the SVT and transportation of the support tube, in addition to the standard BaBar readout system.

The drift chamber monitoring system will be used to monitor the gap between the drift chamber and the support tube during installation of the drift chamber and while the drift chamber is in the detector. The support tube could be moved up to 5 mm in any direction in the plane perpendicular to the beam during tuning of the PEP-II storage ring. The position-monitoring system will measure these motions plus motion due to effects such as diurnal

---

[1] A third position-monitoring system in the interaction region has not been designed yet. The IR group is planning to measure the positions of IR magnets and the support tube relative to a wire stretched through the interaction region. A decision has not yet been made on the technology that will be used for this monitoring system.[2]

[2] As of 04/97, the nominal gap between the support tube and the drift chamber inner cylinder is 1.45 cm. This is an increase from the old nominal gap of about 1 cm.

temperature variations or changes in the BaBar magnetic field.

These position-monitoring systems will also be used in determining the relative alignment of the SVT and drift chamber. Ultimately, the alignment of the tracking systems will be accomplished using tracks from high-momentum charged particles that traverse the SVT and the drift chamber. However, when BaBar is first installed and luminosity is still significantly below the design value, the time over which a sufficient number of tracks is accumulated will be comparable to the time over which the relative positions of the tracking systems can change (hours) due, for example, to diurnal temperature variations. During this phase of the experiment, input from a set of position-monitoring sensors in the tracking region will be important. In addition, even when luminosity is sufficiently high so that a sample of tracks for alignment can be accumulated in a very short time, information from the position sensors can be used to identify which types of motion are significant. This information provides input for optimizing the alignment algorithms and determining the types of time-varying parameters needed for the alignment program.

For both the SVT and drift chamber systems, the sensors must not occupy a significant fraction of the clearance they are monitoring. Therefore, they must be small and/or they must be recessed into material on one side of the gap or be mounted on a retractable mount. The nominal gap sizes to be measured are about 8 mm. The range of the sensors must be 0 to approximately 16 mm. The required accuracy for safety (for monitoring how close the detector and machine components are to coming in contact with each other) is about 100 μm. For alignment, a precision of 10 μm on changes in the relative positions of the cones and the B1 magnets, or the drift chamber and the support tube, over time-scales on the order of 24 hours is desirable. The sensors must be insensitive to temperature and humidity variations (or the temperature and/or humidity must be monitored), magnetic fields, and radiation doses up to 100 kRad for the SVT monitors[3] and somewhat less for the drift chamber monitors.

In this document, we describe the conceptual design for a position monitoring system based on capacitive sensors and signal conditioning electronics commercially available from a company called Capacitec[3]. Detailed performance studies of the Capacitec sensors that we performed at Stanford University are described in BaBar Note #347[4]. In the next section, we

---

[3] This corresponds to ten times the nominal dose for ten years.

justify the choice of sensor. In Sec. 3, we describe the Capacitec sensors and readout electronics. In Sec. 4, we describe the location and mechanical mounting of the sensors. In Sec. 5, we discuss the electronic readout and digitization within the BaBar readout system. In Sec. 6, we describe the power and signal distribution. In Sec. 7, we describe the portable readout system. In Sec. 8, we discuss the calibration that will be done in the laboratory prior to installation. In Sec. 9, we specify the interface with the online slow-control system. In Sec. 11, we give the budget and schedule for the system.

Throughout this document we indicate outstanding design decisions or missing information with an asterisk in the right-hand margin as illustrated here. In addition, we summarize the outstanding design decisions in the last section of the document. *

2 Choice of Sensor

We considered several types of commercially available noncontact sensors as well as a contact sensor made from strain gauges mounted on a leaf spring, proposed by Roy Kerth and Fred Goozen at LBL. We first list the types of sensors we rejected and briefly justify our decisions.

1. Inductive sensors and LVDT's – We considered two types of sensors that use magnetic fields for proximity sensing: inductive sensors (Kaman, Farrand) and linear variable differential transducers (LVDT's) (Kavlico, Tesa). The sensitivity of these sensors meets our requirements. We rejected these sensors because it was not clear that they would work in a 15 kGauss magnetic field and because the sensors with a range meeting our requirements were generally too large. Also, most of these sensors operate with a rod mounted perpendicular to one surface sliding into a sleeve mounted perpendicular to the other surface. This would make detector assembly more complicated, especially for the drift chamber/support tube. The sensor assembly would almost certainly decrease the effective clearance between the detector components being monitored. Also, this type of system would restrict motion parallel to the surfaces of the gap being measured.

2. Reflective sensors – These sensors consist of a light source (optical or infrared) and a light detector on one side of the gap and a diffuse or

spectrally reflective surface on the other side of the gap. The sensitivity of these sensors meets our requirements. There are two main categories of reflective sensors that we considered: those that use an optical fiber to bring in the light and those that use a local source such as an LED. The optical fiber systems (Philtec and MTI) are too large to meet our requirements. The final focussing assembly is typically about 9 cm long and 6 mm in diameter. The reflective sensors with LED's are much smaller. For example, OPTEK makes several sensors that are about 6mm×5mm×5mm. However, the range of these sensors is typically only a few mm. There is some sensitivity out to a couple of cm, but insufficient to meet our requirements.

3. Strain gauges mounted on a leaf spring – This position monitor is a contact device made from a leaf spring with two strain gauges mounted on each side of the spring. The resistances of the strain gauges are monitored with a bridge circuit. To achieve a range of 2 cm, the leaf springs are about 2 inches (5 cm) long. This system was prototyped at LBL. We rejected this system mostly because it is mechanically bulky. For the drift chamber/support tube monitoring systems, it has the additional disadvantages that it could not be used to monitor relative motion in ϕ or z (*i.e.,* relative transverse motion of the two surfaces) and that it would complicate assembly.

Several commercial companies make capacitive devices that have a range of about 2 cm and meet our requirements for resolution. In some cases, the response is linear for the first cm or so, with the sensitivity decreasing for larger distances. However, the resolution in the linear range is so good that the loss in sensitivity at larger distances is not necessarily a problem. We quantify this in Secs. 3 and 5. Of the companies we considered (Capacitec, Ono Sokki, RDP, MTI, and Queensgate), Capacitec's sensors are generally the smallest for a given range. For example, a Capacitec sensor with ≈7 mm linear range and ≈2 cm total range is 17 mm in diameter and 2.4 mm thick. Many high-energy-physics experiments, including Mark II, L3, DELPHI and SLD, have successfully used Capacitec sensors[5]. Capacitec sensors have the advantage of being an appropriate solution for both the SVT and drift chamber systems. In addition, this is a candidate system for monitoring the positions of the IR magnets and support tube with respect to a wire stretched through the interaction region. In the next section, we describe the

Capacitec sensors and readout electronics, and summarize their performance characteristics.

3 Description of Capacitec Sensors and Electronics

Capacitec manufactures the capacitive sensors, small coaxial readout cables, and readout electronics. They offer several types of standard connectors. The principles of operation, the electronic readout system and performance studies of Capacitec sensors are summarized in this section and described in more detail in BaBar Note #347[4].

3.1 Capacitec Sensors

With capacitive position sensors, one mounts a conductor to each of the two surfaces between which one is measuring the gap. The capacitance of this system of two conductors is measured. As the gap changes, the capacitance changes. With the Capacitec system, one conductor is the commercial sensor unit. The other surface is provided by the user and is electrically connected to the ground of the readout electronics (the electronics crate).

A Capacitec sensor is comprised of a conducting disk surrounded by a guard ring as shown in Fig. 1. The sensor is read out through a coaxial cable. The central conductor of the cable is connected to the central disk. The cable shield is connected to the guard ring. The sensor (central disk plus guard ring) is dipped in a polyamide coating so that it is electrically insulated from the support structure. The user supplies the conducting surface (typically larger in area than the sensor and electrically insulated from the support structure) that forms the other part of the capacitor. We will refer to this conducting surface as the target. The target is electrically connected to the ground of the electronics.

The model number of the sensor we plan to use for the SVT position monitoring system is HPB-375A-A-R3-30-M/B. The parts of the model number have the following meaning.

- HPB: button probe. This is the type of probe illustrated in Fig. 1.
- 375A: central sensor diameter = 375 mils (9.525 mm); outer diameter

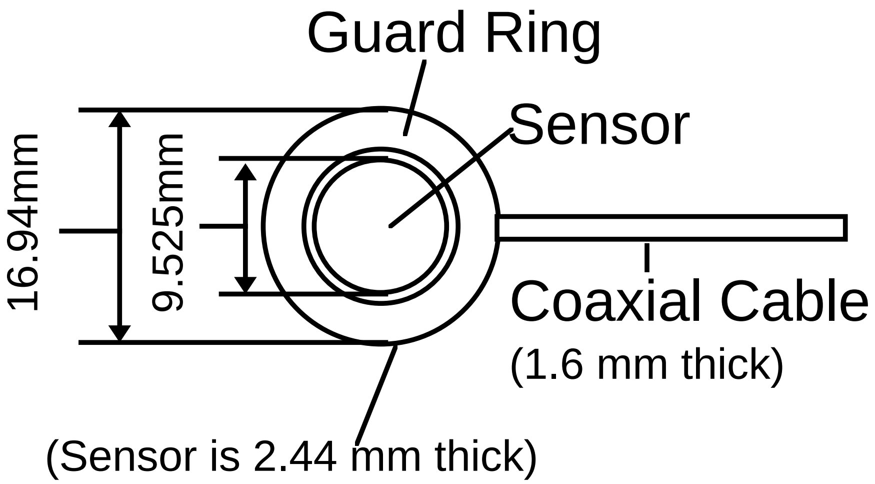


Figure 1: Capacitec button sensor and cable. This figure corresponds to model number HPB-375A which will be used for the SVT monitoring system. Model HPB-450/667sp, which will be used for the drift chamber system, has the same outer diameter but has a larger-diameter inner sensor and is thicker.

(including guard ring) = 667 mils (16.94 mm); thickness = 93 mils (2.4 mm).

- A: 0 to 150°C temperature range.
- R3: 63 mil (1.6 mm) outer diameter coaxial readout cable; radiation resistant cable (Kapton insulation instead of Teflon).
- 30: 30 foot cable length. The actual cable length will be determined by the routing of the cable through the detector. We will split the cable into at least two sections with connectors. See Sec. 6.
- M/B: 10-32 Microdot connector at interconnect; BNC connector at end. For the SVT system, the readout cable will be split at one or two *
  locations, including near the transition/matching cards. For the interconnects, we can use Microdot connectors, or Suhner microax (MCX) *
  or miniature microax (MMCX) connectors. The final connection to the readout electronics will be with a BNC connector. See Sec. 6 for details.

The model number of the sensor we plan to use for the drift chamber position monitoring system is HPB-450/667sp-A-R3-00-MMCX. The parts of the model number have the following meaning.

- HPB: button probe.
- 450/667sp: central sensor diameter = 450 mils (11.4 mm); outer diameter (including guard ring) = 667 mils (16.94 mm); thickness $\geq$ 3 mm. Note that the outer diameter is the same as that for the SVT sensors but the central sensor diameter is larger. This sensor is also thicker to accomodate a connector that is an integral part of the sensor (see below).
- A: 0 to 150°C temperature range.
- R3: 63 mil (1.6 mm) outer diameter coaxial readout cable; radiation resistant cable (Kapton insulation instead of Teflon).
- 00-MMCX: A Suhner 22MMCX-50-0-1 connector is imbedded directly in the body of the sensor.

See Sec. 4.2 for a description of the extension cables for the drift chamber sensors.

3.2 Capacitec Electronics

The electronics measures the capacitive reactance of the sensor and the conducting target by feeding an AC excitation current with constant amplitude and precisely controlled frequency (about 15 kHz) to the sensor and measuring the voltage between it and the ground target with a low-capacitance, narrow-band-pass amplifier tuned to the oscillator frequency. The reactance is inversely proportional to the capacitance:

$$X_C = \frac{V_p}{I_p} = \frac{1}{2\pi f C}$$

where I_p is the peak excitation current, V_p is the peak voltage measured between the sensor and the target, and f is the frequency of the excitation current. Since the capacitance for a parallel plate capacitor of area A and gap d is given by

$$C = \frac{\epsilon A}{d},$$

the reactance is proportional to the gap between the sensor and target if the gap is not large compared to the radius of the central part of the sensor.

The capacitance of the 375-mil-diameter central sensor for a 1 cm gap is approximately 63 fF while the capacitance of the 30-foot readout cable is on the order of a nF. These parallel capacitances would normally add so that the total measured capacitance is dominated by the readout cable, not the sensor. To eliminate the effect of the cable capacitance, the 15 kHz excitation current is applied to both the central sensor and the guard ring (through the central conductor and the shield of the cable, respectively). The electronics maintains the central sensor and guard ring at the same potential, effectively shorting out the cable capacitance. The guard ring has the additional advantage of reducing fringe-field effects.

3.3 Performance Characteristics

3.3.1 Tests of response characteristics

For a complete description of the response characteristics of Capacitec capacitive displacement sensors, see the companion BABAR Note #347 by Brian Kaczinski and Pat Burchat. In that note, we describe studies of the sensitivity of the output voltage to longitudinal displacements with respect to a planar target, the sensitivity to transverse displacements when the sensor is positioned over the edge of a conducting planar target, the effects of the electrical characteristics and the grounding of the target, the effects of conducting material around the sensor (e.g., the mechanical mount for the sensor), and the dependence of the response on temperature and humidity. In addition, we describe a study of the sensitivity of the output to displacement with respect to a wire target.

In Figure 2, we show the output voltage of the HPB-375B-A sensor as a function of longitudinal displacement (gap) for a planar target 0 to 20 mm from the target. The solid curve represents the response of the sensor. The dashed line represents an extrapolation of the linear response of the sensor near zero displacement, with slope 0.95 mV/μm. The dotted line represents the asymptotic voltage determined by measuring the response with the sensor very far from the target. See Table 1 later in this memo for the resulting digitization error expected for the VSAM digitizing module.

3.3.2 Radiation hardness

In tests for the Mark II detector, Alan Breakstone checked the radiation hardness of a sensor by placing it in a ^{60}Co well with an irradiation rate of about 420 rad/hour for 331 hours, for a total dose of about 138 krad.[5] No significant voltage changes occurred. These tests are sufficient to meet our requirement of 100 kRad. Capacitec makes radiation-hard readout cables (developed for Mark II) which have Kapton insulation rather than Teflon. We will use the radiation-hard cables at least in the inner parts of the detector.

3.3.3 Dependence on temperature and humidity

The studies described in BaBar Note #347 showed that although the sensors are not sensitive to humidity, they are sensitive to temperature. We checked that the sensor output is not sensitive to the temperature of the electronics. The fractional temperature sensitivity of the output voltage is about $0.2\%/^{\circ}C$ at 18°C and $0.1\%/^{\circ}C$ at 28°C. This can be compared to the expected digitization error of 0.05% for the BaBar-standard VSAM. Therefore, the dependence on temperature will dominate the uncertainty on position unless we know the temperature to within a fraction of a °C.

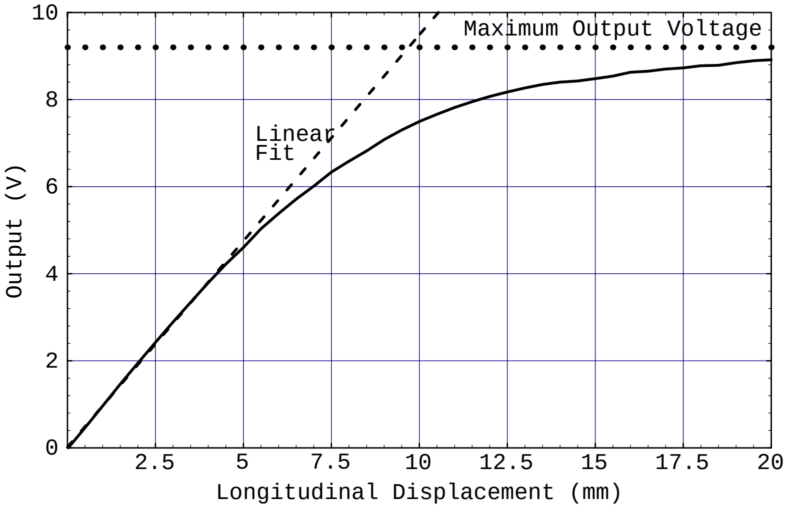


Figure 2: Output voltage of the HPB-375B-A sensor as a function of longitudinal displacement (gap) for a planar target. The solid curve represents the response of the sensor. The dashed line represents an extrapolation of the linear response of the sensor near zero displacement, with slope 0.95 mV/μm. The dotted line represents the asymptotic voltage determined by measuring the response with the sensor very far from the target.

3.3.4 Immunity to noise

The capacitive system is quite immune to noise. As described above, the capacitive reactance is measured by putting a constant AC current of a precisely controlled frequency (about 15 kHz) onto the sensor and measuring the voltage drop across the sensor with a low-capacitance, narrow-band-pass amplifier tuned to the oscillator frequency.

3.3.5 Noise generation

Many experiments (including Mark II, L3, Delphi, SLD) have used Capacitec sensors extremely close to the readout electronics of their detectors with no problems. However they did have to ensure that the sensors were electrically insulated from the detector/sensor support structure. Capacitec sensors are available with a 100-μm-thick coating of polyamide to provide this insulation. In his NIM article[5], Alan Breakstone describes the performance in the Mark II detector: “Similar tests at SLAC using a prototype of the support structure for the Mark-II silicon detector with a dc-coupled silicon detector read out by NMOS Microplex chips showed no difference in calibration signals nor noise levels with or without the capacitive displacement monitoring sensors being pulsed with their 15 kHz driving signals. In this case, the sensors were electronically isolated from the support structures using a nonconductive epoxy.” In SLD, the distance is measured to a wire strung through the IR next to the CCD detector and electronics. They detect no pickup from the 15 kHz excitation signal.

To test the sensitivity of the drift chamber readout electronics to the sensor signal, we positioned a sensor driven with the normal excitation current in the vicinity of the readout electronics in the drift chamber prototype at SLAC. The feedthroughs and wire spacing in this prototype are the same as the final design. However, the prototype electronics are not the final design. Hence, we will redo this test later with the next version of the prototype electronics. We judged that the most sensitive part of the drift chamber electronics is the input to the discriminator. We triggered an oscilloscope on the 15 kHz sensor signal and monitored the output of the discriminator. We lowered the discriminator threshold until we could see the discriminator firing without any signal on the sensor. We then positioned the sensor in various locations near the feedthroughs and the electronics. We could not induce a detectable signal on the drift chamber electronics. The only situation in which we saw an observable increase in the firing rate was when we wound the sensor cable around the feedthroughs. However, the observed pickup was there even with the displacement sensor electronics turned off; the cable was merely acting as an antenna. We tentatively conclude that the Capacitec sensor signals will not affect the drift chamber electronics.

4 Mechanical Mounting of Sensors

4.1 SVT Mechanical Mounting

The gap between the SVT carbon-fiber support cones and the B1 magnets will be measured near the large end of each support cone (the end furthest from the interaction point). In addition, the relative position in z of the support cone and the B1 magnet will be measured in the backward direction. The SVT cones are connected to the B1 magnets via a gimbal system in both the forward and backward regions. See Fig. 3. The gimbal rings allow rotation of the cones relative to the B1 magnets about any axis passing through the center of the gimbal ring and lying in a plane perpendicular to the central axis of the magnet. In addition to these sorts of rotations, the backward gimbal allows relative motion of ± 2 mm in z and unrestricted rotation about the z axis. The B1 magnets are mounted to the Q1 magnets and the Q1 magnets are mounted to the inside of the stainless steel sections of the support tube. Each end of the central beampipe is connected through bellows to the vacuum chambers in the B1 magnets. Therefore, relative motion of the two B1 magnets is not constrained through the beampipe. The B1 magnets are mounted to the Q1 magnets which are in turn mounted to the stainless steel sections of the support tubes. The relative motion of the stainless steel sections of the support tube are constrained by the carbon-fiber section of the support tube. Once the two B1 magnets are mounted inside the support tube, no relative motion in ϕ is expected[2]. Therefore, we do not plan to monitor ϕ motion.

The coefficient of thermal expansion for stainless steel is $16 \times 10^{-6}/^{\circ}$C. Therefore, the thermal expansion over 1 m of steel is about 16 μm/°C. Therefore, if the temperature of the support tube is constant to a couple of °C, we can expect changes in the relative z position of the support cone and B1 magnet in the backward direction on the order of a few tens of microns. We will monitor these changes with two sensors.

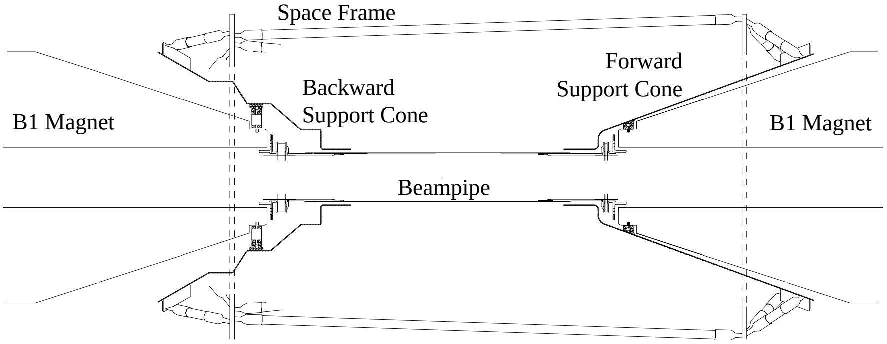


Figure 3: Cross-section (y-z) of the PEP-II interaction region showing the kinematic mounting of the SVT support cones from the B1 magnets with gimbal rings. The two support cones are rigidly connected to each other by a space frame (shown at large radius) and by the ribs supporting each detector module (not shown).

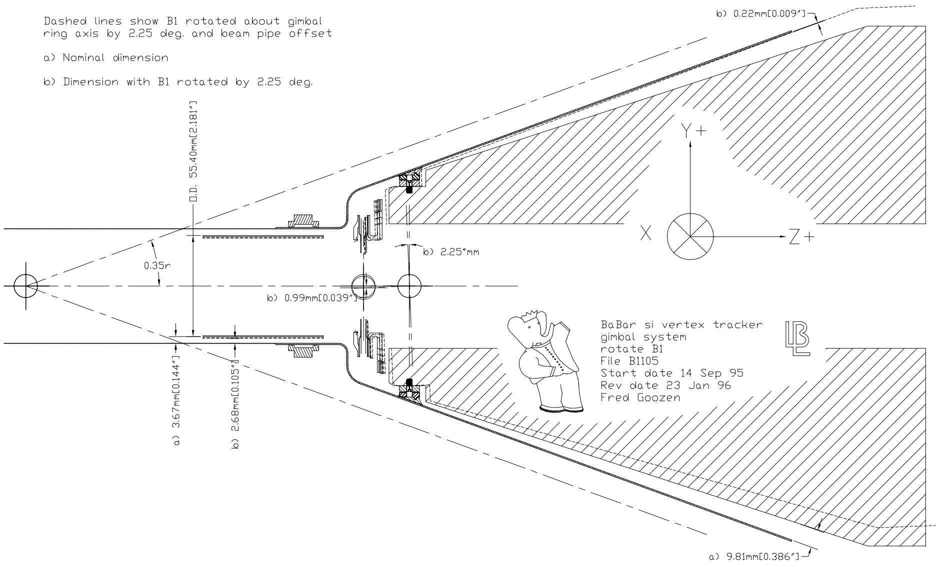


Figure 4: Cross-section through the forward end ($z > 0$) of the interaction region showing the forward B1 magnet in its nominal position relative to the support cone (solid lines) and rotated by 2.25° (dashed lines) when it first makes contact with the support cone at the cone's large end.

The maximum relative motion of the forward B1 magnet with respect to the forward SVT support cone is a rotation of 2.25°, determined by when the inner surface of the support cone and the outer surface of the B1 magnet first make contact. This is illustrated in Fig. 4. During this rotation, the minimum gap between the large end of the cone and the B1 magnet changes from the nominal 9.7 mm to 0 mm, while the minimum gap between the small end of the cone and the beampipe changes from the nominal 3.7 mm to 2.7 mm. Therefore, the forward cone will always touch the B1 magnet at the large end of the cone first. A detailed view of this region is shown in Fig. 5. We will locate the forward sensors so that they measure the gap near the large end of the cone at a point at which the nominal gap is 7.51 mm and the total range of gap sizes is 0 to 15 mm. Details are given below.

In the backward region, the gap between the large end of the cone and the B1 magnet is much larger (about 4 cm). Service lines for the interaction region will run between the backward cone and the B1 at certain locations in azimuth. However, there is room for standoffs to be attached to the B1

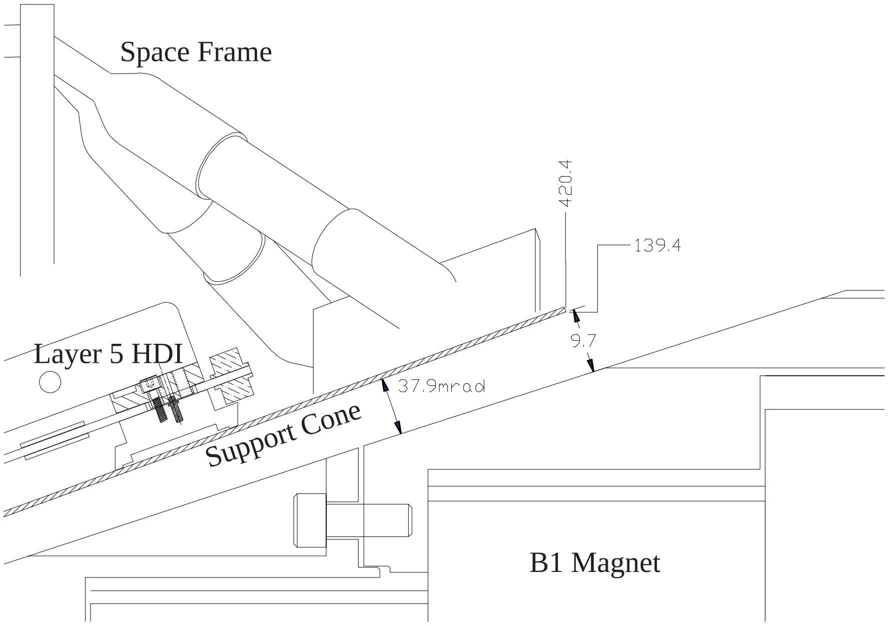


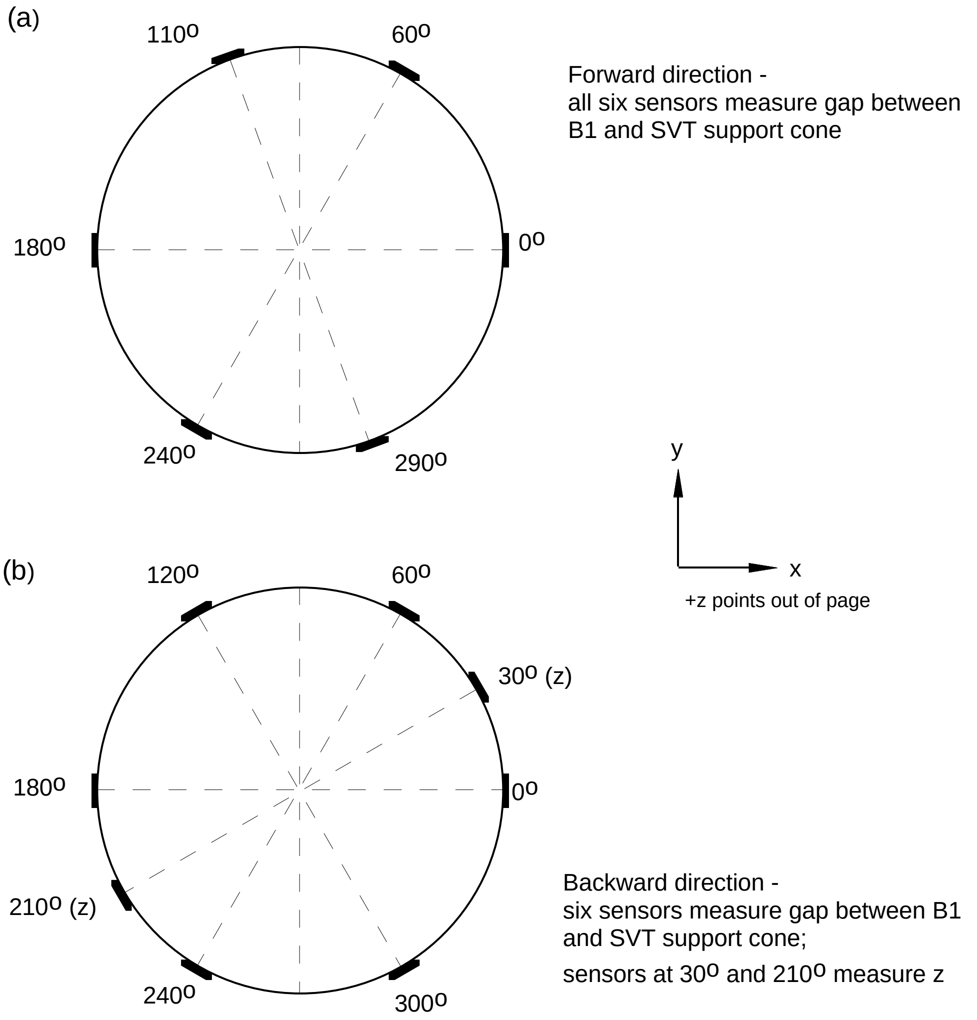
Figure 5: Detail of the space at the large end of the forward support cone. Dimensions are given in milimeters.

magnet near the end of the cones to decrease the gap to ≈ 8 mm so that contact occurs at this point before the narrow end of the cone touches the beampipe. Reducing the gap between the sensor and the cone with the standoffs maximizes the sensitivity of the sensors. However, the standoffs and sensors are still on the magnet side of the stayclear region between the magnet and the support cones. Details are given below.

The SVT support cones are each constructed in two halves and joined in the vertical plane. There need to be enough position sensors to monitor each half of the SVT "clamshell" separately during installation onto the B1 magnets. We will install three sensors for measuring gaps on each half of the clamshell. The locations of the sensors around the B1 magnet are shown in Fig. 6. In both the forward and backward directions, two sensors will be located in the horizonatal plane. In the forward direction, two sensors will be 60° from the horizontal plane and two will be 70° from the horizontal plane. The reason all four sensors are not 60° from the horizontal plane is because of mechanical interference with other components of the B1 magnet collars. In the backward direction, four sensors measuring gap will be 60° from the horizontal plane. In addition, two sensors in the backward region will monitor z motion. These sensors are located 30° from the horizontal. Finally, if space allows, we will locate one sensor with a fixed gap near each end of the SVT as a calibration sensor to detect residual sensitivity to changing conditions such as temperature, humidity, and magnet fields. Therefore, there will be six sensors at the forward end, eight sensors at the backward end, and two calibration sensors, or 16 channels altogether.

The capacitive sensors will be mounted on the B1 magnets and the conducting targets will be mounted on the inside surface of the support cones. The locations of the sensors in the z direction are shown in Fig. 7. The detailed engineering of the sensor mounts on the B1 magnets has been done by Andy Ringwall at SLAC. The drawings for the mounts are in one of the SLAC machine shops. The end of each Aluminum insert or standoff, to which the sensors will be mounted, will be machined flat so that the surface is parallel to the (curved) inner surface of the support cone when the B1 magnet and cone are in their nominal positions. The sensors will be located with respect to scribe lines on the flat faces of the inserts.

In the forward direction, the sensors will be glued onto Aluminum inserts in slice number 7 of the B1 collar. Slice number 8 will be machined to provide a guide for the cable to the end of the sloped face of the magnet. The inserts and sensors are recessed enough so that the sensors themselves



Forward direction -
all six sensors measure gap between
B1 and SVT support cone

Backward direction -
six sensors measure gap between B1
and SVT support cone;
sensors at 30° and 210° measure z

Figure 6: Azimuthal location of the sensors on the B1 magnet in (a) the forward direction (slice 7 of the magnet collar) and (b) the backward direction (slice 5 of the magnet collar). These views show the forward end of the B1 magnet looking towards the interaction point in (a) and the backward end of the B1 magnet looking from the interaction point in (b).

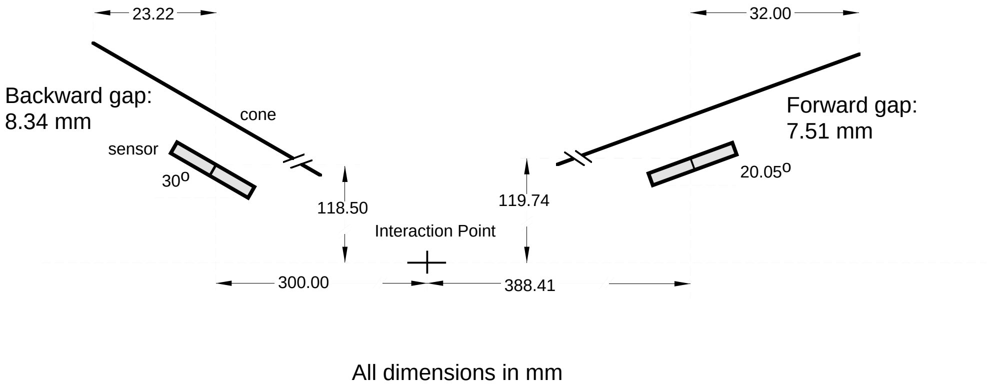


Figure 7: Positions of the SVT position sensors in the z direction.

do not reduce the size of the nominal gap between the support cone and the B1 magnet. The size of the flat face of the inserts is about 1.9 cm by 2.7 cm. The inserts are about 4.7 mm thick. With the B1 magnet and SVT support cone in their nominal positions, the distance from the center of the top surface of the sensor to the edge of the SVT support cone is 32 mm along the z direction, as shown in Fig. 7. The nominal gap between the center of the top surface of the sensor and the surface of the cone is 7.51 mm.

In the backward direction, the sensors will be glued to the flat ends of standoffs mounted to slice number 5 of the B1 magnet collar. The standoffs are about 2.5 cm long. The size of the flat face of the mount is about 2.0 cm by 2.4 cm. With the B1 magnet and SVT support cone in their nominal positions, the distance from the center of the top surface of the sensor to the edge of the SVT support cone is 23.22 mm in the z direction, as shown in Fig. 7. The nominal gap between the center of the top surface of the sensor and the surface of the cone is 8.34 mm.

Each sensor mount has a countersunk hole about 12 mm in diameter and 0.25 mm deep to accomodate the epoxy for gluing the sensor in place. Andy Ringwall is ordering an appropriate 3M epoxy.

Each sensor cable will have a connector near the matching cards. Beyond these connectors, the sensor cables for one half-clam-shell are bundled together and follow the same route out of the detector, near the horizontal plane. Unless there is room for excess cable, the exact distance from each sensor to the connectors near the matching cards will need to be determined before the sensor/cable assembly is ordered. The sensors will be glued in place and the cable connections will be made before the SVT is installed.

The conducting target for all of the sensors measuring the position of one half of an SVT support cone is comprised of a single piece of copper-clad Kapton (illustrated in Fig. 8) glued to the inner surface of each SVT support half-cone. The targets are 4 cm wide. This width is chosen so that the target is about twice as wide as the sensor (1.7 cm), and also about twice as large as the maximum gap (≈15 mm in the forward direction; ≈17 mm in the backward direction). The targets extend to within 5 mm of the two straight edges of each half-cone. In the forward direction, the target extends to within 16.84 mm of the curved edge of the cone. In the backward direction, the target extends to within 11.64 mm of the end of the cone. The exact placement of the target on the forward cone is not critical since only gaps are measured in the forward direction. Placement to within 1 mm of the nominal position is adequate. However, because two sensors in the backward direction measure z, the initial knowledge of the relative z positions of the B1 magnet and the SVT support cone will be determined by how well the position of the Kapton target on the support cone is known. The Kapton in the forward and backward directions will be 2 mil (50 μm) thick with 1 oz. copper (0.001 inch thick). We have not determined the type of adhesive that will be used. * The cable for the target will be either an extension of the target itself (*i.e.,* a copper-clad Kapton tail) or a multistrand single-conductor wire (say, AWG-26) soldered directly to the copper on the Kapton.

The target cables will have a connector near the matching cards. Beyond this connector the target cable will be bundled with the sensor cables. The target cable connection must be made after the SVT half-cones are installed on the B1 magnets.

4.2 Drift Chamber Mechanical Mounting

The purpose of the drift-chamber position monitoring system is to provide information that will allow us to determine the relative positions of the support tube (and hence, indirectly, the SVT) and the drift chamber wires. The endplates of the drift chamber determine the positions of the wires. Therefore, we are locating the position sensors so that we measure the gap between the support tube and the inner cylinder of the drift chamber at a location as close to the endplates as mechanically feasible. The nominal gap between the support tube and the drift chamber inner cylinder is 1.45 cm. Tuning of the

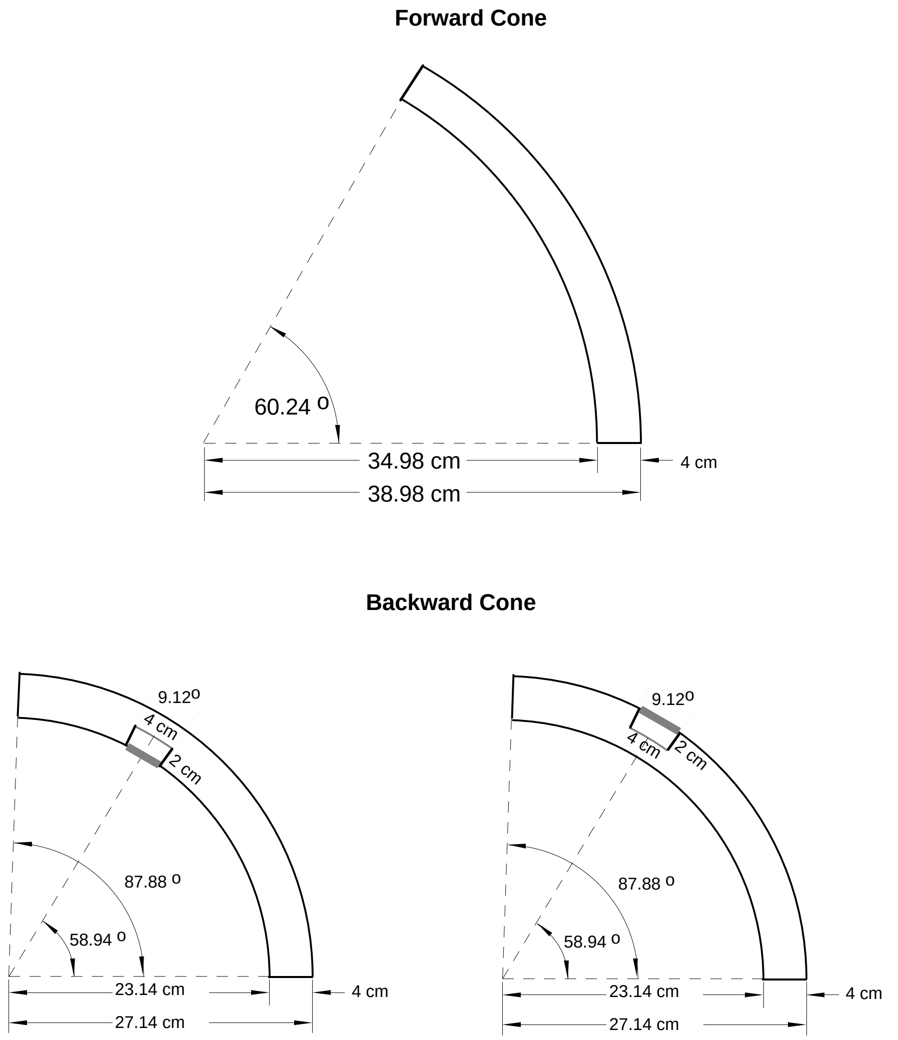


Figure 8: Pattern of copper-clad-Kapton targets on the inner surface of each SVT support half-cone, opposite the sensors mounted on the B1 magnet, in the forward region and the backward region.

PEP-II machine could require the support tube to be moved by up to 5 mm in the x-y plane from its nominal location. Therefore, the expected range of gap sizes to be measured at this location is about 10 - 20 mm, although the mechanically allowed range is 0 - 29 mm. The fact that the nominal gap is greater than 1 cm has led us to choose the HPB-450/667sp sensor for the drift chamber monitoring system, rather than the HPB-375 sensor which is being used for the SVT system. The sensors have the same outer diameter (667 mils) but the HPB-450/667sp has a central sensor diameter of 450 mils while the HPB-375 has a central sensor diameter of 375 mils. Both have an outer diameter of 667 mils. In addition, we are designing a sensor mount for the drift chamber (described below) that allows the sensor to extend into the gap between the drift chamber inner cylinder and the support tube during normal running, thereby decreasing the nominal gap size, but retract during installation and in the case of contact during an earthquake.

The mechanical drawings for the drift chamber inner cylinder, showing the size and location of the holes for mounting the sensors, can be found on the web at `ftp://bbr-boyce.slac.stanford.edu/pub-rfb/vanni/innercyl.dwg` and are available through anonymous ftp from `bbr-boyce.slac.stanford.edu` in the directory `D:/pub-rfb/vanni/innercyl.dwg`.

The inner cylinder of the drift chamber extends beyond the endplates in both the forward and backward direction. The Aluminum cylinder wall in this region is 3-mm thick in the backward direction and 3.5-mm thick in the forward direction. The sensor mounts will penetrate the inner cylinder of the drift chamber just outside the endplates as illustrated in Fig. 9. The distance between the inner surface of the endplate (where the wires are positioned) and the center of each sensor is 50 mm. The penetration holes in the drift chamber inner cylinder have a diameter of 20 mm. Recall that the sensor diameter is 17 mm. The countersink has a diameter of 32 mm. The depth of the countersink is such that the minimum thickness of the cylinder wall is 2.39 mm in both the forward and backward direction. There are three 4-40 tapped holes on a 25 mm diameter to locate the sensor mount.

The details of the sensor mounts are being worked on by the Stanford group, Richard Boyce, Mike Palrang and Adam Boyarski at SLAC, and Capacitec. A conceptual design of the sensor mount is shown in Figure 10. In this figure, the face of the sensor is 5 mm from the inner wall of the inner cylinder when the mount is in its normal extended position. The final value for this distance will depend on the design constraints outlined below. The mounts will be made of Aluminum, possibly anodized.

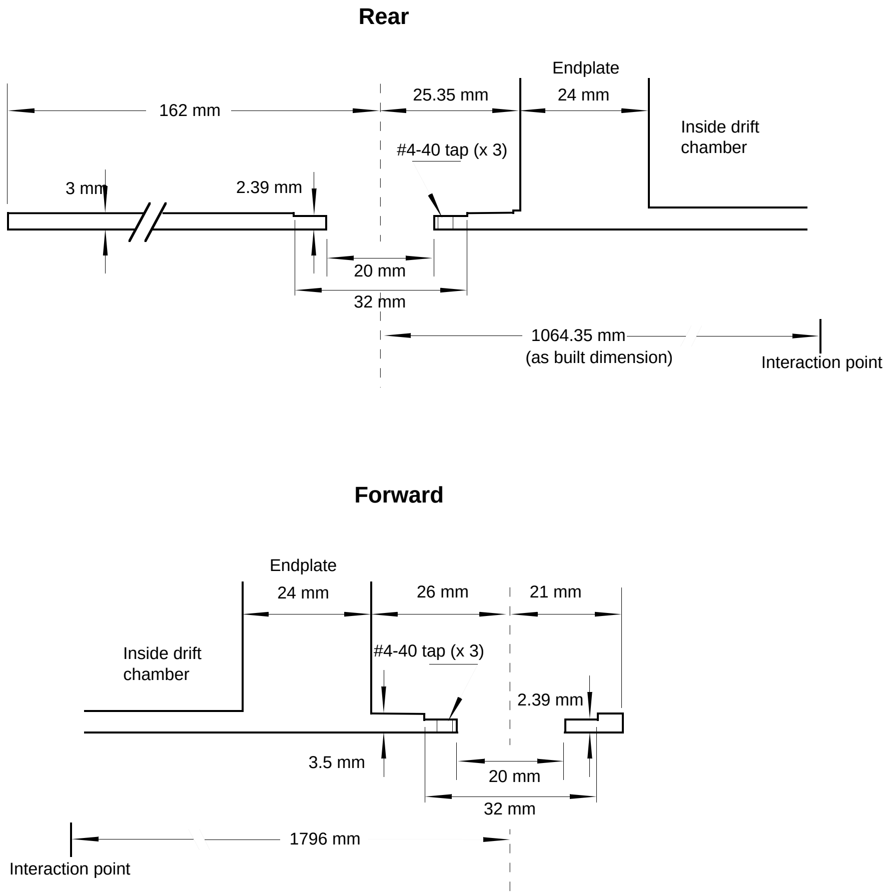


Figure 9: Penetration holes in drift chamber inner cylinder for sensor mounts.

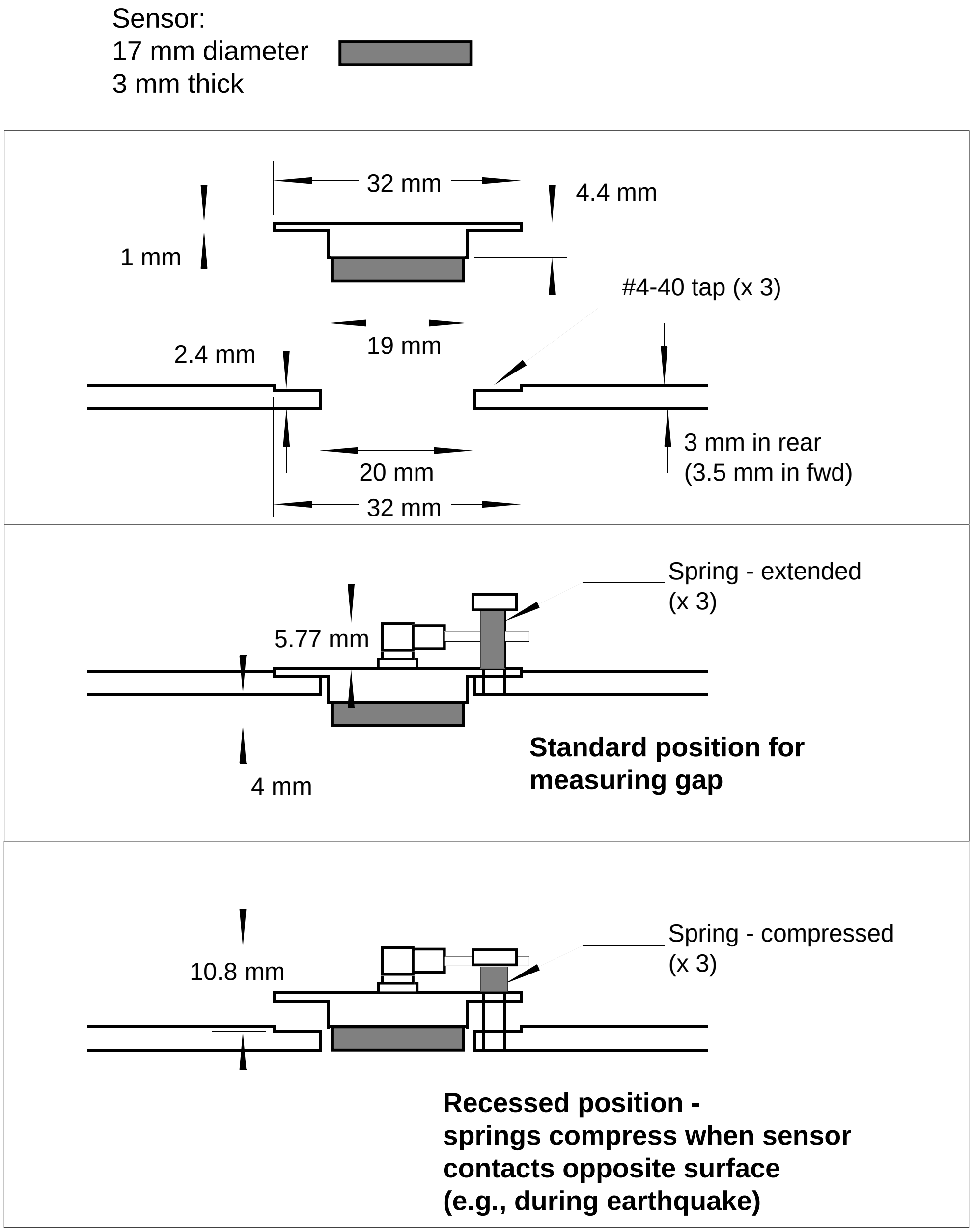


Figure 10: Conceptual design of the sensor mounts for the drift chamber, to be used in the penetration holes in the inner cylinder shown in the previous figure.

Threaded fasteners will be used to position the mount with respect to the three tapped holes in the Aluminum inner cylinder of the drift chamber. The springs shown in the drawing are meant to indicate conceptually that normally the sensor/mount assembly will extend into the gap. The springs will compress in the case of contact between the support tube and the sensors (*e.g.*, during an earthquake) and will return the sensor to the normal extended position when contact is broken. We will design a locking mechanism such that during installation, the sensors can be "locked" into the retracted position, with the springs compressed.

A Suhner connector (female receptacle with solder ends, model 22MMCX-50-0-1, p. 50 in Suhner catalogue) is embedded in the sensor body. A Suhner right-angle connector (model 16MMCX-50-1-1, p. 48 in Suhner catalogue) plugs into the sensor. The right-angle connector can rotate 360° with respect to the connector in the sensor body. The right-angle connector is at one end of an extension cable that goes from the sensor, to a small Suhner bulkhead connector in the bulkhead connected to the inner cylinder at each end of the drift chamber.[4] The connector at the bulkhead is a Suhner bulkhead jack (model 24MCX-50-2-10C, p. 70 in Suhner catalogue). The maximum bulkhead thickness that this connector can accomodate is 5 mm. We will put insulating inserts in the panel for mounting these connectors since we do not want the cable shield (which is connected to the guard ring of the sensor) to be electrically connected to the drift chamber RF shield. We will use the mechanical mockup of the end region of the drift chamber to determine the length of the extension cables.

There are several design issues that have not yet been settled but are being actively worked on in collaboration with Capacitec engineers. Can we * design a mount that will reseat itself after the mount has been forced into its retracted position (*e.g.*, during an earthquake)? What is the tolerance on the reproducability of the sensor position in both the longitudinal and transverse directions, after reseating? How much space will the mount and connectors occupy when the mount is in the retracted position? Will there be interference between the retracted mount and components on the drift chamber endplate? To answer this last question, we are incorporating detailed drawings of the sensor mounts in the mechanical drawings of the drift

---

[4] Another option is for the extension cable to penetrate a "rubber stopper" in the bulkhead. This rubber stopper allows cables to penetrate the bulkhead while retaining a fairly good gas seal. The volume inside the rf shields at each end of the drift chamber will be constantly purged with nitrogen to carry away any helium that leaks from the chamber.

chamber endplate. The item which provides the tightest constraint in the backward direction is the PC cards for the drift chamber electronics.

Capacitec will build the sensor mounts, including attaching the sensors to the mounts. The design details that we need to specify before we can order the sensors are the length of the extension cable, the length of cable needed to go from the RF shield to the Capacitec electronics, and the exact design of the sensor mounts. We need to know all cable lengths before any sensors * can be delivered since the sensors must be calibrated with their final cables at the factory.

There will be eight sensors at each end of the drift chamber measuring the relative positions of the drift-chamber inner cylinder and the support tube: two measuring the radial gap in the horizontal plane, two measuring the radial gap in the vertical plane, two measuring the relative z position, and two measuring the relative ϕ position. The positions of the sensors in azimuth are shown in Fig. 11. This is a view of the outside face of the forward end of the drift chamber, or the inside face of the forward end of the drift chamber.[5] In the BaBar coordinate system, x is increasing to the right, y is increasing up, and z is increasing out of the page. The sensors in both the forward and backward region will be at the indicated ϕ locations. The four sensors measuring the radial gap will be located at 0°, 90°, 180° and 270°. The sensors measuring z and ϕ motion are +12° from the sensors measuring radial gaps. The two sensors measuring the relative z positions will be at 12° and 192°. The two sensors measuring the relative ϕ positions will be at 102° and 282°. For redundancy there are two sensors measuring each type of relative position of the drift chamber and the support tube. The sensors in each pair are located on opposite sides of the inner drift chamber cylinder so that when the gap at one sensor increases beyond its nominal size, where measurement sensitivity is degraded, the gap at the other sensor decreases below its nominal size, where sensitivity is greater. The redundant radial gap measurements can also be used to check whether the overall difference in the outer diameter of the support tube and the inner diameter of the drift chamber inner cylinder is changing with time due to temperature changes, for example. The sensors measuring radial gaps are 12° away from those measuring ϕ or z so that the edges of the sensors are approximately two

---

[5] The positions shown in this figure correspond to the new positions, which are the mirror image of the old positions, to compensate for the mistake made in the drilling of the endplate discovered 3/97.

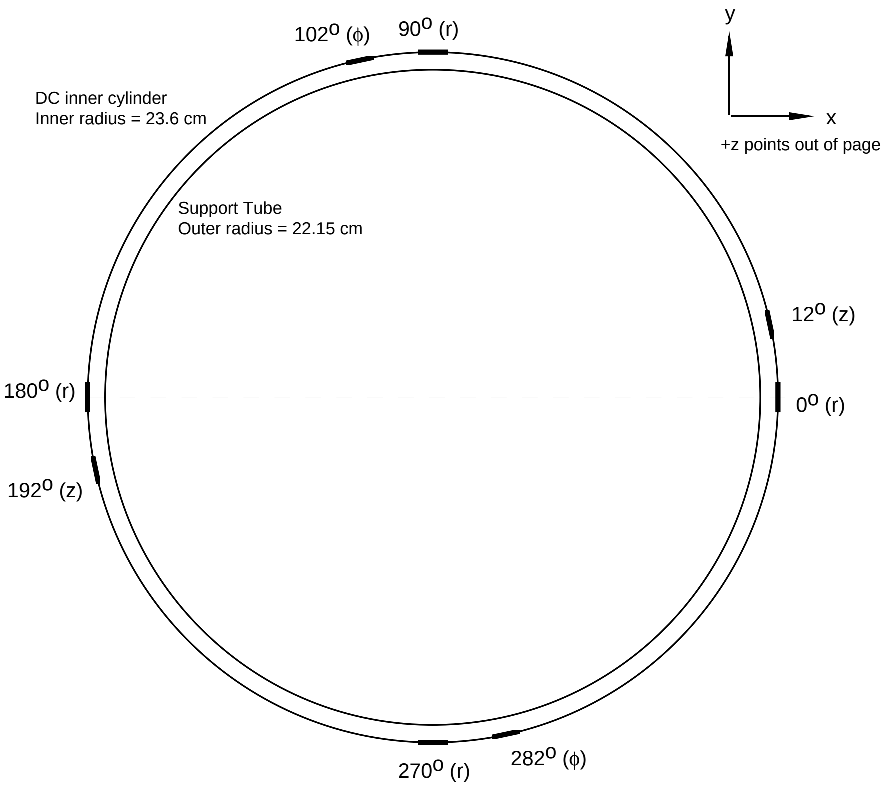


Figure 11: Azimuthal locations of position sensors measuring the relative positions of the inner cylinder of the drift chamber and the outer surface of the support tube. This view shows the forward end of the drift chamber as viewed from outside the chamber or the backward end as viewed from inside the chamber.

sensor-diameters apart, to reduce the influence of the electric fields from one sensor on the other, yet the sensors are close enough so that the radial gap at each sensor measuring ϕ or z can be determined accurately from the nearby sensor that is measuring the radial gap directly.

The conducting target for the eight position sensors at each end of the drift chamber is comprised of one or two 4-cm wide pieces of copper-clad Kapton glued to the support tube opposite the sensors. The width is chosen to be 4 cm so that the target is about twice as wide as the sensor (1.7 cm), and also about twice as large as the maximum gap (2 cm). It is expected that the drift chamber and support tube will initially be placed to within ±2 mm of their nominal relative z position[2]. The shape of the Kapton and the copper pattern on the Kapton is shown in Fig. 12. If the length of the piece (about 120 cm) is a problem for manufacturing, the target can be made in two pieces. Also, since the electronics for the sensors in the forward direction will be located in two different places (for cabling convenience), the target in the forward direction will be split into two pieces to avoid ground loops. The pieces in the backward direction can be made identical to those in the forward direction. The rectangular patches with no copper at 12° and 192° are for the z measurements and those at 102° and 282° are for ϕ measurements. The ϕ patches are 3.4 cm wide and 2.6 cm along the length of the Kapton. The z patches are 1.70 cm wide and 3.4 cm along the length of the Kapton. The Kapton target starts at $-12°$ (12° from the gap sensor at 0°) and ends at 294° (12° from the ϕ sensor at 282°).

The target will be recessed in a groove machined into the outer surface of the support tube so that it will be protected during assembly of the BaBar detector. In addition, the radius and surface of the groove will be machined to tighter tolerances than the rest of the stainless steel portion of the support tube. (Exact tolerances have not been specified. We'll be discussing these issues with Scott Debarger when the detailed design of the support tube starts.) The groove will be 4.1 cm wide and 0.6 mm deep. The radius of the * surface of the groove is (21.15 cm - 0.06 cm) = 21.09 cm. The z position of the center of the forward groove is 179.60 cm; that for the backward groove is -106.50 cm. The Kapton will be 0.5 mm thick and the thickness of the copper will be 1 oz. (0.001 inch). Therefore, we are allowing for 3 mils of glue. The Kapton is relatively thick to increase the sensitivity of the measurements of transverse position (ϕ and z). Because the sensors measure z and ϕ, as well as gap sizes, the initial knowledge of the relative z and ϕ positions of the drift chamber and the support tube will be determined by how well the position of the Kapton target on the support tube is known. We need to specify * the tolerances on the placement of the Kapton on the outer surface of the support tube. The cable for the target will be a multistrand single-conductor wire (say, AWG-26) or could be an extension of the target itself (copper-clad Kapton tail).

There are several issues that have not been settled yet regarding sensor and target cables for the drift chamber postion-monitoring system. *

1. Where in ϕ does each target cable get brought out? Does the target

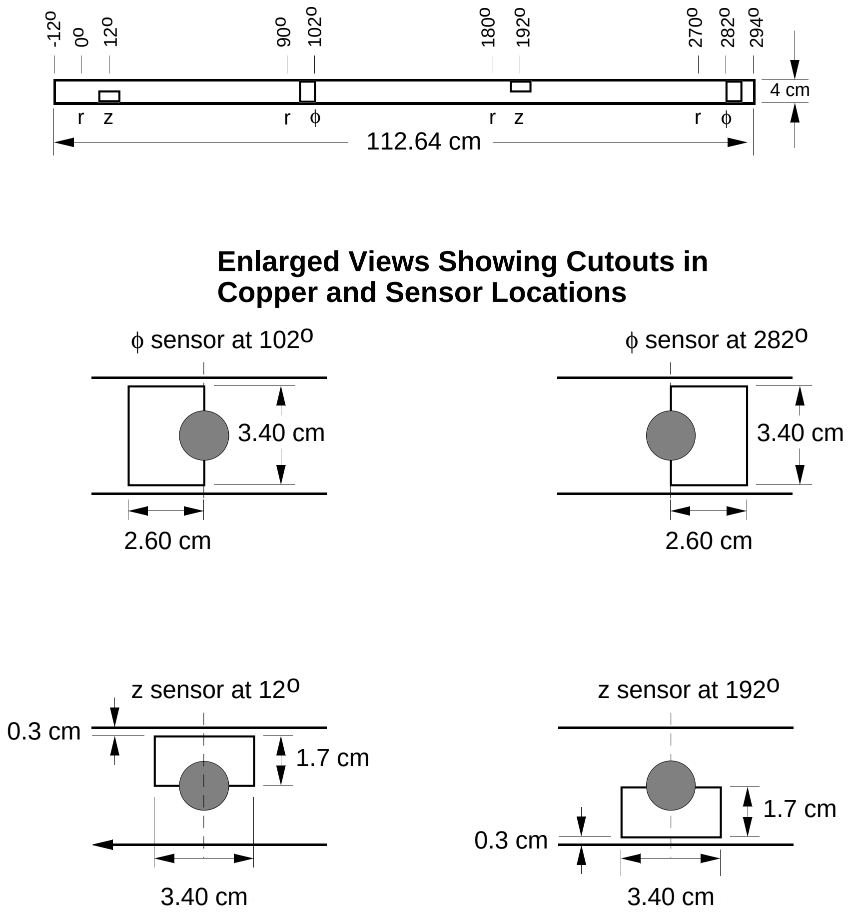


Figure 12: Pattern of copper-clad-Kapton targets on the outer surface of the support tube, opposite the sensors mounted on the inside of the inner cylinder of the drift chamber. The Kapton target in the forward direction will be made in two pieces to avoid ground loops.

cable need to be recessed?

2. What is the cabling path for the sensor and target cables?
3. Where do interconnects need to be made in the sensor and target cables?
4. Which of the choices of connectors for sensor cables is most suitable (miniature MMCX Microax connectors, Microdot connectors or BNC connectors)?
5. What sort of connector should be used for the target cable?

As an extra precaution against the sensor cables generating signals that could be picked up by the drift chamber electronics, we could consider using a triax cable in the region between the sensors and the RF shielding panel. However, the sensitivity of the sensors would be degraded because of the extra capacitance of the outer shield. Since we saw no evidence of pickup when we operated the sensors in the vicinity of the prototype drift chamber electronics, as described in Sec. 3.3.5, we do not plan to use triax cable. If we did find in the final setup that pickup does occur, we could then add an extra cable shield.

5 Readout System Design

Figures 13 and 14 show the physical layouts of the readout systems for the SVT and drift chamber position-monitoring systems. We will use the Capacitec readout system which generates a 0 - 10 V analog voltage output signal proportional to the capacitive reactance of the sensor/target configuration, as described in Sec. 2. A single channel amplifier is housed in a one-inch wide module in a Eurostyle 2u crate (3.45 inches high). Each 19-inch wide crate handles up to 16 channels of amplifiers plus a single clock driver card which supplies the 15 kHz excitation signal. Each crate requires a ±15 VDC regulated power supply at 850 mA. An internal 115, 220 or 240 VAC power supply is available from Capacitec. We plan to use the internal 115 V (850 mA) power supply. These electronics will be housed inside the shielding wall, in SVT monitoring racks near the SVT MUX racks.[6] The SVT support cone/B1 system and the drift chamber/support tube system are each 16-channel systems, requiring two crates between them. For cabling convenience, the channels from the two systems on the backward end will share one crate and those on the forward end will share another two crates located on either side of the detector. Therefore, we are planning to have a total of three crates. Although this is one more crate and clock-card than absolutely necessary, and sixteen of the slots in the crates will be empty, this option minimizes cable lengths and adds flexibility in cable routing.

We should consider supplying the position monitoring electronics and readout system with uninteruptable power if we want to monitor relative motion of the SVT and B1 magnets or drift chamber and support tube continuously during power outages. Examples of motions we might want to monitor continuously, which could be correlated with power outages, are those that occur during earthquakes or when the magnetic field turns off.

The 0 - 10 V signals will be transported from the Capacitec electronics to the monitoring crates outside the shielding wall with 32 twisted pairs as described in the next section. We will use a standard BaBar 32-channel VME Smart Analog Monitor (VSAM) to digitize the analog voltages. The BaBar VSAM module is described in Reference [6], and is essentially the VME-based version of the earlier CAMAC-based SAM that has been widely used at SLAC. A VSAM accepts 32 differential analog voltage inputs which it converts to digital floating-point output values. The module operates by cycling through its inputs at 50 Hz and converting each one in turn. It has an automatically adjusting input range (in steps of 2) from ±2 mV up to ±10.24 V. The internal ADC has a resolution of 15 bits. The conversion accuracy of the new VME-based VSAM is specified as ±0.05% of the reading plus 20 μV. This is the same specification as the old CAMAC-based SAM's which were based on a 12-bit ADC. In Table 1, we show the measured (approximate) voltage output and sensitivity for different gap sizes (see Figure 2 in this memo and Reference [4] for details), and the resulting digitization error for the VSAM. The digitizing error is < 1 μm, 11 μm and 58 μm at $\approx$0, 1 and 2 cm gap, respectively. For gap sizes in the 0 to 1 cm range, the VSAM digitization error meets the requirements for the system. For gap sizes

---

[6] Since the SVT position-monitoring system will be electrically isolated from the SVT readout system (*i.e.,* it will be outside the SVT grounding and shielding), the SVT position-monitoring electronics crate will not be in the SVT MUX racks themselves.

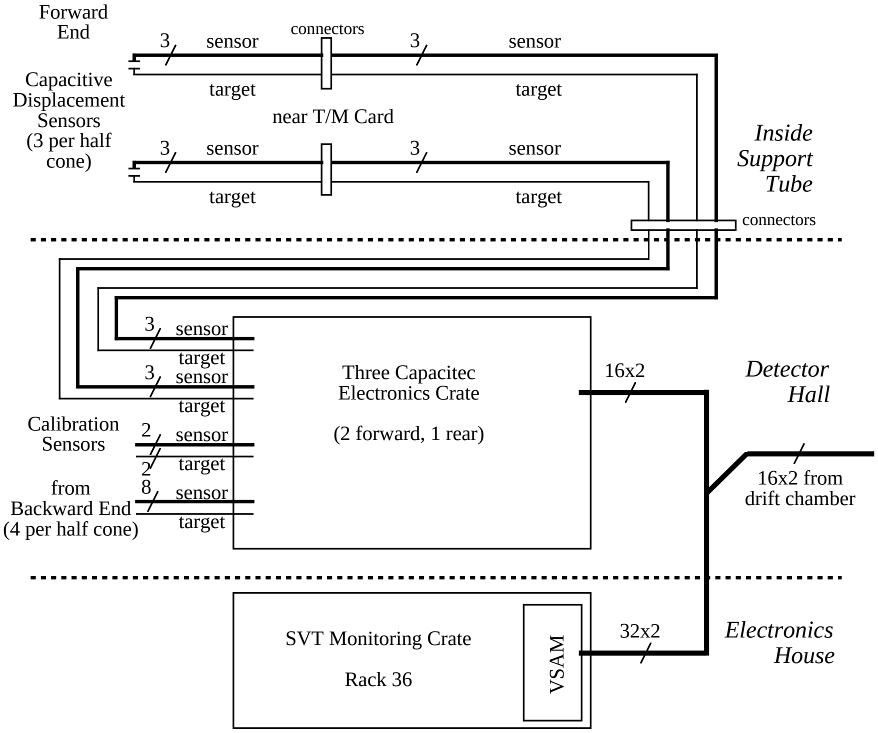


Figure 13: Physical layout of the SVT position-monitoring system showing the location of its components and their interconnections. Note that the sixteen SVT sensor cables will not go to a single sixteen-channel crate; they will go to crates shared with the drift chamber sensor cables. The cables in the backward direction will go to one crate and those in the forward direction will go to two crates.

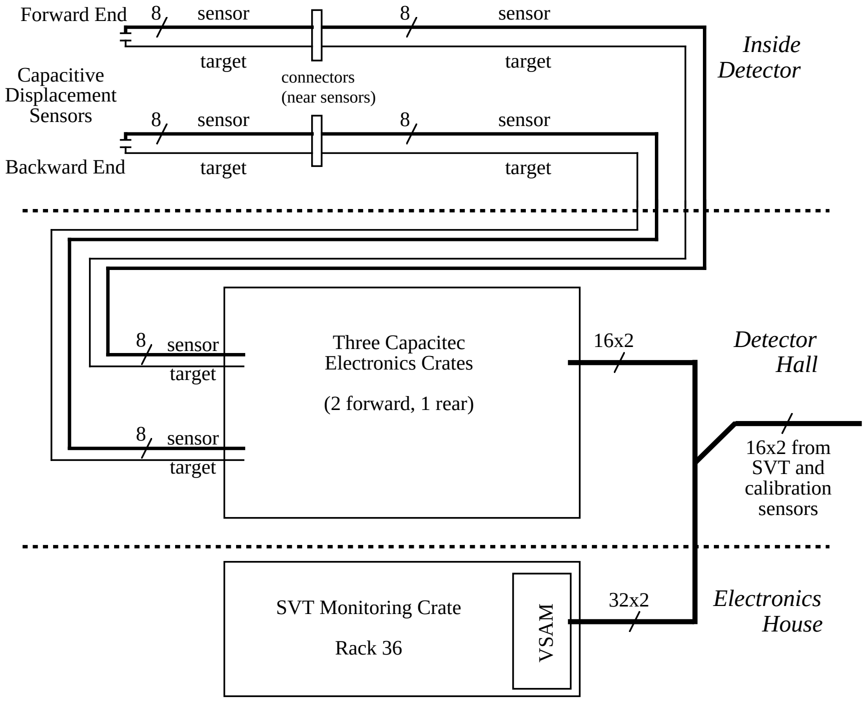


Figure 14: Physical layout of the drift-chamber position monitoring system showing the location of its components and their interconnections. Note that the sixteen drift chamber sensor cables will not go to a single sixteen-channel crate; they will go to crates shared with the SVT sensor cables. The cables in the backward direction will go to one crate and those in the forward direction will go to two crates.

Table 1: Measured output voltage and sensitivity of the Capacitec sensor HPB-375 for different gap sizes, and the resulting digitization error for a conversion accuracy of ±0.05%, as specified for the VSAM digitizing module.

Gap (mm)	Output (V)	Sensitivity (mV/μm)	Dig. Error (μm)
0.5	0.5	1.00	0.24
7	6.0	0.58	5.2
10	7.4	0.33	11
14	8.3	0.17	25
20	9.0	0.08	58

greater than 1 cm, the digitization error is greater than 10 μm. However, in both the SVT and drift-chamber systems, there are two sensors measuring each dimension. The sensors are located azimuthally opposite each other so that when the gap measured by one sensor is greater than 1 cm, the opposite gap is less than 1 cm by at least the same amount.

6 Signal Distribution

Figures 13 and 14 above show the cable connections between the various components of the SVT and drift chamber position monitoring systems. The cables required for these systems are listed in Table 2. We give the name of the cable, the number of cables (N), the module and connector type at the beginning and end of the cable, the length and size of the cable, and the type of conductor used in each cable.

As described above, the cables that carry the 15 kHz current signal to the sensors are special coaxial cables, purchased directly from Capacitec, with the central conductor electrically connected to the central part of the sensor and the conducting shield connected to the guard ring surrounding the central sensor. The readout electronics keeps the central conductor and the conducting shield at the same potential to eliminate the effects of cable capacitance and to reduce fringe effects at the sensor. The cable will be Capacitec's R3-type cable which is made with Kapton insulator for radiation hardness. The outer diameter of the cable is 63 mil (1.6 mm).

Table 2: Summary of the cables used for the SVT and drift chamber position monitoring systems. The following acronyms are used: MD = 10-32 Microdot connector, MCX = Suhner miniature connector, BNC = BNC connector, R3 = Capacitec rad-hard coaxial cable, L3 = Capacitec regular coaxial cable, BP = binding post, TP = twisted pair, PH = 50-pin phone-style connector, P2 = VME P2 connector. T/M card is the SVT transition/matching card located inside the support tube. The connectors are not acutally mounted to the T/M cards, but are located near the T/M cards. CAPMON refers to the Capacitec position monitoring readout electronics modules. SAM refers to the BaBar-standard ADC module.

Name	N	From/To	Length	Size	Type
sensor(SVT)	16	sensor/ T/M card(MD)	≈10 cm	1.6 mm diam	R3 coax
	16	T/M card(MD)/ end of Q1(MD)	2 m	1.6 mm diam	R3 coax
	16	end of Q1(MD)/ CAPMON(BNC)	≈10 m	1.6 mm diam	L3 coax
sensor(DC)	16	sensor/ bulkhead(MCX)	≈1 m	1.6 mm diam	R3 coax
	16	bulkhead(MCX)/ CAPMON(BNC)	≈10 m	1.6 mm diam	L3 coax
target(SVT)	4	target/ T/M card	≈10 cm	≤1.6 mm diam	copper/ Kapton
	4	T/M card/ end of Q1	2 m	≤1.6 mm diam	26 AWG
	4	end of Q1/ CAPMON(BP)	≈10 m	≤1.6 mm diam	26 AWG
target(DC)	2	sensor/ bulkhead	≈1 m	≤1.6 mm diam	26 AWG
	2	bulkhead/ CAPMON(BP)	≈10 m	≤1.6 mm diam	26 AWG
signal (SVT+DC)	1	CAPMON/ VSAM(P2)	≈30 m	flat	32 TP

For the SVT support cone/B1 monitoring, the cable will be split at a location near the SVT transition/matching cards. The connectors will be mounted on the B1 magnet, not on the T/M cards, so that the SVT and position-monitoring electrical systems can be kept separate. The connector will be a 10-32 Microdot connector or one of the small connectors in the Suhner Microax (MCX) or Miniature Microax (MMCX) series that Capacitec uses. Another connection will be made at the end of the support tube. *

For the drift chamber/support tube monitoring, the cable will be split at one or two locations using MMCX connectors. There will definitely be one interconnect at the bulkheads near the inner cylinder at each end of the drift chamber. The cables will penetrate the bulkheads at two locations in azimuth through Suhner miniature bulkhead connectors. The route from the sensors to the bulkheads will first be along the inner cylinder, parallel to the z-axis, and then around the inside of the bulkhead to points near the bottom and top of the inner cylinder. The locations of any other interconnects will be determined by the assembly procedure and have not yet been decided, although the current plan is to have no interconnects besides the one at the bulkhead. *

The connectors at the Capacitec electronics will be BNC connectors. The input to each amplifier is through the front of the module.

The cables that connect the targets to the Capacitec electronics will be multistrand single-conductor insulated wires (*e.g.,* AWG 26). Each target cable connects to a single binding post on the back of the electronics crate containing the amplifiers for the sensors associated with the target. The target cables will most likely have connectors at the same locations as the signal cables. One scenario for routing the target cables out of the detector is that all of the target cables, except for the section between the target itself and the first connector, follow the same path out of the detector as the sensor signal cables. For the SVT, the first section of target cable would go from the target on each half of the SVT support cone to a connector on the B1 magnet near the T/M cards. We need to determine whether it will be possible to make this connection during assembly. For the drift chamber, the first section of target cable would go from the target on the support tube at each end of the drift chamber to a connector somewhere on the end of the drift chamber.

The Capacitec electronics for the SVT and drift-chamber position monitoring systems will share two Eurostyle 2u crates located in racks on a platform on the side of the BaBar detector. The output signals from the Capacitec electronics are 0 - 10 VDC analog signals. The output signals are available in two ways on the back of the each crate: on 16 separate 1/8-inch phone jacks, or on a 50-pin phone-style connector. A total of 32 analog signals will be carried to one 32-channel VSAM located in the SVT monitoring crate in Racks 4 or 5, outside the shielding wall. If there is a standard cable type being used for this sort of purpose in BaBar, we will use it.

We are currently finding out whether or not the cables satisfy the BaBar fire safety requirements. If the cables are not already rated, we will get * an exact description of their composition to determine whether they would satisfy the requirements for an exception to be granted.

7 Portable Readout System

For the SVT system, we will need a portable readout system to use during the practice sessions for mechanical assembly of the SVT on the B1 magnets, during installation of the SVT in the support tube, during transportation of the support tube to the IR hall, and during installation of the support tube in BaBar. For the drift-chamber system, we will need a readout system during assembly of the BaBar detector.

We are currently using a readout system in the laboratory at Stanford University based on an HP multichannel multimeter connected via GPIB to a Power PC running LabView. During installation, we will use the same multimeter connected via GPIB to a PowerBook equipped with a GPIB interface card, running LabView. Note that the digitization error for this multimeter is about a factor of ten smaller than that specified for the VSAM's which will be used in the final readout. Therefore, the sensitivity of the readout during assembly, installation and transportation could be greater than the final sensitivity, if we control or measure the temperature to an adequate degree. If the support tube is assembled in a location other than the BaBar interaction region, we will need a portable power source for the Capacitec electronics crate and the multimeter during transportation of the support tube to the interaction region.

8 Calibration

The capacitive position-monitoring system will be calibrated in the laboratory before installation. Calibration involves determining the sensor output for all the relative sensor-target positions that will be possible in BaBar. The calibrations will be most useful if the geometry and materials of the sensor mount, and the target and target mount are as close as possible to the final design. Also, we must be able to simulate all the possible motions between the sensors and targets, including rotations. Our plan is to have a mechanical mockup of the sensor mounts for both the drift-chamber inner cylinder and the B1 magnet. These mockups need extend only a few cm beyond the edge of the sensors. We will also make a mechanical mockup of the outer surface of a portion of the support tube and the inner surface of a portion of the SVT support cone for the target support. The output will be stored in a calibration database.

9 Interface Specifications

The SVT and drift-chamber position monitoring systems are part of the BaBar detector-control system. In this section, we describe the software elements that will be available during the running of BaBar for interacting with the position monitors through the graphical user interface of the detector-control system.

9.1 Activities

This system will include programmed activities that can either be started manually or else scheduled to occur regularly. The basic activity consists of acquiring, processing and storing readings from the sensors. Samples are acquired by reading 32 long words from the VSAM module located in the SVT monitoring VME crate. We would like to know the absolute time of a measurement so that we can study the time-dependence of observed motions. Since a VSAM module does not timestamp its samples and does not provide an interupt when a sample is complete, we will poll each module at about 1 Hz and add the timestamp in software (relative to the start of the current run). The software will also convert the complete set of sensor readings for the forward cone/B1, the backward cone/B1, and the drift chamber/support tube into the relative positions of the respective detector or machine components. The raw sensor readings, the calculated relative positions and the timestamp will be recorded in a memory buffer that is accessed by the displays described in the next section. Finally, the software will update alarms and warnings to reflect the new measurement. The main warning or alarm condition for which the software will test is a calculated distance between two components that is less than a preset minimum distance.

9.2 Displays

This system's interface will include the following displays which update in real time and refresh approximately every 30 seconds:

1. sensor reading versus time for each of the 16 sensors;
2. numerical data for relative positions of detector and machine components;
3. graphical displays of relative positions of detector and machine components;
4. relative positions versus time.

9.3 Storage

The sensor reading (4 bytes) and timestamp (2 bytes) data arrive at about 1 Hz for each sensor. In addition, the relative positions of each of the three detector/machine components will require six pieces of data, although the SVT gimbal system actually constrains some of these. The precision needed for these data can be estimated from the best precision of the sensors (about 1 μm) divided by the maximum displacement (± 1 cm), or 5×10^{-5}. Therefore, 4 bytes is adequate. The total data rate is then 6 bytes/s for each of the 32 sensors and 4 bytes/s for each of the 18 relative positions, or 264 bytes/s for the system. Therefore, a one-hour record requires a memory buffer of 1.0 Mbytes. Approximately once per minute, the software calculates the average output (4 bytes) for each of the 32 sensors and the average (4 bytes) for each of the 18 relative positions, and stores these values together with an absolute time stamp (4 bytes). The permanent storage requirements are about 98 kbytes for an eight-hour run, or about 2 Mbytes per week.

10 Temperature Monitoring

As discussed in Section 3.3.3, the fractional temperature sensitivity of the output voltage is about 0.2%/°C at 18°C and 0.1%/°C at 28°C. This can be compared to the expected digitization error of 0.05% for the BaBar-standard VSAM. Therefore, the dependence on temperature will dominate the uncertainty on position unless we know the temperature to within a fraction of a °C. We will need to do further studies to determine how the response depends on the temperature of the sensor, the air between the target and sensor, and the cables. Only with these results can we make a decision *
on where it is most important to monitor the temperature.

We plan to measure the ambient temperature in the region of the SVT with thermistors but the exact location of the thermistors has not been chosen yet. We will choose locations so that the measurements are relevant for *
correcting the output of the displacement sensors. We will also try to predict the expected temperature profile of the air between the sensors and the target, given the SVT cooling rings and HDI's in the vicinity of the target. The SVT displacement sensors are mounted directly to the B1 magnet so should all be at the same temperature as the B1 magnet itself. Once we have determined more precisely the temperatures on which the sensor response depends, we will decide where to monitor temperatures for the drift chamber position monitoring system as well. *

11 Budget and Schedule

The cost of a 16-channel position-monitoring system by Capacitec is shown in Table 3 for the SVT system and in Table 4 for the drift-chamber system. The total cost of about $28,000 per system includes 16 sensors, a total of 30 feet of cable per sensor (with one interconnect per cable), 16 amplifier cards, Eurostyle 2u crates (including power supplies) and clock cards. This is a reasonable cost considering the likely development costs that would be required to design, prototype and manufacture a new sensor and readout system.

In addition to the Capacitec equipment shown in Tables 3 and 4, the position-monitoring system requires copper-clad Kapton ground targets and ground cable, about 30 m of cable to take the analog voltage signals from the Capacitec electronics inside the shielding wall to the VSAM digitizing

Table 3: Cost of a 16-channel SVT position-monitoring system by Capacitec, including sensors, cables, amplifier cards, two clock driver cards, and two crates with power supply.

#	Description	Unit Price	Total Price
16	HPB-375A-A-R3-10-B Probe	\$375.25	\$6004.00
16	EC-D-I2-20 Extension Cable	\$175.75	\$2812.00
16	4100-S-LD-BNC Low Drift Amplifier Card	\$875.00	\$14000.00
2	4100-C-LD Low Drift Clock Driver Card	\$425.00	\$850.00
2	4016-P115 Crate and Power Supply	\$2195.00	\$4390.00
	Total Capacitec		\$28056.00

Table 4: Cost of a 16-channel drift-chamber position-monitoring system by Capacitec, including sensors, cables, amplifier cards, clock driver cards, and crates with power supplies. The extra crate in the forward direction (for cabling convenience for both the SVT and DC systems) is included in this table.

#	Description	Unit Price	Total Price
16	HPB-375sp-A-IC-00-MMCX Probe	\$465.50	\$7448.00
16	EC-CMX-L2-20 Extension Cable	\$132.50	\$2120.00
16	4100-S-LD-BNC Low Drift Amplifier Card	\$875.00	\$14000.00
1	4100-C-LD Low Drift Clock Driver Card	\$425.00	\$425.00
1	4016-P115 Crate and Power Supply	\$2195.00	\$2195.00
16	Sensor Mounts (estimated cost)	\$100.00	\$1600.00
	Total Capacitec		\$27788.00

modules outside the shielding wall, and one VSAM module. We will be machining mockups of the mechanical mounting of the SVT and drift chamber sensors to be used in calibrating the sensors. We are using programmable positioning stages for performance tests and will be using them for calibration. These costs are shown in Table 5 along with the cost of two 16-channel Capacitec systems (one for the SVT and one for the drift chamber). The costs of designing the mechanical mounts of the sensors in the drift chamber inner cylinder and the B1 magnets are not included. The engineering design

Table 5: Cost of two 16-channel position-monitoring systems for the SVT and drift chamber (DC).

Quantity	Description	Unit Price	Total Price
1	SVT Capacitec systems	\$28,056.00	\$28,056.00
1	DC Capacitec systems	\$27,788.00	\$27,788.00
4	Ground target for SVT	\$50.00	\$200.00
2	Ground target for DC	\$100.00	\$200.00
4	Ground cables for SVT	\$20.00	\$80.00
2	Ground cables for DC	\$20.00	\$40.00
1	32-channel twisted-pair cable	\$100.00	\$100.00
1	VSAM module	\$800.00	\$800.00
	Machining prototypes		\$2000.00
	Position and rotation stages		\$8000.00
	Total		\$67,264.00

of the mechanical mounts in the drift chamber inner cylinder is being done by Richard Boyce of the drift chamber group and Capacitec. The engineering design of the mechanical mounts on the B1 magnets is being done by Andy Ringwall of the IR group. The total cost of the system is about \$68,000 and is covered under WBS items 1.1.6.2 (\$52,000 allocated) amd 1.1.6.3 (\$41,000 allocated).

The main schedule constraint for the SVT-support-cone/B1-magnet positioning monitoring system is the mechanical tests of the complete support tube assembly scheduled for early 1998. These tests will include assembly of the SVT mechanical structure. We plan to monitor the relative positions of the SVT support cones with respect to the B1 magnets during these tests using the same sensors as for the final BaBar position-monitoring system, and a stand-alone readout system that will also be used during the final support-tube installation into BaBar.

The schedule for the two position monitoring systems is shown in Table 6. The final specifications of cable routing and cable lengths should be finished by June 1, 1997. The mechanical design of the mounting of the SVT sensors is already complete. The mechanical design of the mounting of the DC sensors and the final shapes of the copper-clad Kapton targets should be finished by July 1, 1997. A stand-alone readout system already exists. The

Table 6: Scedule for the SVT and drift chamber (DC) position-monitoring systems.

Item	SVT schedule	DC schedule
Complete all tests	Jan. 1, 1997	Jan. 1, 1997
Finalize mechanical design	June 1, 1997	July 1, 1997
Finalize cable routing and lengths	June 1, 1997	June 1, 1997
Order Capacitec system	June 1, 1997	July 1, 1997
Prototype readout through VSAM	July-Dec., 1997	July-Dec., 1997
Build final mechancial mockups	July-Aug., 1997	July-Aug., 1997
Calibration of sensors	Sept., 1997	Oct., 1997
Install Capacitec monitors	October 1, 1997	March, 1998
Use stand-alone readout for installation	January 1, 1998	Sept.-Oct., 1998
Use final readout	late 1998	late 1998

prototyping of a VME readout system using a VSAM will not start until July 1997, the time at which VSAM's should be available. The leadtime for ordering Capacitec sensors, cables and readout electronics is about ten weeks. We will order the SVT Capacitec items in June 1997 and calibrate them before installation on the B1 magnets sometime after October 1, 1997. The DC Capacitec items will be ordered when the design of the mount is complete. The drift chamber sensors will be installed in the inner cylinder of the drift chamber after the completion of stringing and delivery to SLAC (approximately March 1998).

12 Design Decisions Yet to be Made

In this section, we summarize all the design decisions yet to be made, which were indicated with asterisks in the right-hand margin throughout this document. Most of the remaining items concern cable paths, cable interconnects, and cable lengths, and temperature monitoring.

1. General items:

   (a) Do cables satisfy BaBar fire protection requirements for wire and cables?

   (b) What is the source of the temperature sensitivity of the position monitors (the cables, the sensors, or the air between target and sensor)? Where do we need temperature monitoring?
   (c) What will be the source of portable power for the Capacitec electronics during transportation of the support tube?
   (d) What type of cable will we use to carry the analog voltage signals from the Capacitec electronics to the VSAM? What is its length?
   (e) Should the position monitoring systems be on uninteruptable power?
   (f) Has Capacitec done a failure mode analysis? What is the mean time between failures for the system?

2. SVT-specific items:
   (a) For the SVT sensor and target cables, how many interconnects do we need? Where exactly should the interconnects be? Which connectors should we use – Microdot, Microax or Miniature Microax? How should the cables be routed? Which cables will be bundled together? What is the exact length of each section of cable?
   (b) Which adhesive should we use to glue the copper-clad Kapton target to the inner surface of the carbon fiber support cone?
3. Drift-chamber-specific items:
   (a) For the drift chamber sensor and target cables, how many interconnects do we need? Where exactly should the interconnects be? Which connectors should we use – Microdot, Microax or Miniature Microax? How should the cables be routed? Which cables will be bundled together? What is the exact length of each section of cable?
   (b) Should the target cables be recessed in the support tube?
   (c) What is the final design of the sensor mount?
   (d) What are the tolerances on the machining of the groove in the support tube for the target?
   (e) What are the tolerances on the placement of the copper-clad Kapton target in the groove?
   (f) What is the drift chamber installation schedule?

References

[1] Pat Burchat and David Kirkby, “Monitoring Requirements of the BaBar Silicon Vertex Tracker”, BaBar Note #302 (1996).

[2] Martin Nordby, Chief IR Engineer, private communication.

[3] Capacitec, 87 Fitchburg Road, Ayer, MA, 01432 (508-772-6033).

[4] Brian Kaczynski and Pat Burchat, “Response Characteristics of Capacitec Capacitive Diplacement Sensors”, BaBar Note #347 (1997).

[5] “Design of a Capacitive Displacement-Measuring System for Vertex Detectors at Colliding Beam Machines,” A. Breakstone, W. Kucewicz, N. Redaelli, R. Turchetta, Nucl. Instrum. Methods A281, 453 (1989).

[6] BaBar Standard VSAM modules, http://www.slac.stanford.edu /BF-ROOT/doc/Electronics/Det_Cntrl_ Monitor/sam1.ps