DESIGN AND FABRICATION OF ADVANCED HYBRID CIRCUITS FOR HIGH ENERGY PHYSICS*

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Abstract

Current design and fabrication techniques of hybrid devices are explained for the Drift Chamber and the Liquid Argon Calorimeter for the Stanford Linear Collider Large Detector (SLD) at SLAC. Methods of developing layouts, ranging from hand-cut templates to advanced designs utilizing CAD tools with special hybrid design software were applied. Physical and electrical design rules for good yield and performance are discussed. Fabrication and assembly of the SLD hybrids are described.

1. Introduction

The present generation of detectors for High Energy Physics, and in particular the SLD detector[1,2] under construction at the Stanford Linear Collider, require extensive processing of analog information. The latest improvements in general purpose electronic devices do not suffice, therefore custom devices have to be developed to satisfy the huge data handling requirements of the detector.

For the analog signal processing system of the Liquid Argon Calorimeter (LAC), the Cerenkov Ring Imaging Detector (CRID), and the Drift Chamber (DC) for SLD, several hybridized devices were designed and fabricated. The devices will be mounted directly on the detector. Due to space constraints, a high density of components and a large number of interconnections are accomplished on the hybrids.

For the LAC, three hybrids had to be developed: a protection hybrid, a preamplifier hybrid, and an analog sampling and multiplexing (CDU) hybrid. The interaction of the devices in the system has been described[3]. For the DC, a current sensing hybrid, a preamplifier hybrid[4,5], and an analog sampling and storage (HAMU3)[6] hybrid were designed. The HAMU3 hybrid is also employed in the CRID[7].

In this paper the steps from the circuit level to the assembled hybrids are explained and discussed.

2. Circuit Design and Layout

The circuits of all SLD devices were tested for functionality and performance with discrete prototypes. All components of the circuits were chosen for availability in a form, which could be placed on a hybrid. Integrated circuits used in most of the SLD hybrids are in die form rather than in surface mount packages, which allows a higher degree of circuit density. The maximum dimensions of the hybrids herein described were predetermined by the architecture of the SLD detector.

The layouts of all hybrids were designed in-house with the exception of the LAC preamplifier. Three types of layout design methods were applied for the SLD devices. In the rubylyth method (first version of DC preamplifier) each layer of the layout was designed at a 10:1 ratio using standard drafting techniques. The layers were then hand-cut in rubylyth. Rubylyth is a bi-film material consisting of a clear and a red or ruby colored plastic film. The ruby portion of the film is cut and stripped where metal or dielectric is to be placed. Finally, the layers are photographically reduced. The inaccuracies due to hand drafting and cutting of the templates are eliminated by using a computer with drafting software which can produce output in a format suitable for photo-plotters, e.g., Gerber format. The accuracy through the use of the system grid and the elimination of the rubylyth process lead to a higher production yield for the device. The drift chamber HAMU3 and the LAC protection hybrid were designed with this method which is fast and easily permits layout modifications. The layout had to be verified manually by checking plots of the various layers. More recently, hybrid design software packages are offered which allow schematic verification, auto-routing, and design rule verification. The second version of the DC preamplifier, the DC current sensing hybrid, the LAC preamplifier, and the LAC CDU hybrid were designed utilizing this software.

3. HAMU3 Hybrid

The HAMU3 device is a 4096 cell analog sampling and storage array for high speed transient recording. It is organized as eight signal channels with 512 storage cells each and has been tested up to a sampling rate of 300 MHz[6]. The hybrid approach solves a very complicated interconnection problem where 22 integrated circuit chips are mounted on a single device. Table 1 shows the printing sequence of the HAMU3 hybrid layers.

Table 1

1.	Front Pads	10.	4th Dielectric
2.	Back Pads	11.	3rd Conductor
3.	1st Conductor	12.	5th Dielectric
4.	1st Dielectric	13.	3rd Via
5.	1st Via	14.	6th Dielectric
6.	2nd Dielectric	15.	4th Conductor
7.	2nd Conductor	16.	Back Ground Plane
8.	3rd Dielectric	17.	Overglaze
9.	2nd Via	18.	Conductive Epoxy

The HAMU3 hybrid is designed with four conductor layers. Figure 1 shows a composite drawing of the pin pad layer and the four metal layers. In Fig. 2, a typical plot of a conductor layer is shown. Standard design rules of 0.010" minimum trace width and 0.010" spacing between conductors are applied. Conductor layers are separated by two dielectric layers for reliable isolation. The dielectric layers cover most of the hybrid to insure a flat printing surface for the conductors. The conductor print could therefore be deposited with good resolution on a substrate with many conductor and dielectric layers. Holes 0.010" square were opened in the dielectric layers to interconnect conductor layers. The HAMU3 circuit required approximately 2700 vias and 1000 interconnections on the 2.5" x 1.7" substrate. This includes vias through all conductor layers as well as buried vias which are essential due to the density of the hybrid. To insure a good yield, additional via layers with 0.010" square conductors were printed between each pair of dielectric layers. Figure 3 shows a typical via layer. The top metal layer (4th conductor) includes 22 contact plates for the substrates of the integrated circuits, and bonding pads for the device's 740 bonding wires that connect the ICs. The loaded and bonded hybrid is shown in Fig. 4. This device shows the power of hybrid technology to provide the bulk of the interconnections needed in a complicated system. The remaining interconnections of the hybrids themselves are managed with printed circuit board techniques. The contact plates for the micro-chips extend 10 mils beyond the actual die on all sides. All bonding pads are at least 0.01"x0.03". On the front and on the back side of the substrate, pin pads are printed with centers at 0.050". In the final assembly step, edge-pins are soldered to these .030"x.050" pads. For shielding purposes a ground-plane is printed on the back side of the hybrid. For mechanical and electrical protection, an overglaze (dielectric) layer coats the top of the hybrid, avoiding pin pads, bonding pads, or substrate plates.

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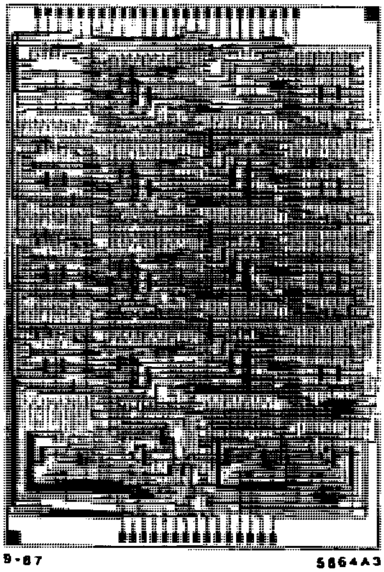

Fig. 1. Composite drawing of the pin-pad layer and the four metal layers of the DC HAMU3 hybrid. For clarity, each 10 mil wide trace is represented by a line in this plot.

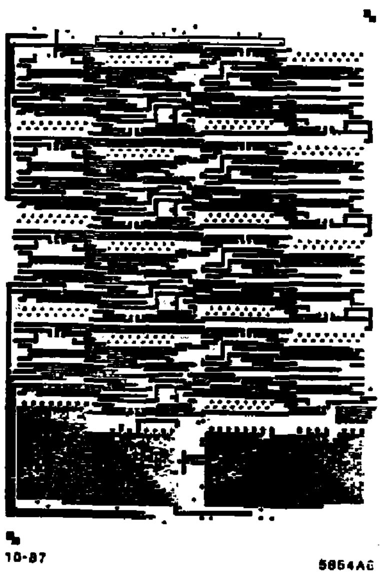

Fig. 2. Typical conductor layer of the DC HAMU3 hybrid.

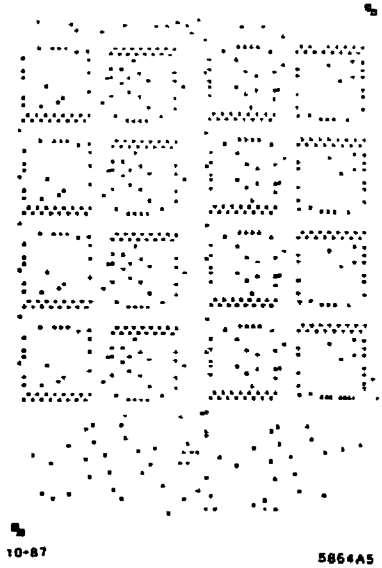

Fig. 3. Typical via layer of the DC HAMU3 hybrid.

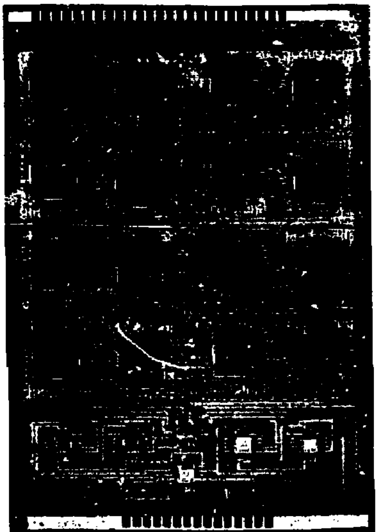

Fig. 4. Loaded and bonded DC HAMU3 hybrid comprising 740 bonding wires on an area of 2.5"x1.7".

For each layer of the design, a film is photoplotted, and the hybrid manufacturer transfers the images of the films onto wire mesh screens. In the printing process the screens are contacted, one-by-one, with the ceramic substrate and the ink is then forced through the screen onto the hybrid. After each deposition the device is placed into a furnace, fired at about 850°C for hardening, and afterwards visually inspected. The 96% alumina substrate for the HAMU3 hybrid is 25 mils thick. The ink material for the device is, PtPdAg for the front and back pads, PdAg for the back ground plane, and gold ink for the conductors. The square resistance of the 15 μm thick gold ink is 2 to 5 ohms. Silver ink is about 1/10 the cost of gold but has approximately 20 ohms/square resistance, which would cause an unacceptable voltage drop even though the traces were designed as wide as possible in the available space.

After deposition of all the layers the substrates are tested for shorts and opens. For a first run of 100 devices the production yield was 90%. After the substrate test the devices are loaded utilizing a technique called chip-and-wire. The wafers of micro-chips are sawed and the dies are placed on the hybrid with conductive epoxy. The circuits are then ultra-sonically bonded with aluminium wires to the hybrid bonding pads. For the HAMU3 an automatic wirebonder is essential since 740 one-mil thick wires have to be bonded. At this stage a test set-up has to be provided to test and, if necessary, to repair the devices. For mechanical, chemical, and electrical protection a lid is then placed on the hybrid, and sealed in a nitrogen environment. The material for the custom lid is aluminium and provides additional shielding when connected to ground. The single-substrate hybrid is then assembled with surface mount edge pins with 0.050" centers, tested, burned in under power for 72 hours at room temperature, and retested.

4. DC and LAC Preamplifiers, LAC CDU and Protection Hybrids

The drift chamber preamplifier hybrid contains eight channels of amplifiers along with associated circuits for calibration, event recognition and power switching functions. The amplifiers have low input and output impedance, less than 15 ns rise time and interchannel crosstalk of less than 3%[4,5]. A separate hybrid associated with the preamplifier permits a measurement of the leakage current from each individual sense-wire via the associated amplifier, and collectively for each drift chamber cell through a locally accessible test point.

The LAC preamplifier hybrid contains eight channels of low noise charge sensitive amplifiers with circuitry for calibration and power pulsing. The dynamic range of the preamplifiers is larger than 14 bits, crosstalk between channels less than 0.3% and the noise referred to the input is 3200 electrons RMS with an 1 nF capacitive load and a shaping time of 4 μsec. A separate protection hybrid associated with the preamplifier prevents its destruction by providing a low impedance bypass to ground for accidental voltage surges at the input.

Layout estimates indicated that the LAC and DC preamplifiers had to be implemented as dual substrate hybrids. One of the substrates of each device contains eight channels of amplifiers. The second substrate consists of an elaborate digitally controlled calibration system and a power pulsing circuit to switch off the power when no signals are present, thereby minimizing heat load on the detector. The drift chamber preamplifier hybrid additionally includes an input signal threshold decision circuit for fast trigger read-out.

The preamplifier, the current sensing, and the CDU hybrids were designed in a conventional method of dielectric utilization. Dielectric is only deposited where it is needed to prevent a short. Figure 5 shows the principle of a crossover of two conductor layers. The dielectric layers are stepped to provide a smoother surface for the deposition of conductor 2, which minimizes discontinuities and hence increases the yield. The reason for this design method was the heavy use of resistors printed on the substrate, and the ratio of components to interconnections. The HAMU3 hybrid has 22 components and 1000 mostly long interconnections, whereas the DC preamplifier is comprised of 462 components and about 600 short interconnections in approximately the same area.

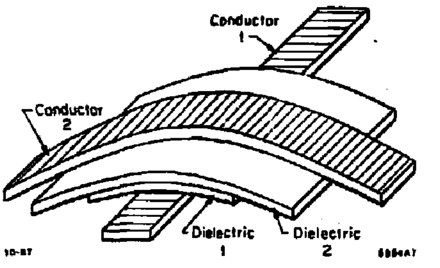

Fig. 5. Principle of a crossover of two conductor layers. The isolating dielectric layers are stepped to obtain a smoother surface for conductor 2.

For all hybrids the basic design rules of 0.010" minimum trace width and 0.010" spacing were applied. The minimum width of printed resistors is 0.025".

Table 2 shows the screen sequence for the DC preamplifier hybrid (bottom substrate of the dual substrate device).

Table 2

1.	Front Pads	10.	5th Dielectric
2.	Back Pads	11.	10 ohm/square ink
3.	1st Conductor	12.	100 ohm/square ink
4.	1st Dielectric	13.	1 kohm/square ink
5.	2nd Dielectric	14.	10 kohm/square ink
6.	2nd Conductor	15.	100 kohm/square ink
7.	3rd Dielectric	16.	Overglaze
8.	4th Dielectric	17.	Conductive Epoxy
9.	3rd Conductor		

For this hybrid five different resistor inks from 10 ohm/square to 100 kohm/square resistance are employed to minimize the space taken by any particular resistor. The temperature coefficient of the resistor ink used is about 100 to 200 ppm/°C. The resistors are commonly designed at 80% of the nominal value and are laser trimmed on the printed substrate to a tolerance of 1% before the components are loaded. This is called passive trimming since the active parts on the hybrid are not loaded. For the trimming each resistor has to be probed at both terminals to measure the resistance, therefore contact pads of 0.02"x0.02" have to be provided in the design. Since the trimming is performed before any components are loaded, pads for components can be utilized as probe pads. The resistors have to be measured individually which prohibits resistor loops. Potential loops can be avoided by introducing gaps in the traces. The traces are then connected when the conductive epoxy is deposited. The loading and bonding of the components require extreme accuracy since the top substrate of the eight-channel preamplifier hybrid consists of more than 450 components on an area 2.4" by 1.27". The yield of the device depends directly on this processing step. Figure 6 shows the top substrate of the DC preamplifier. An additional active trimming process had to be performed to adjust the calibration circuit which is included on the device. For this a test set-up has to be provided to allow in-situ resistor trimming.

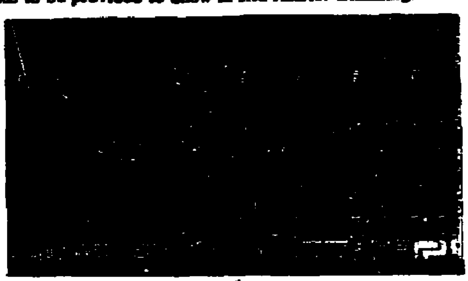

Fig. 6. Loaded top substrate of the DC preamplifier comprising 462 components on an area of 2.4"x1.27".

The performance of the preamplifiers are substantially influenced by the layout. The low square resistance of the gold conductor was described earlier. Power and ground traces have to be designed wide enough to minimize voltage drops which could introduce channel-to-channel crosstalk. An alternative method is to distribute power and ground in a star arrangement from the voltage source. Traces for the input signals should be separated by a ground trace to reduce crosstalk. Another issue is capacitive coupling between conductor layers. The dielectric constant of the material used is between 9 and 10, and the thickness of two dielectric layers is about 30 μm. This results in a capacitance of 266 pF/cm^2, which can influence the frequency response of the amplifier if the device is not carefully laid out. (*e.g.*, 10 mil crossover leads to a capacitance of 0.17 pF)

Figure 7 shows the top-on-top assembly of the drift chamber preamplifier which is comprised of an eight-channel preamplifier substrate and a calibration/power-pulse/threshold-decision substrate. The 2.4"x1.27" top substrate is placed on the ceramic spacers of the 2.6x1.7" bottom substrate. The two substrates are then interconnected by bonding wires. This technique is novel and yields good results. To allow repairs of the device the custom lid consists of a lid ring and a lid cover which is removable. The hybrid is assembled with 100 mils centers J type surface mount pins.

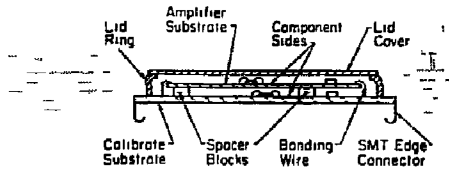

Fig. 7. Top-on-top assembly of the two substrates of the DC preamplifier. The substrates are separated by four ceramic spacers.

The current sensing hybrid for the drift chamber consists of a resistor network and a set of electronic switches. A voltage drop across the resistor due to leakage current is fed as a voltage step into the preamplifier for analysis. The eight-channel device consists of 22 printed resistors and two surface-mount integrated circuits on a 1.6"x0.8" substrate. A polymer film is printed over the loaded unit for protection.

The preamplifier for the Liquid Argon Calorimeter is laid out with most of the same design rules as used for the DC amplifier. The main difference is that resistor printing on dielectric is utilized. This leads to a denser layout since it is not required to print the resistors directly on the substrate. No traces are printed underneath the resistors in order to avoid damage in the trimming process. The technique of printing resistors on dielectric is offered only by a limited number of hybrid manufacturers. The active trimming process for the LAC preamplifier is performed by trimming printed capacitors. The two substrates (eight-channel preamplifier and calibration/power-pulse sections) of the LAC preamplifier are attached back-to-back as illustrated in Fig. 8. To interconnect the devices, a conductor layer is printed on the back side of the amplifier substrate. The top substrate is then surface mounted on the back side of the lower substrate. This is an alternate method of assembly to the DC preamplifier. Figure 9 shows the assembled hybrid.

The basic design of the LAC CDU hybrid is similar to the DC preamplifier in its use of printed resistors. The CDU hybrid[8] is a 16-channel dual range analog storage and multiplexing device with a dynamic range of more than 14 bits. The single-substrate surface-mount hybrid is assembled with 100 mils centers pins. The production yield of the device is approximately 90%.

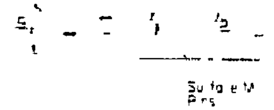

Fig. 8. Back-to-back assembly of the two substrates of the Liquid Argon Calorimeter preamplifier.

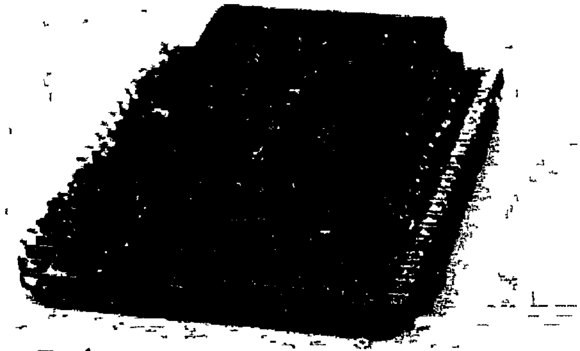

Fig. 9. Assembled LAC preamplifier. Size: 2"x1.6"x0.3".

The LAC protection hybrid is shown in Fig. 10. The design consists of front pads, back pads, and one conductor layer (no dielectric layer). The 16 channel preamplifier input protection hybrid has to withstand 200 Amperes for several micro seconds. A special bonding process is employed to connect the back-to-back diodes on the substrate with 5 mils aluminium bonds. The device is assembled with single in-line pins and the hybrid is protected by a nonconductive die-coat.

Fig. 10. 16-channel protection hybrid for the Liquid Argon Calorimeter.

5. Summary

Several hybrid devices developed for the Stanford Linear Collider Detector are described. The devices are designed, manufactured, and assembled with a variety of methods. To fulfill space constraints on the detector some of the devices are at the limit of density of components and number of interconnections.

Acknowledgments

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Please note that two changes have been made in the top paragraph of the left-hand column on page 3. The old version read as follows:

...thick gold ink is 2 to 5 ohms.

...approximately 20 ohms/square resistance,...

The new version incorporates these changes:

...thick gold ink is 2 to 5 mΩ.

...approximately 20 mΩ/square resistance,...

*Work supported by the Department of Energy, contract DE–AC03–76SF00515.

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