ATLAS project	ATLAS SCT Barrel Module FDR/2001		
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SCT Barrel Module FDR Document

Cu/Polyimide barrel hybrids

abstract

This document outlines the hybrids used in the barrel modules

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SCT	Distribution List	

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1 Introduction

A hybrid based on copper layers and organic insulator material has been developed for the application to the ATLAS SCT silicon microstrip modules. The technology has been widely used in the industry as a flexible circuit. The basic technology used "through-hole"s to connect the traces between layers. As named as "though-hole", the vertical connection between the layers was made with drilled holes penetrating all the layers. This penetration limited the freedom in laying traces and the trace sizes at the "though-hole"s because of the minimum size of the drills. With the advent of micro-via formation, the technology is refined to become "build-up" since a layer can be overlaid over the underneath layer by connecting the two layers with the "via"s. Also, the size of vertical connection becomes smaller due to finer tools to make the via's. The "build-up" flexible circuit is the key technology in industry, the ATLAS SCT has chosen the hybrid made of the "build-up" Cu/Polyimide flexible circuit [2]. Another benefit of the flexible circuit is to make the hybrid-cable in one piece, which eliminates vulnerable connections between the hybrid and cables if they are made from separate pieces.

Electrical function is one face of the hybrid. The other is the thermal and mechanical functions. Since the ASICs dissipate a power of 6 W in one module, a good thermal conduction is required in order to draining out the heat to the cooling pipe. The design of the barrel module is to make the hybrid bridging over the sensors so that the hybrid does not contact the sensor surface, other than the wire-bondings between the hybrid and the sensors. A good mechanical strength is required to make the supersonic wedge bonding of aluminium wire possible. The material of the bridge is also required to be low in radiation length.

2 Electrical schematics

The electrical schematics of the hybrid is shown in the Figure 1 and Figure 2, "Circuit Diagram of Barrel Cu/Polyimide Hybrid for ABCD3T chips". One module requires 12 ASICs; 6 ASICs per side. Two thermistors are equipped to readout the temperature of hybrid; one per side. The digital and analog ground connection is made on the hybrid, aside of every ASICs.

The components of a hybrid is listed in Table 1.

The pin assignment in the connector at the end of pigtail is listed in Table 2.

Electrical properties of the hybrid is listed in Table 3.

3 Dimensions of the hybrid assembly

Dimensions of the hybrid are shown in Figure 3. The main hybrid sections are made of the area of 74.6 mm (L) x 21.3 mm (W). Two such sections are connected with a 8.4 mm long interconnect, and one end is connected to the pigtail cable of 35.4 mm long. These cable sections are the extension of the layers of the hybrid sections so that the hybrids and cables are made in one-piece, saving additional interconnections between the hybrid and cables. The Cu/Polyimide flex-ible circuit is reinforced with a substrate for the thermal, mechanical and electrical performance. The substrate has a cut-out in the bottom side in order bridging over the silicon microstrip sensors.

The highest components in the hybrids are the SMD ceramics capacitors, C51~C58 and

C71~C75 of the size of 3.2 mm (L) x 1.6 mm (W) x 1.25 mm (H), which height, from the bottom surface of the steps of the bridge, is 2.6 mm, including the thickness of the flexible circuit. The height of the wire-bonds on the ASICs is about 2.1 mm, from the bottom, with the ASIC thickness of 0.5 mm.

4 Specification of components

4.1 Cu/Polyimide flexible circuit

4.1.1 Layer structure

The layer structure of the hybrid is shown in Figure 4. The layers are made with a centre core of the double-sided Cu-clad polyimide sheet and two single-sided Cu/polyimide sheets glued on the core, making a four layer structure. The Cu/Polyimide sheet is made with "adhesive-less" technology. The centre core, double-sided Cu/Polyimide sheet, extends the full length of the circuitry, from the pigtail connector to the far-end of hybrid. The single-sided Cu/Polyimide sheets glued on the centre core from top and bottom in order to form a four layer structure in the hybrid section, the Cu layers are removed in the cable section to be flexible and the polyimide sheet to be an insulating cover layer. Through-holes and via's are used for inter-connecting the layers: though-holes for the connections penetrating from the top (L1) to the bottom (L4) layers; via's between the two surface layers where buses and branches are. The via's are formed with a laser.

The layouts of layers are shown in Figure 5. L1 to L4 show the layers from the top to the bottom. The functions of the layers are

- L1 bonding pads, traces from the longitudinal bus lines to the pads, and ground and shield planes
- L2 bus lines, and in the cable section, power supply planes
- L3 analog and digital ground planes all-through the circuit
- L4 power supply planes, and windows for the ground contact to the bridges

4.1.2 Minimum line and gap widths

There are number of bonding pads in the back-end of the ABCD3T chips. The minimum pitch of the pads are 180 μ m. The line/gap of the mating pads on the hybrid are, thus, to be 90 μ m/90 μ m. The industry has recommended the minimum gap of 80 μ m in the large scale mass production, in order to ensure the straight and clean cut of the edges and non-existence of metal residues in the gaps. In the etching, the gap width becomes wider, thus, the tolerance is specified as -0/+20 μ m for the gap. The specification for the line/gap width are 100 +0/-20 μ m for the pads and 80 -0/+20 μ m for the gaps, for the pad pitch of 180 μ m.

4.1.3 Thermal pillars

There are "thermal through-holes" in the "Front part, i.e., analog circuitry" area of each ASIC, which are vertically connecting the backside of the chips to the surface of the carbon-carbon bridge thermally. There are 17 such through-holes per chip. The diameter of each through-hole is $300 \mu m$, plated with Cu, and filled with thermal adhesive when the flexible circuit is glued on the bridges. The effective thermal conductivity of the "pillar" is estimated to be 39.5 W/m/K.

4.2 Carbon-carbon bridge

The bridges reinforcing the Cu/Polyimide flexible circuit is required to have a low radiation length, good thermal conductivity, high young's modulus, and low electrical resistivity. Connecting the bridges to the ground of the hybrid has shown to improve the stability of electronics in the module.

A carbon material called carbon-carbon with uni-directional fibres is chosen for the bridge material for its superb properties of mechanical rigidity, large thermal conductivity, very long radiation length and sufficient electrical conductivity.

The properties of such carbon-carbon is summarized in Table 4 for a product available [3]. The product has a thermal conductivity of 700 W/m/K (in the fibre direction), nearly twice of Cu, and a young's modulus of 300 GPa (in the fibre direction), as strong as ceramics.

The specification of the bridge is shown in Figure 6. The bridge is shaped, with a milling machine, so that the steps of the bridge are part of the original material in order to maximize thermal conduction and easiness of the mechanical construction.

The surface of the bridge is coated with a polymer called Parylene of 10 μ m thick for insulating the surface and improving reliability in handling. The surface of coating is roughened with a laser where adhesion is required. The coating is removed where an electrical and thermal conduction is required.

4.3 Glass pitch-adaptor

The basic pitch of input pads of the ASIC is 48 μ m, while that of the silicon microstrip sensor is 80 μ m. In order to make a simple parallel wire-bonding, a pitch-adaptor is used in front of the ASICs. Since a fine pitch of 48 μ m is required, the pads and traces are fabricated on a separate piece with a thin-film technology: aluminium deposition on a glass substrate. The barrier metal between the glass and the aluminium is an important factor for the adhesion of the aluminium which is an proprietary of vendor.

The specification of the pitch-adaptor is shown in Figure 7. The size of the pitch adaptor is 63 mm (L) x 2.7 mm (W) x 0.2 mm (T). The thickness of aluminium is $1 \sim 1.5 \mu$ m.

4.4 Surface mount components

The components of the hybrids are listed in Table 1. The capacitors are of the type X7R for the best temperature characteristics which has a capacitance change of 5% between -20 and +40 °C. The resistors are of metal film precision type.

The thermistors are R25 = 10 k $\Omega \pm 1\%$ and B = 3435K $\pm 1\%$. The temperature can be readily available from the equation,

$$R = R25 \exp\left(B\left(\frac{1}{T} + \frac{1}{T25}\right)\right)$$
(1)

where T is given in absolute temperature. T25 and R25 are the nominal temperature of 25 $^{\circ}$ C and the resistance at the temperature, respectively.

Loading of the components are shown in Figure 8.

5 Cu/Polyimide hybrid production and Quality Assurance

The barrel hybrids are delivered to the module assembly clusters as "passive component stuffed" hybrids, i.e., the ASIC stuffing, testing, and mounting into the module is the responsibility of the clusters. Essentially, all components and fabrication steps are to be done in industry. The total quantity to deliver is rounded to be 2,500 pieces. Assuming various yields in fabrication steps, the required numbers of components are estimated and listed in Table 5.

5.1 Production of Cu/Polyimide flexible circuits

The Cu/Polyimide flexible circuits will be produced based on the specification described in the section 4.1. The quantity is 3200. Along the fabrication of the circuits, a quality assurance (QA) will be carried out by vendor: (1) visual inspection for all products, (2) specimen tests for mechanical tolerance on outer dimensions, bonding pads/gap widths, plating thicknesses, and (3) integrity test of lines: open/short test for all products, and resistance measurement for samples.

5.2 Production of carbon-carbon bridges

The carbon-carbon (CC) bridges are also fabricated based on the section 4.2 and delivered as finished product. The fabrication quantity of the carbon-carbon bridges is 6300. QA is made for: (1) mechanical tolerance of outer dimensions, (2) mechanical performance of Young's modulus and tensile strength for samples to be greater than 90% of specified values, (3) thermal performance of thermal conductivity to be greater than 600 W/m/K, and (4) electrical resistivity less than 25 m Ω measured on the two farthest windows.

5.3 Production of glass pitch-adaptors

The glass pitch-adaptor is made according to the drawing in the section 4.3 for the quantity of 5700. QA is made: (1) visual inspection of the mechanical finish, tolerance, and open/short of the traces for all products, (2) tape-peel test of the aluminium traces and (3) wire-bond pull test, for samples. The wire-bond pull strength is to be greater than 6 gr for the 30% height/distance ratio (H/L) setting.

5.4 Production of Cu/Polyimide/CC hybrids

This is the gluing process of the Cu/Polyimide flexible circuit and the CC bridges. This process produces "bare" hybrids, i.e., no components on the hybrid, yet. Two epoxy adhesive sheets are used: thermally conductive and electrically conductive. A set of small windows has been cut out on the surface of the bridges in order to improve the thermal and electrical contact between the carbon bridge and the ASICs. The area other than the windows is covered with the thermally conductive adhesive sheet, ABLEFILM 563K-.002, 50 μ m thick, alumina-filler filled, and at the windows with the electrically conductive sheet, ABLEFILM 5025E-.002, 100 μ m thick, silver loaded ref. The electrically conductive film is thicker so that the adhesive will fill up the throughholes in the hybrid.

Both adhesive film require an elevated temperature curing at 125 deg.C for two hours. The flexible circuit and the bridges are pressed at 4 kg/cm^2 by a press jig.

QA is made for: (1) visual inspection for excess adhesives, residuals on the surface, and mechanical tolerance for the alignment and thickness, and (2) bows of the hybrid section at the room temperature, which are less than 75 μ m in the long and the across directions, for all products.

5.5 Production of "Passive component loaded" hybrids

This is the process soldering the surface-mount components (SMDs) and the connector on the hybrids and adhering two pitch-adaptors. About 50 SMD parts: resistors, capacitors, and thermistors as listed in Table 1, are to be installed on the hybrid. A component loading diagram is shown in Figure 8. Since a high temperature application is not recommended after the flexible circuit and CC bridge adhesion, the solder reflow technique is not usable. A method being used is to place and hold the components with a dot of epoxy, cured, and then apply soldering manually. The detail of the soldering process is to be refined further incorporating the process involved in industry.

Two pitch-adaptors are glued on the hybrid by using a room temperature curing epoxy, Araldite 2011. No filler is used as a relatively low viscosity epoxy makes the glue layer as thin as possible and without trapping air bubbles. The surface of the hybrid is protected beforehand with a masking tape in order to prevent contamination with the epoxy. The pitch-adaptor is positioned under a microscope to align the edge of the pitch-adaptors to the fiducial marks on the flexible circuit. The width of the line of the fiducial mark is 100 μ m and alignment of the edge of the pitch-adaptor.

QA is made for all hybrids: (1) visual inspection of component placement, solder fillet, surface contamination and residuals, (2) electrical measurement from the connector for the termination resistors and the capacitancies of the Vcc-GND and the Vdd-GND, and (3) a wire-bond pull test at the test pads to be greater than 6 gr for the 30% H/L setting.

After this process, the hybrid is ready for ASIC attaching and is called "passive component loaded" hybrids.

5.6 Thermal cycling

The passive-component-loaded hybrids are thermal-cycled between -30 and +60 $^{\circ}$ C for 5 times. QA is made for: (1) visual inspection for component loss, cracks, (2) mechanical tolerance for thickness and bows, (2) electrical performance of resistance, capacitance, and leakage current in the low and high voltage lines, the latter at 500 V.

6 Hybrid datasheet

A datasheet per hybrid is prepared summarising the QA in the section 5. The datasheet of a module is shown in the appendix 7.1 as an example. An ATLAS parts identification number (atlas id) is given to the hybrid, as registered in the datasheet, and a barcode label is attached on the pigtail section of the hybrid. The datasheet will be uploaded to the database in a similar fashion as the detector datasheet.

7 Appendix

7.1 Hybrid datasheet

An example of the hybrid datasheet is appended in the following pages.

Hybrid datasheet	
ATLAS ID classification (KEK)	20220170100051
Mfr serial number	K4211
Overall Quality	Good
Parts:	
220 nF capacitors/batch	20220170111002
330 nF capacitors/batch	20220170112001
10nF/630V HV capacitors/batch	20220170113001
100 ohm resistors/batch	20220170114001
5.1K ohm resistors/batch	20220170115001
1K ohm resistors/batch	20220170116001
0 ohm resistors/batch	20220170117001
Semitec 103KT1608-1P thermistors/batch	20220170118001
Connector Samtec SFMC-140-L3-S-D/batch	20220170119001
Pitch adaptors/batch	20220170121001
Carbon-carbon bridges/batch	20220170122001
Conductive epoxy glue (Eotite P-102)/batch	20220170131001
Electrically non-conductive epoxy glue for hybrid/batch	20220170132001
Araldite+BN filler/batch	20220170133001
Attaching CC bridges to flex circuit/batch	20220170141001
Stuffing passive components/batch	20220170142001
1 Cu/Polyimide Flex circuits	Good
1.1 Visual inspection by vendor	Good
(1) Design features sizes and structures	Good
(2) Nicks and pin holes on conductor	Good
(3) Protrusions and residual conductor	Good
(4) Entrapped foreign materials	Good
(5) Wrinkles and fold lines	Good
(6) Air bubbles under cover film	Good
(7) Dents and delamination of conductor	Good
(8) Scratches on conductor	Good
(9) Discoloration and corrosion	Good
(10) Adhesive squeeze-out	Good
(11) Adhesive stain	Good
(12) Non-plating	Good
1.2 Integrity test of lines by vendor	Good
2 Cu/Polyimide/Carbon-bridge hybrid	Good
2.1 Visual inspection by vendor	Good
(1) Cracks	Good

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(2) Alignment between flex circuit and Carbon-bridge	Good
(3) Fill up electrical conductive adhesive	Good
(4) Adhesive residuals	Good
(5) Adhesive squeeze-out	Good
2.2 Mechanical tolerance	Good
(1) Thickness measurement (microns) (6points)	Good
Link0 (average)	599.830000
Link1 (average)	597.830000
(2-1) Flatness measurement Bow (long)	Good
Link0 (<75)	29.727000
Link1 (<75)	36.600000
(2-2) Flatness measurement Bow (across)	Good
Link0 (<75)	42.705000
Link1 (<75)	40.815000
(2-3) Flatness measurement Twist	Good
Link0 (<100)	44.670000
Link1 (<100)	70.650000
3 Passive-component-stuffed hybrids	Good
3.1 Visual inspection by vendor	Good
(1) Passive-component alignment	Good
(2) Soldering	Good
(3) Residuals and foreign materials on surface	Good
3.2 Wire-bond pull test	
(1) pull strength (>6gr)	
4 Passive-component-stuffed hybrids with pitch adaptor	Good
4.1 Visual inspection by vendor	Good
(1) Pitch adaptor crack	Good
(2) Pitch adaptor alignment	Good
(3) Adhesive residuals	Good
(4) Adhesive squeeze-out	Good
5 temperature cycle tests	Good
5.1 Capacitance and impedance measurement by vendor	Good
Vcc-GND (microF) at 1KHz (2.4 <x<3.0)< td=""><td>4.108700</td></x<3.0)<>	4.108700
Vdd-GND (microF) at 1KHz (2.4 <x<3.0)< td=""><td>4.057000</td></x<3.0)<>	4.057000
HV-GND (kOhm) at 100Hz (30 <x<36)< td=""><td>34.500000</td></x<36)<>	34.500000
HV-GND (kOhm) at 1KHz (9 <x<11)< td=""><td>10.060000</td></x<11)<>	10.060000
HV-GND (kOhm) at 10KHz (5.7 <x<7.7)< td=""><td>6.737000</td></x<7.7)<>	6.737000
HV-GND (kOhm) at 100KHz (5.1 <x<7.1)< td=""><td>6.070300</td></x<7.1)<>	6.070300
5.2 temperature cycle test by vendor	Good
5.3 Visual inspection by vendor	Good
(1) Component loss	Good
(2) Cracks	Good
(3) Residuals and foreign materials on surface	Good
5.4 Mechanical tolerance	Good
(1) Thickness measurement(microns)(6points)	Good

Link0 (average)	602.830000
Link1 (average)	599.670000
(2-1) Flatness measurement Bow (long)	Good
Link0 (<75)	36.277000
Link1 (<75)	37.700000
(2-2) Flatness measurement Bow (across)	Good
Link0 (<75)	50.430000
Link1 (<75)	38.615000
(2-3) Flatness measurement Twist	Good
Link0 (<100)	57.880000
Link1 (<100)	47.100000
5.5 Resistance and capacitance measurement by vendor	Good
Vcc-GND (microF) at 1KHz (2.4 <x<3.0)< td=""><td>4.129000</td></x<3.0)<>	4.129000
Vdd-GND (microF) at 1KHz (2.4 <x<3.0)< td=""><td>4.081300</td></x<3.0)<>	4.081300
HV-GND (kOhm) at 100Hz (30 <x<36)< td=""><td>34.400000</td></x<36)<>	34.400000
HV-GND (kOhm) at 1KHz (9 <x<11)< td=""><td>10.060000</td></x<11)<>	10.060000
HV-GND (kOhm) at 10KHz (5.7 <x<7.7)< td=""><td>6.738000</td></x<7.7)<>	6.738000
HV-GND (kOhm) at 100KHz (5.1 <x<7.1)< td=""><td>6.070000</td></x<7.1)<>	6.070000
R27 (Ohm) (99 <x<101)< td=""><td>100.060000</td></x<101)<>	100.060000
R28 (Ohm) (99 <x<101)< td=""><td>100.020000</td></x<101)<>	100.020000
R29 (Ohm) (99 <x<101)< td=""><td>99.960000</td></x<101)<>	99.960000
R30 (Ohm) (99 <x<101)< td=""><td>99.980000</td></x<101)<>	99.980000
TM0 (kOhm) (9.8 <x<10.2) 25="" at="" degc<="" td=""><td>10.097000</td></x<10.2)>	10.097000
TM1 (kOhm) (9.8 <x<10.2) 25="" at="" degc<="" td=""><td>10.150000</td></x<10.2)>	10.150000
ASIC die pad No.1-No.6 (milliOhm) (<4)	3.600000
ASIC die pad No.7-No.12 (milliOhm) (<4)	3.600000
5.6 LV leakage current measurement by vendor	Good
Icc (nA) at 10V (<10)	9.000000
Idd (nA) at 10V (<10)	9.000000
5.7 HV leakage current measurement by vendor	Good
HV current (nA) at 500V (<10)	9.000000
6.Barcode and data sheet entry	Done

7.2 ASICs stuffing and replacing

After the receipt of the passive-component-stuffed hybrids, the module assembly sites attach ASICs on the hybrids. Some cautions and instructions are given here from the supplier of the hybrids.

7.2.1 ASIC stuffing

The ASICs are glued on the chip pads with electrically conductive epoxy, Eotite p-102, in order to have a good heat and electrical conduction. Four fiducial marks are prepared at the corner of the chip pad for the alignment of the ASIC. Mask the bonding pads near the ASICs for not contaminating the bonding surface. Apply a correct amount of glue such that the glue extends full area of the ASICs and form a smooth fillet at the side of the ASICs. Cure the glue at 50 °C for

more than 2 hrs., while holding the hybrids at the steps of the bridges.

7.2.2 ASIC replacing

An ASIC can be replaced on the hybrid. A simple special jig for the ASIC replacement has been developed. It is made of a Cu block on a soldering iron. The Cu block is a 8 mm x 8 mm x 12 mm which has a trench of 6.5 mm wide and 0.3 mm deep where the ASIC can be fit and picked-off with vacuum-chucking. The block is attached on the tip of a conventional soldering iron. Heat the block at 250 °C. Apply the head to the ASIC. The glue underneath becomes soft in about 5 sec. By applying a small twist to the ASIC, it can be picked off easily. We recommend to use a high power soldering iron (e.g., 20W) in order to have a heat capacity and heat-up time as short as possible. A photo of the jig is shown in Fig.xx.

References

 Y. Unno, "High-density low-mass hybrid and associated technologies", 6th Workshop on Electronics for LHC Experiments, pp 66-76, CERN 2000-010

[2] M. Tyndel, et al., "Internal Design Review of the SCT Barrel Hybrids", reference id, 5 July, 2000

[3] A product is available from Nippon Mitsubishi Oil Corporation, catalog no. NCC-AUD28

[4] These adhesive sheets are made by ABLESTICK co. Ltd..

parts No.	# of piece	dimensions (mm)	specifications	products		
	8					
U1 ~ U12	12	6.550x8.400	ABCD3T chip			
C1 ~ C28	28	1.6x0.8x0.8	Ceramic capacitor 220 nF, 10V,	Murata GRM39-X7R-224-K-10		
C51 ~ C58	8	3.2x1.6x1.25	Ceramic capacitor 330 nF, 25 V,	Murata GRM42-6-X7R-334-K-25		
C71 ~ C75	5	3.2x1.6x1.25	Ceramic capacitor 10 nF, 630 V	Murata GHM1530-B-103-K-630		
$R27 \sim R30$	4	1.6x0.8x0.8	Resistor, 100Ω			
R33, R34	2	1.6x0.8x0.8	Resistor, 5.1 kΩ			
R35	1	1.6x0.8x0.8	Resistor, 1 kΩ			
R36	1		jumper wire			
TM1, TM2	2		Thermistor	Semitec 103KT1608-1P		
CON	1		Connector, 2x18pins, 1.27mm pitch,	Samtec SFMC-120-L3-S-D or 0.05"x0.05" 40 square-pins female		
PA	2		pitch adaptor	pa4880		

Table 1 List of components

Table 2
Pin assignment of the hybrid connector.

1	+bias(HV)	10	analog ground	19	digital ground	28	com0-bar
2	+bias(HV)	11	V _{CC}	20	digital ground	29	clock0
3	NC	12	analog ground	21	V _{DD}	30	clock0-bar
4	NC	13	VCC	22	V _{DD}	31	led
5	-bias(ag)	14	analog ground	23	digital ground	32	led-bar
6	-bias(ag)	15	com1	24	digital ground	33	ledx
7	tempret	16	com1-bar	25	reset	34	ledx-bar
8	analog ground	17	clock1	26	select	34	temp1
9	V _{CC}	18	clock1-bar	27	com0	36	temp2

Trace/Plane	Capacitar	nce [pF]	Resistance [mΩ]		
	bare flex circuit	with bridge	pigtail section	rest of hybrid section	
Analog ground (AGND)			13	24	
Digital ground (DGND)			13	46	
Analog power (Vcc)	1.2	1.9	15	46	
Digital power (Vdd)	0.9	0.9	15	46	
Command bus line	39)	500	1700	
Data/token longest lines	32	32 1800			
Data/token short lines	3	3 100			

Table 4 Properties of Carbon-carbon				
Material	Uni-directional fibres			
Thermal conductivity (fibre direction) [W/m/K]	700 ± 20			
Thermal conductivity (transverse to fibres) [W/m/K]	35±5			
Density [g/cm ³]	1.9			
Young's modulus (fibre direction) [GPa]	294			
Tensile strength (fibre direction) [MPa]	294			
Thermal expansion coefficient (CTE) (fibre direction) [ppm/K]	-0.8			
Thermal expansion coefficient (CTE) (transverse to fibres) [ppm/K]	10			
Electrical resistivity (fibre direction) [Ωm]	2.5 x 10 ⁻⁶			

Table 5 Required numbers of components (numbers rounded t	to 100)
"passive component stuffed" hybrids	2500
Cu/Polyimide flexible circuits	3200
Carbon-carbon bridges	6300
Pitch-adaptors	5700
SMDs and connector (set)	3000

Figure captions:

Figure 1 Schematic circuit diagram of the barrel hybrid (version 4), connector side

Figure 2 Schematics circuit diagram of the barrel hybrid (version 4), far-end side

Figure 3 Dimensions and profile of the Cu/Polyimide barrel hybrid (version 4)

Figure 4 Layer structure of the Cu/Polyimide flex circuit of the barrel hybrid (version 4)

Figure 5 Layer layouts of: top traces (L1), bus traces (L2), ground planes (L3), and power planes (L4)

Figure 6 Hybrid bridge made of carbon-carbon

Figure 7 Glass pitch adaptor

Figure 8 Component loading diagram

Figure 9 Radiation length and weight of the barrel hybrid (version 4)





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Figure 4 Layer structure of the Cu/Polyimide flex circuit of the barrel hybrid (version 4)

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Figure 6 Hybrid bridge made of carbon-carbon







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Total	Thermal adhesive (93% area)	Conductive adhesive (7% area)	Substrate-hybird adhesive	Parvlene bottom laver (10 µm)	Domilana ton lavar (10 mm)		Substrate	Polyimide cover+adhesive $(13\mu+33\mu)$ layer	L4:Copper($12 \mu m$)+TH plating ($13 \mu m$)	Polvimide/adhesive (25µ+25µ) laver	Folytmide tayer(25µm) I 3:Conner and plane (12µm)	L2:Copper tracking $(12\mu m)$	Polyimide/adhesive $(25\mu+25\mu)$ layer	L1:Copper(12µm)+TH plating(13µm)	Photoresist (20μ) layer	Gold Hash(U.4µm)	Connector pad	Polyimide/adhesive $(25\mu+25\mu)$ layer	L3:Copper gnd plane(12µm)	Polyimide plane	L2:Copper tracking(12µm)	Polyimide tadhasiya (75/1275/1) lavar	Polyimide+adhesive $(25\mu+25\mu)$ layer	Copper gnd plane	Polyimide layer	Polyımıde+adhesıve (25µ+25µ) layer Copper tracking	Interconnect	Polyimide cover+adhesive $(13\mu+33\mu)$ layer	L4:Copper(12 μ m)+TH-plating(13 μ m) (60% hash)	L5:Copper gnd plane(12µm) Polvimide+adhesive (25µ+25µ) laver	Polyimide layer (25μ)	L2:Copper tracking(12µm)	Polyimide+adhesive $(25\mu+25\mu)$ layer	L1:Copper(12 μ m)+TH-plating(13 μ m) (60% hash)	Nickel plating(2µm) Photoresist (20m) laver	Gold flash(0.4μ m)	Main hybrids (2-in-1)	Item	Normalise to 74.6 x 21 mm ^{2} =
1	2	2	2	12 1	4 c	- 2	2	2					-		0 -			-	-	1			1					2	2	2 2	2 12	2	2	2	2 10	22	2	No. off	1566.6
	74.6	74.6	74.6	74.6	ן ל 12 ל	74.6	74.6	5	S	un (איט	n Un	S	S	Un U	nυ	n Un	30	30	30	30	30	9	9	9	ي د	9	74.6	74.6	74.6	74.6	74.6	74.6	74.6	74.6	74.6	74.6	Basic x (mm)	
	21	21	21	21	21	21	21	25	25	25	3 0	25	25	25	12 1	2 2	25	24.5	24.5	24.5	24.5	24.5	21	21	21	21 21	21	21	21	21 21	21	21	21	21	21	21	21	Basic y (mm)	
	1566.6	1566.6		1566.6	15666	1566.6		125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	735.0	735.0	735.0	735.0	735 0	189.0	189.0	187.1	189.0	1000	1566.6	1566.6	1566.6	1566.6	1566.6	1566.6	1566.6	1566.6	1566.6		Basic area	
	105	1462		0	105	0		0	08	0 i	7 0	105	0	08	08	8 8	3	0	87	42	192	40	0	4	•	72 0	>	0	873	0	; 0	1268	0	881	567	881		Less , area	
1566.6	1462	105	1566.6	1567	14 63	1567	1566.6	125	45	58 125	5	120 125	125	45	125	£ £	125	735	648	693	543	735	189	176	187	117	189	1567	694	1455 1567	1567	298	1567	686	1000	686	1566.6	Actual S area	
	0.933	0.067		1.000	0.033	1.000		0.080	0.029	0.080	0.030	0.013	0.080	0.029	0.027	0.029	222	0.469	0.414	0.442	0.347	0.44.7	0.121	0.112	0.119	0.121		1.000	0.443	1.000	1.000	0.190	1.000	0.438	0.438	0.438		Scaled	
	0.050	0.050	0.100	0.010	0.000	0.300	0.337	0.046	0.025	0.050	0.012	0.012	0.050	0.025	0.020	0.000	0.267	0.050	0.012	0.025	0.012	0.149	0.050	0.012	0.025	0.012	0.149	0.046	0.025	0.050	0.025	0.012	0.050	0.025	0.002	0.000	0.267	Thickness (mm)	
																						0.141					0.141										0.233	Thickness mea (mm)	
0.681	0.0466	0.0034	0.0500	0.0100	0.0208	0.3000	0.3108	0.0037	0.0007	0.0040	0.0020	0.0002	0.0040	0.0007	0.0016	0.000	0.0173	0.0235	0.0050	0.0111	0.0042	0.0658	0.0060	0.0013	0.0030	0.0009	0.0173	0.0460	0.0111	0.0500	0.0250	0.0023	0.0500	0.0109	0.0009	0.0002	0.2203	Scaled thickness	
59.27	165.65	42.77	277.80	286	218.10	218.10	199.42	357.5	14.3	357.5	007.0 14-3	14.3	357.5	14.3	14.7 357.5	3.35	110.15	357.5	14.3	357.5	14.3	357 5	357.5	14.3	357.5	357.5 14.3	90.43	357.5	14.3	14.3 357.5	357.5	14.3	357.5	14.3	3575	3.35	86.13	X0 (mm)	
1.150	0.056	0.016	0.072	0.007	0.049	0.275	0.338	0.002	0.005	0.001	0.003	0.001	0.001	0.005	0.000	0.000	0.019	0.007	0.035	0.003	0.029	0.080	0.002	0.009	0.001	0.002	0.020	0.026	0.155	0.136	0.014	0.032	0.028	0.153	0.007	0.010	0.621	Rad len (%)	
	1.87	3.68		1.42	C8C0.7	2.0385		1.136	8.93	1.136	5 0 8 0 3	8.93	1.136	8.93	0.040 1.136	0 0/5	10.0	1.136	8.93	1.136	8.93	1136	1.136	8.93	1.136	1.136 8.93	1 100	1.136	8.93	8.93 1.136	1.136	8.93	1.136	8.93	8.845	19.3		Density (g/cm^3)	
4.683	0.273	0.039	0.312	0.044	0.342	1.916	2.345	0.013	0.010	0.007	0.004	0.002	0.007	0.010	0.000	0.000	0.060	0.042	0.069	0.020	0.058	0.228	0.011	0.019	0.005	0.011	0.058	0.164	0.310	0.312	0.089	0.064	0.178	0.306	0.024	0.011	1.681	Weight (gm)	
-	<u>+</u>																4	4									4	1									2.0	Summed weight (gm	
		L					2.36																														3 2.04	Measu) weight (

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Figure 9 Radiation length and weight of the barrel hybrid (version 4)

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Figure 10 An ASIC replacement jig