U of S Subatomic Physics Internal Report SPIR-109

Design Considerations for Cable Adaptors for CAEN V792AA QDC in the Blowfish Electronics

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19th February 2003

Contents

Introduction

The CAEN V792AA QDC is a high density VME V430 standard ADC, with two 16 signal inputs. The inputs are standard 0.1” x 0.1” pitch, dual row, 17 connection, rectangular latch/ejector headers (3M 3431). However, these headers are typically used with ribbon cables that have 100 ohm intrinsic impedance rather than the 50 ohm impedance of coaxial cables typically used in nuclear and subatomic physics experiments (e.g. RG-58, RG-174). The use of this ADC requires a hybrid cabling solution.

In particular, the Blowfish neutron detector array used at Duke University’s High Intensity Gamma Source has at least 88 RG-58 cables for signal transmission that must be converted in order to use the V792AA. It is expected to be used with a wide range of neutron energies, and the lowest measurable light output. To facilitate gain changes, attenuators would allow the detector to be used at higher neutron energies without having to change photomultiplier gains. Blowfish is capable of pulse shape discrimination (PSD), which requires double the number of ADCs: the analog pulse is split and sent to one ADC with a long gate and another with a short gate. In the past, its cables were patched to a cable terminated with a custom edge connector that was plugged into a FASTBUS ADC, the highest density ADCs at the time Blowfish’s electronics was assembled. Furthermore, this connector was twinned so that the signal was split and sent to adjacent ADCs for PSD right at the ADCs, AND included a piggy-back plug-in board for the signal attenuation.

The rectangular connectors necessary with the V792AA are not as robust as the old connector and require two to three times more dense wiring and circuitry. One consequence is that the cable going into the requisite plug could not be RG-58 since that standard is rather large compared to the pitch of the connector. The weight of 16 such cables on the connectors was also a concern. Three possible solutions seemed available: 1) individual RG-174 bundled, 2) coaxial ribbon cable, 3) flat ribbon cable with an impedance matching adapter. All are terminated with the rectangular connector at the output. Both 2) and 3) must be terminated that way at both ends (manufacturers do not recommend splitting and attaching BNC or LEMO connectors on either of these), but 1) can be terminated with BNC or LEMO connectors (BNC is preferred). Additional problems with 3) are that these are more susceptible to cross-talk and they require impedance matchers at both ends.

Initial concepts involved attenuating and splitting the signal at a patch panel then running twinned cable assemblies to each ADC terminated with the necessary plug. However, it was found that splitter and attenuator circuits could be made small enough that at least the splitter could be placed at the ADC inputs. This was particularly desirable because even the smallest reflections due to slight impedance mismatch between cable and ADC input would have significant repercussions on PSD. Placing the splitter right at the inputs kept reflected signals well away from the critical tail of the pulses. Subsequently, concerns about noise pickup and crosstalk, as well as a experimental considerations, resulted in breaking up the adaptor into separate components: 1) a cable assembly with just the respective termination, 2) a splitter, 3) an attenuator. The attenuator was actually considered a lower priority component that could later be integrated in either a redesigned splitter or cable assembly.

1. Assembly Requirements

1.1. General considerations

1.1.1. Circuit boards

Regardless of what scheme was decided on, there were common concerns with the use of circuit boards, printed and plain. Much of what follows was affected by these concerns. The main concerns were the intrinsic impedance of the circuit (impedance matching to cables), crosstalk between traces and leads, and component geometry. Earlier incarnations of the splitter benefitted from ample space on the circuit boards, but the latest version could require as much as 4 times more reduction in scale.

Traces on a circuit board with a ground plane (microstrip) can be layed out for 50 ohm intrinsic transmission line impedance if the traces are about 0.1” wide for standard 1/16” thick boards. This was possible in the previous version, but with the pitch of the new connectors being 0.1”, this is no longer possible. This means that the traces must be kept as short as possible. Transmission line conditions become apparent when the line length is of order of 1/6 to 1/4 wavelength, or comparable to the rise time of our signals. Our Phillips XP2262 phototubes are capable of 2 ns risetime, so line lengths should be kept below 40 cm. This rules out any (ridiculous) ideas of a patchpanel-sized circuit board to concentrate cabling to the necessary connector size. This does not preclude boardmounted coaxial cables which were part of a consideration of putting the splitters behind the patch panel.

Crosstalk depends inversely by the square of the distance between conductors, and depends on the square of the thickness of the board to the ground plane. That is, one should keep the traces as far apart as possible. The rule of thumb seems to be

$$V_{cross} \sim \frac{V}{1+\left(\frac{d}{t}\right)^2}$$

where d is the center-to-center distance between traces and t is the thickness of the board. The other solution is to implement ground striping, that is, interleaving grounded traces between signal traces. This can result in a 10 to 20 dB reduction in crosstalk. Crosstalk can also stem from ground return currents, particularly if the path passes ground return junctions of neighboring circuits. One must be careful to provide adequate and judicious pathways for ground return currents. The rule of thumb is to allocate enough copper equivalent to individual ground traces, to steer ground currents away from critical circuit points, and to avoid obstructing ground paths (e.g. with excessive via density).

If wires need to be used, they should be shielded, probably coaxial cable such as RG-174. Pins and tails on connectors are unshielded, and as shown in Appendix A, they are a source of crosstalk. Unfortunately, these are unavoidable. The only thing that can be done is to keep these short.

The primary effect of component geometry is an uncertainty in the placement of traces and sizing of circuits. Generally, the placement was a minor issue, since most types of components in consideration have standard geometries or are similar enough to accomodate through larger tolerances. However, components like the connectors have different footprints (e.g. via diameters) depending on manufacturer and model line. So finalizing a circuit board drawing requires knowing exactly which components (manufacturer, model, options) will be used.

1.1.2. Connectors

Connectors (e.g. headers, sockets, BNC) must have gold plated contacts. Past experience has shown that oxidization is a frequent culprit in signal failures.

1.2. Cable Assembly

The cable assembly was separated from the splitter as a means to maximize signal for the very lowest energy measurements. In this regime, PSD doesn't work, so that half of the signal strength going to the second (short gate) ADC is wasted. The second ADC can be sacrificed. By going directly into one ADC, the full strength of the signal goes to that one channel. A separate cable assembly also allows for future use of our V792 in different experimental setups on individual bases.

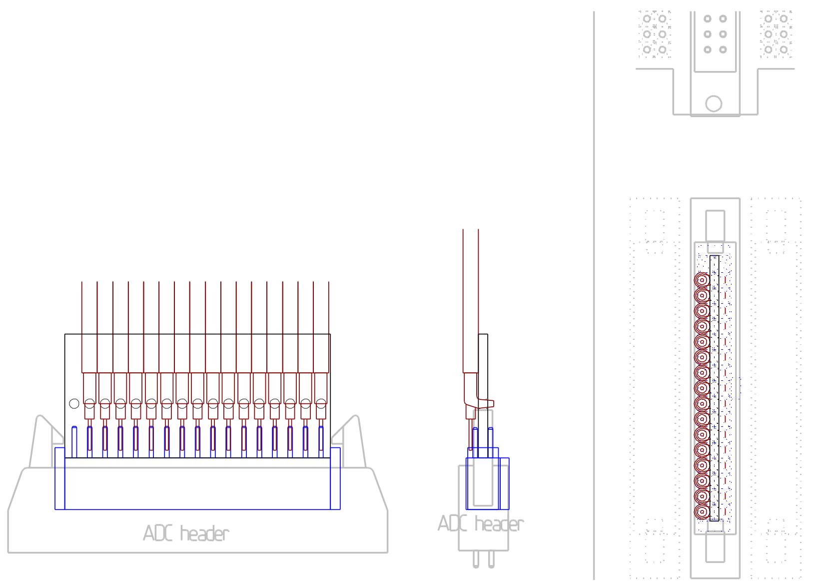
Cable assemblies that might satisfy our requirements are manufactured by CAEN and VORG Electronics. The CAEN A392 consists of 16 separate LEMO-terminated RG-174 wired to a printed circuit board at right angles to the ADC input, which is connected via a standard ribbon connector. At the time of this report, it cost over $700 CDN, and two would be needed to service a single ADC.

VORG Electronics makes cable assemblies with coaxial ribbon terminated by standard ribbon cable connectors. These sell for substantially less, about $400 CDN, however, an interface panel would be needed. VORG provides a 64 signal panel for $600 CDN.

VORG Electronics also has indicated that they can make a cable assembly with individual RG-174/U cables terminated with BNC. The cost would be about $500 CDN.

It should be possible for our group to make these for less. The simplest solution was to wire 16 RG-174 coaxial cables to a boardmount socket. To move the weight of the cables away from the solder points, the socket connector is mounted on a small piece of circuit board by fitting the board between the tails lengthwise to the connector as shown in the middle figure in Figure 1.1, and the cables glued to the board. A right angle socket connector cannot be used because these variants tend to either not fit latching headers, or the right angle tails are too weak to withstand repeated plugging. Placement of the circuit board between the tails transmits force directly to the body of the connector, leaving only torsion to the tails. To improve rigidity, a longer tail version of the connector should be used and these are either soldered or glued to the board. Figure 1.1 assumes a 0.2” tail. The rigidity from the length of the tails had to be balanced against making the assembly too large. A large assembly would present a longer leaver arm with which the tails of the socket connector could be bent or broken. Longer tails also increased the likelihood of noise pickup and crosstalk. The placement or shape of the tails should be such that the space between should be about 1/16”, the thickness of a standard circuit board, and such that they present a surface to solder or glue to the board. Flat solder tails are sometimes oriented such that they would be perpendicular to the board, and if oriented as required, they tend to be too bendable. Square tails are most desirable.

Figure 1.1.: Conceptual Drawings of Cable Assembly

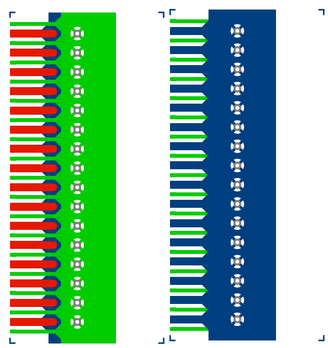


The socket connector should also be polarized with a center ridge or center bump commonly found on cable sockets. This ensures the signal and ground sockets mate with the correct pins. “Tabs” should be added to the ends of the connector so that the latch headers can latch to the connector assembly. Attachments to the circuit board are not possible due to the lack of space, and a protrusion milled directly out of the board would be too small, and thus weak, to be useful. These tabs only need to be about 1/16”, so unperforated circuit board can be used as raw material.

It is not clear whether the circuit board needs to be etched. Both the core conductor and the ground braid can be attached directly to the tails of the connector, but working with the ground braid this way can be awkward, and potentially unreliable. If a plain copper-clad circuit board is used, the ground braid could be soldered to the ground plane, in this case via a hole in the board. It has been found that thermals should not be necessary. This also minimizes the cable's exposure to heat during soldering. The signal conductor as depicted in Figure 1.1 is at the minimum workable length, so that the connectors are the main source of crosstalk so far. Etched boards do not seem to be necessary.

If chemical etching is required for some other reason, it might be a good idea to add ground stripes between the tails on the component side to try to reduce crosstalk (see Figure 1.4).

Figure 1.2.: Printed circuit board layout for cable assembly. Component side is on the left, solder side is on the right.



A more expensive, but more reliable design would have a rigid housing into which all components can be mounted, with significantly short conductor lengths. That is for future consideration, particularly if crosstalk is found to be a significant problem.

1.3. Splitter

The splitter circuit is the easiest to finalize, barring component idiosyncracies. It simply has to accept a 0.1" x 0.1" pitch wire-mounted rectangular socket connector in a header, split the signal with a voltage splitter, and terminate in a pair of 0.1" x 0.1" pitch boardmounted socket connector (see Figure 1.3). Single width VME modules are 2 cm wide so the placement of the output socket connectors was fixed as was the footprint on the circuit board. The V792 uses 3M 3431 Latch/Ejector headers, so for the sake of interoperability of the cable with the splitter and the bare V792, those have been chosen. It could be argued that latchless headers could be used instead because these types of connectors do have a substantial extraction resistance, enough that ordinary applications with flat ribbon cables often do not use latches. However, given the relatively more massive cables and possibly more fragile components, it would be prudent to use latch/ejector headers.

With the footprint of the connectors fixed, the printed circuit could be layed out as shown in Figure 1.4. To ensure 50 ohm impedance matching with the cable, 50 ohm 0805 package surface mount resistors are placed in series with each output so that each branch of the split with the ADC has an impedance of 100 ohms each. The input line does not need an impedance matching resistor

Figure 1.3.: Conceptual Drawing of Splitter

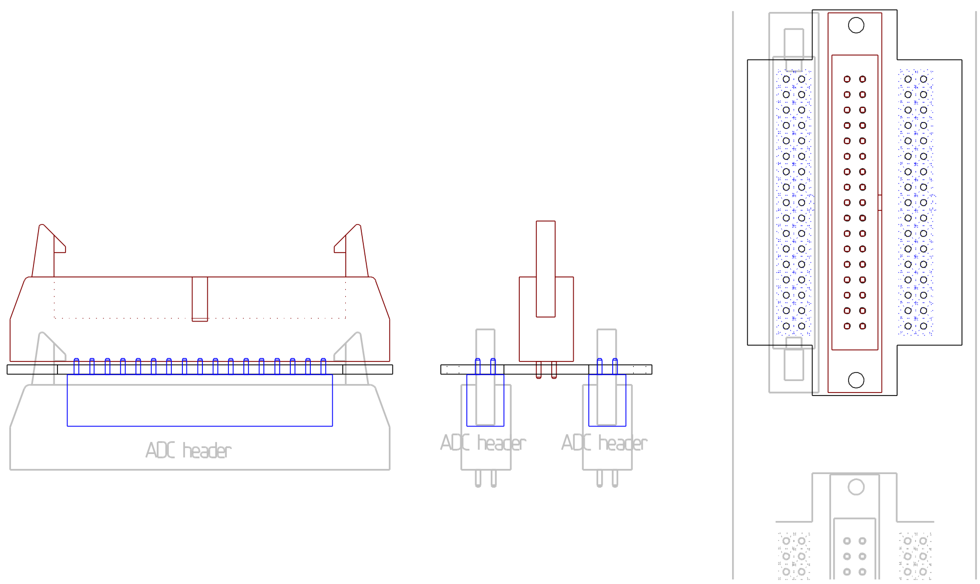
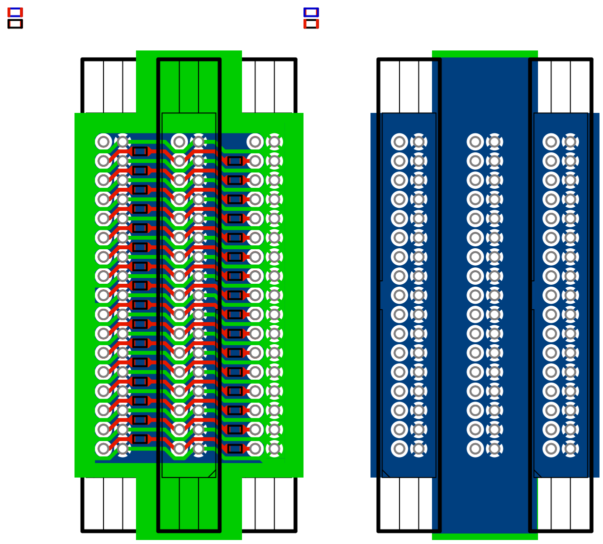


Figure 1.4.: Printed circuit board layout for splitter. Component side is on the left, solder side is on the right.

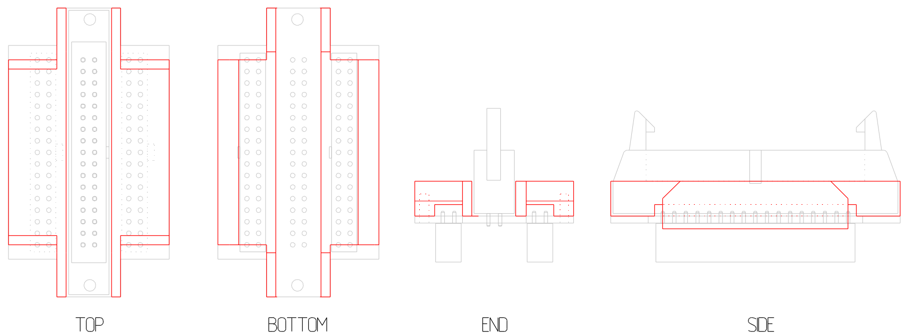


since the circuit is too small to satisfy transmission line conditions.

Unlike the old splitters, there is little room on the circuit boards for manual handling. In fact, the surface mount resistors are extremely close to the logical pressure points to seat the connectors. Furthermore, the tails from the socket connectors, which necessarily stick out of the board, are also at the logical pressure points and present an uncomfortable surface to press upon. It might be sufficient to press along the outside edges of the board. Failing that, a housing may be necessary to provide a reasonable surface to press upon, transmit the requisite seating force to the connectors, and protect the resistors and circuitry. If made of metal, such as aluminium, it should also shield the circuit somewhat from external noise. However, it cannot be made of sheet aluminum bent to the appropriate shape because tests show a piece of sheet thick enough to be rigid (e.g. 1/16”) would be too narrow to safely or reliably cut and bend.

A possible housing is shown in Figure 1.5. The main difficulty in design is finding adequate support points on the circuit board. Due to the density of the circuitry, there is no space in the middle of the board for support. Fortunately, the headers on the ADC force space between the two cable assemblies and that provides contact points at the ends. However, with so much of the interior bulk of the housing removed, the roof must be made quite thick so that the end support legs can withstand the force of connection. A thicker roof also makes manufacture easier, as this would provide more clamping area during milling. There is also some space between the ADCs, so that the circuit board can be made a little wider than the absolute minimum. In this case, stock 1/2” Al stock is available, so for convenience the side wall is about 180 mil thick, and can take most of the load. The circuit board should be made at least this much wider to accomodate a housing if found

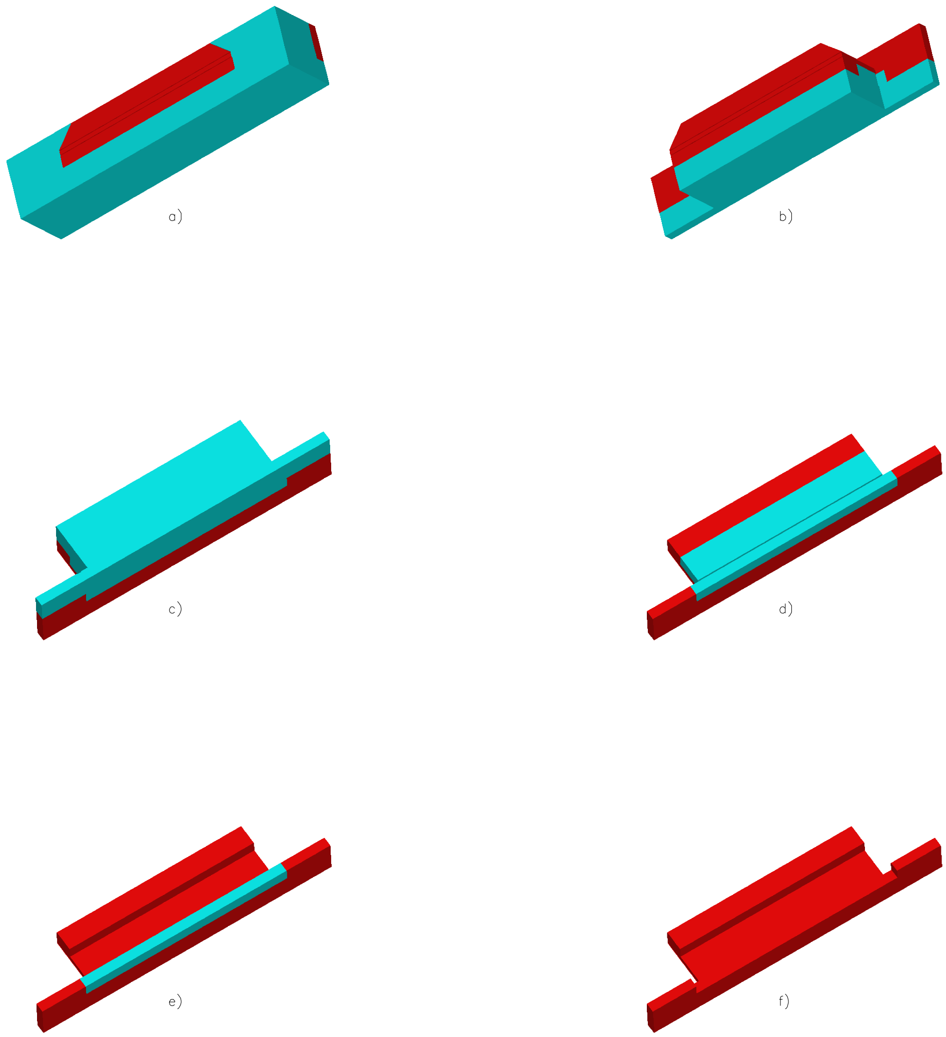
Figure 1.5.: Conceptual drawing of housing for splitter.



necessary (the conceptual design of the splitter in Figure 1.3 assumes this housing). The 45° bevels provide more room for fingers on the latches of the header under the splitter. Given the limited space due to the latch, the end legs are too thin for screws. The housing would be fastened to the circuit board with screws at the sides. However, there is limited space under the board for the head of screws, so despite the abundant thickness of the wall above, smaller screws are required. 1-72 and 0-80 screws are under consideration.

This housing should be made of aluminium. It was designed so it can be milled in two passes with simple linear cuts (see Figure 1.6). The first pass cuts the corners out and bevel cuts two edges. Then the piece is turn onto its top so that a channel can be cut, part of the wall that will be adjacent to the center header will be removed, and holes for screws can be drilled and tapped.

Figure 1.6.: Milling sequence of splitter housing. Starting with ingot (a) ,remove corners for header latch clearance (b). Rotate piece 90 degrees (c) then remove bulk (d). Cut channel (e) then remove part of thinner wall (f) for PCB component clearance.



1.4. Attenuator

Attenuators will be used to effectively reduce the gains of the ADCs without changing PMT gains. This is a quicker and more predictable means, and it allows the trigger thresholds to remain lower than when reducing PMT gains, useful for neutron detection efficiencies. Of course, this means that more than one set of attenuators will be needed.

The attenuator could be implemented either as a separate inline component (between the cable assembly and the splitter), or as a piggyback component in the splitter, cable assembly, or even the patch panel. The key concerns are introducing more crosstalk, noise reception, and lever arm on connectors. Since an inline component presents the highest risk in all of these, it is the least recommended. Implementing the attenuator at the patch panel implies either cable-by-cable components, or switching to high density connectors on both ends of the cable. In the latter case, the circuit boards would have to be made accessible (e.g. rear access) to users, and there would be extra signal propagation time introduced as the signals would have to be rerouted to the attenuators. The former would abuse the workers that would have to regularly change the attenuators whenever the detected energy regimes required it. The alternative, then, is to build modified versions of the cable assembly or of the splitter. The problem with incorporating the attenuator in the splitter is that there is no room on it for the necessary extra connectors. All of the ideas for extensions suffer in mounting the extra connectors in such a way that forces from the cable don't break something. The least obtrusive point of integration is on the cable assembly. With only the addition of 1 cm more length to the board, it would be possible to accomodate a plug. Even with extra connectors for additional grounding, the increase in lever arm is quite short compared to the other solutions.

The simplest means of attenuating a signal is with resistor networks, basically voltage dividers. The input impedance has to be matched to the coaxial cable, so an attenuation resistor placed in series is inappropriate. A shunt resistor to ground provides the necessary balance. There's practically no concern for matching the output impedance because of the proximity of the attenuator circuit to the ADC. However, matching at both ends leads to symmetric circuits and this can be useful from a practical standpoint. Given that, two types of layouts are possible, the classic T and π networks shown in Figure 1.7. The circuit connected to the ADC, or the load R_L, must present 50 ohms to the incoming signal. The combination of the attenuation resistor, R_A, and the shunt resistor, R_S, reduces the signal strength to the fraction ρ at the load, while also maintaining a 50 ohm impedance. The choice of network in this application is determined more by geometry than by electrical characteristics (higher speed applications apparently prefer T networks because the component resistance tend to be low and that reduces the effects of stray capacitance and series inductance).

For the T network, the resistances are

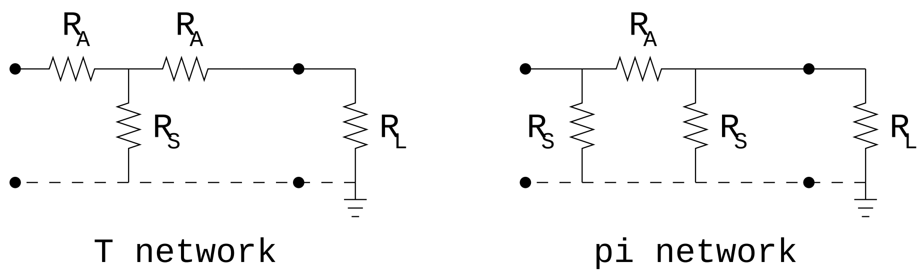
$$R_A = \frac{(1-\rho)}{(1+\rho)} R_L$$

$$R_S = \frac{2\rho R_L}{(1-\rho^2)}$$

For the π network, the resistances are

$$R_A = \frac{(1-\rho^2)}{2\rho} R_L$$

Figure 1.7.: Types of attenuator resistor networks. R_L is the load (the ADC in this case), R_S is the shunt resistor, R_A is the attenuation resistor.



$$R_S = \frac{(1+\rho)}{(1-\rho)} R_L$$

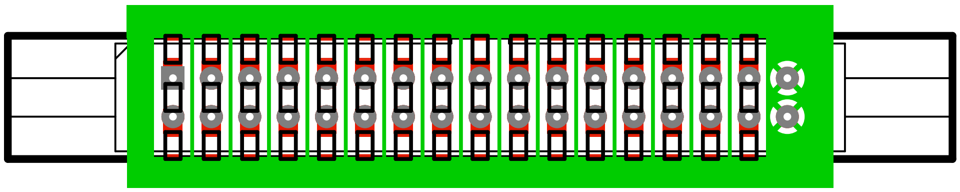
These are tabulated in Table 1.1 for attenuation factors ranging from 10% to 100%.

Table 1.1.: Resistors for attenuator. Values for both T and pi network variants are shown.

%signal	T net		π net	
	R_A	R_S	R_A	R_S
10	45	5.6	450	55.6
20	40	12.5	200	62.5
30	35	21.4	116.7	71.4
40	30.0	33.3	75	83.3
50	25	50	50	100
60	20	75	33.3	125
70	15	116.7	21.4	166.7
80	10	200	12.5	250
90	5	450	5.6	500
100	0	open	0	open

It was actually with the design of the attenuator that the size of the circuits were found to be small enough to move directly to the ADC. Type 603 surface mount resistors can fit between the solder tails of a standard 0.1” x 0.1” pitch rectangular connector. This means a “pi” network can be used for the splitter, with the attenuator resistor between the solder tails, and shunt resistors on either side of the solder tails. This assembly would then plug into a 0.1” x 0.1” pitch boardmount socket, and since it is a symmetric layout, the orientation is not a concern. The requisite circuit board would only need to be not much more than twice the width of the connector.

Figure 1.8.: Printed circuit board layout for attenuator with π net.



If an in-line variant of the attenuator is preferable, something like Figure 1.9 might be considered. In this case, a T network is used, with an 0603 surface mount resistor as the shunt resistor. The problem with this variant is that adequate space must be given for the latch handles on the splitter's header, and that means longer lever arms on the primary connectors as well as more unshielded leads.

These solutions are based on 0.1" geometries. Clearly, crosstalk is going to be an issue. Ground striping will be used on the circuit boards, and that necessarily is a 0.05" geometry. It might be possible to use 0.05" pitch connectors, such as the Samtec RSM series, to keep ground lines between signal lines throughout the connectors in the piggyback variant (see Figure 1.10).

Figure 1.9.: Printed circuit board layout for attenuator with T net.

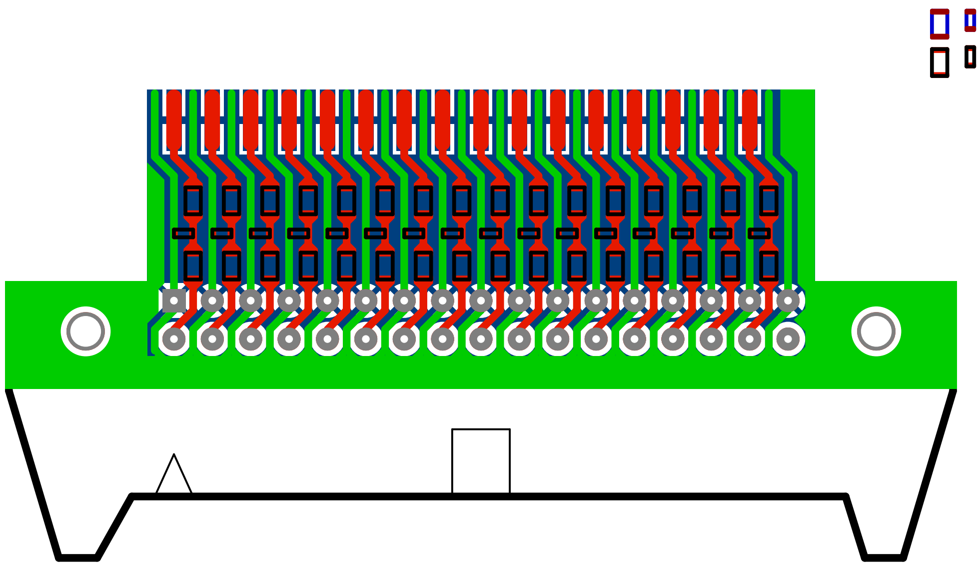
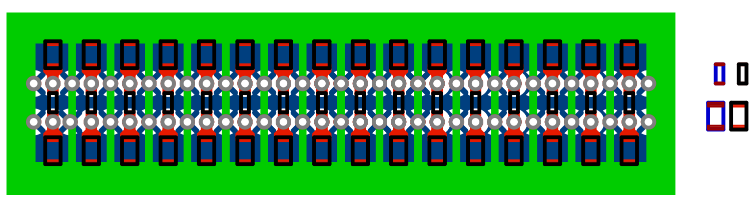


Figure 1.10.: Printed circuit board layout for attenuator using 0.050” pitch connector to keep ground shield throughout the connector. Attenuator is a πnet.



2. Parts and Costs

2.1. Cable Assembly

2.1.1. Specifications

Two coax cable manufacturers were considered based on availability at two or more suppliers: Alpha Wire Company and Belden. Alpha has only one RG-174 in their line, Alpha 9174. Belden has two, however, Belden 9239 is not a typical RG-174, leaving Belden 8216. Both manufacturers' cables are nearly the same with identical specifications except outside diameter (see Table 2.1). Alpha 9174 is 0.100" and Belden 8216 is 0.110". Because the cables will be lined up together in association with connectors with a 0.100" geometry, the Alpha cable is more desirable. The slightly smaller diameter should not be a problem for the reliability of the crimp. For example, the Amphenol 31-315-RFX is designed for use with RG-174/U and RG-316A, the latter having 0.100" OD.

Table 2.1.: Specifications for two RG-174/U. Sources: http://www.alphawire.com/ and http://bwcecom.belden.com/

Specification		Alpha 9174	Belden 8216
Core	AWG	26	
	Stranding (#/AWG)	7/34	
	Material	Copper Covered Steel	
Dielectric	Material	Polyethylene	
	OD (in.)	0.060	
Shield	Material	Tinned Copper Braid	
	Coverage	88	?
Jacket	Material	Polyvinyl Chloride	
	OD (in.)	0.100	0.110
Speed of Propagation (%)		66	
Capacitance (pF/ft)		31.1	30.8

Four BNC connector manufacturer's were initially considered, AMP/Tyco, Amphenol, SPC Technologies, and Kings. Kings connectors seemed uniformly very expensive, so they were no longer considered. Each of the remaining companies makes a variety of BNC connectors for RG-174/U cables. Variants differ primarily by body plating, assembly type (e.g. crimp vs. solder), dielectric material, and grade (e.g. commercial vs. military - this often translates to different component materials). Gold or silver plating the body of the connector seems to triple or quadruple the cost, and our application requires robustness more than external electrical conductivity, so those variants were rejected. However, past experience with oxidation of signal contacts indicates gold plating on the core contact is required. Crimp assembly was preferable over clamp in the hopes that crimping will ease and speed the construction of the cable assembly, and withstand handling better. Crimped connectors also seem to be consistently less expensive than solder/clamp variants (because of the simpler parts). However, it is not clear if hex crimping is preferable to “dual crimping” or “O crimping”. Hex crimping normally distorts the dielectric more (flattening it at the 6 points of compression), however, RG-174 variants typically use a sleeve under the shield braid to expand the effective diameter at the crimp, so the dielectric is not affected. Polyethylene dielectric seems to be the cheapest material, with the more expensive connectors using Teflon, polytetrafluorethylene (PTFE), etc. The most common alloy used in the body of the connector is brass, but less expensive alloys are used for less expensive connector variants.

Taking availability into account and demanding single unit prices under $5 CDN, the field was narrowed to the following connectors: Amphenol 31-315-RFX, and AMP 2-221128-1, 1-227079-6, 225395-7. All of these are nickel plated on the body and gold plated on the core contact, are crimp-on (both core and sleeve), and have brass bodies, . The differences are shown in Table 2.1. The “Approx. price” is for a single unit and 200 units at a popular mail-order outlet in $CDN.

Figure 2.1.: Specifications for RG-174/U BNC connectors.

Specification	Amphenol 31-315-RFX	AMP 2-221128-1	AMP 1-227079-6	AMP 225395-7
Cable type	174,188,316	174,188,316	174,188	174,188
Crimp type	hex	hex	O	O
grade	commercial	commercial	commercial	military
dielectric	Delrin	polyethylene	polyethylene	Teflon
Approx. price	3.30 (1.64)	4.00 (3.60)	2.60 (1.75)	4.50 (3.00)

The Amphenol 31-315-RFX is a commercial variant of the 31-315 connector. The AMP 1-227079-6 and 225395-7 are not related. RG-316 is a 0.100” OD cable, so any specification that includes it assures compatibility with the Alpha 9174 cable. The 31-315-RFX and 1-227079-6 are the two most economical, but the assured 0.100” compatibility, tougher dielectric, and better volume price suggests choosing the Amphenol 31-315-RFX. Past experience with this connector on the SAL Tagger also suggests this is a sufficiently reliable connector.

The socket header needs to have longer tails than usual, as noted in Section 1.2. The tails must also be square, rather than flat. The contacts must be gold plated, and the tails should be tinned. Samtec seems to be the only socket header manufacturer that produces long, square tailed variants. However, in Section B.1, it was found that longer tails resulted in somewhat more crosstalk, so the tail should not be as long as Samtec's longest ones. The 0.2" tail variant was found to be suitable, so the SSQ-117-02-S-D is the suggested header. This variant has 30 μm gold plated conductors and pre-tinned tails.

As noted in Section 1.2, the socket header should be polarized, preferably with a center ridge. This was because there is a definite orientation of the connector, and because it was found that it is possible to insert the connector offset by one pin (or one signal channel). Samtec advertises that they can customize their connectors, and they are currently investigating the possibility of our request. Accordingly, the custom part number ASP-104465-01 has been designated for an SSQ-117-S-D modification. This incorporates the 34 gold plated contacts and square, tinned, 0.194" tails. The cost of such a modification seems to be of the order of 20% extra.

The circuit board must be 1/16" thick to snuggly fit between the socket connector pins. This allows for the additional thickness of copper plating. The substrate should be standard FR4 epoxy glass. The copper layers should be 1.5 to 2 oz and be tinned.

2.1.2. Cost

The cost of parts for the cable assembly is given in Table 2.2, in Canadian Dollars, taxes and other fees not included. Initially, 3 pairs of ADCs will be in service and 1 pair in Saskatoon for development, with 2 more added when Blowfish is expanded. Each pair requires 2 cable assemblies, and 2 spares should be available, for a total of 14 cable assemblies. Each assembly consists of sixteen RG-174 cables terminated by a BNC connector at one end, glued to a small copper clad circuit board, and connected to a socket connector. The RG-174 cable is 3m long (see Appendix A), and 224 of these are needed, for a total 672m or 2240 feet. The U of S group does not have any BNC terminated RG-174 of adequate length, so the full inventory will have to be ordered. RG-174 is typically sold in quantities of 200, 500, and 1000 feet, so two 1000-ft spools will be needed.

Table 2.2.: Cost breakdown for Cable Assembly. Currency is Canadian Dollars. Tax and other fees are not included.

Item	Qty	Cost	
		unit	total
RG-174 Cable, 1000' spool (Alpha 9174)	2	320	640
RG-174 Cable, 500' spool (Alpha 9174)	1	185	185
BNC plug for RG-174 cable (Amphenol 31-315-RFX)	224	2	448
Circuit Board, single sided, 2 oz. copper, 6"x6"	1	10	10
Socket connector (Samtec SSQ-117-02-S-D)	14	4	56
Subtotal	14	95.65	1339
Assembly Labor			
Total	14		

The labor costs have not yet been determined. If an undergraduate student is hired as a Part-time Student Assistant, the pay rate is about $10 per hour. Tests indicate that one cable assembly can be fully soldered within an hour. Cutting out and gluing a circuit board and socket connector would take 15 to 20 minutes. It is expected that attaching 16 BNC connectors to their cables will be the most time consuming, as it requires a more elaborate procedure than the rest of the assembly. If we cannot obtain a center-ridge variant of the socket headers, there will be additional labor involved in attaching our own.

It is not yet clear if the circuit board will need some modification. If crosstalk tests indicate ground striping is necessary, the board may have to be etched. This will increase the cost of the boards (see the next section).

Also not factored into the cost is tooling costs for the U of S group. A crimp tool (and typically a die set) will be required to attach the BNC connector to the RG-174. The choice of the tool depends on the choice of connector and often the part number of the connector. In this case, the Amphenol 31-315-RFX requires the Amphenol CTL-2 crimp tool which costs $70 CDN. Wire strippers that strip jacket, ground braid, and dielectric simultaneously can reduce workload. Typical prices range from $100 CDN for Xcelite strippers to $150 for Paladin strippers. However, Paladin and Ideal Industries manufactures economy versions. Information for Ideal Industries strippers is difficult to obtain, and the Paladin LC CST-mini, part #1258, has the exact spacing required for the Amphenol 31-315-RFX connector. It costs about $50 CDN.

2.2. Splitter

2.2.1. Specifications

As indicated in 1.3, the V792AA QDC uses 3M 3431 Latch/Ejector headers and these were chosen for the splitter for consistency. Samtec SSQ-117-01-S-D were chosen for consistency with the cable assembly with the minor difference of having the regular tail length for normal board mounting.

0603 SMD resistors are available with a variety of precision and two power ratings. The most common precisions are 1% and 5%, though 0.1% and 0.5% are available for 8 times the cost. The most common power rating is 1/16 Watt, while 1/10 Watt are about 4 times more expensive and not so widely available. The price difference between 5% and 1% is small, and since this is the range of precision of interest for the splitter, the 1% precision has been chosen.

0805 SMD resistors are available with a similar variety of precisions and power ratings. As with the 0603, the 1% precision has been chosen. The most common power ratings are 1/10 and 1/8 Watt.

Circuit boards for the splitter require etching. The substrate should be 1/16" FR4 epoxy glass. The copper layers should be 1.5 to 2 oz. The PCB etch facility needs to be able to handle 15mil spacing (any commercial facility can do this), 20 mil trace thicknesses, through-hole plated vias, two layered boards. The Physics department does not have etching facilities. Photoresist techniques provide the best results. For about $100 CDN, it would be possible to buy kits to make simple boards. The electrical engineering shop at the U of S Engineering department can do small jobs of simple boards, but cannot do plated through-holes. This is a shortcoming of kits, too. That means the splitters must be etched at an external facility. There are no commercial facilities in Saskatoon.

The two nearest facilities are **Custom Circuits** of Regina and **Alberta Printed Circuits** (AP Circuits) of Calgary. Both accept layouts by e-mail. Production costs are broken down into a fixed setup fee and board areal charge. Custom Circuits charges $275 for setup fee and AP Circuits charges $365. The board related charges would be of the order of $275 and $160, respectively. One of the restrictions with Custom Circuits is that their minimum run is for 60-70 splitter sized boards. AP Circuits does not have a number limitation other than an even number of boards be ordered. Furthermore, AP Circuits has a more economical prototype package, “Prototype 1”, with a startup fee of about $70 and about $90 for the board related charges. The restrictions are that the boards must be rectangular and there are no component or solder masks (copper is fully tinned). The corners can be clipped by us, and the solder masks are not crucial for us. For more economy, AP Circuits encourages clients of Prototype 1 to array multiple boards and layouts on a single board, and cut them out themselves. Finally, AP Circuits accepts files generated by a number of different software packages, including the Linux freeware **PCB**, and has information pages and scripts on their website to help users format their files correctly.

2.2.2. Cost

The cost of parts for the splitter are given in Table 2.3, in Canadian Dollars, tax and other fees not included. As outlined for the cable assembly, 12 splitters will be needed. Each splitter requires 1 circuit board, two socket connectors, one latch/ejector header, 32 resistors, and a pair of housing pieces. Printed circuit boards are economically produced in a larger quantity than needed, so the total given is actually the cost of all boards produced, regardless of actual usage here, and that was divided by the quantity tabulated to give the unit cost shown. In case a housing is not required, a subtotal shows the cost of the splitter parts without the housing costs.

Table 2.3.: Cost breakdown for Splitter.Currency is Canadian Dollars. Tax and other fees are not included.

Item	Qty	Cost	
		unit	total
Circuit Board (AP Circuits)	14	11.43	160.00
Type 0805 Surface Mount Resistors, 50 Ohm	448	0.05	22.40
0.1” pitch, dual row, boardmount, latch/ejector headers (3M 3414)	14	6.05	84.70
0.1” pitch, dual row, boardmount socket connector	28	4.00	112.00
Subtotal	14	27.08	379.10
Housing, 2 pieces for each splitter	28	28.57	400.00
Subtotal	14	55.64	779.10
Assembly Labor			
Total	14		

The U of S DPEP shop estimates the housings will take 12-16 hours to manufacture, including programming time for the CNC. It charges $25/hr. The estimate in Table 2.3 is for a conservative estimate of 16 hours.

Estimates for assembly time are not known yet. No one on the U of S campus provides surface mounting services. It is not known if a commercial service is available. The U of S Electrical Engineering shop and Canadian Light Source technical staff both suggest that this can be done by our group, providing an illuminated magnifying lense, good tweezers, and a sharp soldering iron. A Part-time Student Assistant may be a possiblility.

2.3. Attenuator

2.3.1. Specifications

For the attenuation circuit itself, only 3 components need to be considered: circuit board, SMD resistors, and pin header. SMD resistors of the type considered here are industry standardized. The pin header should be a low profile variant. The 3M 2300 series and Samtec TSW series pin headers have a 0.100” pitch and are 0.100” thick. However, the 3M header is limited to a minimum contact pin length of 0.230” which would be too long for low profile socket headers, whereas the Samtec TSW can be 0.105”.

2.3.2. Cost

The cost of parts for a π network attenuator is given in Table 2.4, in Canadian Dollars, tax and other fees not included. As explained for the cable assembly, a base quantity of 12 attenuators is needed. However, as explained in Section 1.4, there will be a need for different levels of attenuation. Each attenuation factor requires a set of 12 attenuators with the appropriate attenuation and shunt resistances. Hence, Table 2.4 is the cost for one level of attenuation, and must be multiplied by the number of levels required. The unit cost of the circuit boards is derived the same as with the splitter.

Table 2.4.: Cost breakdown for a πnetwork Attenuator for one attenuation factor. Currency is Canadian Dollars. Tax and other fees are not included. Actual total cost must be multiplied by the number of different attenuation levels required.

Item	Qty	Cost	
		unit	total
Circuit board	12	10.00	285.00
Type 0805 Surface Mount Resistors	384	0.05	19.20
Type 0603 Surface Mount Resistors	192	0.05	9.60
0.1” pitch, dual row, pin strip header	12	3.00	36.00
Subtotal	12	29.15	349.80
Assembly Labor			
Total			

A. Cabling in the Old Electronics Layout (2001)

An example of the old ADC cable assembly appears as a bundle of cables on the lower left side of Figure A.1, taken in 2001. An expansion of Blowfish will result in 5 more delay boxes (8 delays each). Thus the worst case cabling scenario would be where the VME crate is at the bottom left of the racks, and the furthest delay box would be in the upper right racks. If one assumes that cables are run horizontally then vertically to avoid impeding access to other electronics, the minimum cable length is 2 meters, and 3 meters would provide for delay boxes in the back of the rack. If the VME crate can be situated more centrally, 2 meters is more than adequate. Ultimately, it was concluded that an extra meter in signal delay was not a problem (perhaps even beneficial for gate generation time), and that it would provide for contingencies during the expansion of Blowfish. Thus the cable assembly would use 3m long RG-174.

Figure A.1.: Blowfish electronics racks in 2001.

B. Design Tests

B.1. Cable Assembly

B.1.1. Crosstalk measurements

The primary concern was with the length of the solder tail of the output connector, and the degree of crosstalk that might result. Lengths greater than 0.4” was considered unnecessary for structural strength and lengths less than 0.2” was considered insufficient. Two sample SSQ series connectors were obtained from Samtec, one having a 0.2” solder tail and the other having 0.4”. Three RG-174 cables were soldered directly to three pairs of adjacent solder tails, with empty pin pairs on either side of the group. Two types of pulses were used, a square pulse 20 ns long and a shaped pulse with 20 ns rise time and 50 ns fall time.

Table B.1.: Crosstalk measurements for 0.4” tails

Square Pulse			Shaped Pulse		
Pin	mV	Notes	Pin	mV	Notes
1	1.5±0.1V	primary signal	1	10.0±0.5V	primary signal
2	5.0±0.5		2	9.5±0.5	
3	3.0±0.4		3	2.0±0.4	
0	10±1	no cable	0	30±2	no cable
4	6±1	no cable	4	6±1	no cable

Table B.3.: Crosstalk measurements for a copper-clad PCB and connector with 0.2” tails. Pins 0 and 4 have no cable attached.

Primary in Pin 1		Primary in Pin 3		Primary in Pin 2	
Pin	mV	Pin	mV	Pin	mV
0	12±1	0	2±0.5	0	3±0.5
1	7V±0.3	1	1.0±0.5	1	5.5±0.5
2	5±0.5	2	5.5±0.5	2	7V±0.3
3	1.5±0.5	3	7V±0.3	3	6±0.5
4	2±0.5	4	12±1	4	3±0.5

Table B.2.: Crosstalk measurements for 0.2” tails

Square Pulse			Shaped Pulse		
Pin	mV	Notes	Pin	mV	Notes
1	1.5±0.1V	primary signal	1	10.0±0.5V	primary signal
2	5±0.5		2	8±0.5	
3	1.5±0.4		3	2±0.4	
0	25±2	no cable	0	20±2	no cable
4	5±1	no cable	4	4±1	no cable

Measurements of the adjacent outputs were done with the cables terminated at 50 ohms. Unterminating the cables resulted in about 1mV extra signal with the square pulse and significant ringing with the shaped pulse. Moving the pulser to the other pins yield very similar results.

Similar measurements made on a single-sided copper-clad PCB with a 0.2” tail connector yielded very similar results to Table B.2, with the ground braids of cables soldered to the copper cladding (i.e. the ground plane). Further measurements were made with the test assembly plugged into the V792 (powered down). The results in Table B.3 indicate very little effect from the ground plane.

Some tests were made to exacerbate crosstalk. The core conductor was stripped of an extra 0.3” of ground braid. The first 3 sets of data in Table B.4 compared to Table B.3 indicate only a very small effect on neighboring cables, with the larger effect on unconnected connector tails. If the cable assembly is plugged into the tails of another connector, with a 0.4” tail in this case, and that is plugged into the 50 ohm terminator instead of lengthening the lead (i.e. same short leads as previously), the fourth data set in Table B.4 results. There is little effect on the unconnected pins, but larger effects on the neighboring cables. This is consistent with the approximate doubling of unshielded conductor in the main cable assembly, and is consistent with measurements with a longer tail. The main difference between these measurements is that the “long lead” measurements

Table B.4.: Crosstalk measurements with long leads to tails, and one with a 0.5” extension connector. Pins 0 and 4 have no cable attached.

Primary in Pin 1		Primary in Pin 3		Primary in Pin 2		Extender	
Pin	mV	Pin	mV	Pin	mV	Pin	mV
0	15±1	0	2±0.5	0	5±0.5	0	5±0.5
1	7V±0.3	1	1.0±0.5	1	4±0.5	1	8±0.5
2	6±0.5	2	5±0.5	2	7V±0.3	2	7V±0.3
3	1.5±0.5	3	7V±0.3	3	5±0.5	3	7±0.5
4	2±0.5	4	15±1	4	4±0.5	4	5±0.5

involved conductors that retained an insulating dielectric up to the tails.

The conclusion seems to be that as long as the solder tails are kept to minimal lengths, the crosstalk can be kept to the order of 0.1% for two connectors in series (i.e. cable assembly plus splitter).

B.1.2. Connector seating

It has been discovered that some socket connectors have narrow enough walls that they can be plugged in offset by 1 socket. This would result in signals appearing in the neighboring ADC channels and one channel not reporting. A polarized connector with a center ridge or center bump would ensure the proper alignment, in addition to the proper orientation.

B.1.3. Soldering cable assemblies

In constructing test cable assemblies, some problems that need to be avoided and some solutions were evident for the final design of the cable assembly.

It should not be necessary to etch thermals on the PCB. The use of soldering flux and moderate pre-tinning is ample preparation of the board, and results in rapid connections, barring the problems below.

Pre-tinning the core and the ground braids is crucial. Use of solder flux is highly recommended so that the dielectric is not exposed to heat for too long.

Soldering just one row of tails on the socket connector was sufficient for a sturdy assembly, even with 0.2” tails. Applying epoxy cement on the other row and along the edge between the board and the connector should guarantee a solid assembly.

It is clear that the cables must be glued or otherwise clamped to the PCB, as the cable braids that are solderd to the boards are not rugged enough to withstand the continual load of cables. If glued only, the glue should encase the cable rather than adhere to the side.

If the core and dielectric are fed through the PCB, there must be adequate distance between the through-hole and the point at which the solder braid is soldered to the board. The heat transmited through the copper tends to melt the dielectric, thus allowing the edge of the hole to cut into the dielectric and potentially short out the core. Initial designs had these points 0.1” apart. It is recommended that this be increased to 0.2” or 0.3”.

The ground braid does not contact surfaces if only 0.1” is exposed. That is also too short a length to otherwise manipulate. Even with 0.2” exposed, soldering the braid to the copper is not easy. Either 0.3” of the braid should be exposed, or another means of soldering the braid should be used. It’s not clear if the braid should be partially parted and bunched before being soldered to bring more of the braid in contact with the ground plane. If so, 0.2” may be adequate.

The alternative for the ground braid is to put all of the cable on the component side and only feed through the bundled ground braid. This exposes the core only to heat from the core soldering and the ground braid on the other side of the board, both of which are simple and quick solders.