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The HITL Differential Analog Receiver

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Technical Note

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BACKGROUND

GROUND ISOLATION

Isolation of the grounds between the AGS and Tandem is difficult when precise transmission of analog signals is required. Simple optical isolators deteriorate with age. More sophisticated designs have up to 10's of kHz bandwidth, however that is too low. It is often acceptable to limit the current in the return line between a remotely grounded, single-ended driver and the local ground by a large but finite resistance. This is generally done by the use of a differential input analog receiver.

The receiver must have a differential input since both the signal and return lines will follow the variations of the remote ground potential but only the difference contains the real information. While the voltage between grounds is usually not large, several hundred volts may appear when high current, fast pulsers are nearby and the "good" ground is too inductive. In this case special circuits may be required if it is necessary to observe the signal under those conditions. For most applications, even at the AGS, this environment is present only during fault conditions and survival of the circuit is all that is required.

COMMON MODE CONSIDERATIONS

CABLE CHOICES

The benefit of the differential amplifier is lost if the signal transmission cable doesn't have good common mode characteristics; that is, if it doesn't expose the signal and return lines to the same noise along the cable run. External voltages and currents coupling equally to the signal and return lines of the cable will be subtracted by the differential receiver and won't appear at the output. Twisted pair cable is designed to keep the two leads close together. The twisting not only improves the uniformity of exposure;it also minimizes the area of any loop for magnetic pickup from nearby currents. Adding a shield around the pair further reduces the coupling. Non-twisted, unshielded pairs (ribbon cable) are much worse for noise pickup. Coaxial cable is a poor choice for use with a differential receiver since the noise couples to the outer conductor but much less to the inner. When the signals are subtracted the noise appears at the output. Coax is a single ended cable of poor common mode impedance.

CIRCUIT CONSIDERATIONS

With proper design the circuit can have 60 db (1000:1) common mode rejection ratio (CMRR). This is accomplished by adjusting the gain for the positive input to equal that for the inverting input. Since fixed resistors would require tolerances less than 0.1% to give 1000:1 CMRR a pot is generally used.

If both the gain and common mode adjustments are made on the same amplifier stage they will be non-orthogonal: they will fight each other. If the gain is adjusted then the common mode must be too, but this effects the gain, etc. In most cases, since the gain must be adjusted in place for the particular cable run to compensate for losses, a simple, fast setup procedure is desirable. If the common mode is adjusted in a first stage amplifier and the gain in the second there is no conflict. The common mode can be set on the bench and the gain in the field with no problem.

It is important to recognize that the CMRR is a bandwidth related parameter. Opamps do not have the same frequency characteristics on the inverting and non-inverting terminals: the non-inverting bandwidth is generally less. Unless the inverting input bandwidth is limited to be the same, noise frequency components above this range will not be rejected and appear at the output. This can be seen by putting the same square pulse simultaneously into both inputs. A transient appears at the leading and trailing edges of the pulse while in between the output is reduced by the CMRR. To eliminate this the inverting input bandwidth is reduced by means of a feedback roll-off capacitor to be less than that for the inverting input. A small trimmer capacitor can then be used to reduce the non-inverting input bandwidth. If this is not done high frequency noise will still appear at the output.

Another problem can develop when RF is present. If the frequency is sufficiently high it will be rectified by the input stage of the opamp causing the RF envelope to appear at the output. This is often observed at Linac frequencies of 200 MHz and its higher harmonics. In this case the bandwidth of the input signal must be limited by a) using input cable which is lossy at RF frequencies, b) using capacitors to limit the bandwidth, c) using RFI filters, d) significantly improving the RF shielding. A combination of all of these may be necessary.

THE HITL RECEIVER CIRCUIT

The differential analog receiver circuit used in HITL is shown in Fig. 1 (BNL drawing number D32-E171-4 B). It has a bandwidth of 350 kHz (1 microsecond risetime), 1000:1 dc CMRR and high frequency common mode adjustment. Provision is made for an input cable matching resistor and gain adjustment to compensate for cable loss when the resistor is installed. Back-to-back diodes reversed biased at the power supply voltages provide input protection up to several hundred Volts, limited by wiring insulation. The output stage can drive a terminated cable, but care must be taken to prevent shorting the output since no current limiting is provided.

An OP-37EZ opamp (Precision Monolithics Inc.) is used in both stages. Its specifications feature very low noise, 63 MHz GBW, 17 V/microsec slew rate and proper behavior. Although it has a very low offset voltage (10 microVolts), an offset current of 50 nanoAmperes results in an output offset of from 2 to 5 mV. The OP37EZ is pin compatible with the LF356 opamp. The OP37EZ is much preferred because of its greater stability when driving cacitive loads and much lower noise. While the LF356 may result in a lower output offset voltage, adjustment may still be required to compensate for the upstream driver. The second stage includes an LH0002 current driver (National Semiconductor Inc.) within the feedback loop to allow the circuit to drive a terminated cable and function as a repeater.

The printed circuit board layout contains 4 channels on a half-NIM format, allowing 8 channels in a single width NIM module. The board is designed in a way to allow 1 to 4 channels to be built in other packaging formats by shearing at the indicated lines. Because the circuits are fairly wide band, care in shielding the input leads from the output is required to minimize the chance of oscillation.

SET-UP AND CALIBRATION PROCEDURES

COMMON MODE ADJUSTMENTS

1. DC

   Using a dc power supply or a pulse generator set for atleast a 200 microsecond width, apply a 5 volt signal to BOTH inputs of the channel under test. Adjust the dc common mode pot (R6, R18, R30, R42) to give less than 5 mV signal on the scope. For a pulse input measure at the mid-time. If there is more noise (or oscillation than 5 mV) check test signal wiring layout.

2. AC

   Using a pulse generator connected to BOTH inputs as in 1, apply a 5 Volt pulse of risetime faster than 1 microsecond and width 20 microseconds. A transient will appear at both leading at trailing edges of the pulse. Adjust the AC common mode capacitor(C2, C12, C22, C32) to minimize the transient. If adjusted too far it will change polarity. Often the trans -ient will show a submicrosecond spike. Ignore this since it comes from direct pickup of the input signal.

INPUT CABLE IMPEDANCE MATCHING

When it is important to preserve the risetime of a pulse sent over a long cable run, the cable must be matched in its characteristic impedance. While this parameter is well known for a specific type of coaxial cable this is not the case for twisted pair cable. Some low quality cable can't be matched by a simple resistor and thus can't give microsecond risetime transmission. Good twisted pair cable can be matched but quite often the value is not known beforehand, making it necessary to measure it in place.

The cable impedance can be measured in the laboratory or at the actual cable run. The cable being tested should be several hundred feet long to make the test valid. Apply a pulse between the 2 signal leads with the shield grounded at the sending end. Adjust a pot connected between the signal wires at the receiving end until the rise and fall times of the pulse appear closest to the original. If the resistance is too small an overshoot may appear. If it is too large the rise and fall will be too slow. Measure the pot resistance. Most twisted pairs will give a value between 50 and 100 Ohms. The 4-pair twisted, individually shielded cable used in HITL appears to be matched at 52 to 53 Ohms. Use of a standard 51 Ohm resistor is satisfactory.

The printed circuit board has provision for the matching resistor as R1, R13, R25 and R37.

OFFSET VOLTAGE

While the OP37 opamps used in the receiver have very low offset voltages, the offset current and large input resistors used can cause a net dc offset of up to 5 mV to develop. In most applications this is not important, but, if the circuit is used as the input to an integrator it may be significant. Provision was made for an offset adjustment on the circuit board but the upstream drivers should be zeroed first. Once this has been done the offset voltage of the receiver can be zeroed by adjusting R49, R51, R53 or R55.

GAIN CALIBRATION

When the cable is terminated in its characteristic impedance, the signal is divided between the series cable losses and the terminating resistor. It is estimated that as much as one half the voltage may be dropped in the HITL cable runs depending on cable length and loss characteristics . To allow for this the differential receiver has gain adjustment of 0.95 to 2 built into the second stage. This must be set individually for each channel using the actual cable run.

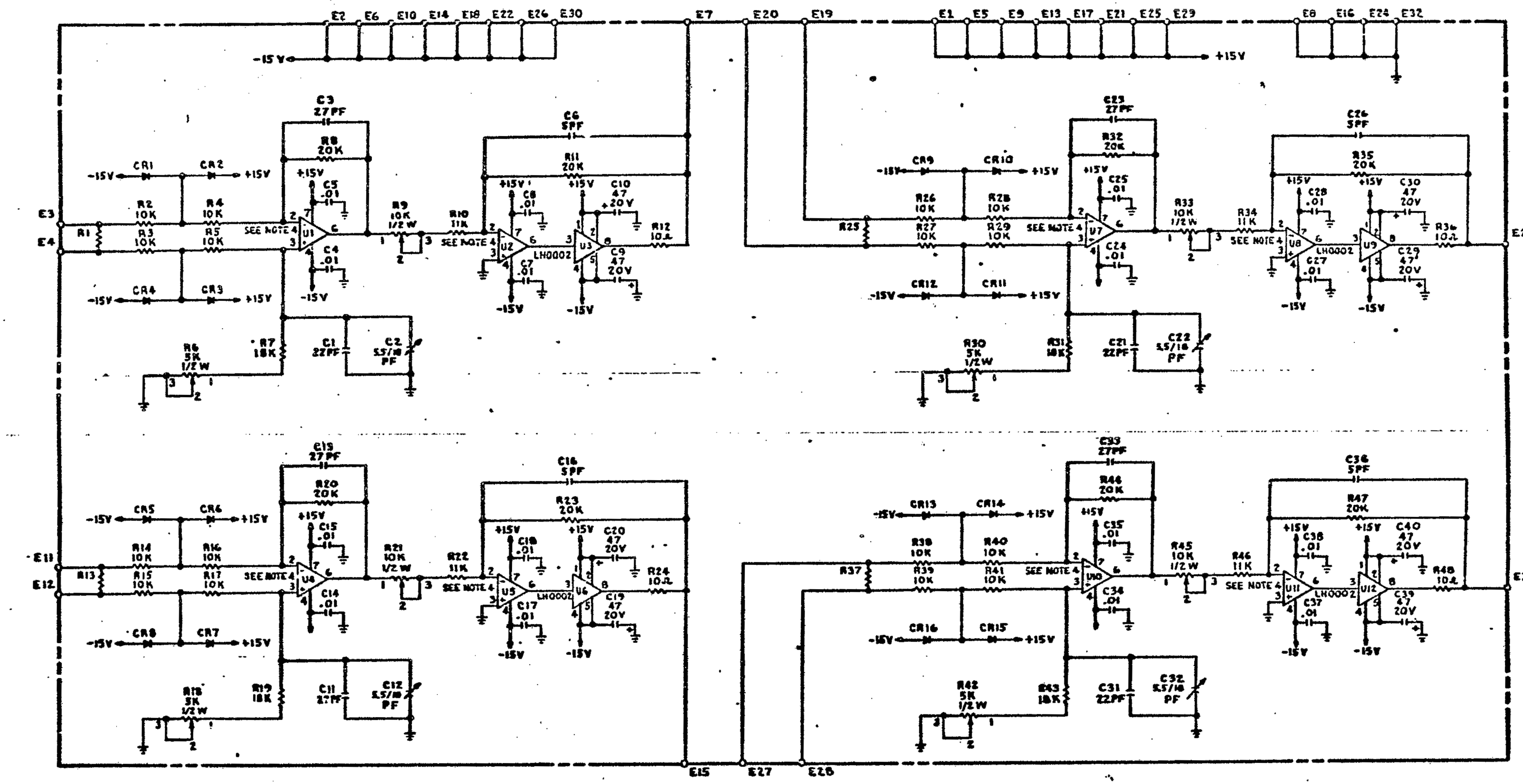
The gain is most easily set using a dc voltage and a DVM. A scope does not have the linearity, resolution or precision to set the gain to 1.000 +/- 0.001. The procedure is as follows:

1. Put a 1.000 volt signal directly on the cable between the high and low side signal leads. Connect the low side lead to ground at the source.

2. Put the DVM at the channel output. Read the output voltage with the signal disconnected. This offset voltage must be added to the 1.000 volts at the output.

3. Connect the signal cable. Adjust the gain using R9, R21, R33 or R45. Set the gain so the DVM reads 1.000 volts plus the offset voltage measured in step 2.

4. If the gain cannot reach this voltage the cable loss should be checked and if valid, R10, R22, R34 or R46 may be jumpered to increase the gain. BE SURE TO NOTE THE CHANGE.



E2 E6 E10 E14 E18 E22 E26 E30
E7
E20
E19
E1 E5 E9 E13 E17 E21 E25 E29
E8 E16 E24 E32
-15V
+15V
E3
E4
E11
E12
E15
E27
E28
C3 27PF
R8 20K
C6 5PF
R11 20K
CR1
CR2
CR3
CR4
R1
R2 10K
R3 10K
R4 10K
R5 10K
SEE NOTE 4
U1
C5 .01
C4 .01
R9 10K 1/2W
R10 11K
U2
U3
LH0002
C8 .01
C7 .01
C10 47 20V
C9 47 20V
R12 10Ω
R6 5K 1/2W
R7 18K
C1 22PF
C2 5.5/18 PF
C23 27PF
R32 20K
C26 5PF
R35 20K
CR9
CR10
CR11
CR12
R25
R26 10K
R27 10K
R28 10K
R29 10K
U7
C25 .01
C24 .01
R33 10K 1/2W
R34 11K
U8
U9
C28 .01
C27 .01
C30 47 20V
C29 47 20V
R36 10Ω
R30 5K 1/2W
R31 18K
C21 22PF
C22 5.5/18 PF
C13 27PF
R20 20K
C16 5PF
R23 20K
CR5
CR6
CR7
CR8
R13
R14 10K
R15 10K
R16 10K
R17 10K
U4
C15 .01
C14 .01
R21 10K 1/2W
R22 11K
U5
U6
C18 .01
C17 .01
C20 47 20V
C19 47 20V
R24 10Ω
R18 5K 1/2W
R19 18K
C11 27PF
C12 5.5/18 PF
C33 27PF
R44 20K
C36 5PF
R47 20K
CR13
CR14
CR15
CR16
R37
R38 10K
R39 10K
R40 10K
R41 10K
U10
C35 .01
C34 .01
R45 10K 1/2W
R46 11K
U11
U12
C38 .01
C37 .01
C40 47 20V
C39 47 20V
R48 10Ω
R42 5K 1/2W
R43 18K
C31 22PF
C32 5.5/18 PF