CP01 - A Preamp for the CLAS DWC

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Introduction

The CP01 is a fast complementary output, single channel transimpedance preamp with wide dynamic range. Its design is based on the ARGUS microvertex preamp [1] topology.

Its layout uses all SMT components on 0.79 mm (0.031") FR-4 and measures 2.54 x 1.14 cm^2 (1"x0.45") as a 10 pin SIP.

Requirements

For 10^5 gas gain, the discriminator level must be set at 10^4 e^- for good time resolution. Considering a transimpedance preamp, one primary e^- produces a peak current of about 5 uA and for good time resolution, sensitivity to 0.5 uA is required. Assuming 5 mV noise voltage at the discriminator input, the overall gain must be larger than 10 mV/uA (5 mV/10^4 e^-) and equivalent noise (eni) less than 0.5 uA or 10^4 e^-_{rms}. The dynamic range should be of the order of 200 uA.

Other requirements are low power dissipation, fast rise and fall time, good linearity, reliability and low cost. Conductive cooling is effected (10 pins) to a ground plane [2].

Gain(pre+post amps)	>10 mV/uA
Noise	<10^4 e^-_{rms}
Dynamic range	200 uA
Rise/Fall time	<5nS
Power dissipation	<100 mW
Linearity	<5%
Size	2.54 cm x 1.25 cm (1"x0.5")

Design

The circuit schematic for the preamp is shown in figure 1.

The first stage uses the traditional CE configuration with feedback, resulting in good noise and bandwidth characteristics. The input impedance may be lowered by increasing R4. If better noise characteristics are needed, a few transistors in parallel with Q1 may be added to effectively reduce the base spreading resistance.

The second stage serves as buffer/ complementary driver and uses "bootstrapping" for DC stabilization of both stages. Notice that the current through R5 is constant - a change in the operating characteristics of Q1 causes a compensation in the bias point of Q2 and vice-versa. R6, R8, R9 and R10 provide proper complementary loading.

Besides feedback and "bootstrapping", notice that the output stage never saturates: quiescent power dissipation is maximum and for large negative input signals, Q2 gets cut-off. Recovery from a cut-off condition is much faster than from a saturation condition.

BFT25 and BFT92 are optimal choices for Q1 and Q2, respectively, for their large ft, low noise and large hfe at low currents. Similar characteristics could be obtained with the MMBR931 and MMBR536.

Preliminary calculations were performed using the Ebers-Moll small signal model for BJTs (see Appendix).

For the transistors used, component values were: R1=10, R2=10k, R3=1.5k, R4=2.4k, R5=510, R6=200, R7=130, R8=67, R9=100, R10=50.

More accurate results were obtained by simulating and optimizing the circuit using the Gummel-Poon small signal model in PSPICE V5.0. Component values thus obtained, are used on the first version of CP01. The schematic is shown in Fig.2 and results of simulation are:

Iin(uA)	G(mV/uA)	Tr(nS)	Tf(nS)
1	2.55	2.52	2.54
100	2.46	2.58	2.51
200	2.12	2.60	2.32

Tests

Fig. 3 shows a test setup using a current source. The input impedance was measured to be between 110 and 150 ohm. Table 1 lists relevant parameters. Gain linearity is seen to be 5% at 200 uA input current and integral non-linearity was determined to be 2.3%. Worst case rise time is 2.7 nS at 200 uA after input rise time correction. Equivalent input noise was measured to be better than 0.25 uA.

Fig. 4 shows the setup used for ADC measurements (integrating ADC) under CAMAC control. Fig. 5 shows a charge linearity scatter plot for input currents ranging from 5 uA to 200 uA, 40 nS wide current pulses and 60 nS ADC Gate. From this, the system noise contribution was measured at 1.02 channels. Fig. 6 shows the ADC signal for 100 uA with a sigma of 1.28 channels (0.25pC/CH). Thus the amplifier noise contribution is 0.733 channels or

$$dQin = dQout/22.5 = 5090\ e^{-}_{rms} \text{ per single output.}$$

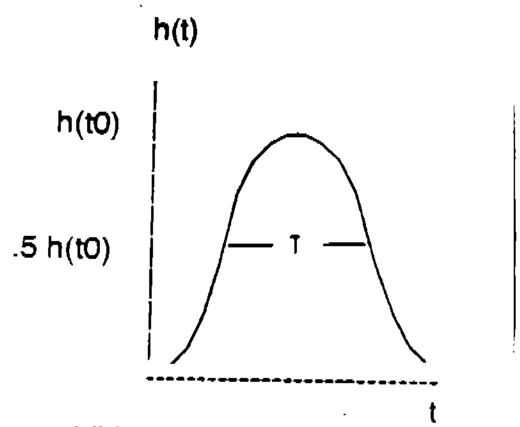
The noise for both outputs is 7200 e^{-}_{rms} @ 10 pF.

Fig. 7 shows a test setup normally used for charge amplifiers, the idea being to produce a step output from an impulse input. This test is not recommended for testing transimpedance amplifiers because of non-linearities at "band-edge" frequencies. For instance, Table 2 shows data obtained with this test setup and charge linearity is seen to be better than 5% up to 0.4 pC. However, from Table 1 and Fig. 5, charge linearity was measured to be better than 5% up to 200 uA and 40 nS or 8 pC !!!

For this setup, an input voltage signal produces a impulse signal which is useless in measuring the true linear characteristics of a transimpedance amplifier (perhaps one should review some publicized results...?). In fact, rise time is about the only relevant parameter to be obtained with this test setup. A analytic formulation of rise time is [3,4]:

$$t_r = \frac{\int_{-\infty}^{\infty} h(t)\, dt}{h(t0)}$$

$$T = t_r$$



Note: This formalism is normally used to prove additive quadrature of rise/fall times and bandwidth on multi-stage systems.

Fig. 8 shows CP01 impulse response for 1 pC input charge. The "FWHM" turns out to be 3 ns, like the rise time obtained for 200 uA input currents.

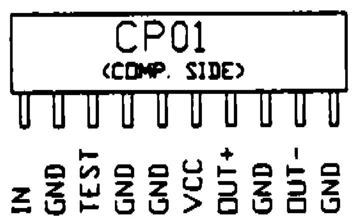
Fig. 9 and Fig. 10 show CP01 outputs to 100 uA input currents. In Fig. 9, the pulse is 10 nS wide at the base and fall time is less than the rise time. In Fig. 10, the CP01 shows excellent DC stability and very little shaping.

Conclusion

It has been shown that the CP01 fulfills all the requirements for the CLAS DWC preamp. Hybrid ceramic substrate manufacturing of the CP01 is a cost consideration being given full attention at present.

CP01 Specifications

Gain	2.25 mV/uA (complementary outputs)
Input impedance	110-150 ohm
Tr/Tf	< 2.7 nS
Noise(eni)	< 7200 e-rms (preliminary)
Dynamic range	200 uA @ 5% linearity
Int. non-linearity	2.3%
PD	65 mW
Vcc	+5 V
Size	2.54 x 1.14 cm^2 (1"x0.45")
Cost	$3-$4



Aknowledgements

Thanks to Bob Conner and Linda at Delta III and Philips Components for providing transistor and diode samples.

Also, thanks to Elsa Adrian for assembling the CP01 preamp prototypes.

References

[1] "The ARGUS microvertex drift chamber", E. Michel et al.
NIM A283(1989)-pp. 544-552.

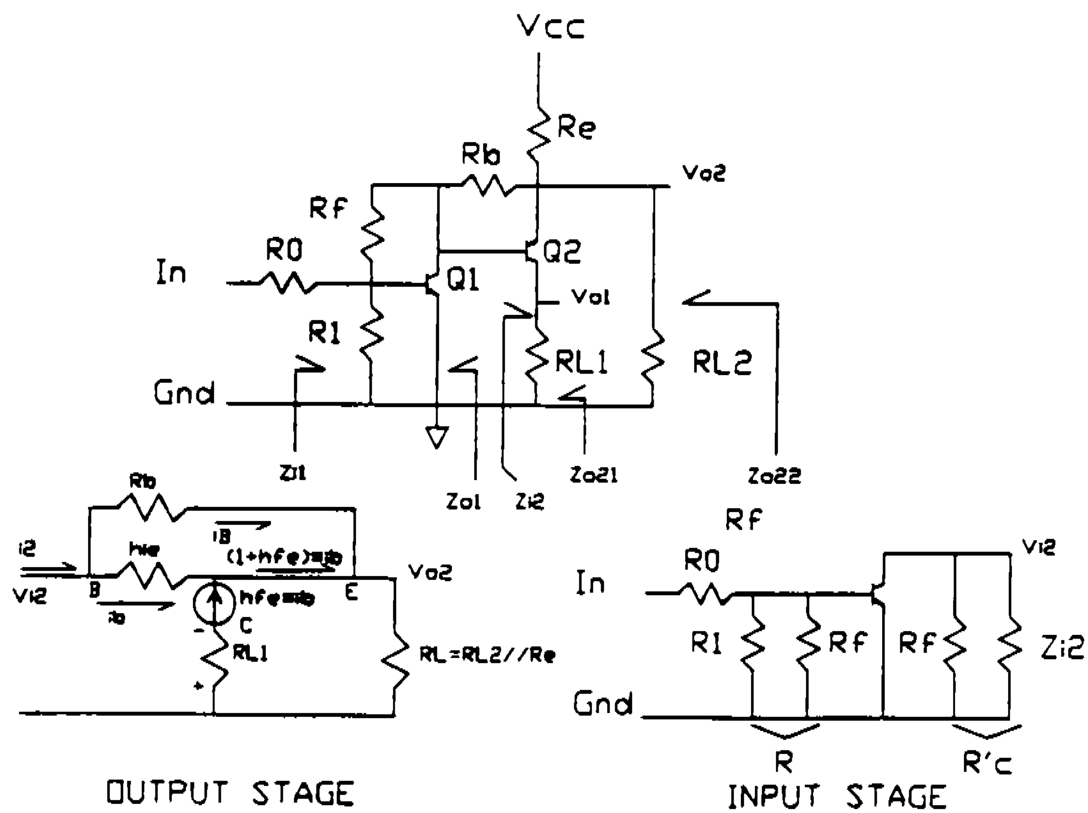
[2] "Cooling Of Clas Drift Chamber Electronics", F. J. Barbosa
CLAS-NOTE 91-014, CEBAF, 17 June 1991.

[3] "Signals and Systems", A. Oppenheim et al.
Prentice-Hall, Inc.

[4] "Circuits, Signals, and Systems", W. Siebert
The MIT Press / McGraw-Hill Book Co.

Appendix

The following schematics are used for the analysis of the CP01 preamp configuration. Equivalent input and output circuits are also shown.



The equations obtained assume Ebers-Moll device modeling:

Vo2 = [(1+hfe)*ib+iB]*RL (1)

Av22 = Vo2/Vi2 = 1-(hie//Rb)/Zi2 (2)

Av21 = Vo1/Vi2 = -(hfe*RL1*Rb)/[Zi2*(Rb+hie) (3)

Z'o21 = (4)

Z'o22 = [(Zo1/Rb)+hie]/[(1+hfe)+(hie/Rb)] (5)

RM = -hfe*R'c*R/(R+hie) (6)

B = -1/Rf (7)

D = 1+B*RM = 1+hfe*R'c*R/[Rf*(R+hie)] (8)

RMf = RM/D (9)

Ri = R//hie (10)

Zi1 = Ri/D (11)

Zo1 = Rf/D (12)

Zin = R0+Ri/D (13)

G = 2*RMf*Av2 (14)

where Av2 is the single output gain with proper loading. Also, proper choice of the bias point is required. For example, for Q1 and Q2 :

Q1 (BFT25) @ Ic=0.8mA - ft=2.3GHz, F=3.5db, hfe=40

Q2 (BFT92) @ Ic=10mA - ft=4.8GHz, F=3db, hfe=50.

Then,

Vo2=Vcc-(Ib+Ic2)*Re=Ic2*Rc+Vce (15)

and

Zin=114 ohm, G=2.4mV/uA.

Component values are presented on page 2.

Iin(uA)	Vout(mV)	G(mV/uA)	Tr(nS)	Tf(nS)
4.5	10.2	2.27	2.55	2.61
8.9	19.9	2.24		
13.4	30.0	2.24		
17.9	40.0	2.23		
26.8	59.8	2.23		
35.7	80.0	2.24		
44.6	100.0	2.24	2.69	2.46
53.6	120	2.24		
62.5	142	2.27		
71.4	163	2.28		
80.4	182	2.26		
89.3	201	2.25	2.80	2.32
98.2	221	2.25		
107.1	240	2.24		
116.1	260	2.24		
125.0	276	2.21		
133.9	295	2.20	3.18	2.32
142.9	315	2.20		
151.8	331	2.18		
160.7	354	2.20		
169.6	372	2.19		
178.6	386	2.16	3.40	2.14

(Tr and Tf have not been corrected)

Table 1 - CP01 measurements

Qin(pC)	Vout(mV)	G(mV/pC)
0.05	15.3	306
0.1	30.0	300
0.15	44.6	297.3
0.2	59.5	297.5
0.25	73.0	292
0.3	86.5	288.3
0.35	99.5	284.3
0.4	116	290
0.5	142	284
0.6	162	270
0.7	180	257
0.8	200	250
0.9	218	242
1.0	234	234

Table 2 - Impulse response

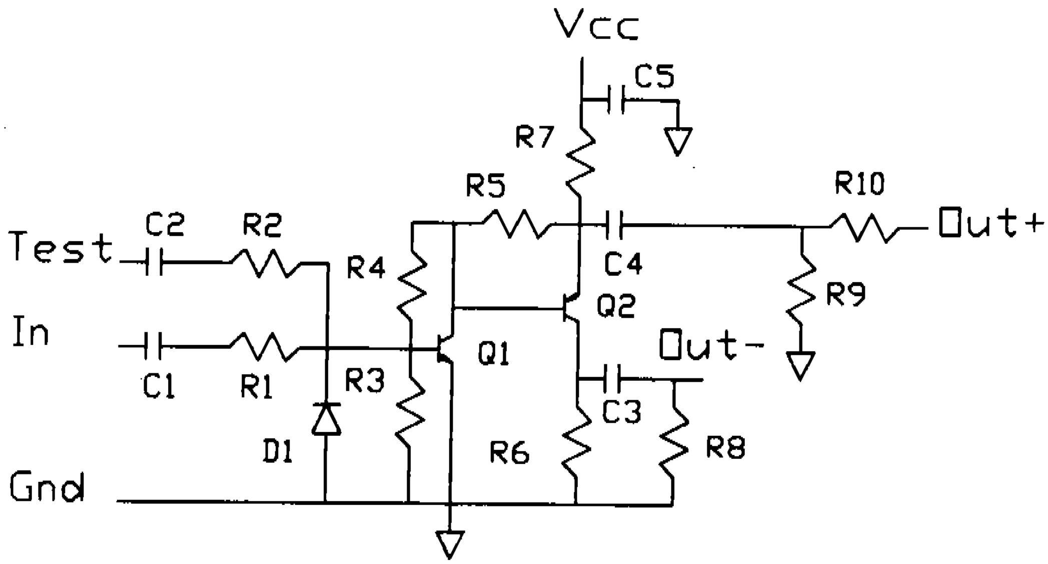


Fig. 1 - Preamp schematic

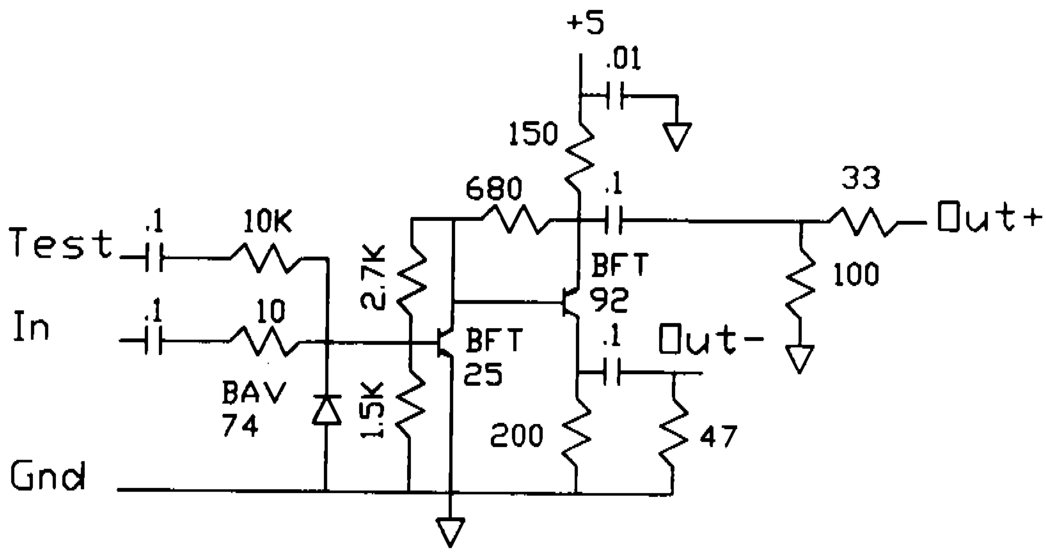


Fig. 2 - CP01.1

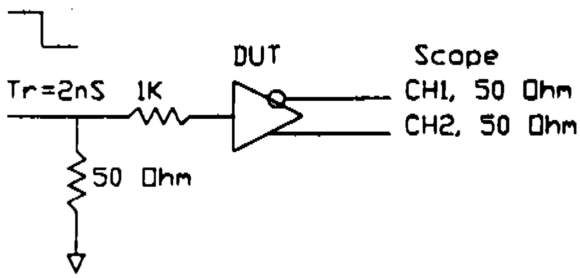


FIG. 3 - Testing Transimpedance Amps.

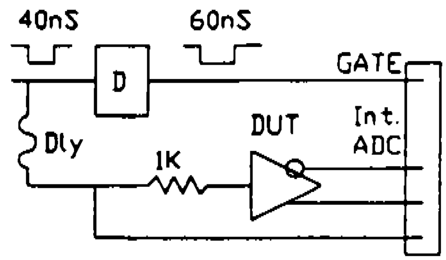


Fig. 4 - ADC Measurements

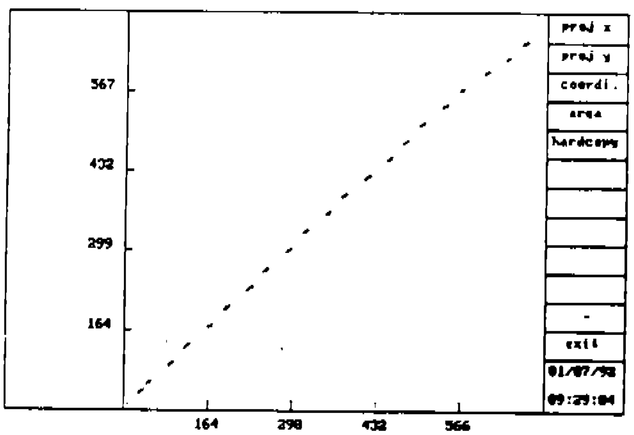


Fig. 5 - Charge linearity

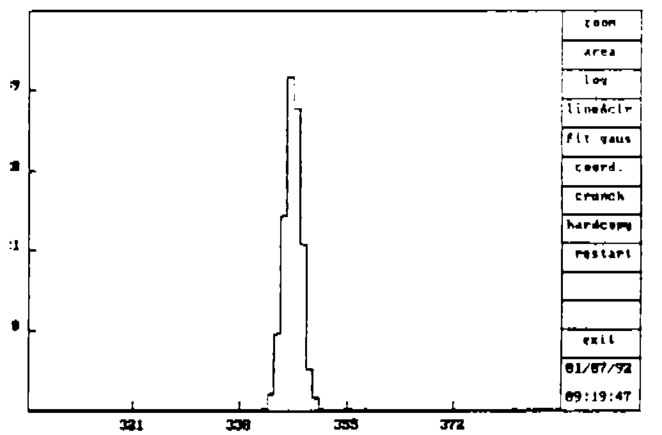


Fig. 6 - ADC Histogram

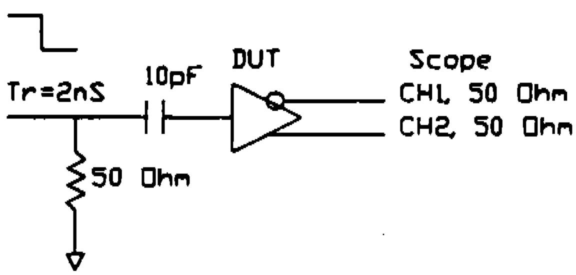


Fig. 7 - Almost USELESS Test

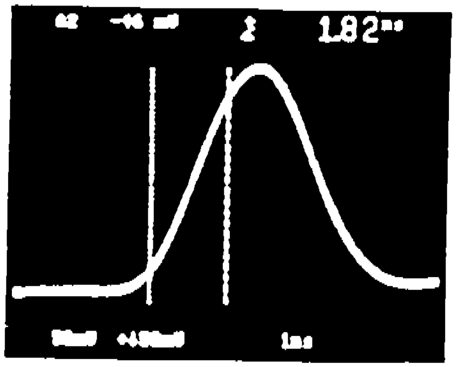


Fig. 8 - CP01 impulse response to 1 pC charge.

Fig. 9 - CP01 response to short, 100 uA pulse.

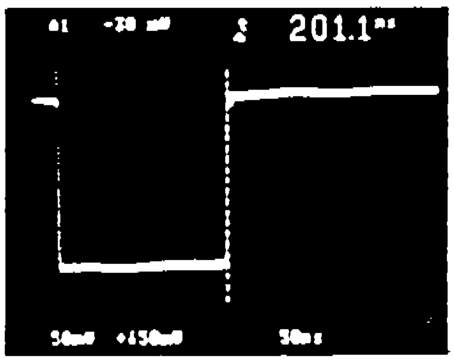


Fig. 10 - CP01 response to long, 100 uA pulse.