11553-2002

DL/CSE/TM09

technical memorandum Daresbury Laboratory

DL/CSE/TM09

AN "ELECTRONICALLY COOLED" PRE-AMPLIFIER

by

M.M. PRZYBYLSKI, Daresbury Laboratory

JANUARY 1979

Science Research Council
Daresbury Laboratory
Daresbury, Warrington WA4 4AD

1. INTRODUCTION

Most detectors used in nuclear physics experiments provide electrical outputs which may be charge, current or voltage. To process such signals sensitive wideband pre-amplifiers are used. The requirement for large bandwidth results in an increased noise, as typically the pre-amplifier output noise is directly proportional to $\sqrt{\text{bandwidth}}$. It is essential that a pre-amplifier should intorduce as little noise as possible, thus it should have the minimum equivalent input noise.

The report describes a low noise wideband pre-amplifier suitable for processing low level output signals from delay lines.

2. PRINCIPLE OF OPERATION

The pre-amplifier was developed for use with delay line readout from MWPC's. For optimum performance the pre-amplifier should provide an impedance match to the line. In order for the output to be independent of the characteristic impedance of a line, a charge sensitive configuration was chosen. The simple solution shown in fig. 1 where a low input impedance charge sensitive pre-amplifier with a matching resistor R_o is used to terminate a line, suffers from a major disadvantage, namely the unwanted Johnson noise generated in R_o. This noise has a spectral density

$$v = \sqrt{4kTR_o} \qquad V.\ Hz^{-\frac{1}{2}} \tag{1}$$

where

k = Boltzman's constant

T = temperature of the resistor

A pre-amplifier with a resistive input impedance and an equivalent input noise voltage independent of that resistance has been described(1). It uses a gain element with a transconductance $-g_m$ and an infinite input impedance as shown in fig. 2. It can be seen that

$$i_F = i_i \tag{2}$$

and the output current is given by

$$i_o = -g_m V_i \tag{3}$$

The output voltage is

$$V_o = V_i - i_F \frac{1}{sC_F} \tag{4}$$

The current in the load capacitor is

$$i_L = i_F + i_o = i_i - gm\, V_i \tag{5}$$

which gives rise to an output voltage

$$V_o = i_L \frac{1}{sC_o} = (i_i - g_m V_i) \frac{1}{sC_o} \tag{6}$$

From eqns (4) and (6)

$$(i_i - g_m V_i) \frac{1}{sC_o} = V_i - i_F \frac{1}{sC_F} \tag{7}$$

from which the input impedance can be found

$$Z_i = \frac{V_i}{i_i} = \frac{1/sC_o + 1/sC_F}{1 + g_m/sC_o} \tag{8}$$

which for $g_m/sC_o >> 1$ gives

$$Z_i \doteq \frac{1}{g_m} + \frac{C_o}{g_m C_F} = \frac{1}{g_m} (1 + \frac{C_o}{C_F}) \tag{10}$$

Thus for real values of transconductance g_m the input impedance will also be real. For a practical circuit $C_o >> C_F$ and the input resistance becomes

$$R_i \doteq \frac{C_o}{g_m C_F} \qquad (11)$$

In a pre-amplifier the equivalent input noise is mainly due to the input active device and its biasing resistors. If a low noise input FET which has an equivalent input noise resistance r_n is used in implementing a pre-amplifier with an input resistance, given by eqn (11), greater than r_n, then the pre-amplifier input resistance will have a noise temperature $T_n < T$

$$T_n = T \frac{r_n}{R_i} \qquad (12)$$

where T = ambient temperature.

Thus the pre-amplifier will appear to have a cooled input resistance.

3. CIRCUIT DESCRIPTION

If the pre-amplifier is to provide a good match to the delay line it is necessary to stabilize its input resistance. Figure 3 shows a schematic diagram of a charge sensitive pre-amplifier in which the transconductance can be precisely defined by passive components and made independent of the active components. The transconductance is given by:

$$g_m = \frac{(1 + R_2/R_1)}{R_3} \qquad (13)$$

which, for $R_2 >> R_1$, simplifies to:

$$g_m = \frac{R_2}{R_1 R_3} \qquad (14)$$

A feedback resistor R_F is provided to restore the output to its quiescent value with a time constant

$$\tau' = R_F C_F \qquad (15)$$

To facilitate the use of the circuit as a timing amplifier, a wide-band differentiator and current amplifier are provided. Figure 4 shows a schematic diagram of the differentiator timing circuit.

The output of the charge sensitive pre-amplifier is fed into the timing circuit. The output voltage of which is given by:

$$V_o' = -\frac{R_6 R_L (R_4 + R_5)}{(R_6 + R_L) R_5} C \frac{dV_o}{dt} \qquad (16)$$

which for $R_L << R_6$ and $R_5 << R_4$ simplifies to

$$V_o' = -\frac{R_L R_4}{R_5} C \frac{dV_o}{dt} \qquad (17)$$

But the input voltage V_o is the integral of the pre-amplifier input current i_i

$$V_o = -\frac{1}{C_F} \int i_i \, dt \qquad (18)$$

Thus

$$V_o' = \frac{R_4}{R_5} \frac{C}{C_F} i_i$$

The complete circuit of the charge sensitive pre-amplifier with timing output is given in fig. 5. Transistors TR1 - TR4 form a high gain amplifier with an open loop gain of approximately 10^3 and a stabilized closed loop gain of 23 determined by R_7 and R_3. Transistor TR5 supplies the current into the variable load capacitor C_o.

The circuit has an overall transconductance

$$g_m = \frac{R_7}{R_7 + R_3} \; \frac{1}{R_{17}} \doteq 100 \;\; \text{mA/V} \qquad (19)$$

and an input resistance

$$R_i = 10 \; \frac{C_o}{C_F} \; \Omega \qquad (20)$$

which can be varied by adjusting C_o.

The sensitivity is determined by the feedback capacitor C_F and is $1 \frac{V}{pc}$. Transistors TR7 and TR8 buffer the output of the charge sensitive pre-amplifier and drive the fast differentiator. Transistors TR9 - TR11 form a high gain amplifier with an open loop gain of approximately 250 and a closed loop gain of 38 determined by R25 and R34.

4. PERFORMANCE

The charge sensitive pre-amplifier has a 17×10^6 gain bandwidth product. When fed by a 1 pF capacitor it gives a minimum output signal risetime of 18 ns. The input resistance can be varied over the range 50Ω to 500Ω by adjusting C_o.

Figure 6 shows the measured equivalent input noise as a function of capacitance connected across the input of the pre-amplifier. The noise was measured using an Ortec 450 spectroscopy amplifier with equal 1 μs differentiating and integrating time constants.

ACKNOWLEDGEMENTS

My thanks to Mr G Hughes for his encouragement during the work described in this note.

REFERENCES

1. E. Gatti, P.F. Manfredi, "Low noise current pre-amplifiers for large capacitance semi-conductor detectors and high counting rates", Proc. 2nd Ispra Nuclear Electronics Symposium.

Figure Captions

Fig. 1 Charge sensitive pre-amplifier terminating a delay line.

Fig. 2 Schematic diagram of "electronically cooled" charge sensitive pre-amplifier.

Fig. 3 Schematic diagram of "electronically cooled" charge sensitive pre-amplifier with stabilised input resistance.

Fig. 4 Schematic diagram of timing circuit.

Fig. 5 Circuit diagram of "electronically cooled" charge sensitive pre-amplifier and timing amplifier.

Fig. 6 Equivalent input noise as a function of input capacitance measured using an Ortec 450 amplifier with 1 μs equal shaping time constants.

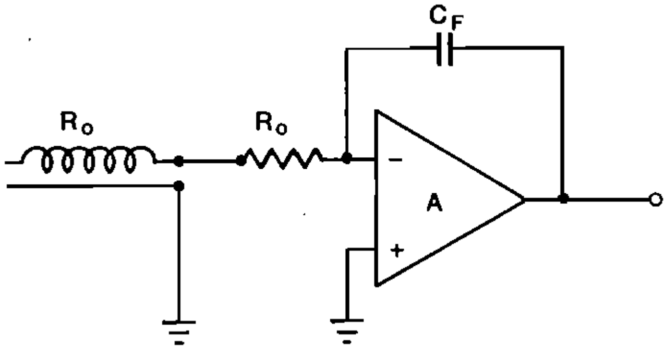


Fig.1

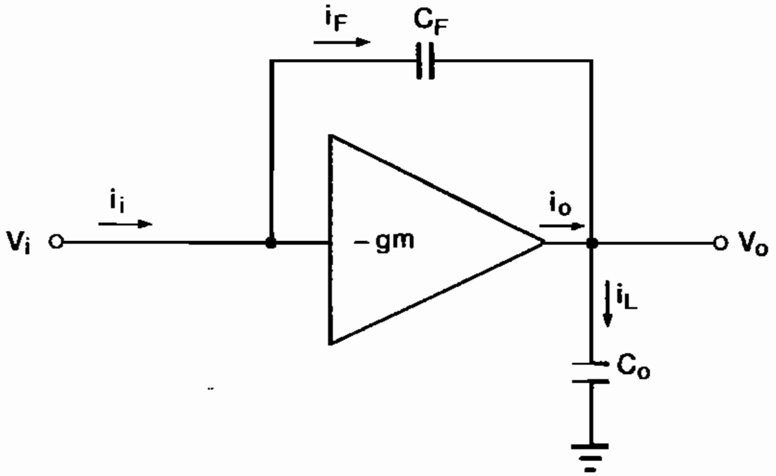


Fig. 2

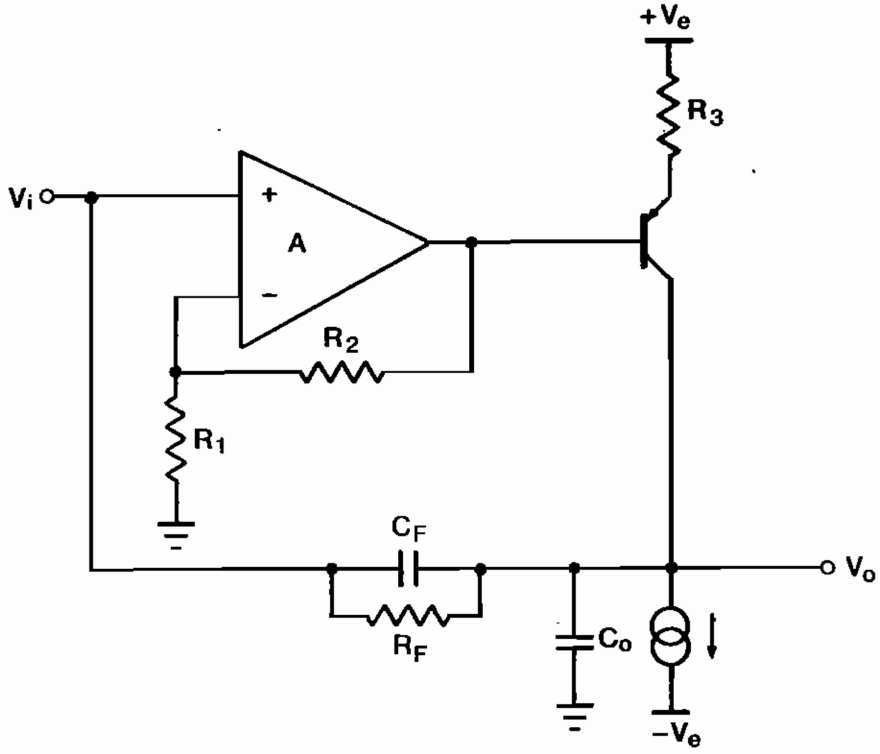


Fig.3

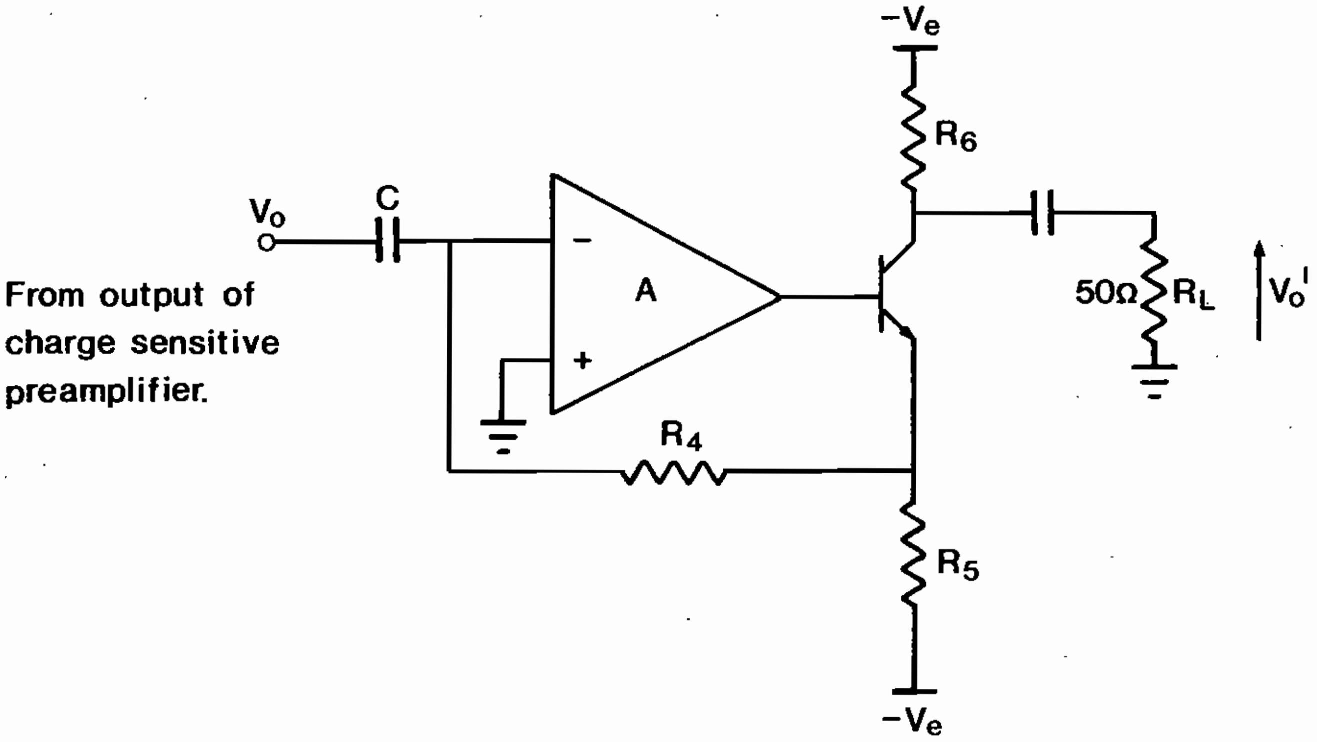
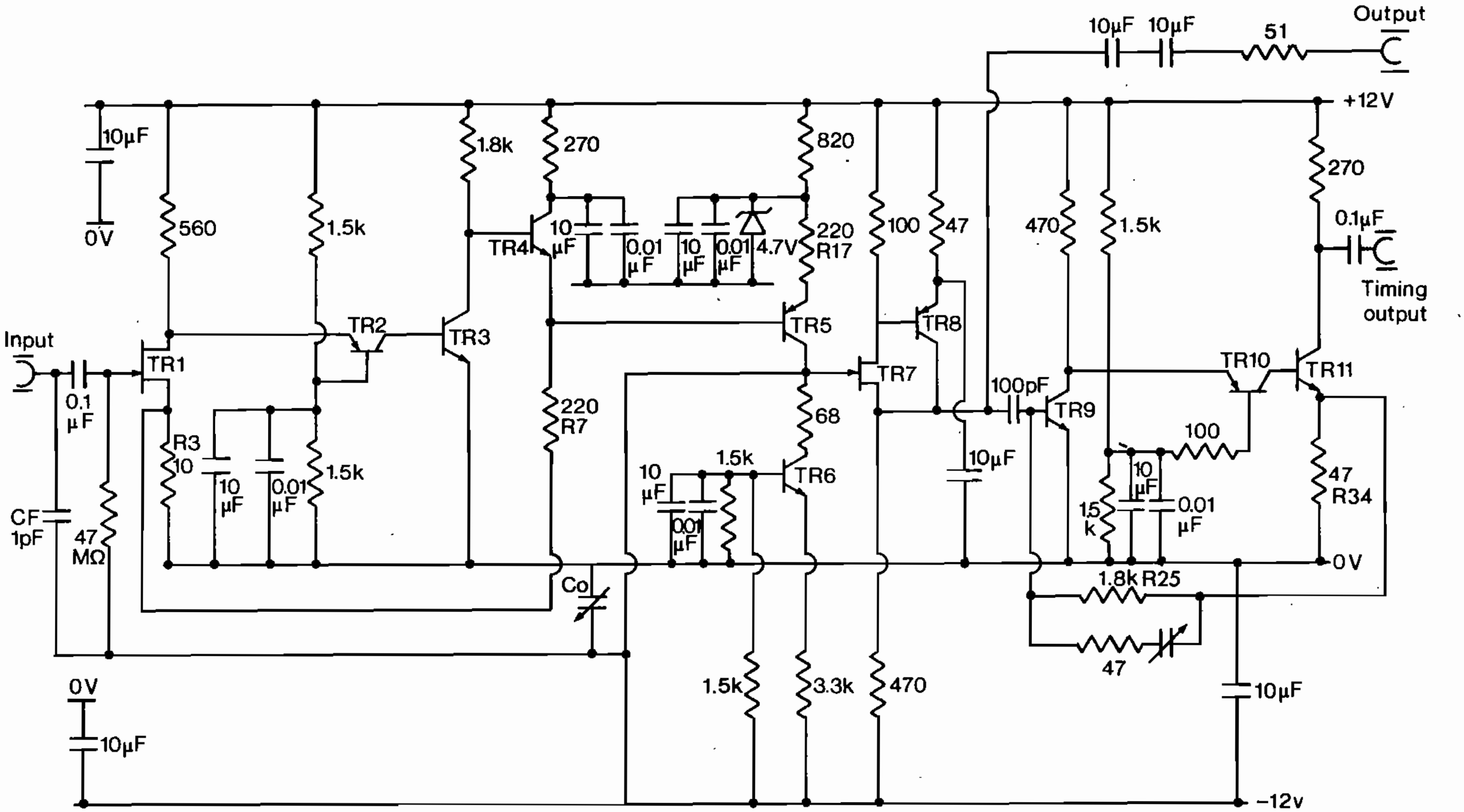

−Ve
R6
Vo
C
A
50Ω
RL
Vo'
From output of
charge sensitive
preamplifier.
R4
R5
−Ve

Fig.4



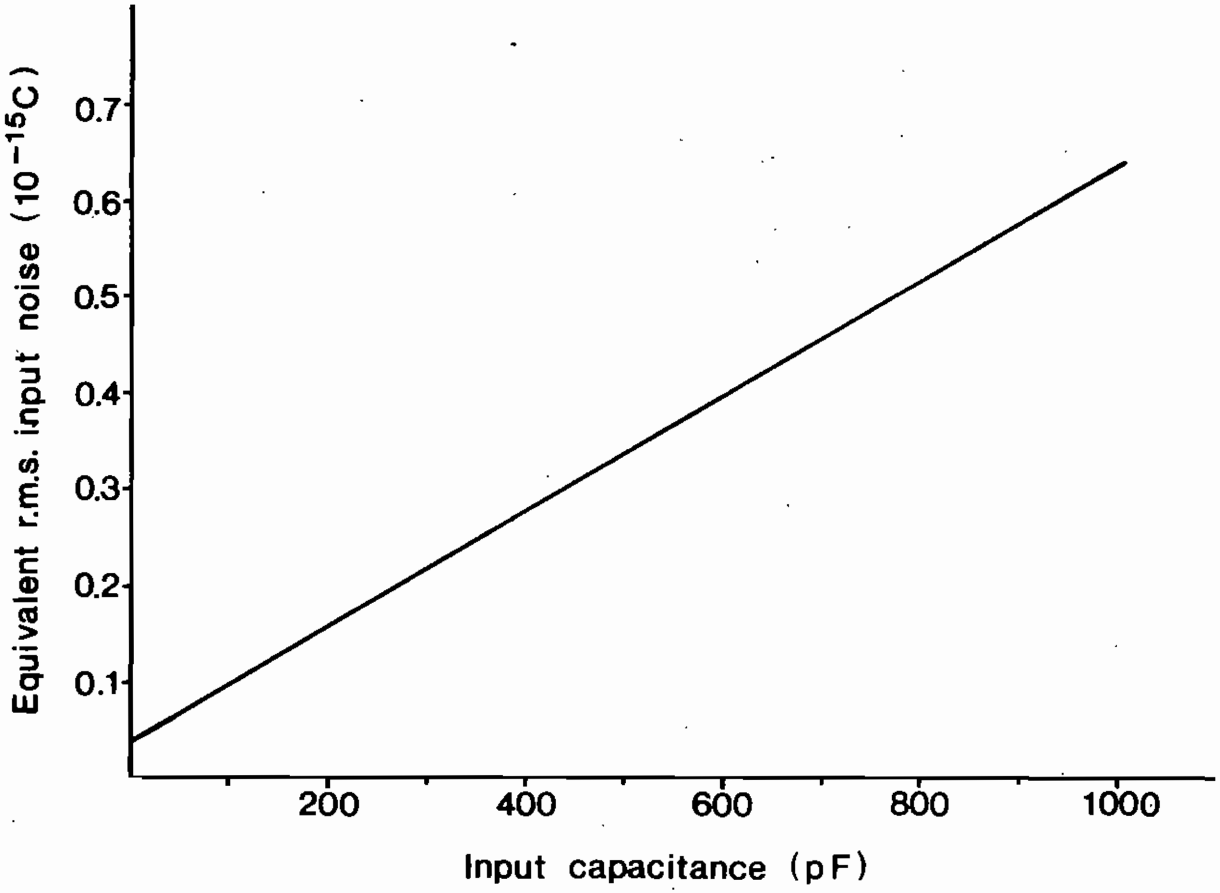
TR1 –J108

TR7 – E309

TR2,5,8,10 – BFR99

TR3,4,6,9,11 – BFY90

Fig. 5



Equivalent r.m.s. input noise (10^{-15}C)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
200
400
600
800
1000
Input capacitance (pF)

Fig. 6