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A MULTIPLICITY TRIGGER FOR A CHERENKOV DETECTOR

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Abstract

The Multiplicity Trigger (MT) is a device for deciding if, in a given time window, the number of wires that are "hit" in a multi wire proportional chamber (MWPC) is within given limits. The MT is designed for a Cherenkov detector, using a MWPC with 155 sense wires. It has ten inputs with sixteen channels on each, for 160 ECL input signals from the MWPC. With the MT, it is possible to decide if the number of "hits" is greater than n out of 160, where n is called the multiplicity. Here, $2 \leq n \leq 30$, with an accuracy of ± 1.
The time window can be adjusted from 0.7 to 4 µs. The MT has four separate NIM outputs, to make it possible to have four different values of n at the same time. The propagation delay from input to output is at the most 100 ns.

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PREFACE

This is a project report in Applied Electronics, made for the Master of Science degree in Engineering Physics. The work was carried out at Teknikum and the Gustav Werner Institute (GWI), Uppsala and CERN, Geneva.

Examiner and supervisor at Teknikum has been Dr Anders Westman. Supervisor at GWI has been Dr Allan Hallgren.

I wish to express my warmest thanks to everybody whose help I have greatfully received during the design work. I would especially like to express my appreciation to my supervisors, Anders Westman and Allan Hallgren for their constructive criticism, and to Mr Ysbrand Kornelis for his encouragement, and for passing on some of his extraordinary knowledge in electronics to me.

" PER ASPERA AD ASTRA "

CONTENTS

I INTRODUCTION

In experiments in high energy particle physics, the tendency is to build larger accelerators, giving vast amounts of data to collect in short time periods. This has created a need of sophisticated systems for data collection and data treatment.

The Cherenkov detector is a type of detector for velocity determination and particle type identification for charged particles Eg. π^+, π^-, e^+, e^-.
The data collection system of such a detector gives mostly to much data to handle, unless one uses a trigger to pick out only the interesting events.

The Multiplicity Trigger (MT) described in this report is constructed for a Ring Imaging Cherenkov Detector (RICH) [3,4] developed at the Centre Européenne pour la recherche nucléaire (CERN). It is meant to be used as a part of a larger trigger system, in order to decrease the number of recorded uninteresting events.

The task of the MT is to decide if, in a given time time window, the number of "hits" in the photon detector of the RICH, a Multi Wire Proportional Chamber (MWPC) is within given limits. This number is called the multiplicity, and is here denoted n.

Because of the relatively short time in which a decision has to be made, a computer-oriented solution is not possible. Instead, the MT is made in a hybrid technique, ie. both analog and digital circuitry are used, which makes it very fast.

The propagation delay is less than 100 ns, and the resolution of the MT is $\pm$ one from adjusted multiplicity. If the multiplicity is n, then $2 \leq n \leq 30$.

The MT is built in seven Nuclear Instrument (NIM) standard modules:

-Five Memory and Adding units (MADs). Input to the MADs are 155 ECL signals coming from the detector, and signals from the MAD controller (MAD-C), defining the time window.

-One MAD-C. It has ten inputs for signals from the MADs and four adjustable trigger outputs, to make it possible to have four different multiplicities simultaneously. There is also one linear output.

On the front panel of the MAD-C, there is a potentiometer for time window adjustment and also an output for time window measurements.

With an NIM input signal, it is also possible to "gate" the MT from an external trigger.

-One testing device called Testgrunka. It is used when adjusting the MT, for pre-setting the multiplicity and adjusting the time window.

The total cost of one system is 1230 sFr.

II THE EXPERIMENT

II.1 Cherenkov radiation

A charged particle travelling through a dielectric medium, with a velocity higher than the group velocity of light in the medium, emits light. [1,2]. The phenomenon is analogue to the Mach-wave created by an aeroplane going faster than the speed of sound, and is called Cherenkov radiation, or Cherenkov light.

The angle of emission of this light is characteristic of the particle's velocity. It can be focused with the aid of a spherical mirror to form a ring image, situated halfway between the mirror and its center of curvature.

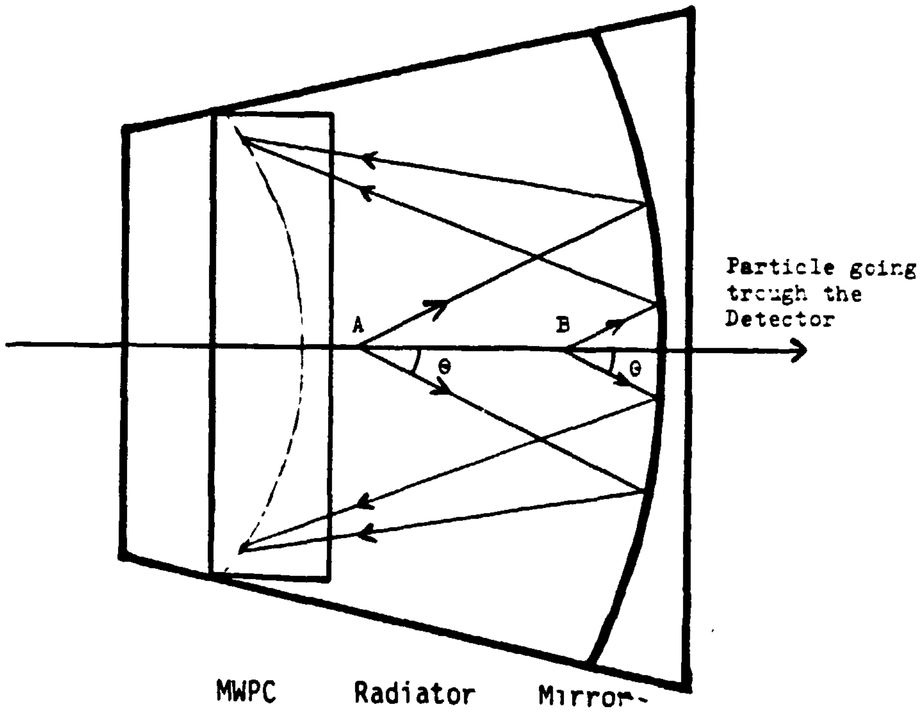


Fig. 1.

Fig. 1 is a schematic drawing of a Cherenkov detector, with a particle going through it. The particle emits two photons in A, and two photons in B. The angle of emission of the Cherenkov light is θ. The photons form a ring image in the photon detector.

The radius of the ring is proportional to the angle of emission of the Cherenkov light (can be shown with simple geometry), and thus gives a measure of the particle's velocity.

If one also measures the momentum of the particle, the mass can be calculated, and the particle's identity determined.

II.2 The detector

The Cherenkov detector [3] for which the MT is developed consists of three major parts: A radiator, a spherical mirror and a photon detector, fig 1.

The radiator contains a gas, with a refractive index slightly larger than one, giving the Cherenkov effect. The radiator gas can be, for instance 50% Isobuthane + 50% Helium, giving a refractive index of n = 1.00083. It is adopted [4] to fit into an experiment, that will be carried out at the Super Proton Synchrotron (SPS) at CERN.

The mirror has a focal length of f = 600 mm.

The photon detector contains a gas mixture, in which the Cherenkov photons are converted into electrons via the photoionization mechanism:

$$h\nu + M \longrightarrow e^- + M^+ \quad \text{(M is a photosensitive molecule)}$$

The gas in the photon detector is methane, with an admixture of a photoionizing vapour, for example TEA or TMAE.

In the photon detector a high transverse electric field is applied, in order to make the converted electrons drift towards one of the walls of the chamber where sense wires are situated every 1/20 inch, fig. 2.

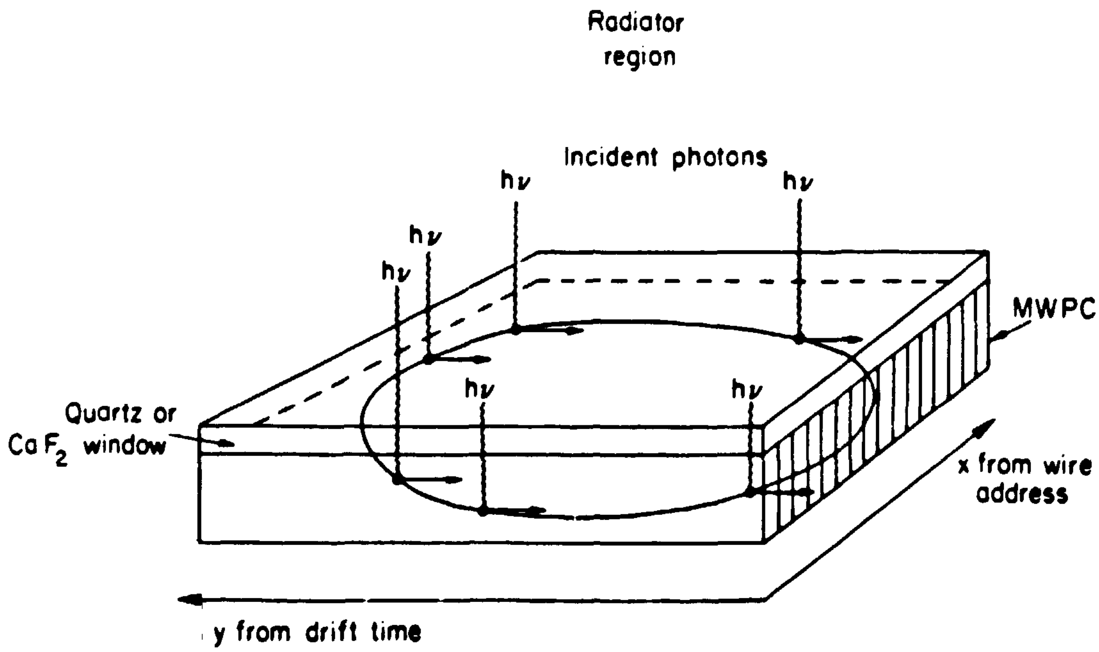


Fig. 2

For every converted electron, it is possible to deduct a X-Y coordinate pair in the focal plane of the mirror:

-The X coordinate is read out as the wire address.

-Knowing the drift velocity, the Y coordinate of each electron is obtained by measuring the time of arrival of the electron on the sense wire and the time of the particle passage, obtained from other detectors.

The MWPC is equipped with 155 sense wires, with a sensitive area of 20 X 20 cm. To each sense wire a preamplifier is connected. The signals are then conducted to an amplifier-discriminator unit a few meters away, which sends ECL logic signals to the data collection system in the counting room, situated 80 m away.

II.3 Data collection

For every sense wire there are two drift time recorders (DTRs), which reads out the wire.

A DTR is a type of equipment that stores data sequentially in a memory, and is clocked with a fixed frequency. Normally a DTR can record a drift time of 2 μs, ie. it takes two μs before it stores data in an already used cell. With two DTRs, the second one starting when the first one have worked in 2 μs (and then stopped), it is possible to record a drifttime of 4 μs.

When the main trigger confirms a particle going trough the detector, one waits for a fixed time, (2 - 4 μs) in order to let all converted electrons drift in to the sense wires, and then stops the second DTR clock and reads both of them out.

In the memories, the last four μs of information can give the time of arrival (the Y coordinate) for any hit wire.

The experimental data, and the storing of interesting events is then taken care of by the aid of a minicomputer.

II.4 Experimental set-up

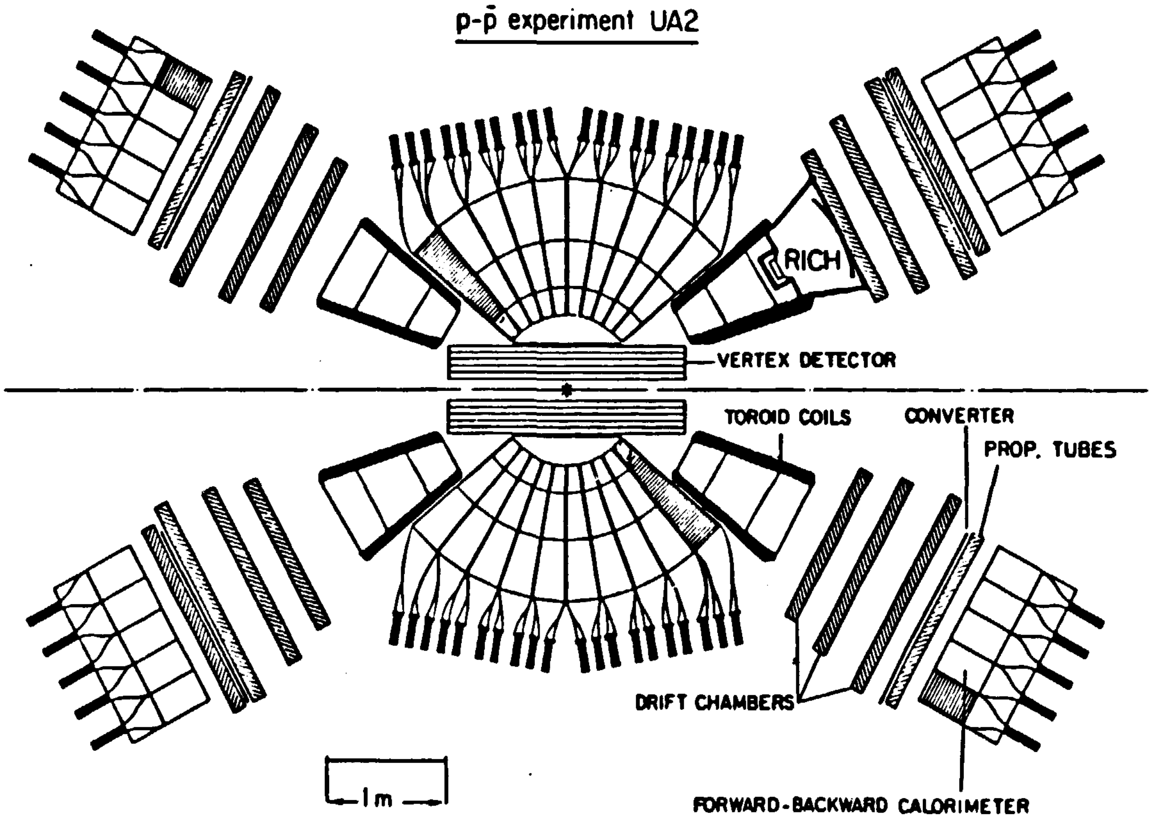


Fig. 3.

Fig. 3. is a (simplified) drawing of the experimental area UA2 at CERN. It shows an experiment with protons and antiprotons (p-p̄) colliding in the middle of the picture. At the upper right (at one of the endcaps), the RICH is proposed to be situated. After it there are driftchambers + calorimeters, for energy measurements.

III THE MULTIPLICITY TRIGGER

III.1 Principle of the multiplicity trigger

As already mentioned, the MT is a part of a larger trigger system. It will be used to count the number of converted photoelectrons in the photon detector for every event.

For an interesting particle,there should be on average eight electrons converted [4] to form a Cherenkov ring. In reality, one must set the trigger level much lower due to the large deviations from the average value.

Still, if the multiplicity is chosen too low, uninteresting particles and background radiation might give a false trigger output.

The ECL signals from the discriminators are received via balanced twisted pairs, in 10 groups of 16 channels in each.

The idea of the MT is to add the 160 channels in a time window, slightly longer than the difference in drift time for photons in a maximum size ring. This gives the total number of electrons in one ring, created by one particle going trough the detector, as shown in fig. 2.

Fig. 4. on the next page shows the basic blocks of the MT:

-A time window is created by "stretching" of every incoming signal. It is done in units called time window units (TWUs).

-The "stretched" signals are then added in groups of 16, with analog adders called type 1, giving linear output signals.

-These signals are then summed in a analog adder, called type 2. Obviously, the output signal of this adder must be proportional to the number of electrons created in one event, which is what we want to know.

-If this signal is compared with a reference level, that corresponds to the number of converted electrons we want to detect, one can say if there has been an interesting event or not.

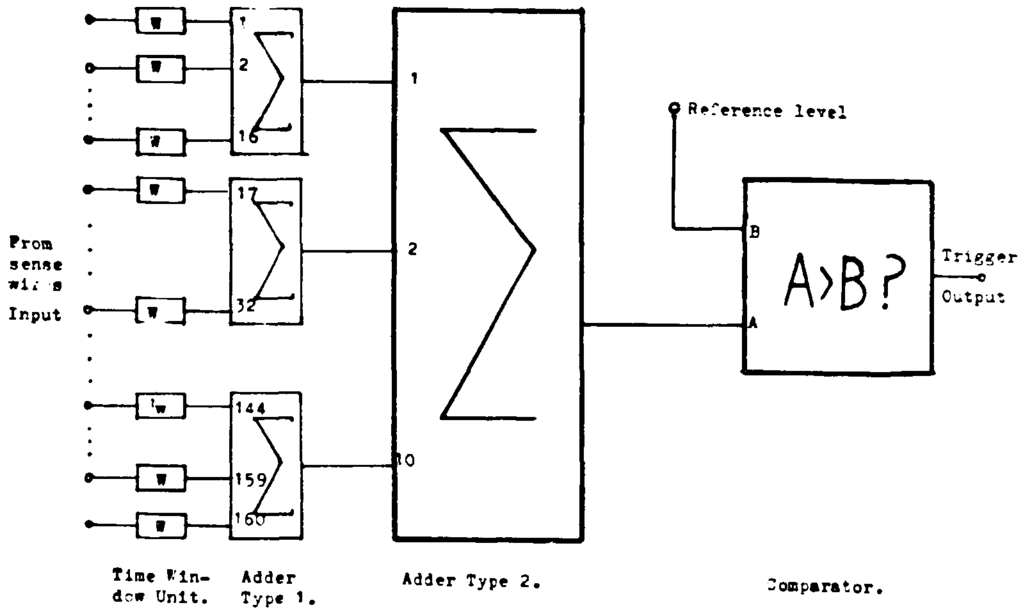


Fig. 4. Block diagram, Multiplicity Trigger.

When a signal comes in to any of the 160 inputs of the MT, the linear output will raise a fixed amount and, after a time corresponding to the time window, fall off again. Hence, if there are several electrons arriving within a time, shorter than the time window, the linear output will be built up as a step function.

In fig. 5. the height of one step is proportional to one converted electron and the length of one step is proportional to the time between two electrons arriving. After the time window (measured from the arrival of the first electron), the signal falls off in the same manner as it was built up.

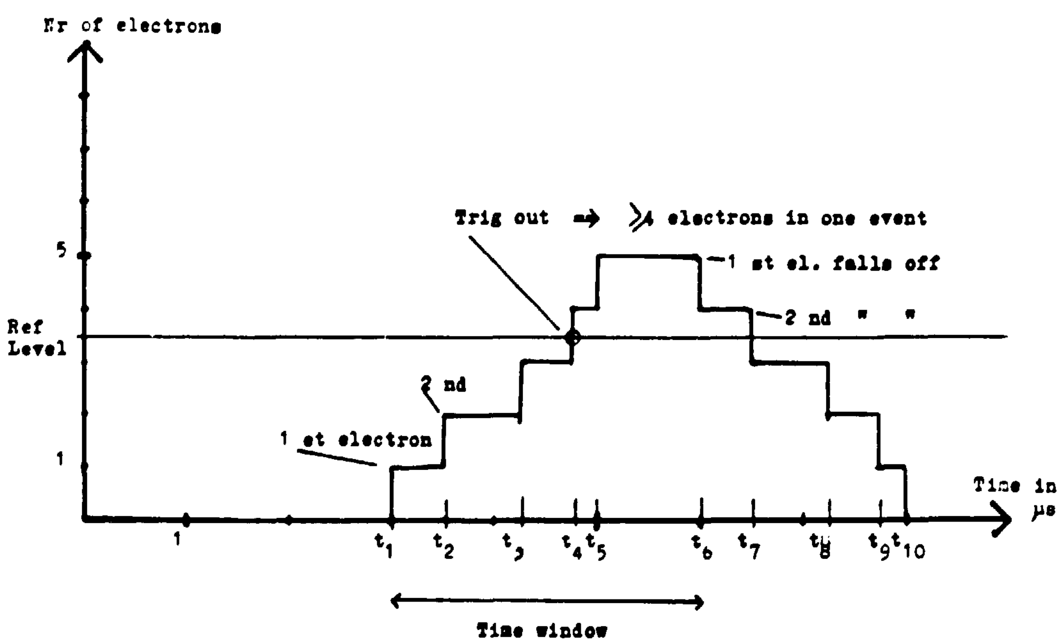


Fig. 5. Input signal to comparator.

III.2 The parts of the multiplicity trigger

The MT is built in seven NIM standard modules:

-Five Memory and Adding units (MADs). Every MAD contains 32 TWUs, two adders of type 1 and ECL -> TTL converters on the input. It has two 3M connectors for two groups of ECL input signals and a LEMO input that defines the time window. The linear signals from the MADs are conducted to the MAD-C via 2 ns LEMO cables.

-One MAD-C. It contains an adder of type two, four comparators, gate logics (it is possible to gate the MT from an external source), output trigger and display logics and time window circuitry. The MAD-C has ten inputs for the MADs, gate input, five time window outputs, one test output for time window display, one linear output and finally, four NIM trigger outputs. All in- and outputs are made with LEMO coaxial connectors. On the front panel there is light emitting diodes, that indicates the triggering and also potentiometers for multiplicity ,time window and offset adjustments.

-One testing device called Testgrunka. It is used to pre-set the multiplicity and to adjust the time window. It has two inputs for TTL signals and 32 ECL output channels. It can be connected to the MADs via a 3M connector.

III.3 Components

The logic used is mainly TTL. Input conversions are accomplished by ECL -> TTL translator MC10125 and TTL -> NIM output conversions by TTL -> ECL translator MC10124, with a 3906 pnp transistor on the output. Both translators from the MECL 10k family.

The time window, and the time window display are build with 9602 one-shots and an adjustable voltage regulator, LM 317T.

The adders are built with high speed OP-amplifiers, the NE5539 (or the TDA1078). For the offset adjust of the MAD-C, a µA741 is used.

Comparators used are NE521N.

Amplifier power supplies are made with the voltage regulators µA7808 and µA7908.

III.4 Memory and adder module

4.1 Time window unit.

Conversions. -Since the input is ECL signals, they have to be converted, as the following logics are TTL. This is done with MC10125 converters.

Principle. -To be able to add the electrons from one event, one needs a time window slightly longer than the maximum drifttime of the chamber. Because of the different drift gases used, it needs to be adjustable. For the stretching of the input pulses, one-shots (9602) are used.

Time window. -The timing network is slightly modified compared to recommendations in the datasheet of the 9602. Instead of connecting the timing resistors to Vcc, they are connected to a variable voltage supply. The voltage supply is described in III.4.4.

Timing resistors are 12 kΩ, 1% and capacitors are 220 pF, 5% Mica capacitors with high temperature stability. This RC combination gives a time window, adjustable from 0.7 to 4 µs. In supplement 13, the relation between minimum and maximum time window and some timing resistors is shown.

Explanations of abbreviations. -Also used in the datasheets.

L = Low logic level, "0"
H = High logic level, "1"
I = Input
Q = Output

A bar (-) over the letter means inverted, or active low in- or output.

$\bar{C}\bar{D}$ = Clear (active low)

Inputs. -The 9602 contains two one-shots with two signal inputs and a clear entrance each. It manages booth L -> H and H -> L transitions.

In this application, $\bar{I}_0 = \bar{I}_2 = \bar{C}\bar{D}_0 = \bar{C}\bar{D}_1 = H$ (Clamped high.)

I_1 and I_3 are used as inputs to provide a trigger on the L -> H transition of the input pulse. See datasheet for further information.

Output. -The output is taken from $\bar{Q}$ because the falltime is approximately one third of the rise time for an ordinary TTL device. This is due to parasitic capacities in the output stage, and in the summing resistors.

There is one more reason, why the output is taken from $\bar{Q}$. Because of variations in the output voltage for different chips ("1" is defined between 3.7 and 5 V), $\bar{Q}$ must be "pulled up " with a resistor of 1 kΩ to Vcc. Since there are normally very few wires that are hit in the MWPC, there are very few signals coming to the MADs in average. This means that almost all inverted outputs of the one-shots are high most of the time.

Let I_p be the current trough the "pull up" resistor R_2.

$\bar{Q} \approx 4$ V, $R_2 = 1$ kΩ ==> $I_p \approx 1.0$ mA per output, ie. 160 mA in total.

With Q used as output, it is low most of the time.

$Q \approx 0$ V, ==> $I_p \approx 5$ mA, ie. 800 mA in total.

The $\bar{Q}$ configuration reduces in other words the current on the +6 V voltage supply with 650 mA.

Decoupling. -There is (roughly) one 0.1 µF capacitor for every two digital cirquits.

Since all pull up resistors of one group end up at the same point on the printed card, there is a large capacitor at the end of it, for both the groups.

4.2 Adder type 1.

Principle. -For a summing amplifier, the output voltage is given by:

$$V_{out} = -\frac{R_F}{R_i} * \sum_n V_n$$

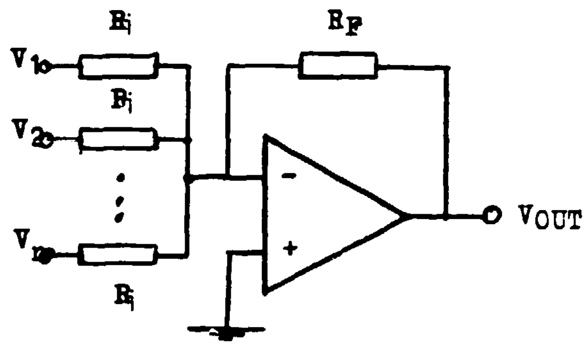


Fig. 6. Summing amplifier.

In this case (diagram 4.3), $R_F = R_7$, $R_i = R_3$, $V_1, V_2 \ldots = \bar{Q}_1, \bar{Q}_2 \ldots$

The output swing for all channels going from high to low at the same time is choosen to one volt.

R_3 is choosen to 10 kΩ. (Gives acceptable high speed.)

$$-1\ V = -\frac{R_7}{R_3} * 16 * 4\ V \implies R_7 = 150\ \Omega$$

The standard value R_7 = 147 Ω, gives that one electron corresponds to 60 mV.

Level shift. -Since inverting amplifiers are used, together with inverted inputs, an increasing output signal is the result of an increasing number of electrons.

It should normally go between -1 and 0 V, but with the potentiometer R_5, the output is shifted 1 Volt, so that 0 e^- gives 0 Volt out and 16 e^- gives +1 Volt out.

Output current. -For maximum output swing, the current trough R_F is 1 V / 147 Ω ≈ 7 mA. The maximum possible output current is choosen a bit higher, (17 mA). This current must be supplied by the output transistor of the NE5539, trough R_9 in parallel with the internal emitter resistor of 2.2 kΩ, se fig. 7.

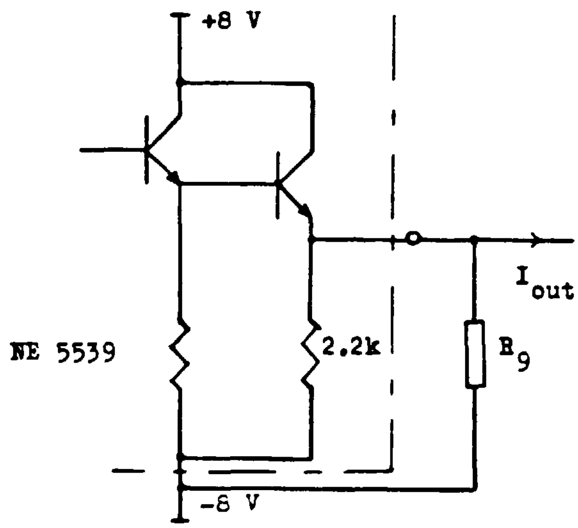


Fig. 7. Output stage of the NE5539.

V_{out} = 1 V ==> 9 V /(R_9 ‖ 2.2 kΩ) = 17 mA

==> R_9 =...= 697 Ω, standard value R_9 = 680 Ω

Output. -Since the NE5539 is very sensitive for capacitive load, a resistor R_{10} = 330 Ω is connected in series with the output. This must be considered when the second amplifier is designed.

<u>Decoupling.</u> -A series resistor and a capacitor, soldered directly to the voltage supply pin of the NE5539, creates a lowpass filter. R_8 = 12 Ω together with C_5 = 0.1 µF (C_4 optional) gives a breakpoint of approximately 8 MHz. This arrangement avoids high frequency disturbances from the power supply.

<u>Compensation.</u> -Lead-lag compensation is done according to the recommendations in the datasheet of the NE5539.

Equations:

$$C_{Lead} = \frac{C_{Distr.}}{|A_v|} \qquad \text{(}C_3 \text{ in diagram.)}$$

$$R_{Lag} \leq \frac{R_F}{7 - |A_v|} \qquad \text{(}R_6 \text{ in diagram.)}$$

$$C_{Lag} = \frac{5}{\pi * R_{Lag} * GBW} \qquad \text{(}C_2 \text{ in diagram.)}$$

$C_{Distr.} \approx 3.5$ pF (From datasheet.)

GBW = 350 MHz (From datasheet.)

$$A_v = \frac{147}{10\ k} * 16 = 0.24 \qquad \text{(Voltage gain.)}$$

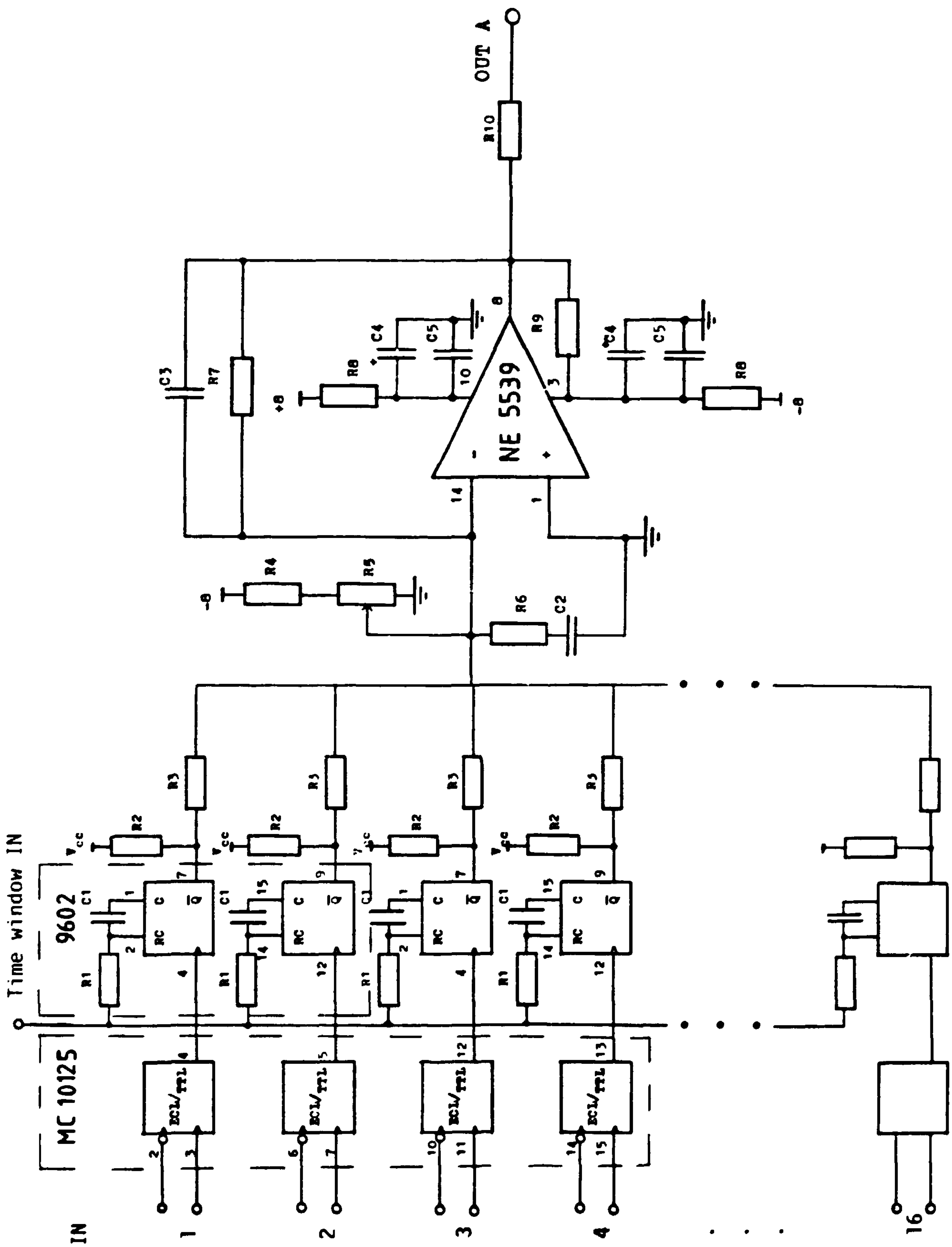
This gives the following values:

$C_3 \approx 3.5 * 10^{-12} / 0.24 = 14.6$ pF, standard value C_3 = 10 pF

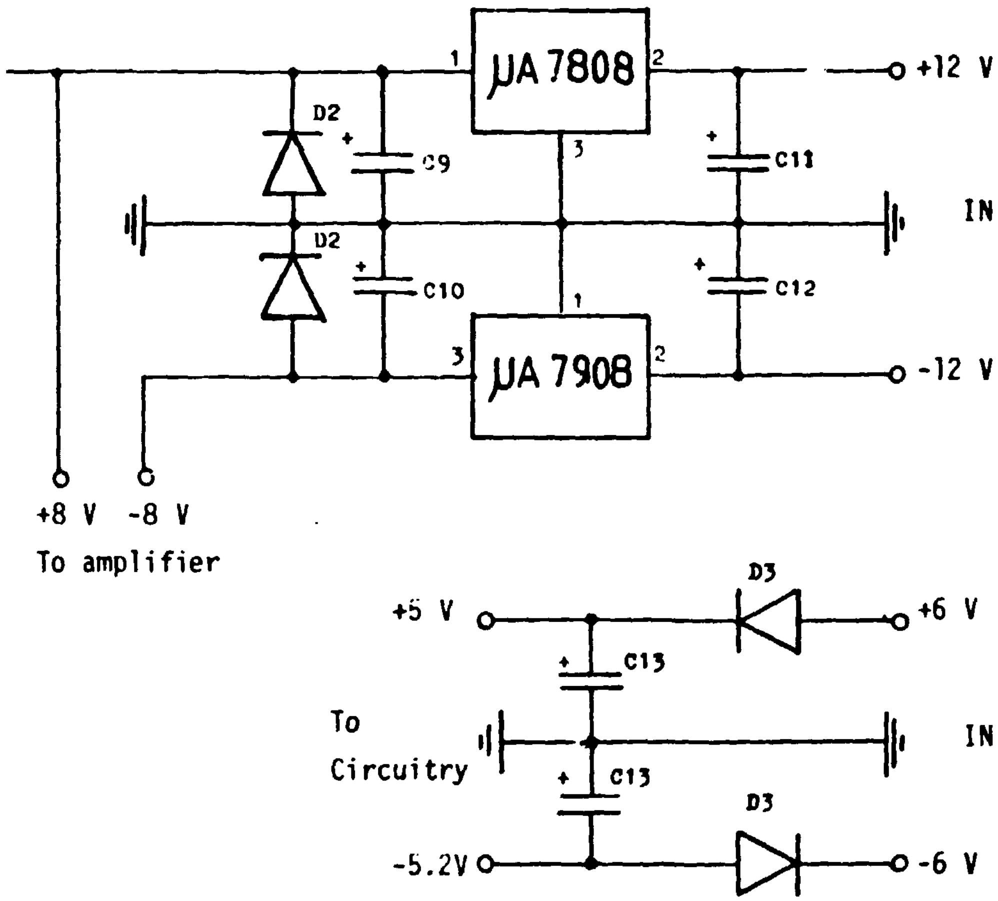
$R_6 \leq 147 / (7 - 0.24) = 22$, standard value R_6 = 18 Ω

$C_2 = 5 / \pi * 18 * 350 * 10^6 = 250$ pF, standard value C_2 = 220 pF

4.3 Diagram, 1/2 MAD



4.4 Power supply



4.5 Component list

MC 10125

Pin nr	Conn	Component	Value	
1	Nc	R1	12.1	kΩ 1%
16	GND	R2	1	kΩ
9	Vcc	R3	10	kΩ 1%
8	Vee	R4	330	Ω
		R5	5	kΩ
		R6	18	Ω
9602		R7	147	Ω 1%
Pin nr	Conn	R8	12	Ω 0.5 W
		R9	680	Ω
6, 10	Nc	R10	330	Ω 1%
8	GND			
3, 5, 11,		C1	220	pF, 5% MICA
13, 16	Vcc	C2	220	pF
		C3	10	pF
		C4	1	µF Optional
NE 5539		C5	100	pF
Pin nr	Conn	C9	100	nF
		C10	1	µF
2, 4, 5, 6,		C11	330	nF
9, 11, 12, 13	NC	C12	2	µF
7	GND	C13	10	µF
UA 7808	+12V Supply	D2	IN4006	or eq.
		D3	30S1	or eq. (3A)
UA 7908	-12V Supply			

III.5 Mad controller module

5.1 Adder type 2

The design of this adder is similar to that of the first type, with the following changes:

-When calculating A_v, one must use $R_{10} + R_{11}$ as input resistor.

-Since not all inputs can be high at the same time, only one input can be used when calculating the lead-lag compensation.

-The resistor R_{14} raises the output impedance and thus makes the amplifier more stable against feed-back oscillations.

-The offset adjust potentiometer is placed at the front panel. To avoid noise pickup, a µA 741 is used as a voltage follower and a large capacitor, C_4 = 1 µF is used as a decoupling capacitor.

-The adder has a linear output on the front panel, where one electron corresponds to 55.2 mV on the output. This output should <u>not</u> be terminated.

5.2 Comparators

The output from the last adder goes negative for a rising number of electrons, which means that the trigger level must be negative.

The multiplicity of the comparators can be choosen by the voltage divider R_{18} - R_{19}.

Example: R_{18} = 1 kΩ, maximum multiplicity 20 electrons ==> linear output for 20 high inputs:

$$V_{out} = 20 * -55.2 \text{ mV} = -1.1 \text{ V}.$$

Trigger level (maximum multiplicity)

$$V_T = \frac{R_{18}}{R_{18}+R_{19}} * V_{ee}$$

Choose R_{19} = 4 kΩ ==>

$$V_T = \frac{1}{1+4} * -5.2\ V \approx -1.1\ V$$

In this application there are four separate outputs, two with multiplicity 0 - 40 electrons (R_{19} = 2.7 kΩ), and two with multiplicity 0 - 20 electrons (R_{19} = 4 kΩ).

The comparator hysteresis is chosen to be approximately one half of a step, (25 mV) with the resistors R_{20} and R_{21}. This makes the comparators less sensitive for disturbances.

5.3 Input gate logic

When the gate is left open, the MT works continously. With the potentiometer R_{24}, it is possible to set a gate level, from -5 to +5 V.

In this application NIM-signals will be used to gate the MT, and the level is therefore set to -0.5 V.

Gate = "0" ==> gate is open, the output follows the input.

Gate = "1" ==> gate is closed, output = "0" all the time.

5.4 Output trigger logic

The output from the comparators are TTL signals. They are converted to ECL signals via MC10124 TTL-ECL converters, and then level-shifted with pnp transistors 3906 (T_1), to NIM output signals.

The resistor R_{27} is dimensioned for one standard NIM load. A NIM "0" is 0 mA, and a "1" is -16 mA over 50 Ω, ie ≈ -0.8 V.

Output resistor. -The resistor R_{27} is connected to Vee. The NIM standard (-16mA) then gives R_{27} = 300 Ω. Standard value R_{27} = 270 Ω.

One-shots (9602) with a time constant of approximately 1/10 second, (adjustable) are arranged in parallel with the converters.

Together with light emitting diodes on the front panel, this indicates the triggering.

It is important to notice that the LEDs indicate the transition, so a constantly high output is not seen on the LEDs.

5.5 Time window adjustment

As described in III.4.1, the RC combination which gives the time window is not connected to Vcc, but to a variable voltage supply. The same voltage supply is used for all the 160 channels, and they can thus be simultaneously controlled.

One RC combination consumes approximately 0.5 mA, ie. the power supply should be able to give 800 mA in total. The variable voltage regulator LM317T can give maximum 1.5 A output current, and output voltages between 1.2 and 37 volts.

The one-shots cannot be triggered below approx. 2.4 volts, and this gives the maximum time window. The resistor R_{31} prevents the voltage to drop further.

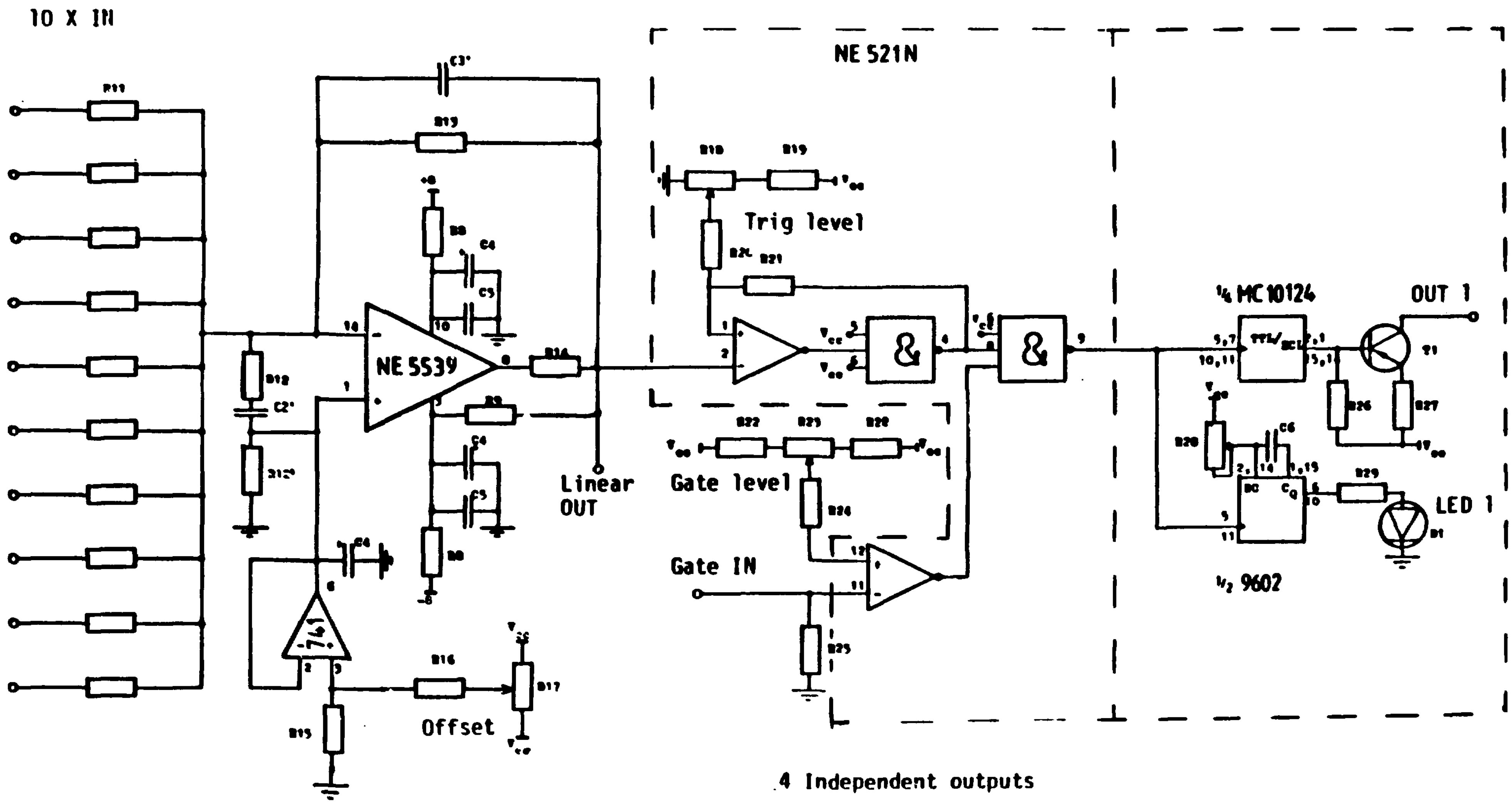
The input voltage to the LM317T is 8 V (from amplifier supply), and the maximum output voltage is then approx. 6.5 V and this gives the minimum time window.Higher voltages can be dangerous to the one-shots.

With this voltage range, the time window can be adjusted from 0.8 to 4 µs with the potentiometer R_{32} on the front panel.

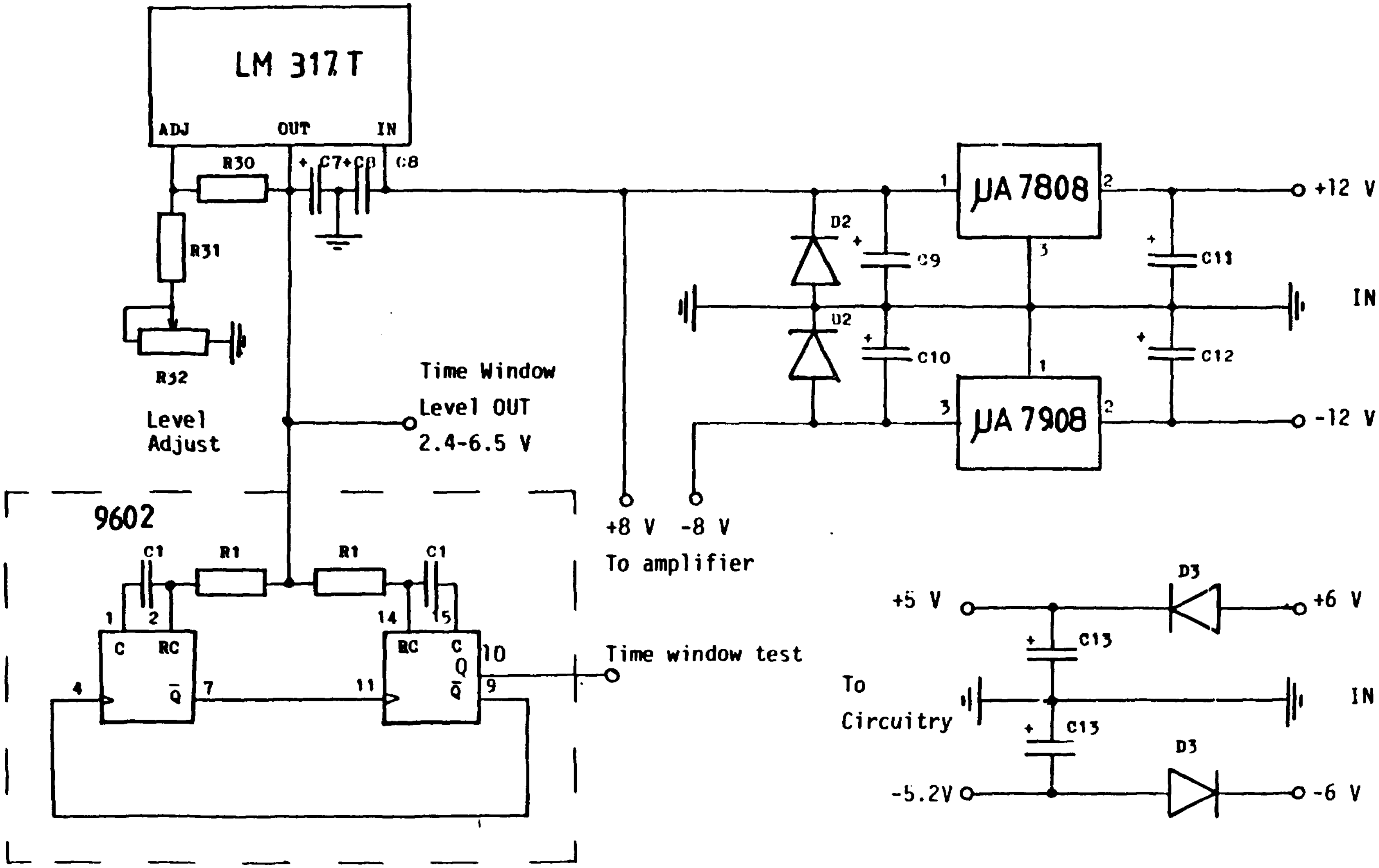
As an option, an astable monovibrator is built in with the same RC combination as in the MADs and the output is brought out on the front panel. If this output is connected to an oscilloscope, the time window can be measured.

An alternative is to measure the frequency, invert and divide by two.

The accuracy of the time window adjustment is better than $\pm$ 10 %, see measurements in IV.4.



5.6 Diagram, MAD-C



5.7 Diagram, time window adj. and power supply

5.8 Components

NE 521N

Pin nr	Conn
3, 10	NC
7	GND
14	Vcc
13	Vee

MC 10124

Pin nr	Conn
3, 4, 12, 13	NC
16	GND
6,9	Vcc
8	Vee

9602

Pin nr	Conn
7, 9	NC
4, 8, 12	GND
3, 13, 16	Vcc

LM 317 T	Variable voltage supply
UA 7808	+12V supply
UA 7908	-12V supply

Component		Value	
R1		12.1	kΩ 1%
R8		12	Ω0.5 W
R9		680	Ω
R11		3.16	kΩ 1%
R12		470	Ω
R12'		100	Ω
R13		3.16	kΩ 1%
R14		47	Ω
R15		1	kΩ
R16		100	kΩ
R17		20	kΩ
R18		1	kΩ 1%
R19	2x	2.7	kΩ 1%
R19	2x	4	kΩ 1%
R20		1	kΩ 1%
R21		100	kΩ 1%
R22		1	kΩ
R23		20	kΩ
R24		1	kΩ
R25		50	Ω
R26		1	kΩ
R27		270	Ω
R28		20	kΩ
R29		75	Ω
R30		240	Ω
R31		330	Ω
R32		1	kΩ
C1		220	pF 5% MICA
C2'		5-60	pF Trimmer
C3'		6.8	pF Ceramic
C4		1	μF
C5		100	nF
C6		100	μF
C7		1	μF
C8		100	nF
C9		100	nF
C10		1	μF
C11		330	nF
C12		2	μF
C13		10	μF
D1		LED	2 V, 20 mA
D2		IN4006	or eq.
D3		30S1	or eq (3 A)
T1		3906	pnp transistor

III.6 Testgrunka

6.1 Description

The testgrunka has two 50 Ω LEMO inputs for TTL signals. Each input is coupled to eight switches, so that it is possible to connect from one up to sixteen channels. (2-32 with two connectors.)

The TTL signals are translated into complementary ECL output signals with four MC 10124 translators. The lack of internal termination in the MAD:s, makes it necessary to use the MT in parallel with DTRs, or with external termination.

The DTRs have 56 Ω from each input to Vbb, ie. 112 Ω between the inputs. With maximum voltage swing 0.85 V (ECL signals), this gives a current of 7.5 mA. This current must be provided trough R_{33}. The voltage drop over R_{33} is (-5.2 + 0.9) V = -4.3 V.

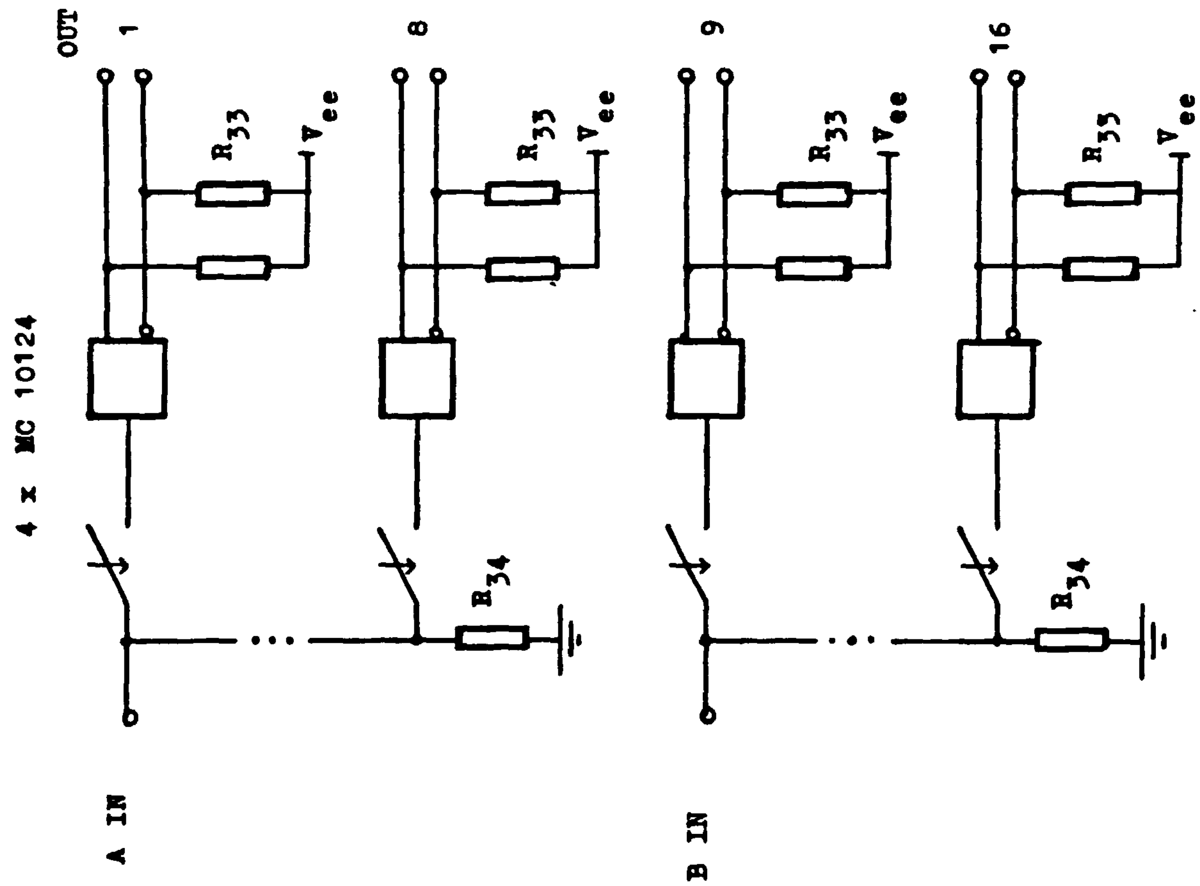
$$R_{33} = \frac{4.3}{7.5 * 10^{-3}} = 570\ \Omega.$$

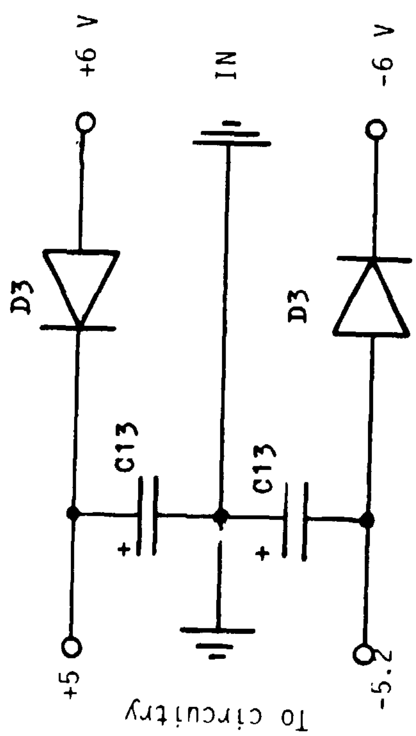
Standard value R_{33} = 560 Ω.

In the experiment there will be two DTRs used for each group of 16 channels, which means that the termination will be 56 instead of 112 Ω. The output swing of the testgrunka will thus be slightly reduced during tests.

This is not serious. The input of the MT has been tested down to one tenth of full swing without any problems.

6.2 Diagram, Testgrunka





6.3 Components

MC 10124

Pin nr	Conn	Component	Value	
16	Gnd	R33	560	Ω
6, 9	Vcc	R34	50	Ω
8	Vee	C13	10	μF
		D3	30S1	or eq (3 A)

IV MEASUREMENTS

IV.1 Sensitivity

The sensitivity of the MT has been tested all over the multiplicity range. Deviations from an adjusted value of the multiplicity is ± one, at the most.

The only thing that can spoil the results is the offset of the OP-amplifiers, and attention must be paid to the linear output on the MAD-C, in order to notice drift.

IV.2 Minimal input pulse length

With a Philips pulse generator, pulses down to a length of 20 ns were sent to all the MAD:s without any failing channel.

IV.3 Linearity / uniformity

In order that the MT will work properly, the linearity and uniformity of the parts in the MT must be very good.

Errors in the linear output voltage, caused by non-linearity and/or non-uniformity, have to be less than one half of a step to give correct results.

The values given in table IX.14 and IX.15 for the signal is with 95 % confidence, assuming Gaussian distribution. ($x = \bar{X} \pm 1.96\sigma$)

3.1 MADs

In measurements of linearity and uniformity, the difference between the channels has been less than 1 %, with a tendency to be a bit progressive for increasing number of electrons. This is not serious, the error is within the margin given above. The maximum output difference between two MADs, is 24 mV for 16 channels high on each, adjusted for offset. That is less than 40 % of one step, for an extreme situation.

On the output, one electron corresponds to 62.6 ± 0.8 mV.

3.2 MAD-C

The linearity of the MAD-C has been found to be better than 1 %. For very high multiplicity (> 25), the MAD-C tends to be a bit progressive, still within the margins, as in 3.1.

On the output one electron corresponds to 55.2 ± 0.7 mV.

IV.4 Time window

In measurements over the range from the shortest to the longest (0.76 to 4.04 μs) time window, the differences are within ± 10 % between different channels and the adjusted value, with three exceptions out of 160 channels.

IV.5 Current consumption

The current consumption on the different power supply voltages are:

+ 12 V,	0.3 A
+ 6 V,	4.3 A
- 12 V,	0.4 A
- 6 V,	1.8 A

IV.6 Propagation delay

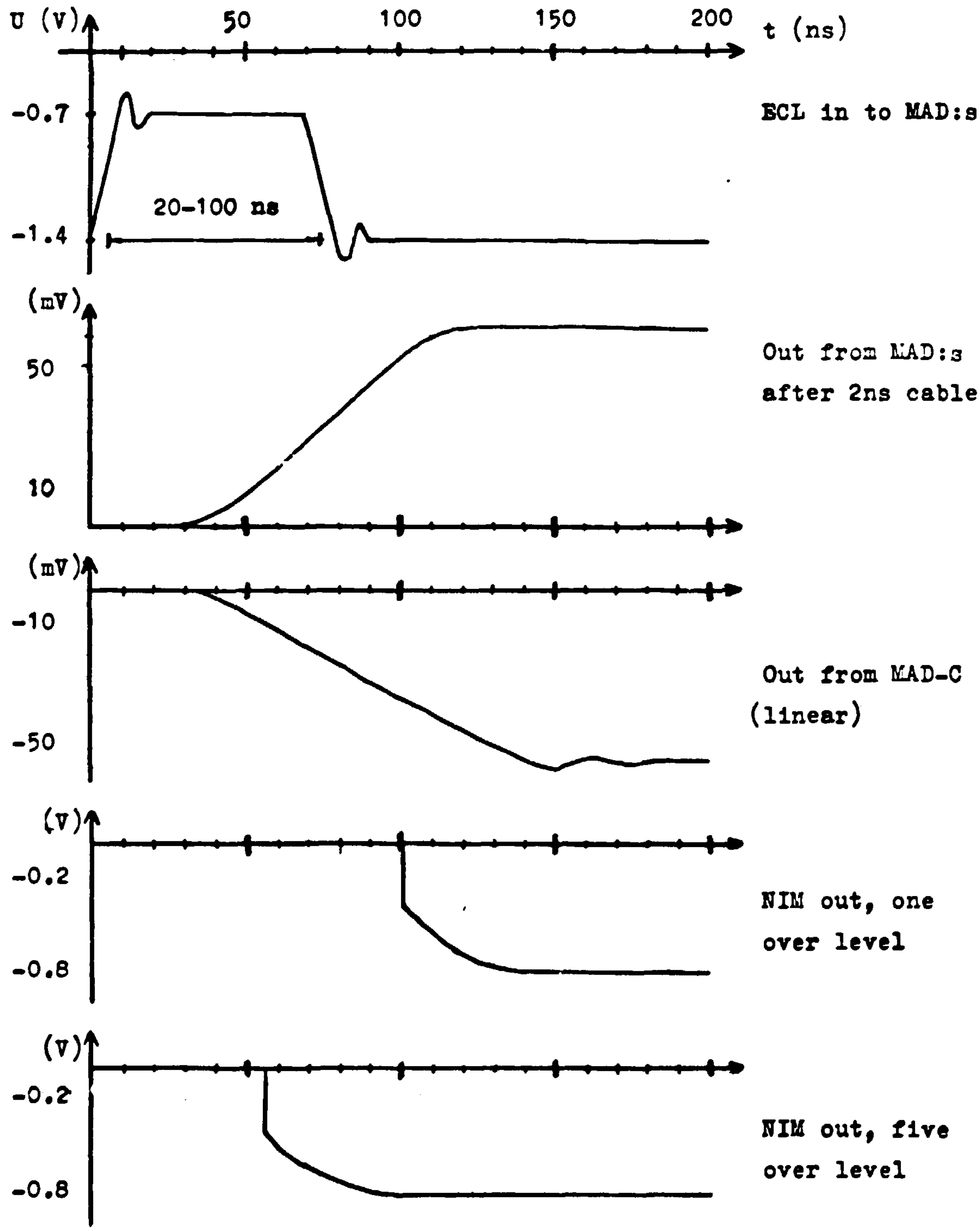
With one electron more than the multiplicity chosen, the propagation delay has been measured (V.1) to be 100 ns. With more than one electron over chosen level, the delay can be as short as 60 ns.

V MISCELLANEOUS

V.1 Signal flow

The input pulses to the MT have a length greater than 20 ns, and a rise time of approx. 4 ns. The overshoot is 50 % due to clipping. In the following timing diagram, the delay caused by different parts is shown. One cm corresponds to 20 ns. From the diagram it is obvious that it is the rise time of the pulses coming from the MAD:s that make the MT slow. (Read not so fast.) With changes done according to recomendations in VI.1, the delay can probably be decreased to 50 ns.

V.1.1 Timing diagram



V.2 Components and prices

The prices are given in Swiss Franc.

2.1 MAD:s

Amount	Part (one MAD)	P.U	Total
110	Resistors	0.10	11.00
2	Potentiometers, Cermet	1.00	2.00
50	Capacitors	1.00	50.00
4	Diodes	1.00	4.00
8	MC 10125	1.85	14.80
16	9602	3.00	48.00
2	NE 5539	9.00	18.00
1	uA 7808	0.70	0.70
1	uA 7908	0.70	0.70
2	3M connectors male. 34 pin	4.85	9.70
3	LEMO connectors	3.25	9.75
1	NIM-box	29.65	29.65
		SUM	198.30

2.2 MAD-C

Amount	Part	P.U	Total
47	Resistors	0.10	4.70
11	Potentiometers, Cermet	1.00	11.00
21	Capacitors	1.00	21.00
4	Diodes	1.00	4.00
4	LEDs	1.30	5.20
4	Transistors	0.10	0.40
1	NE 5539	9.00	9.00
4	NE 521N	2.20	2.20
1	MC 10124	1.85	1.85
2	9602	3.00	6.00
1	UA 741	0.80	0.80
1	LM 317 T	1.35	1.35
1	UA 7808	0.70	0.70
1	UA 7908	0.70	0.70
25	LEMO connectors	3.25	81.25
1	NIM-box	29.65	29.65
		SUM	179.80

2.3 Testgrunka

Amount	Part	P.U	Total
34	Resistors	0.10	3.40
2	Capacitors	1.00	2.00
2	Diodes	1.00	2.00
2	3M connectors female, 34 pin	6.40	12.80
2	LEMO connectors	3.25	6.50
1	NIM-box	29.65	29.65
		SUM	56.35

2.4 Total

One complete Multiplicity Trigger system contains five MAD:s, one MAD-C and one Testgrunka.

Part	P.U	Total
5 x MAD	198.30	991.50
1 x MAD-C	179.80	179.80
1 x Testgrunka	56.35	56.35
	SUM	1227.65

VI PROPOSAL OF REFINEMENTS

There are several things that can be done to make the MT work even better than it does in its present configuration.

VI.1 MAD:s

-The printed circuit design has (at least) one error. The falling edge of pulses on channel six and seven causes a small "dip" on the output. The reason is that channel six and seven are to close to the summing point wire on the printed board, and cause crosstalk on the output. One possibility to get rid of this problem is to connect a grounded wire between channel six and seven and the summing point wire.

-This makes it possible to decrease the resistor R_{10} down to 50 Ω, and the risetime of the pulses can be minimized.

-Changing the one-shots from common TTL to Schottky-TTL decreases the propagation delay with approx. 10 ns.

-In order to make the offset adjustment easier, a similar arrangement as in the MAD-C can be used.

-Since the multiplicity is seldom over 20, one adder can probably be removed in every MAD, and the other one can be used for 32 channels, instead of 16.

VI.2 MAD-C

-If the common strobe possibility is used on the MC10124:s, one NE521N can be used for two outputs.

VII OTHER METHODS

During the design work, I have been suggested several other methods to solve the same problem. I will only describe them superficially.

VII.1 Time window

A time window part would be needed in some form, since it is the number of electrons converted for one specific event that is of interest. Below, two methods are described.

-For the stretching of the input pulses, ring counters which toggle bistable multivibrators can be used. One ring counter and one bistable monovibrator would be needed for every channel. With this configuration, a change in frequency for all the counters alters the time window.

-ECL one-shots are faster than TTL. The propagation delay could be shortened with 20 ns. One disadvantage is the current consumption. For example, on the -6 V power supply, 160 one-shots would need 16 A !

VII.2 Flash ADC

With fast comparators it is possible to build a very fast analogue to digital converter. If 16 inputs are added together to form one hexadecimal word, they can then be added with binary adders. The summing can be made more exact in this way.

VII.3 Memory mapping

With the possibility of making fast programmable memories, another method is possible. By programming a memory with ones in every position with an address containing a "1", for instance 0001, 0010, 0100, 1000, and twos in positions with an address containing two "1":s, 0011, 0101 and so on, the address points out how many channels are high at the same time, and the result is shown on the data outputs, in the form of a hexadecimal word. The outputs of this memories can then be added with binary adders as in VII.2. A 1k memory can handle ten channels, (2^{10}=1024). For 16 channels, a 64k memory would be needed.

VIII REFERENCES

VIII.1 Cherenkov radiation

1. H. Enge. Introduction to nuclear physics. Massachusetts 1966.

2. Panofsky. Phillips. Classical electricity and magnetism. Massachusetts 1962[2].

VIII.2 The experiment

3. E. Barrelet et al. A two-dimensional, single photoelectron drift detector for Cherenkov ring imaging. Nuclear Instruments and methods. 200(1982) 219-236.

4. P. Baillon et al. The installation and use of a ring-imaging Cherenkov counter in the UA2 experiment to measure inclusive electron production at transfer momenta up to 5 GeV/c. CERN 1982.

VIII.3 Logics and analogue circuitry

5. A. Barna. E. L. Cisneros. Integrated circuit interfaces between nuclear instrument module and emitter coupled logic levels. Stanford 1969.

6. Per Erik Danielsson. Digital teknik. Lund 1979.

7. M. H. Jones. A practical introduction to electronic circuits. Cambridge 1977.

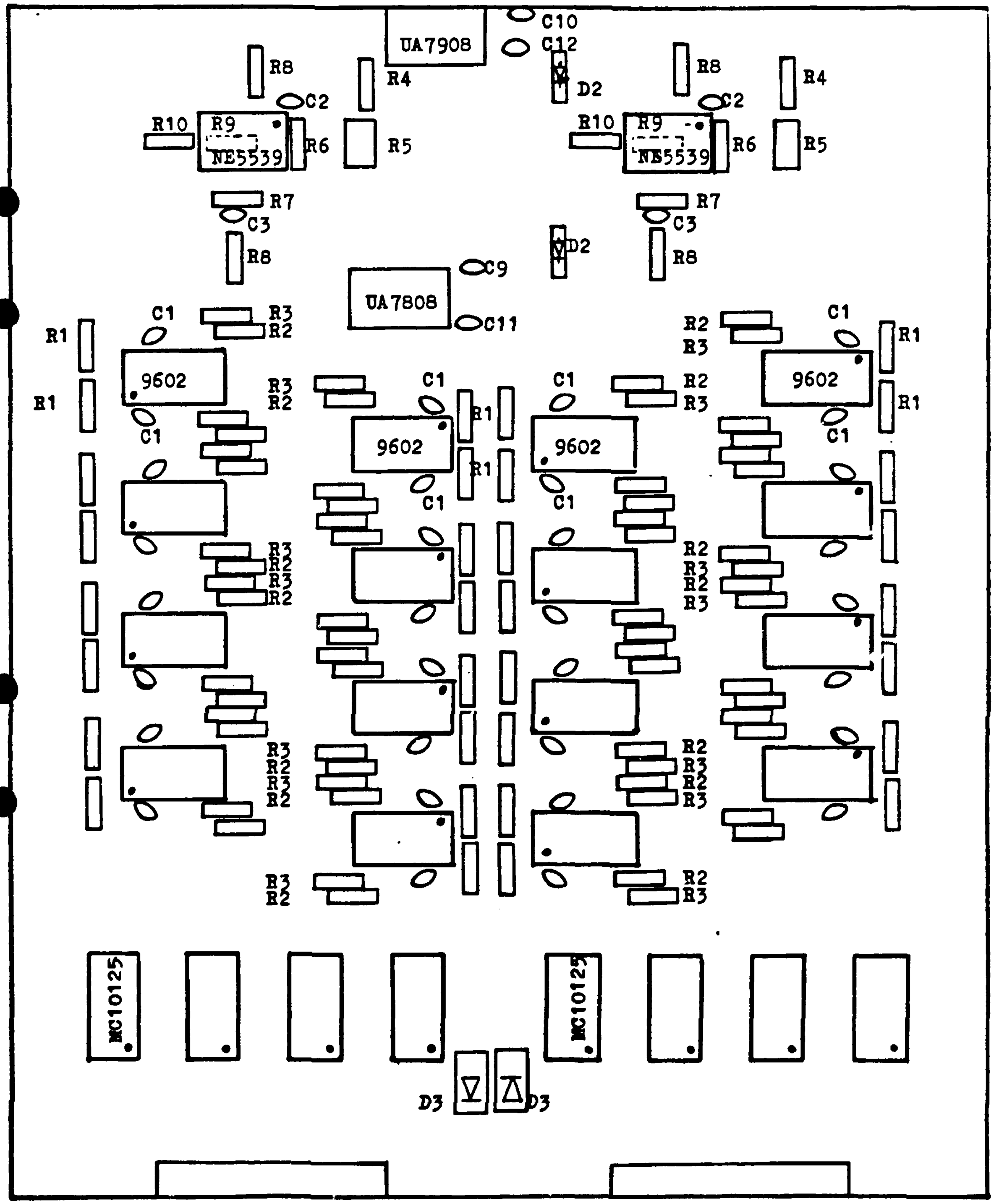
8. Millman. Halkias. Integrated electronics. Kosaido 1972.

9. Motorola semiconductors. MECL data book 1982/83.

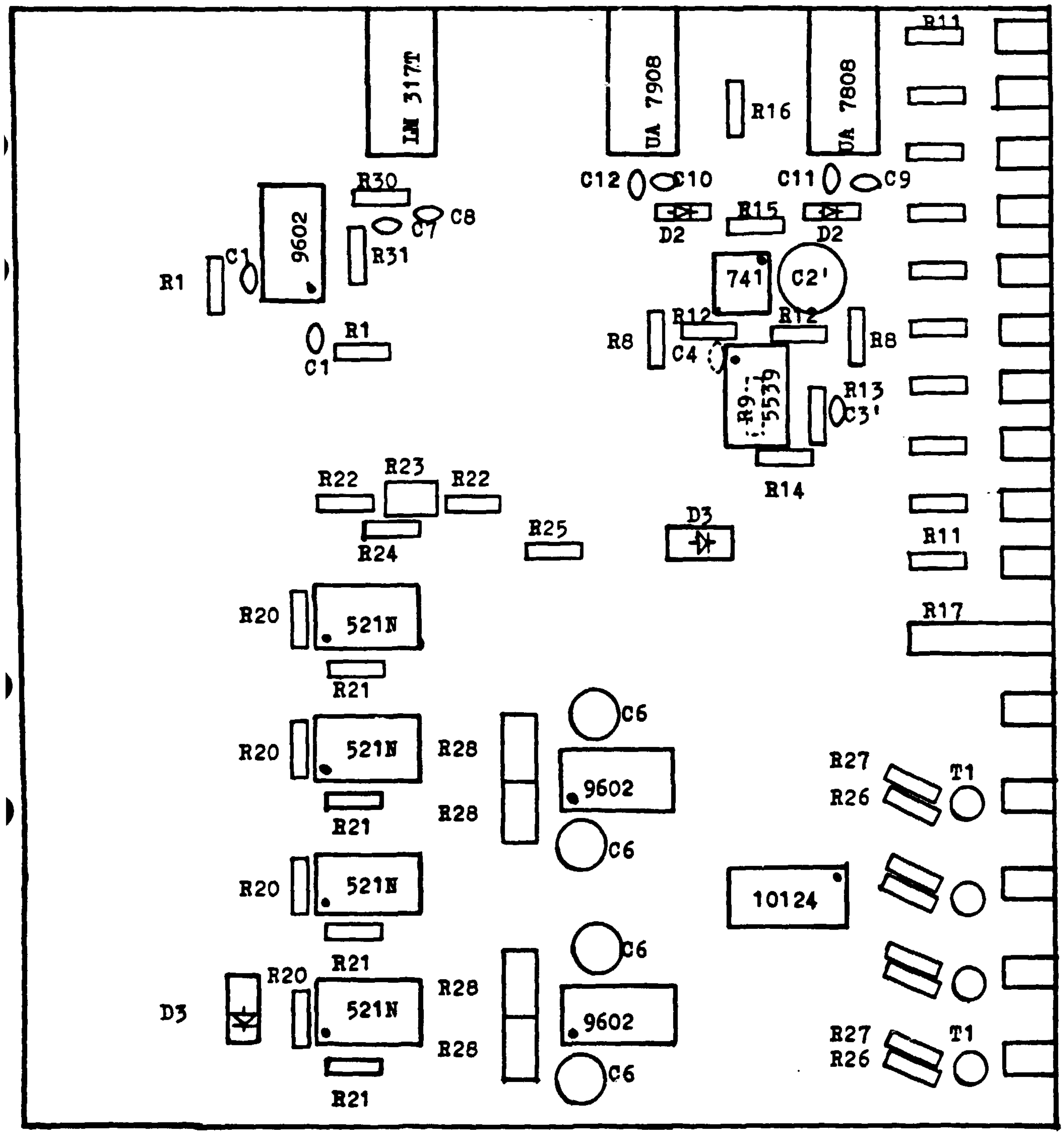
10. Gerald E Williams. Digital tecnology. USA 1977.

IX SUPPLEMENTS

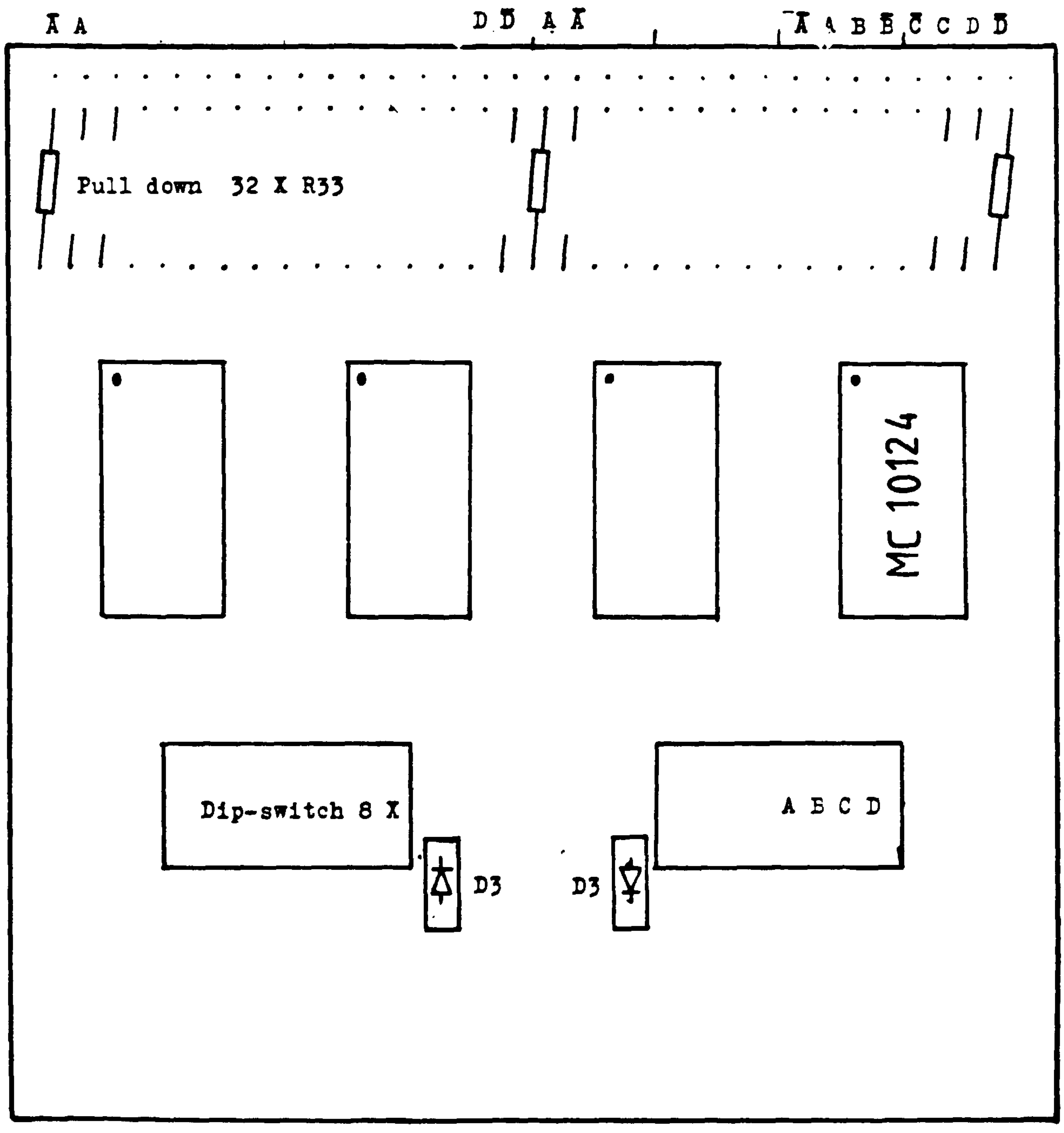
IX.1 Component diagram MAD



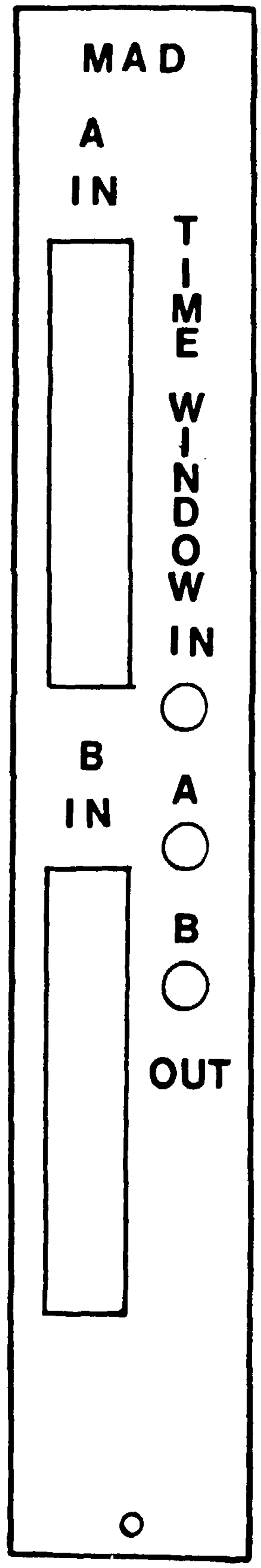
IX.2 Component diagram MAD-C



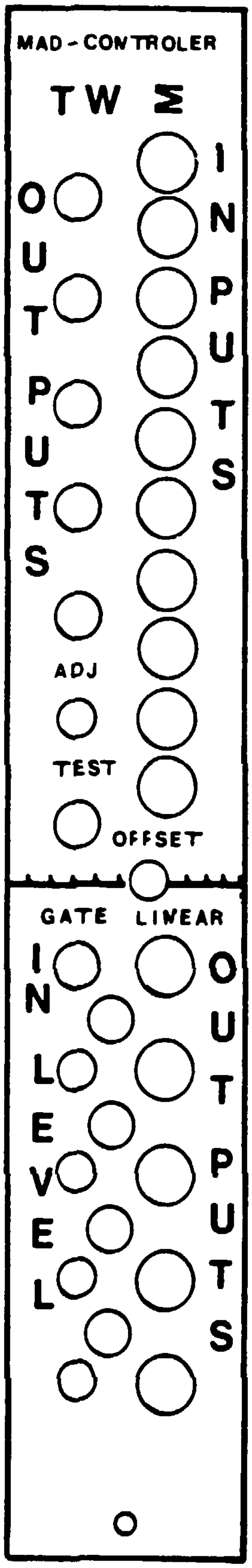
IX.3 Component diagram Testgrunka



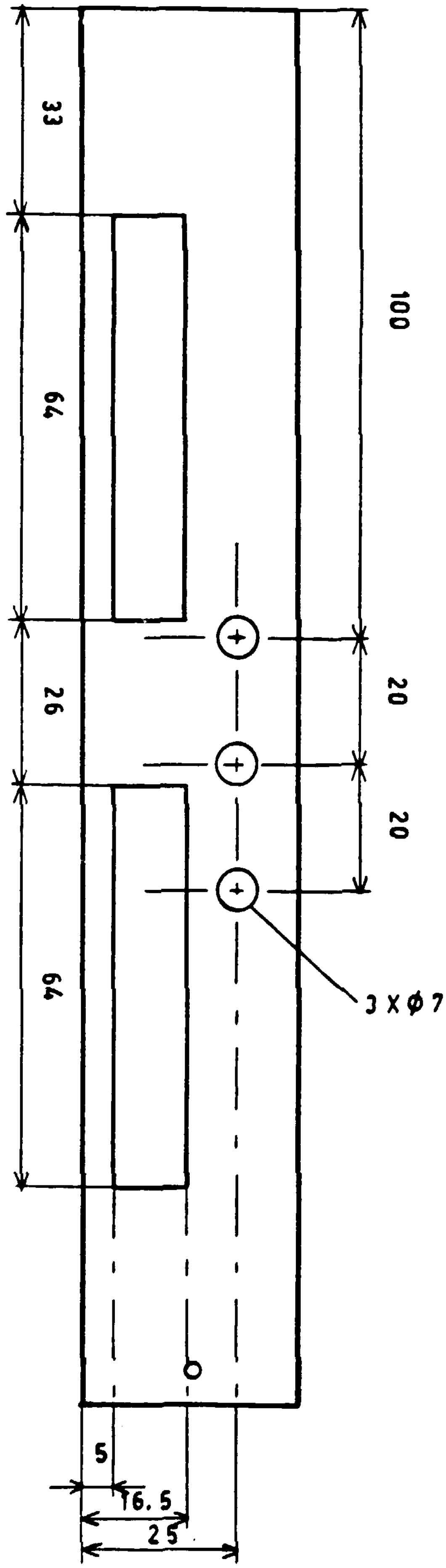
IX.4 Drawing of front panel MAD



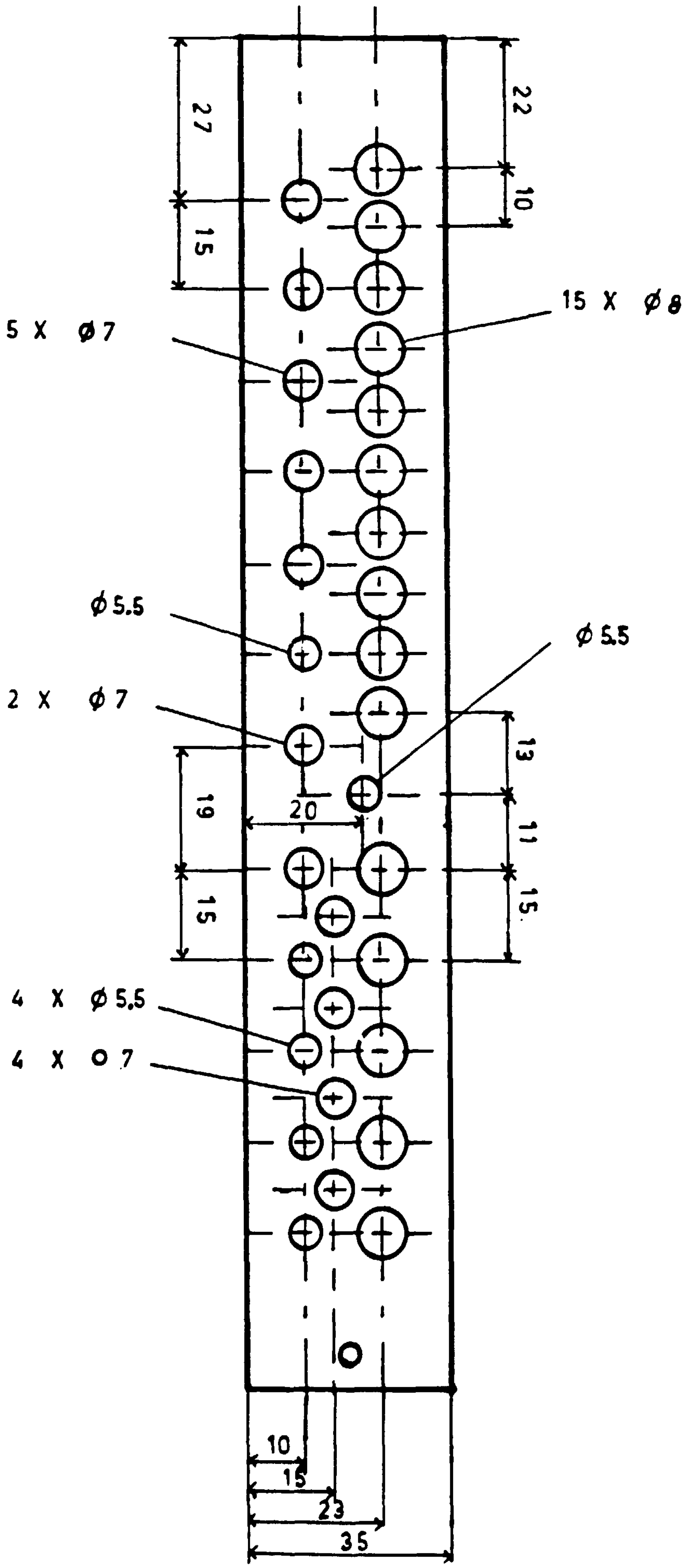
IX.5 Drawing of front panel MAD-C



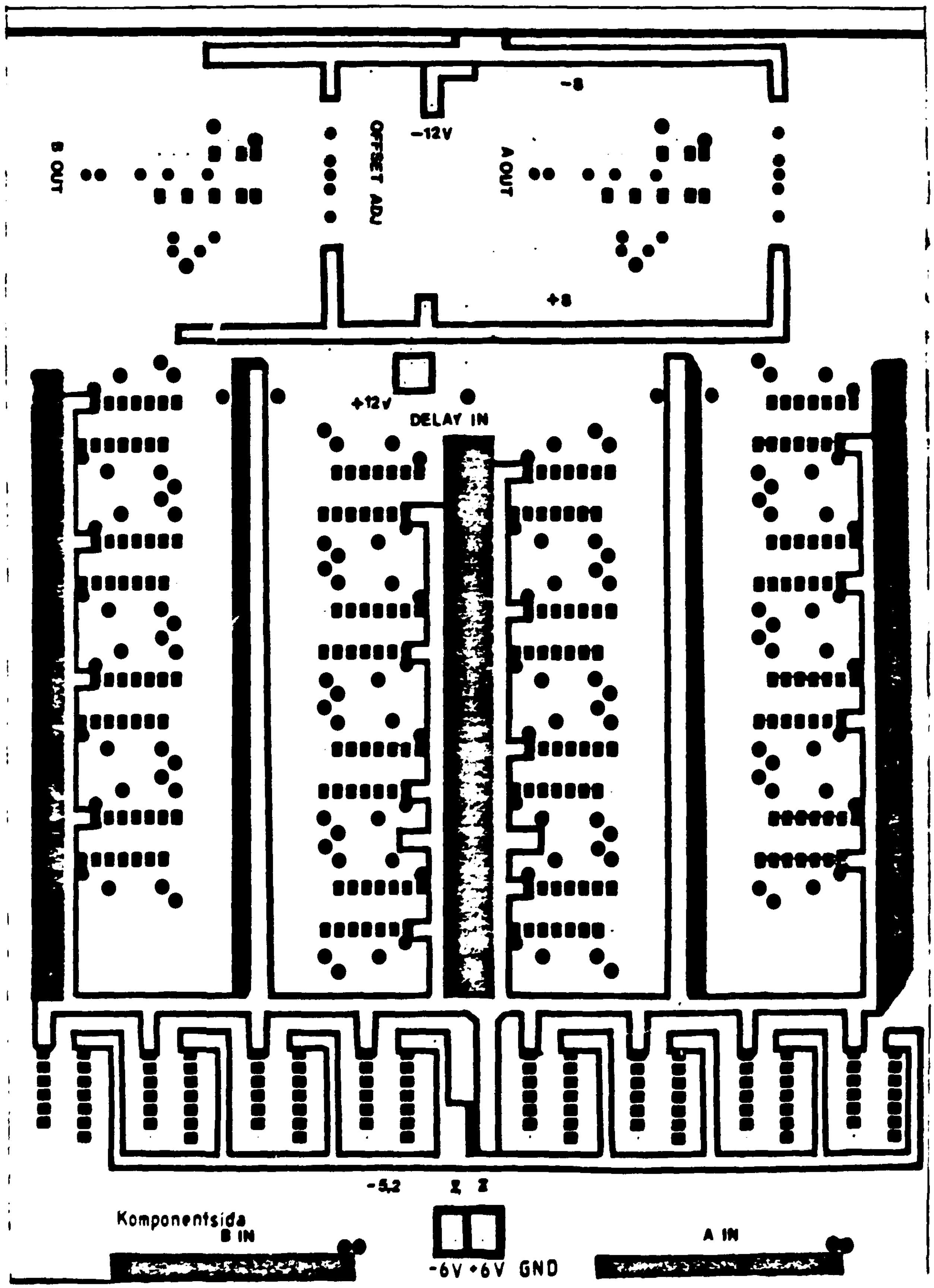
IX.6 Measures of front panel MAD



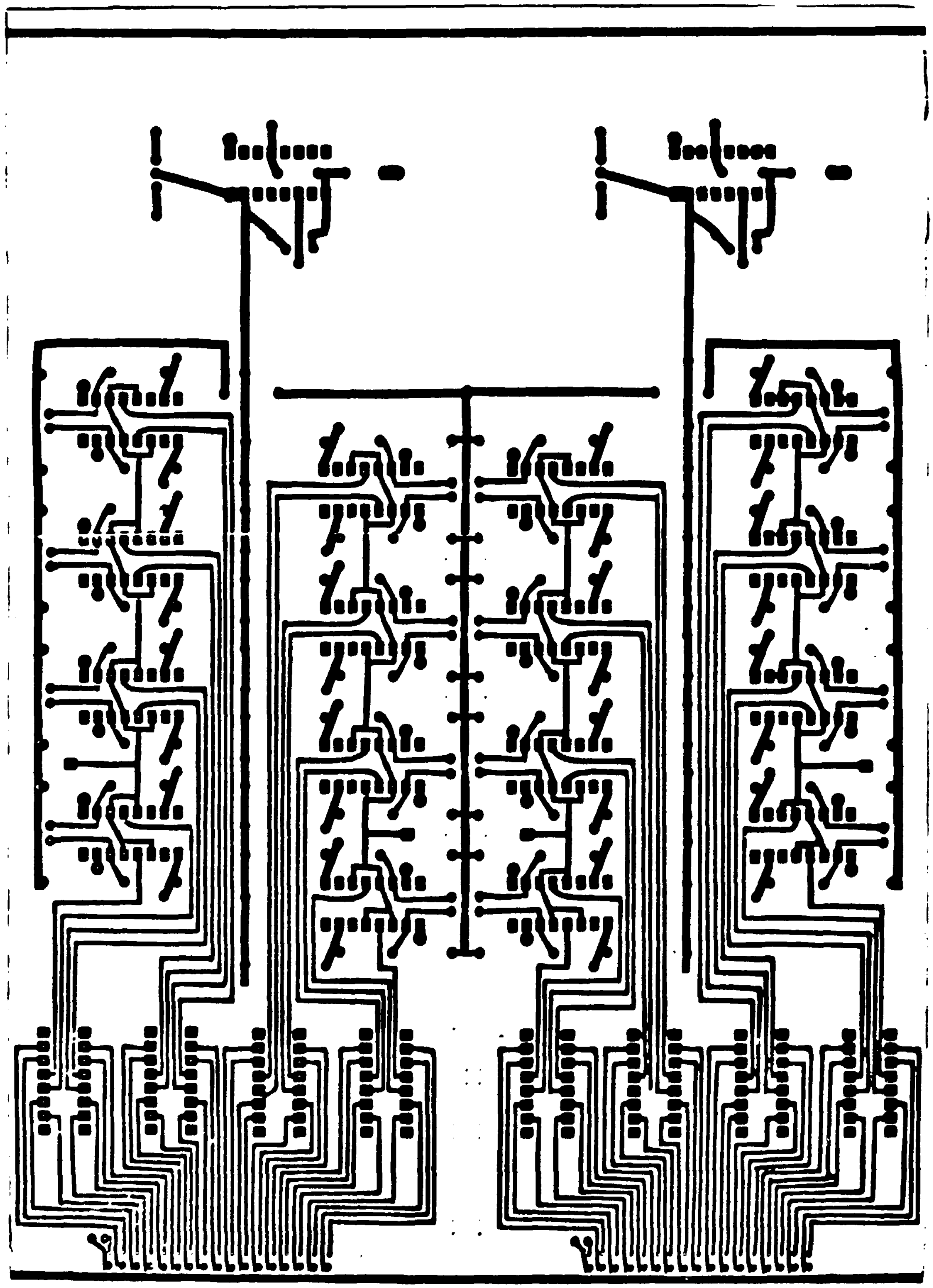
IX.7 Measures of front panel MAD-C



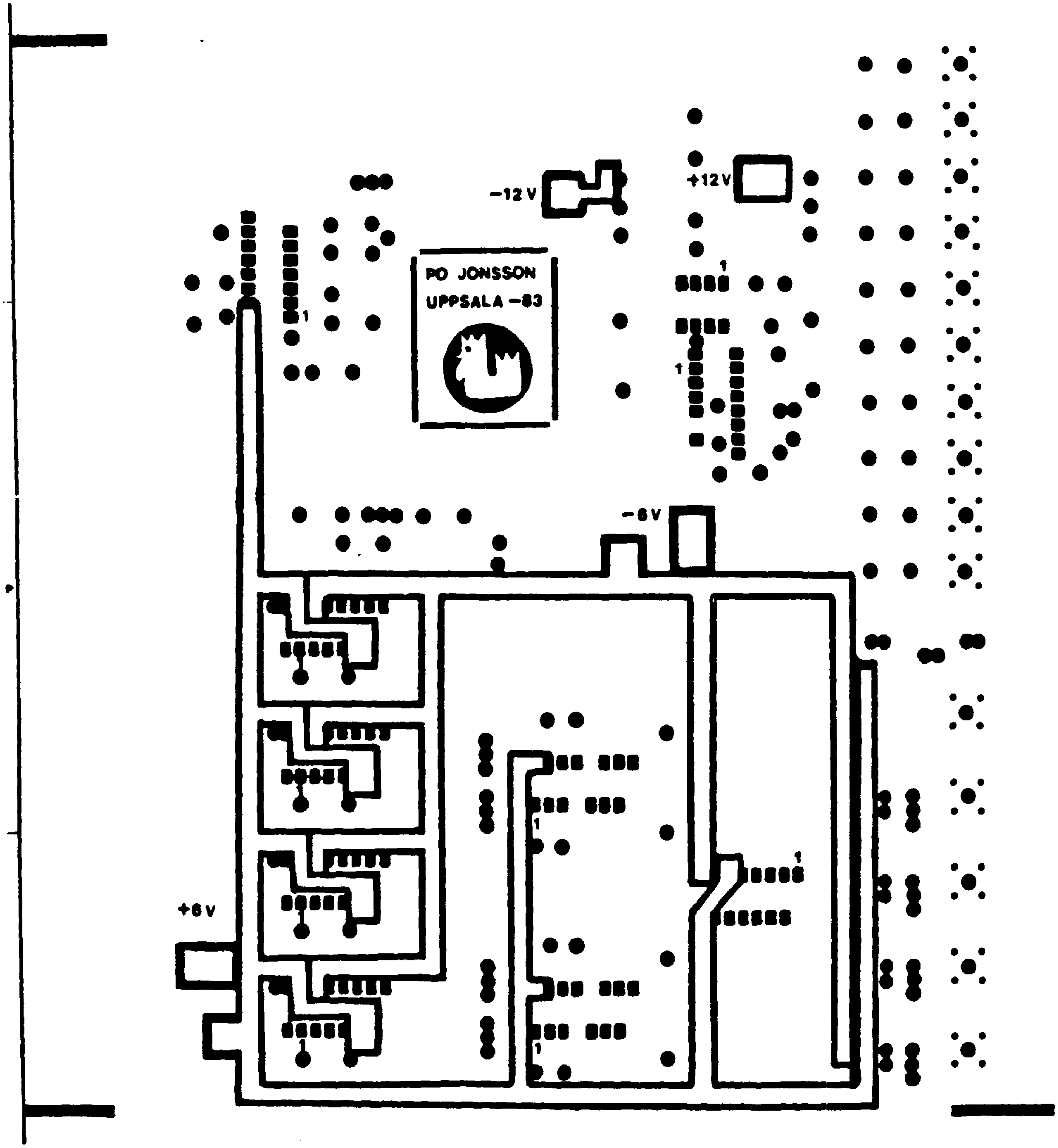
IX.8 Printed circuit design MAD, front side



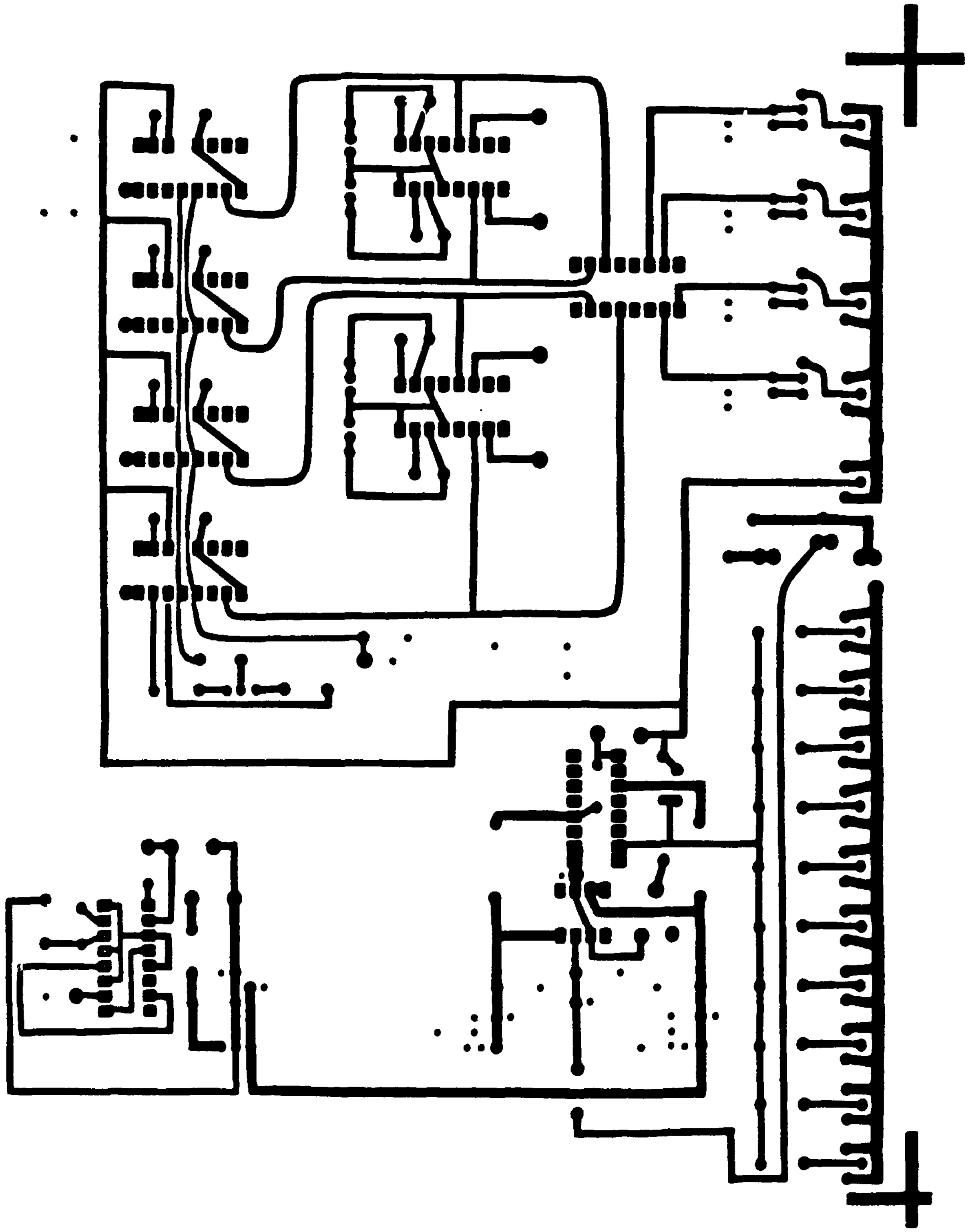
IX.9 Printed circuit design MAD, back side



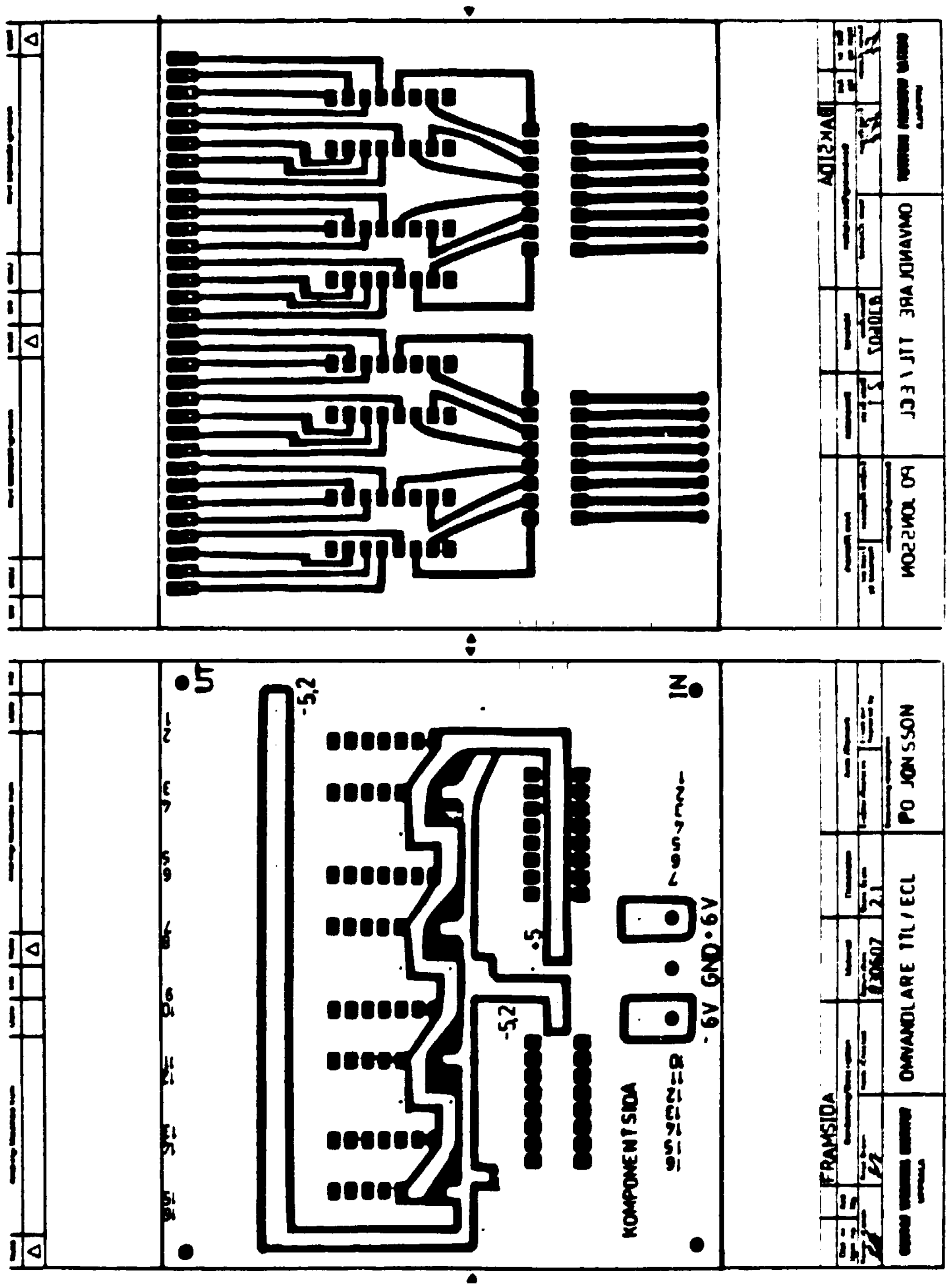
IX.10 Printed circuit design MAD-C, front side



IX.11 Printed circuit design MAD-C, back side



IX.12 Printed circuit design Testgrunka



IX.13 Table, timing resistors

Time window (τ) as a function of resistor values. Different resistors (R_1) in the RC combination in the MADs are given. C = 220 pF 5% MICA. $\Delta\tau = \pm 10\%$

Resistor	Time window Minimum		Maximum
6.8 kΩ	0.45 μs	-	2.2 μs
8.2 kΩ	0.50 μs	-	2.6 μs
10 kΩ	0.60 μs	-	3.2 μs
12 kΩ	0.70 μs	-	4.0 μs
15 kΩ	0.83 μs	-	4.9 μs

IX.14 Table, linearity and uniformity MADs

14.1 Table one, uniformity

One electron at the time on every channel, values in mV. The averages below are compensated for offset. 95% confidence limits are given, assuming Gaussian distribution.

MAD nr	Offset	1	2	3	4	5	6	7
1A	-0.3	62.0	62.0	61.9	61.7	61.9	61.8	61.7
1B	-2.7	59.4	59.5	59.8	59.7	60.0	59.8	59.9
2A	-5.2	58.0	57.6	57.8	57.5	57.7	57.5	56.9
2B	-6.0	56.2	56.3	55.6	55.5	56.2	56.3	55.9
3A	-4.3	57.5	57.9	57.3	57.9	57.5	57.3	57.4
3B	-5.0	57.2	56.9	56.5	56.0	57.0	57.0	56.7
4A	-0.5	61.6	61.7	61.5	61.8	61.7	61.5	61.4
4B	-3.1	60.2	59.5	59.5	59.6	59.9	59.7	59.5
5A	-2.8	59.3	58.8	59.2	59.1	59.4	59.2	59.9
5B	-3.5	58.5	58.5	59.0	58.9	59.1	58.9	59.1
6A	+5.2	68.3	67.6	67.3	67.8	68.2	68.2	67.7
6B	-3.4	59.1	58.8	59.3	58.8	58.9	59.3	59.5

8	9	10	11	12	13	14	15	16
61.7	62.2	61.9	61.4	61.5	61.8	61.9	61.3	61.6
60.0	59.1	59.3	59.5	59.5	59.5	59.4	59.0	59.2
57.1	57.5	57.5	57.6	57.6	57.4	57.3	57.2	57.6
56.0	55.7	55.8	56.2	56.1	56.2	56.2	55.7	56.0
57.3	57.3	57.1	57.1	56.0	57.2	57.0	57.2	56.9
56.3	56.6	56.6	56.4	56.5	56.4	56.9	56.7	56.5
61.2	61.9	61.7	61.5	61.7	61.8	61.9	61.6	60.8
59.4	60.2	59.7	59.4	59.5	59.7	59.6	59.4	59.3
60.0	59.5	59.2	59.3	59.8	59.2	59.2	59.5	59.3
59.0	59.4	58.4	58.8	59.1	59.6	59.2	58.7	58.4
68.1	67.6	68.1	68.3	67.7	67.6	67.6	67.7	68.0
59.6	59.7	59.5	59.2	59.0	58.9	59.4	59.3	59.3

MAD nr	Average
1A	62.1 ± 0.5
1B	62.2 ± 0.6
2A	62.7 ± 0.5
2B	62.0 ± 0.5
3A	61.6 ± 0.6
3B	61.6 ± 0.5
4A	62.1 ± 0.6
4B	62.7 ± 0.5
5A	62.2 ± 0.6
5B	62.4 ± 0.6
6A	62.7 ± 0.6
6B	62.6 ± 0.6

$\bar{X} = 62.2 \pm 0.8$ mV

14.2 Table two, linearity

One to sixteen channels on, values in mV. Uncertainty in measurements ± 1 mV

MAD nr	Offset	1	2	3	4	5	6	7
1A	-0.5	62	124	186	248	311	373	435
1B	-2.9	59	121	184	246	310	372	435
2A	-7.0	56	119	182	244	308	371	433
2B	-7.0	56	118	180	241	304	366	429
3A	-6.0	57	119	181	239	301	363	425
3B	-7.0	57	118	180	241	303	366	428
4A	-2.0	61	124	186	248	310	372	435
4B	-4.0	60	123	185	248	311	374	437
5A	-4.0	59	121	183	245	308	370	433
5B	-4.0	58	120	183	246	308	371	434
6A	+4.0	68	131	193	256	319	382	445
6B	-5.0	59	121	184	247	309	372	435

8	9	10	11	12	13	14	15	16
497	560	623	685	747	810	873	935	998
499	561	623	686	749	812	875	937	999
495	558	621	684	747	810	873	936	998
491	553	615	678	740	802	865	926	988
486	548	610	672	734	796	858	920	981
489	551	613	674	736	797	858	919	978
497	560	622	685	747	810	873	936	998
500	563	626	689	752	815	878	941	1004
497	560	622	685	748	811	877	937	1000
497	560	623	686	749	812	875	938	1001
508	571	634	698	761	824	887	950	1013
498	562	625	688	751	813	876	939	1003

MAD nr	Average step
1A	62.3 ± 1
1B	62.5 ± 1
2A	62.9 ± 1
2B	62.3 ± 1
3A	61.8 ± 1
3B	62.1 ± 1
4A	62,5 ± 1
4B	63.1 ± 1
5A	62.6 ± 1
5B	62.6 ± 1
6A	63.1 ± 1
6B	63.0 ± 1

$\bar{X}$ = 62,6 ± 1 mV

IX.15 Table, linearity and uniformity MAD-C

15.1 Table one, uniformity

One channel on at the time. 1B are arbitrary choosen as input MAD. (Not all the input combinations are tested.) 95% confidence limits are given, assuming Gaussian distribution. Values in mV.

Offset	1	2	3	4	5	6	7	8
0	-55.0	-54.8	-55.0	-55.1	-55.2	-55.1	-55.2	-54.9

	9	10	11	12	13	14	15	16
	-56.1	-55.5	-55.3	-55.6	-55.0	-55.3	-55.1	-54.8

Average: $\bar{X} = 55.2 \pm 0.7$

15.2 Table two, linearity

One to sixteen channels on. 1B used as input MAD. Uncertainty in measurements $\pm$ 1 mV, all values in mV.

Offset	1	2	3	4	5	6	7	8
0	-55	-110	-165	-220	-276	-332	-387	-442

	9	10	11	12	13	14	15	16
	-498	-554	-610	-666	-722	-778	-834	-889

Average: $\bar{X} = 55.6 \pm 1$

15.3 Table three, linearity

1A + 1B Are choosen as input MADs. 2 - 32 channels on at the same time. Uncertainty in measurements $\pm$ 1 mV, all values in mV.

Offset	2	4	6	8	10	12	14	16
+2	-110	-220	-330	-441	-552	-663	-774	-885

	18	20	22	24	26	28	30	32
	-996	-1107	-1218	-1330	-1440	-1552	-1663	-1774

Average: $\bar{X} = 55.5 \pm 1$

IX.16 Table, time window difference

Four different time windows (τ) are tested. Values in μs.

16.1 Table one

τ =0.76	Time window		% of τ	
MAD nr	Min	Max	-	+
1A	0.71	0.82	7	8
1B	0.70	0.82	8	8
2A	0.74	0.82	3	8
2B	0.71	0.82	7	8
3A	0.71	0.80	7	5
3B	0.70	0.79	8	4
4A	0.72	0.82	5	8
4B	0.72	0.81	5	7
5A	0.73	0.82	4	8
5B	0.71	0.83	7	9
6A	0.72	0.82	5	8

16.2 Table two

τ =2.00	Time window		% of τ	
MAD nr	Min	Max	-	+
1A	1.82	2.08	9	4
1B	1.80	2.02	10	1
2A	1.88	2.92	6	1
2B	1.82	2.04	9	2
3A	1.80	2.00	10	0
3B	1.78	1.90	11	-5
4A	1.86	2.08	7	4
4B	1.84	2.02	8	1
5A	1.86	2.04	7	2
5B	1.84	2.04	8	2
6A	1.80	2.04	10	2
6B	1.60	2.04	10	2

16.3 Table three

MAD nr	Min (τ =3.00 Time window)	Max	% of τ -	+
1A	2.75	3.20	8	7
1B	2.72	3.10	8	3
2A	2.80	3.10	7	3
2B	2.80	3.10	7	3
3A	2.80	3.00	7	0
3B	2.70	2.95	10	-2
4A	2.80	3.15	7	5
4B	2.80	3.05	7	2
5A	2.80	3.15	7	5
5B	2.85	3.10	5	3
6A	2.70	3.15	10	5
6B	2.70	3.10	10	3

16.4 Table four

MAD nr	Min (τ =4.04 Time window)	Max	% of τ -	+
1A	3.70	4.35	8	8
1B	3.70	4.20	8	4
2A	3.70	4.15	8	3
2B	3.70	4.10	8	1
3A	3.65	4.10	10	1
3B	3.60	3.95	11	-2
4A	3.80	4.20	6	4
4B	3.85	4.10	5	1
5A	3.75	4.4	7	9
5B	3.75	4.20	7	4
6A	3.60	4.30	11	6
6B	3.65	4.15	10	3

IX.17 Table, current consumption

Values in mA.

MAD nr	+12	-12	+6	-6	Voltage supply
[illegible]	57	66	813	255	
2	54	82	797	255	
3	57	67	803	256	
4	53	81	808	257	
5	52	79	796	257	
6	52	86	804	259	
Average	54	77	804	256	
5 MAD:s	270	384	4017	1282	
MAD-C	44	24	203	160	
Testg.	0	0	56	370	
Total	310	410	4280	1810	