GS/ab

MPS/Int. SR/69-6
15. 4. 1969

PICK-UP SIGNAL-SIMULATOR

(MPS 2872)

by G. Schneider

PS/7139

1. Abstract

This report describes a pulse generator which simulates the bunch pick-up signals at the CPS corresponding to three different proton-momenta: p_1 = 28 GeV/c, p_2 = 580 MeV/c, p_3 = 50 MeV/c, and the spiraling beam at 50 MeV. The simulator permits to calibrate and test the pick-up stations at these energies and also the closed orbit digital display (CODD). For the latter some synchronizing circuits are included.

2. Requirements

a) The P.U. signal simulator should generate pulses with the length τ and the repetition frequency f corresponding to the proton momentum p as follows [1].

	τ[ns]	f [MHz]	p [GeV/c]	beam mode
I	15	9,55	28	bunched
II	50	7	0,58	bunched
III	150	2,9	0,05	bunched
IV	3300	0,15	0,05	spiraling

Table 1

The shape of the pulses can be approximated by half sine wave signals in the cases I, II and III. In the case IV rectangular pulses are desired. The amplitude of the pulses should be variable from 0 to 10 V_p.

b) The signals defined in 2a) should be available on one simulator output. The same signal shape coming from another simulator output should appear on the electrodes of the compact pick-up (P.U.) stations in the ring. The cables (RG 216) which are provided for the transmission of the testsignals have relatively high losses. The - 3 db point for a cable of 165 m length is at 8 MHz. This means that a high-pass filter, compensating for the high frequency losses, must be inserted.

c) A sine-wave signal with 1 V_{pp} should be available for synchronization. The phase of this signal must be variable within 180 degrees.

d) The PU-calibration must be possible between the machine cycles. Therefore a switch (triggered by a standard pulse) should be provided which cuts off the test signal during the machine cycle. The swith-off-time should be variable between 0.2 and 2 sec.

3. Compensation of the Cable Distortions

The attenuation a and phase lag φ_c of the 165 m test-cable (RG 216) were measured and are shown in curve 1 of figs. 1 and 2. For a distortion-free signal transmission the attenuation should be constant, and the phase should increase linearly with frequency. In order to present the deviation of a linear phase, a linear term k•f was added to the phase difference φ_c between in- and output signal.

$$\varphi = \varphi_c + kf; \qquad k = 3 \cdot 10^{-4} \; [^\circ/\mathrm{Hz}]$$

The curve 1 in fig. 2 shows that the negative phase error first increases with frequency. After a maximum at 15 MHz, it decreases down to zero at 55 MHz.

A similar, but positive phase response can be realized with a high-pass filter given in fig. I.

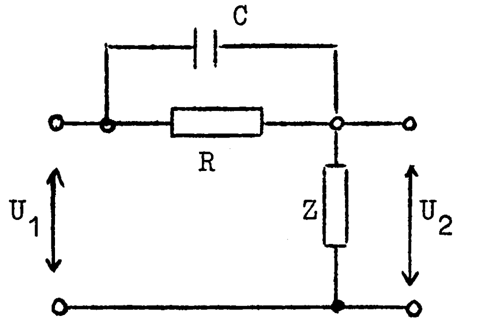


Fig. I

The parameters C and R are calculated in the appendix so that the phase and amplitude error of the cable are compensated as far as possible.

The values are

$$C = 50 \text{ pF}$$

$$R = 240 \text{ ohms}$$

Curve 4 of fig. 1 shows the attenuation of the filter with these values. Curve 5 is the frequency response of the filter plus cable. It is flat $\pm$ 1,2 db up to 120 MHz.

A transmission system for pulses of τ = 15 ns (28 GeV) length needs a cut-off frequency

$$f_c \approx \frac{1}{\tau} = 66{,}7 \text{ MHz}.$$

A filter with the same time constant $T = R \cdot C$ but with

$$C' = 2\,C = 100 \text{ pF}$$

and

$$R' = \frac{R}{2} = 120 \text{ ohms}$$

yields less bandwidth but also less attenuation.

Curve 2 of fig. 1 shows the filter response, and curve 3 the total frequency response filter plus cable. Up to 80 MHz the response is flat $\pm$ 1 db.

Fig. 2 shows the phase response of the filter (curve 2) and the phase response of the filter plus cable (curve 3). The phase is constant between 15 and 55 MHz. This means that the propagation time for these frequencies is constant:

$$t_p = \frac{d(\alpha+\varphi)}{d\,\omega} = \frac{d(\alpha+\varphi)}{df} \cdot \frac{df}{d\,\omega} = k \cdot \frac{1}{2\pi} = 0.833 \text{ µs}$$

with $k = 3 \cdot 10^{-4}$ [°/Hz] from the cable phase measurement (s. fig. 2).

Photo 1 of fig. 3 shows the signal distortion of the cable without compensation network, photo 2 the in- and output signals with the filter included ($R' \approx 120$ ohms, $C' = 100$ pF).

4. Circuit Discussion of the

4.1 15 ns Pulse Generator (see fig. 4) (with step recovery diode)

Transistor T_1 oscillates with the crystal frequency f = 9.55 MHz. Transistors T_2 and T_3 decouple the oscillator from the non-linear step-recovery diode. The output impedance at the emitter of T_3 is a few ohms. The sine wave voltage at this point is about 10 V_{pp}.

The step recovery diode (SRD) can be considered as a very fast switch. When the SRD is forward biased, the voltage at point P is about - 0.7 V. The diode current passes also through the inductance L. When the diode current becomes reverse biased by the sine wave signal, a very high voltage

$$U = L \cdot \frac{di}{dt}$$

appears at point P, which tries to maintain the current in the inductance. As the diode is switched off, there remains a damped oscillating network with L, R, and C. (C is the input capacity of transistor T_4). After half an oscillation with about the time

$$t = \pi \sqrt{LC}$$

the diode becomes forward biased and the voltage at point P remains - 0.7 V until the next cycle of the input signal.

The pulses at point P are therefore half sinewave signals with a period much shorter than that of the input signal. The amplitude of these pulses (approx. 30 V) is much higher than the input voltage, as the energy of in- and output signals must be the same (losses neglected).

At the output of emitter followers T_4 and T_5 the pulse signals are available directly (point C) or pass through the filter described in paragraph 3.

With the variable voltage at point J the biasing of transistors T_2 and T_3 can be changed. This permits to vary the amplitude of the output pulses between 0 and 10 V_p.
The shape of the generated pulse can be seen in fig. 11, photo a.

At the collector of the oscillator-transistor T_1 a signal is decoupled via transistor T_6 and selectively amplified by T_7. The emitter follower T_8 delivers a sinewave signal to the output (point N) for synchronizing.

4.2 <u>50 ns Pulse Generator</u> (see fig. 5)

Transistor T_1 oscillates with the crystal frequency f = 7 MHz. After the impedance transformation of the emitter followers T_2 and T_3, the signal is amplified by transistor T_4. The negative part of the sine wave signal is clipped with diode D_1. The clipping level with respect to the sine wave signal can be adjusted with the variable resistance R_1. The signal amplitude can be varied continuously from 0 to 10 V_p at the output by means of potentiometer P_1 at the emitter of the transistor T_5.

In the rest position of the relay X_2 the signal passes through the high-pass filter.

When the relay is excited, the undistorted pulse signal is directly available at the front panel.

At the collector of the oscillator-transistor T_1 a signal is decoupled via transistor T_6 and selectively amplified by transistor T_7. The emitter follower T_8 delivers a sine wave signal to the output point N for synchronizing.

4.3 <u>150 ns Pulse Generator</u> (see fig. 5a)

This pulse generator is similar to the one described in paragraph 4.2 (see fig. 5).
The differences are:

Transistor T_1 oscillates with the crystal frequency f = 2.9 MHz and some condensors in the filters have other values as indicated in fig. 5a.

4.4 3.3 µs Pulse Generator (see fig. 6)

The transistors T_1, T_2 and T_3 work as a multivibrator with the frequency f = 150 kHz. The emitter follower T_4 delivers an imperfect square wave signal to the amplifier stage with transistor T_5. The amplitude of a proper square wave signal at the collector of T_5 can be varied by potentiometer P_4.

The two complementary emitter follower stages deliver the square wave signal to the output with maximum 10 V_{pp}.

The filter for compensation of the cable distortions requires 2 adjustments. The variable resistor R_1 permits to adjust the top of the square wave pulses horizontally (at the end of the 165 m cable). With R_2 the rise and fall of the pulses can be adjusted without overshoot.

At the collector of the multivibrator transistor T_1 a trigger signal is decoupled via transistor T_{10} and selectively amplified by transistor T_{11}. The emitter follower T_{12} delivers a sine wave signal to the output point M with the frequency of the multivibrator (for synchronizing).

4.5 Phase Shifter (see fig. 7)

The phase shifter circuit permits to vary the phase of the synchronizing sine wave signal within 180 degrees.

The synchronizing signals from the 4 pulse generators described in paragraphs 4.1 .... 4.4 appear on the input contacts K, L, M. N. The relays L_1, L_2 and L_3 choose the one which is selected. This signal passes through the emitter follower T_1.

The signals at the collector and emitter of transistor T_2 have a phase difference of 180 degrees. The elements R_1, R_2, P_2 and C_1 represent a normal phase bridge. The phase of the signal at point D can be varied with constant amplitude by means of P_2. When the 3.3 µs pulse generator (f = 150 kHz) is selected, relay P switches a condensor C_2 parallel to C_1. This is necessary for this low frequency to obtain the same phase range. Via the emitter follower T_3 the signal goes to the output point B which is connected to the BNC jack on the front panel.

4.6 One-Shot (see fig. 8)

The one-shot generates a positive output pulse exciting the relays U_1 ... U_4. It starts with a standard pulse (40 V/1 µs) and terminates after a time to be chosen between 0.2 and 2.2 sec.

The circuit consists of two normal one-shot stages in series. The first one-shot stretches the trigger pulse. This longer pulse applied to the second one-shot permits to discharge condensor C_2 at the trigger moment. The condensor C_2 is then recharged with the time constant $T_2 = R_2 C_2$. The variable resistance P_1 allows to change the output pulselength within the range mentioned above.

The positive pulse at the collector of transistor T_4 is smaller than the supply voltage and superimposed upon a DC-level. The Zener diode D_1 shifts the DC level. The transistors T_5 and T_6 amplify the pulse height with constant phase up to the supply voltage. Transistor T_7 serves as an emitter follower. The resistor R_3 permits to adjust the current pulse in the relays U_1 ... U_4.

When relay U_5 is excited, relays U_1 ... U_4 are also excited. This is the case when the signal pulses are desired directly without passing through the filter (see paragraph 4.8 and fig. 10).

4.7 Supply Card (see fig. 9)

On the supply-card the ecessary supplemc itary voltages ar derived from the power supply voltages.

4.8 Control Circuit (see fig. 10)

The control circuit shows the four pulse generators, the one-shot, the phase shifter, the power supplies and the control elements.

Switch S_1 selects the desired pulse generator (via relays D_1, D_2, D_3, K_1, K_2, K_3 and their contacts). Each generator has two outputs, one with filter and the other directly coupled.

When switch S_2 is in position "DIRECT", the relay U_5 of the one-shot is excited. This means that the relays U_1, U_2, U_3 and U_4 on the 4 pulse generators are excited and the selected signal comes to the BNC output "DIRECT" (passing through the contacts d_1 - d_2 - d_3).

When switch S_2 is in position "CABLE", the relays U_1 ... U_4 are not excited. The signals pass through the filters and the contacts k_1 - k_2 - k_3 and come to the BNC jack "CABLE".

If in this position of the switch S_2 a standard pulse is applied to the trigger input, the one-shot excites the relays U_1 ... U_4 for a time which can be chosen by potentiometer P_1 between 0.2 and 2.2 seconds (for testsignal suppression during the PS machine cycle).

Switch S_1 has a fifth position "REMOTE". When switch S_1 is in this position, the desired pulse generator can be selected by remote control (via 24 pin amphenol plug on the rear panel). The supply voltage - 14 V on pin 1 must be switched on one of the pins 2, 3, 4, and 5.

The potentiometers P_3, P_4, P_5 and P_6 which are on the front panel and connected to the pulse generators, control the amplitude of the pulses between 0 and 10 V_p.

The phase between trigger signals and the pulses can be changed by potentiometer P_2.

The relays L_1, L_2 and L_3 on the phase shifter which are excited in series by the relays D and K select the trigger signal.

The contact of relay P which is excited in series with relay L_1 adds a supplementary condensor in the phase bridge when the 150 kHz/3.3 µs pulse train is selected.

The relays Q_1 ... Q_4 switch the supply voltage only to the pulse generator selected by S_1.

5. Results

The pulse shape of the 4 different pulse generators at the end of the 165 m testcable RG 216 is shown in fig. 11. The maximum amplitude is 10 V_p.

Fig. 12 photo a. shows the four generated pulse shapes at the output "DIRECT". Photo b. shows the four simulated bunch shapes in the pick-up station at the end of the 165 m testcable.

A sine wave signal is available at the trigger output of 1 V_{pp} and the frequency of the selected pulses. The phase between this signal and the generated pulses can be varied within 180 degrees.

A standard pulse (40 V/1 µs) applied to the trigger input switches the generated pulses from the output "CABLE" to the output "DIRECT". The time of this commutation can be varied between 200 and 2200 ms.

Fig. 13 shows the front panel of the P.U. signal-simulator.

ACKNOWLEDGEMENTS

I wish to thank Mr. D. Boussard for his interest in this work, and Mr. H. Schubel*) for his help in the development of this device.

REFERENCES

1) G. García-Alcaine : Mesure de la largeur des paquets dans le P.S.
MPS/Int. RF 67-17, November 1967

*) Vacancy student from University Hamburg.

Distribution: (open)
List MD/2
List SI/2

A P P E N D I X

Calculation of the Filter Elements

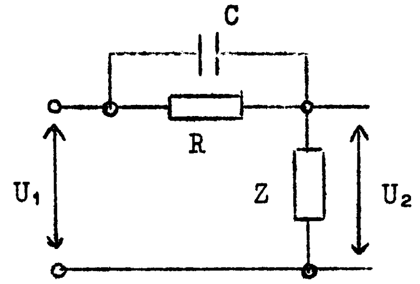


Fig. I

$$\frac{U_2}{U_1} = \frac{Z}{Z + \frac{1}{\frac{1}{R} + j\omega C}} = \frac{Z(1 + j\omega CR)}{R+Z+j\omega CRZ} \qquad (a)$$

The absolute value of

$$\left| \frac{U_2}{U_1} \right| = \frac{Z}{R+Z} \sqrt{\frac{1+(\omega CR)^2}{1+\left(\frac{\omega CRZ}{R+Z}\right)^2}} \qquad (b)$$

and the phase between U_2 and U_1

$$\alpha = \text{arc tg} \frac{\omega CR^2}{R+Z+(\omega CR)^2 Z} = \text{arc tg} \frac{\frac{CR^2}{R+Z}\,\omega}{1+\frac{C^2R^2Z}{R+Z}\,\omega^2} \qquad (c)$$

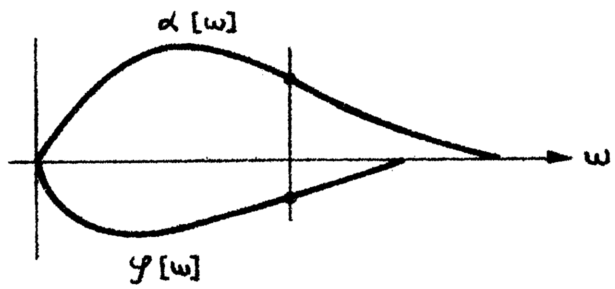


Fig. II

The experimentally determined curve $\varphi(\omega)$ can be developed in a Taylor serie around the point $f_p = 30$ MHz.

$$\varphi(\omega) = \varphi(\omega_p) + (\omega-\omega_p)\ \varphi'(\omega_p) + \ldots\ldots \tag{d}$$

with

$$\left.\begin{aligned} \omega_p &= 2\pi\cdot 30\cdot 10^6\ [\tfrac{1}{s}] \\ \varphi(\omega_p) &= -\ 0.197 \\ \varphi'(\omega_p) &= 1.175\cdot 10^{-9} \end{aligned}\right\} \text{from fig. 2}$$

The phase response $\alpha(\omega)$ of the filter (equ. (c)) expanded into a series around $f_p = 30$ MHz yields

$$\alpha(\omega) = \alpha(\omega_p) + (\omega-\omega_p)\alpha'(\omega_p) + \ldots. \tag{e}$$

If the slope of α at the frequency f_p could be made

$$\alpha'(\omega_p) = -\ \varphi'(\omega_r) \tag{f}$$

the phase error could be compensated.

Differentiating equ. (c)

$$\alpha' = \frac{d\alpha}{d\omega} = \frac{-\ 1}{1+\left(\dfrac{\frac{CR^2\omega}{R+Z}}{1+\frac{C^2R^2Z\omega^2}{R+Z}}\right)^2} \cdot \frac{CR^2(R+Z)}{(R+Z+\omega^2C^2R^2Z)^2} \tag{g}$$

and for $\omega = \omega_p$

$$\alpha'(\omega_p) = \frac{-\ CR^2(R+Z)}{(R+Z+\omega_p{}^2(RC)^2Z)^2 + \omega_p{}^2(RC)^2R^2} = -\ \varphi'(\omega_p) \qquad \text{(h)}$$

The second equation for the two unknowns R and C can be found from the condition that the attenuation at f_a = 15 MHz and 1 MHz be the same. Then an attenuation of 3.2 db (1 : 1.45) must be compensated at the frequency f_a.

The filter attenuation for very low frequencies is from equ. (b) :

$$d_o = \left/\frac{U_2}{U_1}\right/_o = \frac{Z}{R+Z} \qquad \text{(i)}$$

and for $\omega = \omega_a$

$$d = \left/\frac{U_2}{U_1}\right/_{\omega_a} = \frac{Z}{R+Z}\sqrt{\frac{1+(\omega_a CR)^2}{1+\left(\omega_a\frac{CRZ}{R+Z}\right)^2}} \qquad \text{(j)}$$

and with the condition mentioned above

$$\frac{d}{d_o} = \sqrt{\frac{1+(\omega_a CR)^2}{1+(\omega_a\frac{CRZ}{R+Z})^2}} = 1.45 \qquad \text{(k)}$$

this leads to the capacity

$$C = \frac{1}{R\omega_a} \cdot q \qquad \text{(l)}$$

with $$q = \sqrt{\frac{(\frac{d}{d_o})^2 - 1}{1 - (\frac{d}{d_o})^2 \cdot (\frac{Z}{R+Z})^2}} \qquad (m)$$

Insertion of equ. (l) in (h) gives

$$\varphi'(\omega_p)\left[(R+Z)^2+q^2(\frac{\omega_p}{\omega_a})^2 \cdot \left[2(R+Z)Z+R^2\right]+(\frac{\omega_p}{\omega_a})^4 q^4 Z^2\right] - \frac{qR(R+Z)}{\omega_a} = 0 \qquad (n)$$

This equation for R can be solved graphically (see fig. III) for

$$\varphi'(\omega_p) = 1.175 \cdot 10^{-9} \; [s]$$

$$Z = 75 \; [\Omega]$$

$$\omega_a = 2\pi \cdot 15 \cdot 10^6 \; [s^{-1}]$$

$$\omega_p = 2\pi \cdot 30 \cdot 10^6 \; [s^{-1}]$$

$$\frac{d}{d_o} = 1.45$$

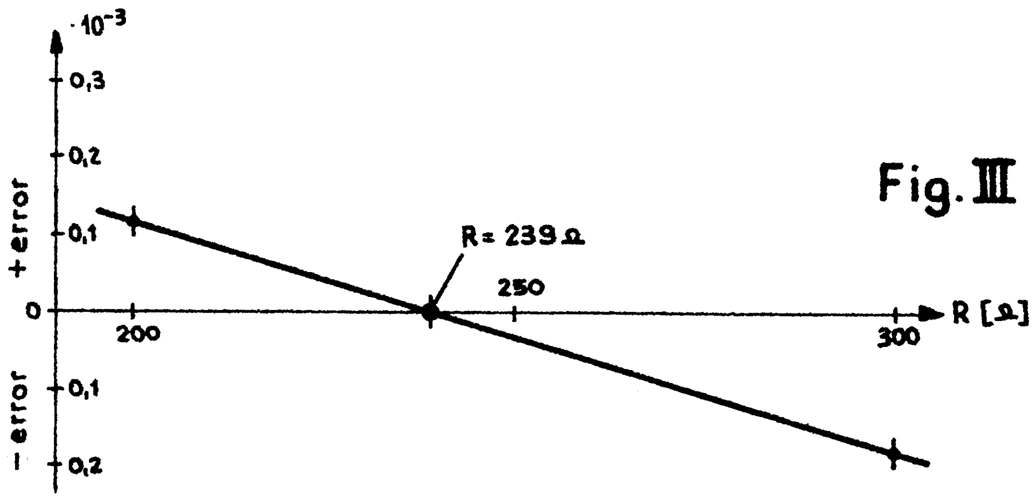


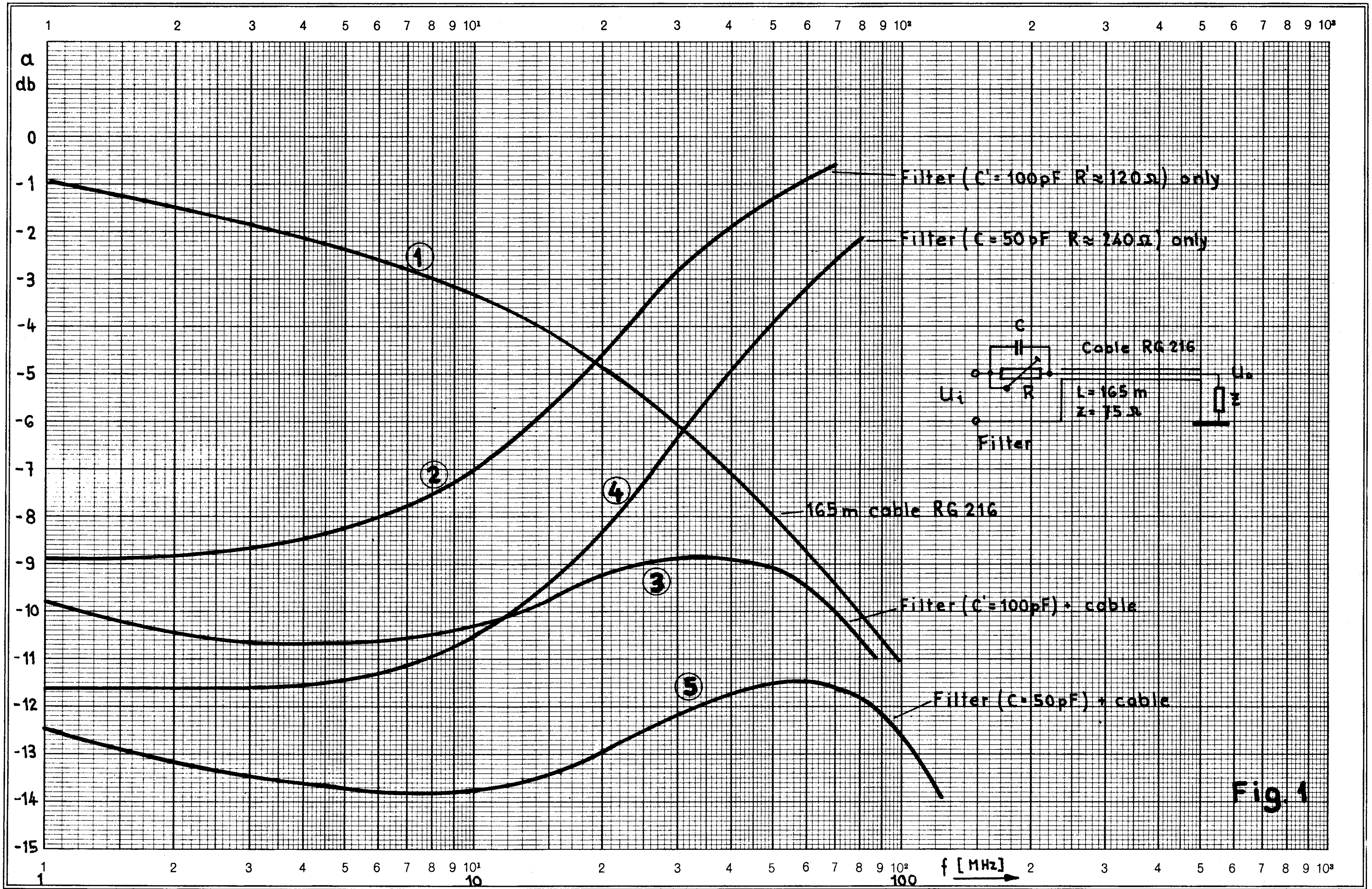
Fig. III

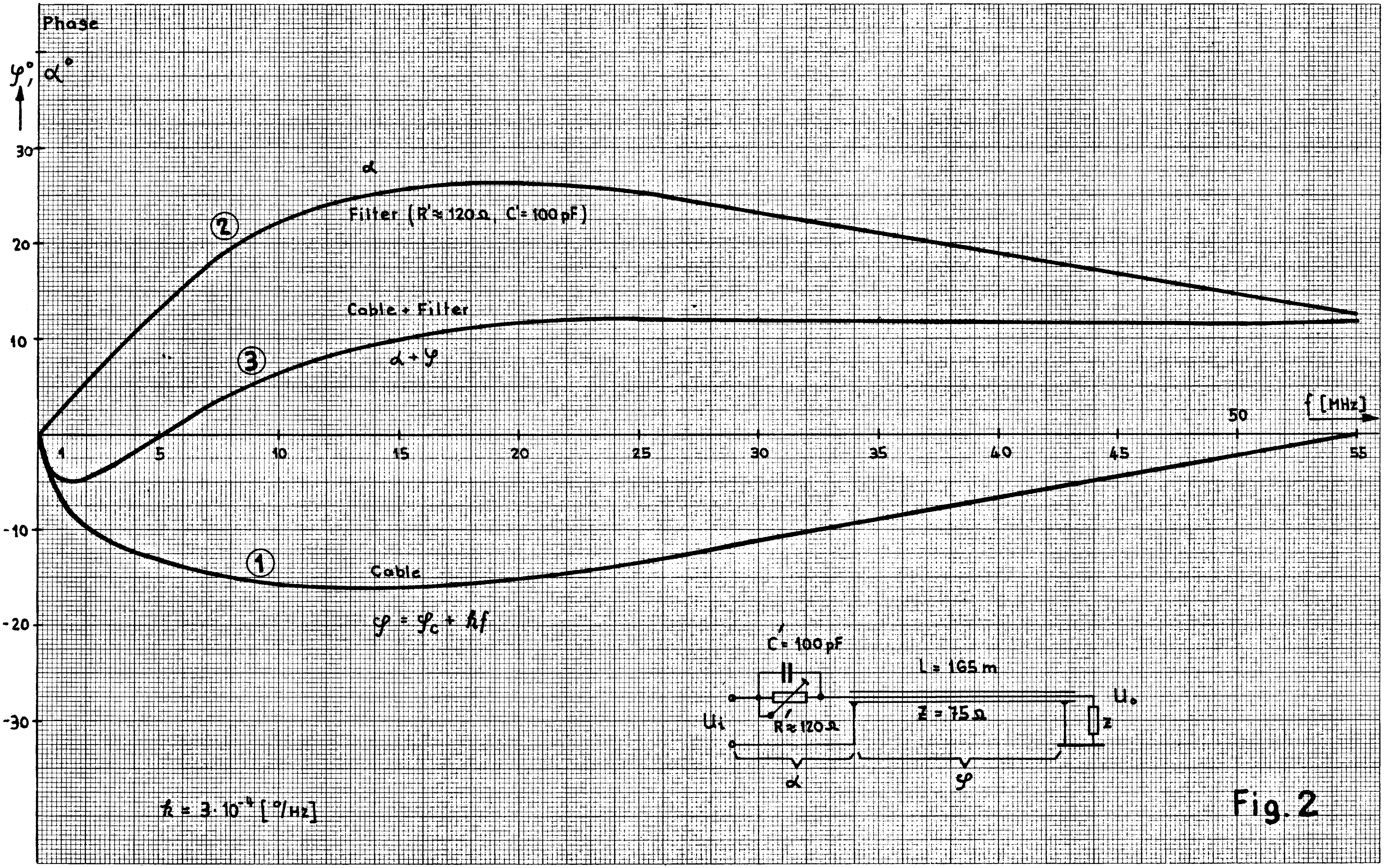
The solution is $\underline{R = 239 \; \Omega}$.

The capacity C from equ. (l) and (m)

$$C = \frac{1}{R\omega_a} \sqrt{\frac{(\frac{d}{d_o})^2 - 1}{1-(\frac{d}{d_o})^2(\frac{Z}{R+Z})^2}} = \frac{1}{239 \cdot 2\pi \cdot 15 \cdot 10^6} \sqrt{\frac{1.1}{1-2.1(\frac{75}{314})^2}}$$

$$\underline{\underline{C = 50 \text{ pF}}}$$


a
db
Filter (C' = 100 pF R' ≈ 120 Ω) only
Filter (C = 50 pF R ≈ 240 Ω) only
165 m cable RG 216
Filter (C' = 100 pF) + cable
Filter (C = 50 pF) + cable
C
Cable RG 216
R
U_i
U_o
L = 165 m
Z = 75 Ω
Filter
f [MHz]
Fig. 1

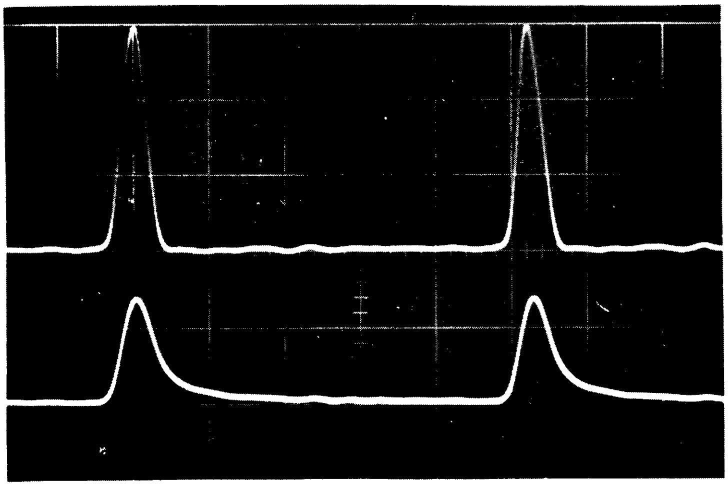


Phase
φ°, α°
30
20
10
-10
-20
-30
1
5
10
15
20
25
30
35
40
45
50
55
f [MHz]
α
Filter (R' ≈ 120 Ω, C' = 100 pF)
2
Cable + Filter
3
α + φ
1
Cable
φ = φc + kf
C' = 100 pF
L = 165 m
Ui
R' ≈ 120 Ω
Z = 75 Ω
Uo
z
α
φ
k = 3·10⁻⁴ [°/Hz]

Fig. 2

In- and Output Signals of

a) cable only (165 m RG 216)



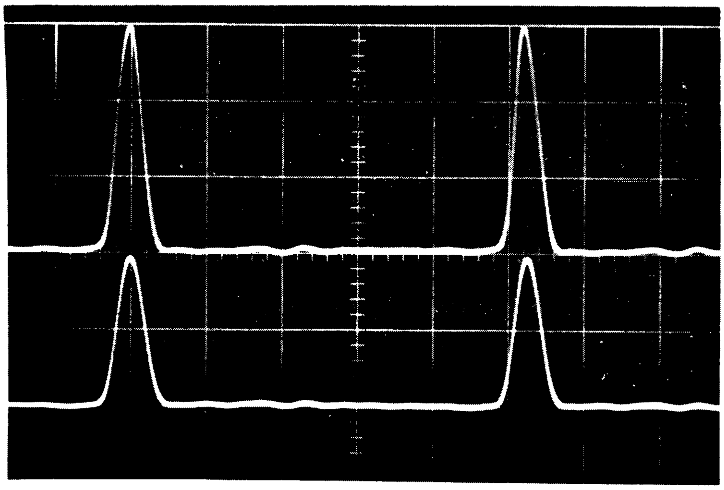
input signal
2 V/cm

output signal
2 V/cm

⟶ 20 ns/cm

Photo 1

b) filter plus cable



in
2 V/cm

out
1 V/cm

⟶ 20 ns/cm

Photo 2

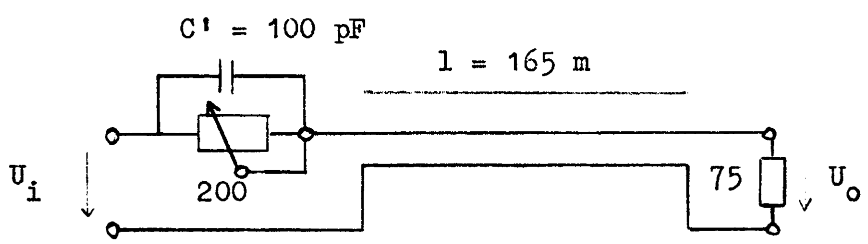


Fig. 3

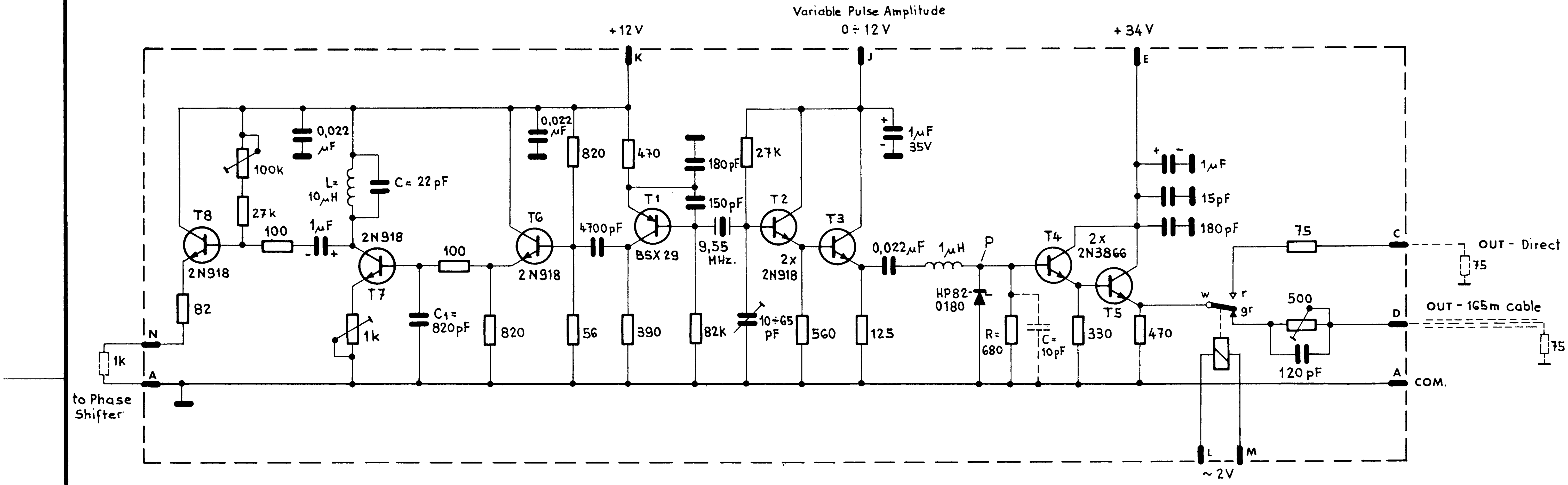
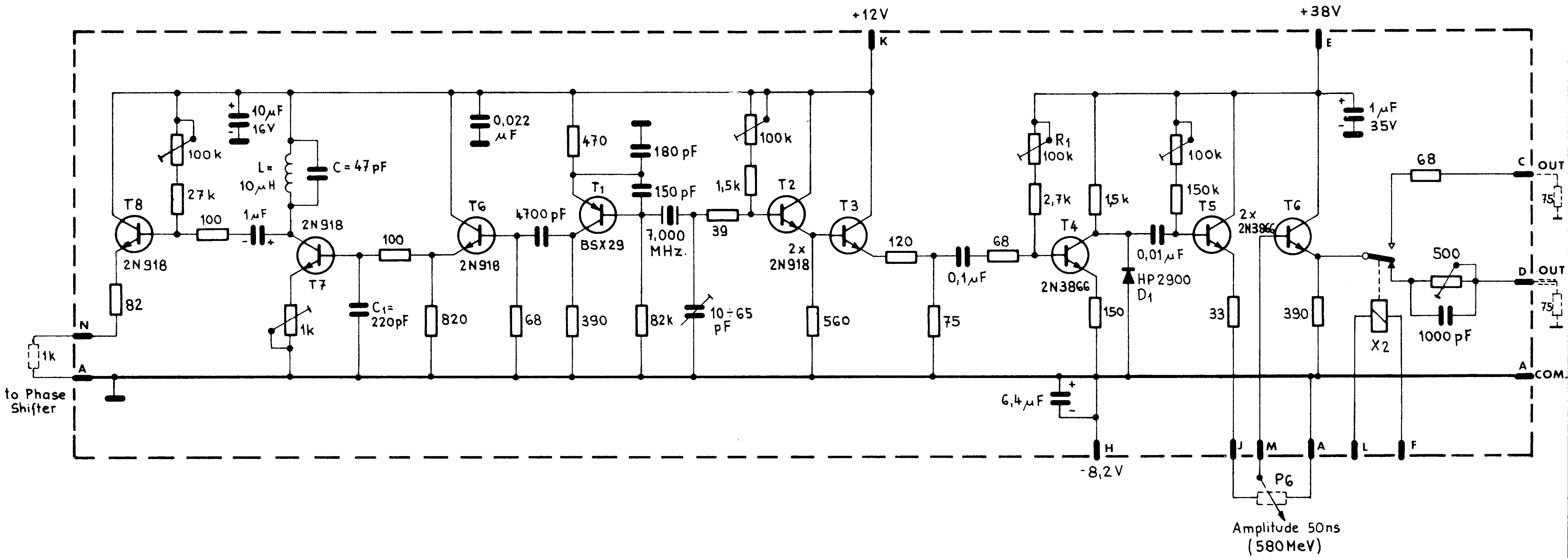


Fig. 4

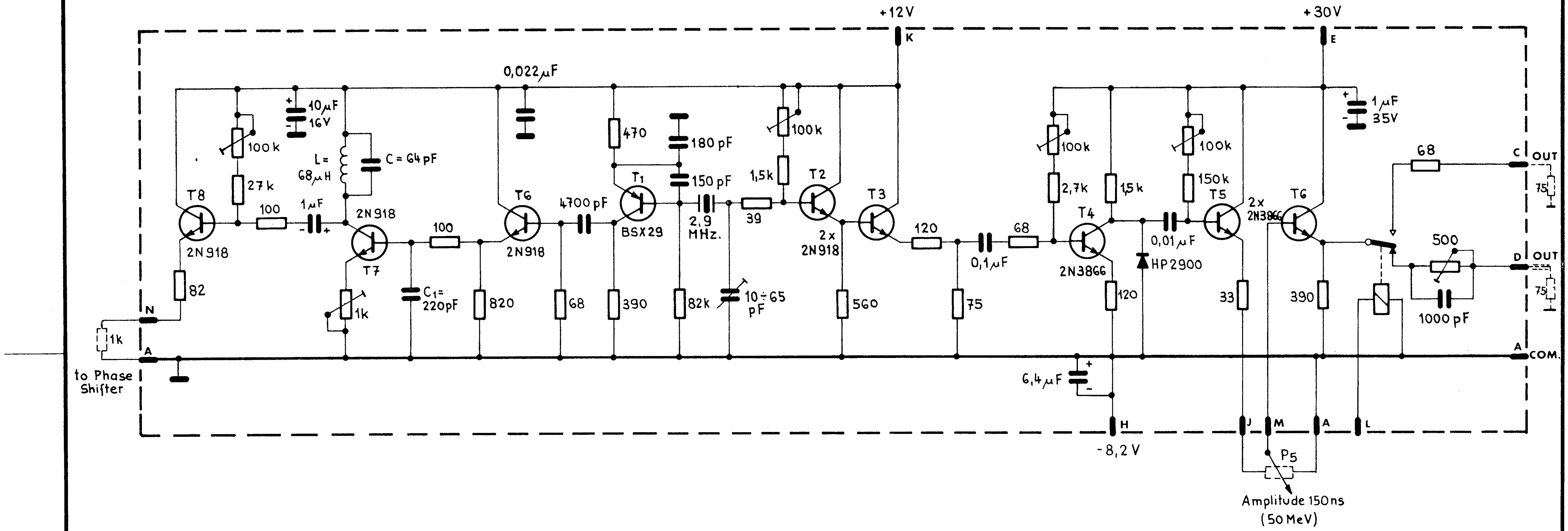
CERN	App P.U. SIGNAL SIMULATOR	DATE	2.5.69.
		SIGN	[signature]
MPS-RF	Title 15ns PULSE GENERATOR	2872-RF2-3	



C-OUT Direct
D-OUT 165 m. cable

Fig. 5

CERN	App. P.U. SIGNAL SIMULATOR	DATE	2.5.69.
		SIGN.	[signature]
MPS-RF	Title **50 ns PULSE GENERATOR**	**2872-RF3-3**	



C-OUT Direct
D-OUT 165 m. cable

Fig. 5a

CERN	App. P.U. SIGNAL SIMULATOR	DATE	2.5.69.
		SIGN.	
MPS-RF	Title **150 ns PULSE GENERATOR**	**2872-RF4-3**	

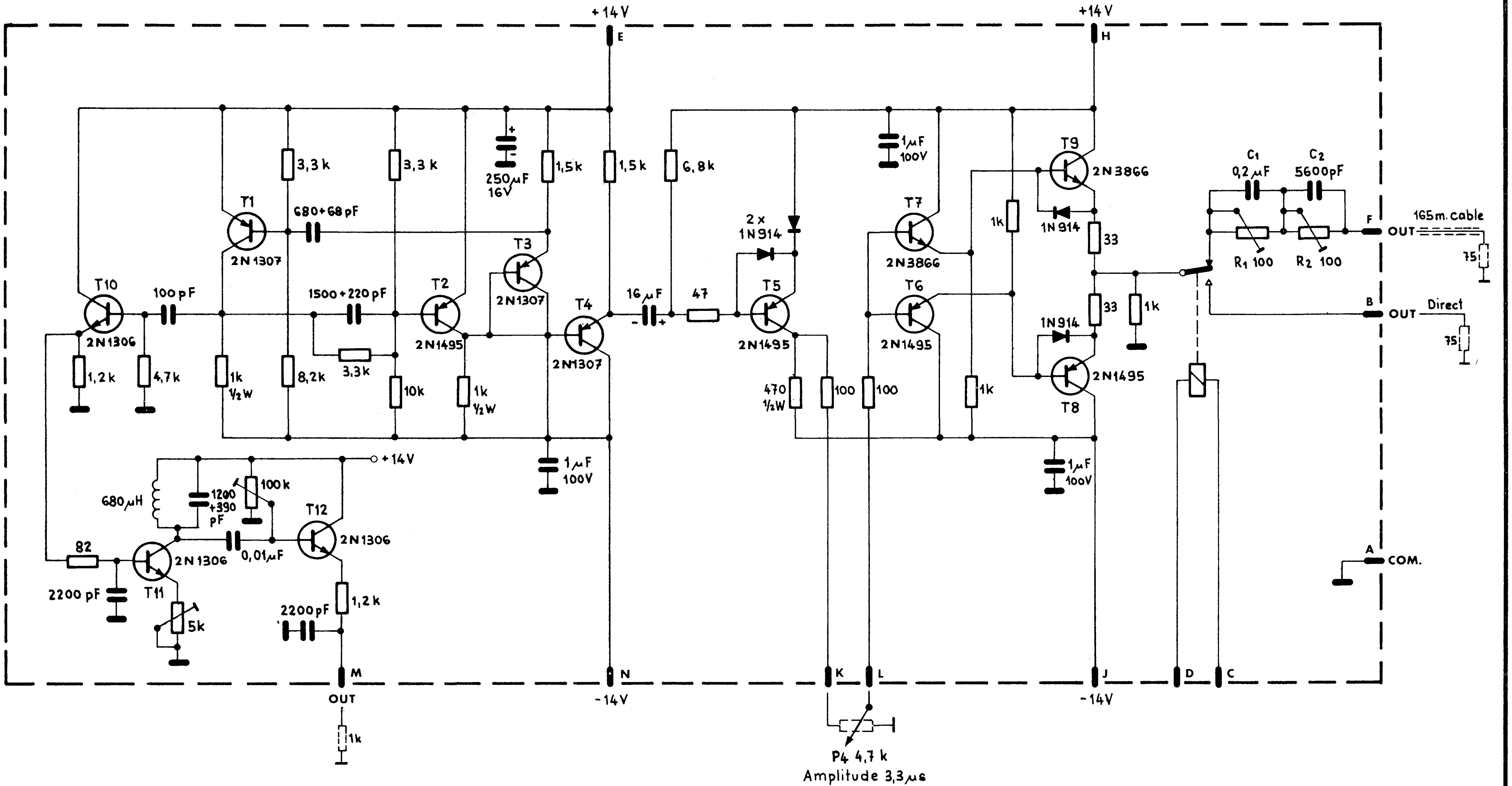


Fig. 6

CERN	App. P.U. SIGNAL SIMULATOR	DATE	2.5.69.
		SIGN.	[signature]
MPS-RF	Title 150 kHz MULTIVIBRATOR 3,3 μs	2872-RF5-3	

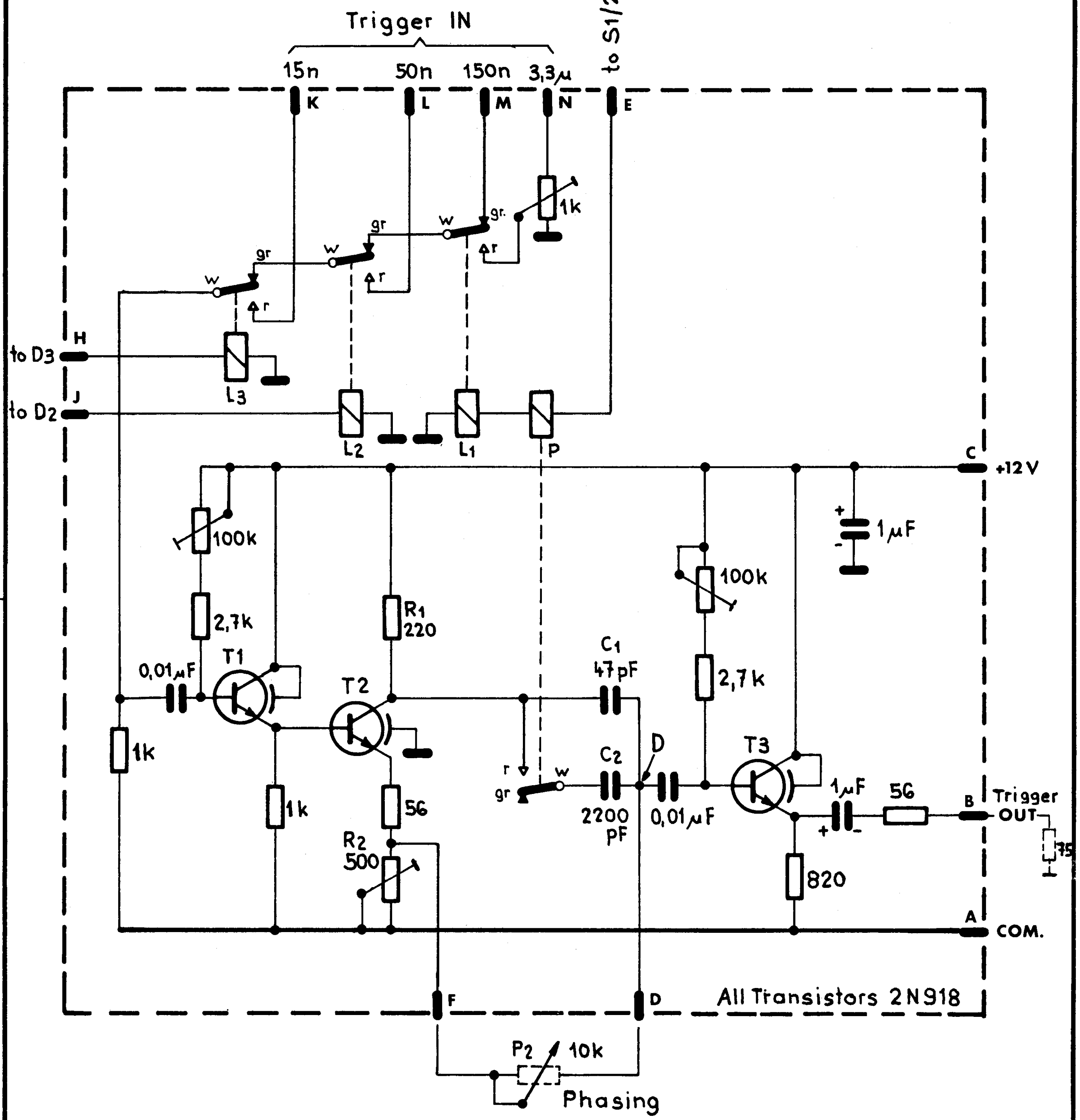


Fig. 7

CERN	App. P. U. SIGNAL SIMULATOR	DATE	28. 5. 69.
		SIGN.	
MPS-RF	Title **PHASE SHIFTER**	**2872-RF7-4**	

SIS/R/11000

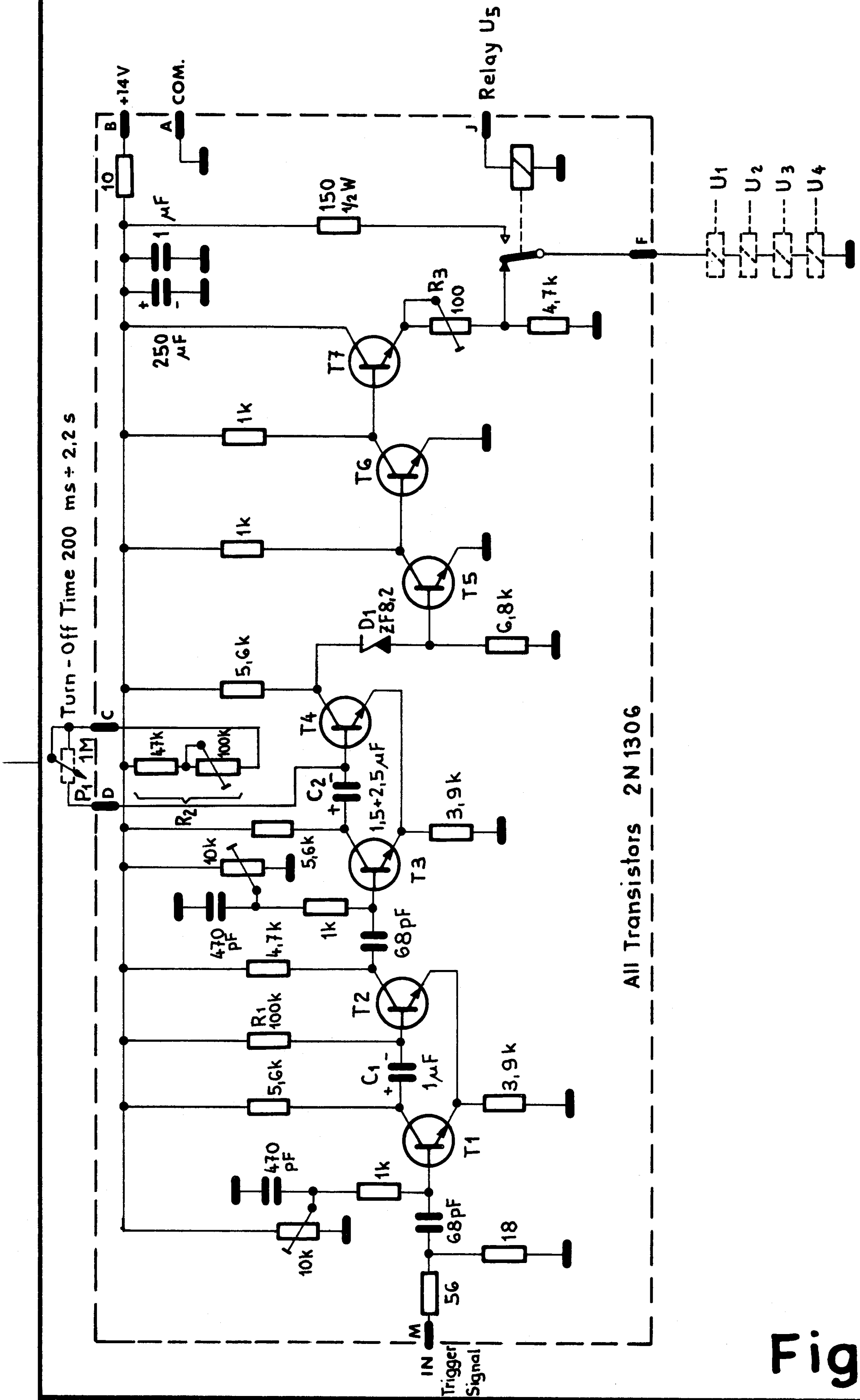


Fig. 8

CERN	App. **P.U. SIGNAL SIMULATOR**	DATE	28. 5. 69.
		SIGN.	[signature]
MPS–RF	Title **ONE SHOT**	**2872–RF6–4**	

SIS/R/11000

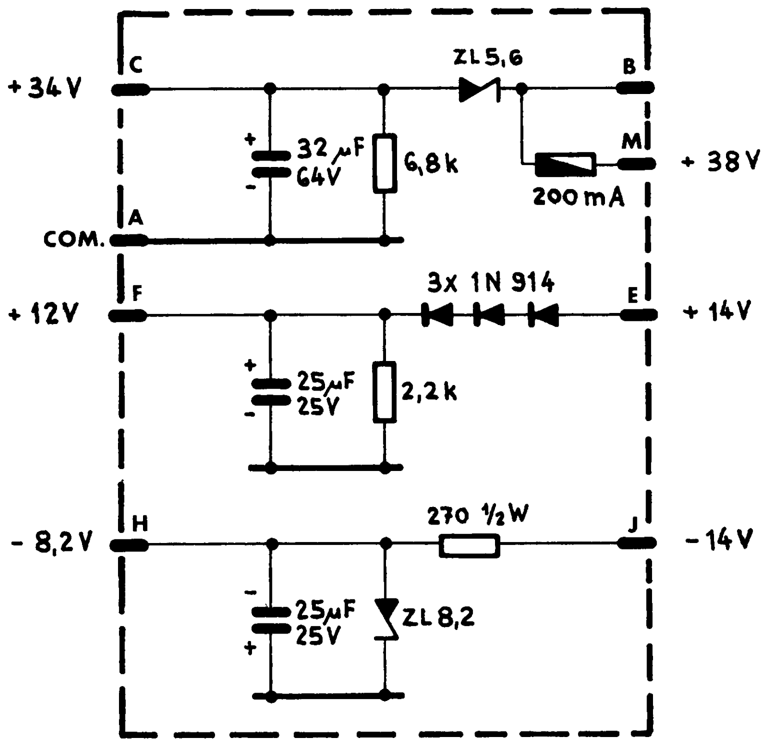
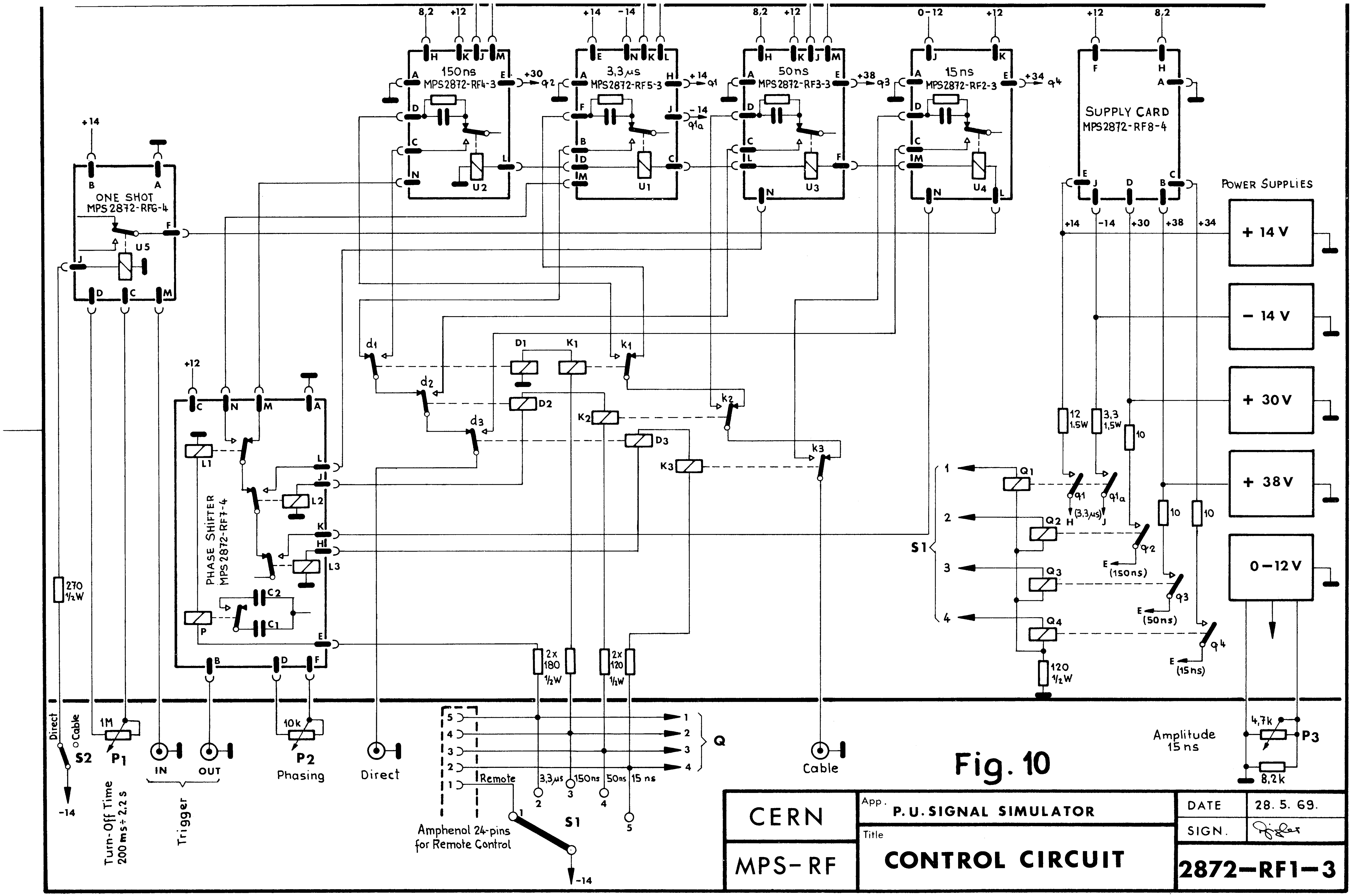


Fig. 9

CERN	App. P.U. SIGNAL SIMULATOR	DATE	28. 5. 69.
		SIGN.	
MPS-RF	Title SUPPLY CARD	2872-RF8-4	

SIS/R/11000

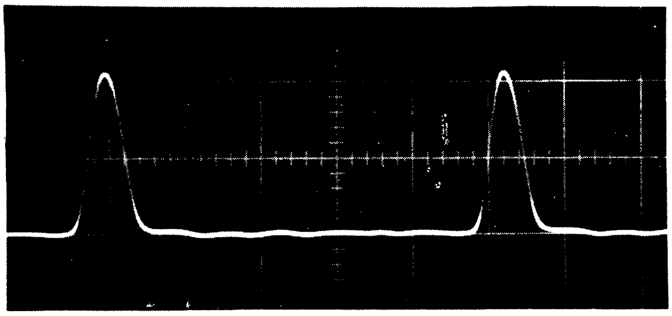


150ns
MPS2872-RF4-3
3,3 μs
MPS2872-RF5-3
50ns
MPS2872-RF3-3
15ns
MPS2872-RF2-3
SUPPLY CARD
MPS2872-RF8-4
ONE SHOT
MPS2872-RF6-4
PHASE SHIFTER
MPS2872-RF7-4
POWER SUPPLIES
+ 14 V
− 14 V
+ 30 V
+ 38 V
0 − 12 V
Direct
Cable
S2
P1
1M
Turn-Off Time
200 ms ÷ 2,2 s
IN
OUT
Trigger
10k
P2
Phasing
Direct
Amphenol 24-pins
for Remote Control
Remote
3,3 μs
150ns
50ns
15 ns
S1
Q
Cable
Amplitude
15 ns
4,7k
8,2k
P3
CERN
MPS-RF
App.
P.U. SIGNAL SIMULATOR
Title
CONTROL CIRCUIT
DATE
28. 5. 69.
SIGN.
2872-RF1-3

Fig. 10

Signals from the PU Signal-Simulator at the End of the 165 m Test Cable (RG 216)

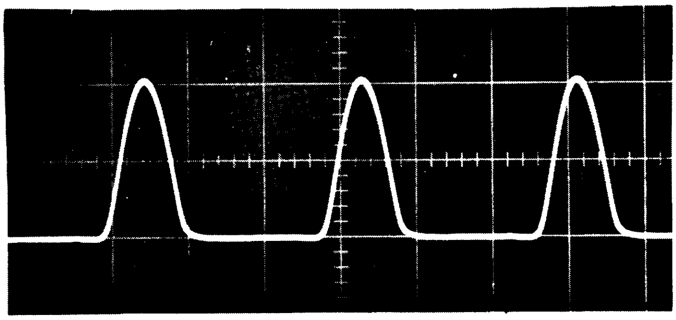
a) 15 ns/9.55 MHz pulse generator (28 GeV)



↑ 5 V/cm

⟶ 20 ns/cm

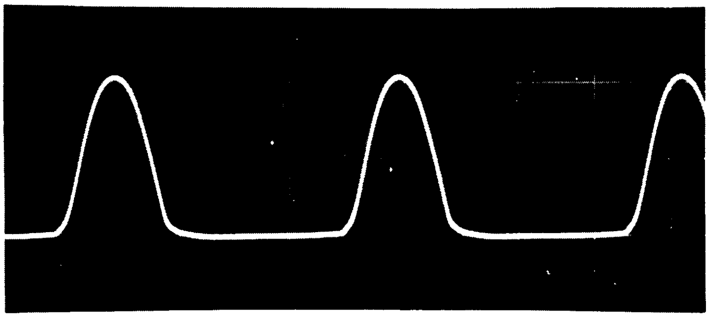
b) 50 ns/7 MHz pulse generator (580 MeV)



↑ 5 V/cm

⟶ 50 ns/cm

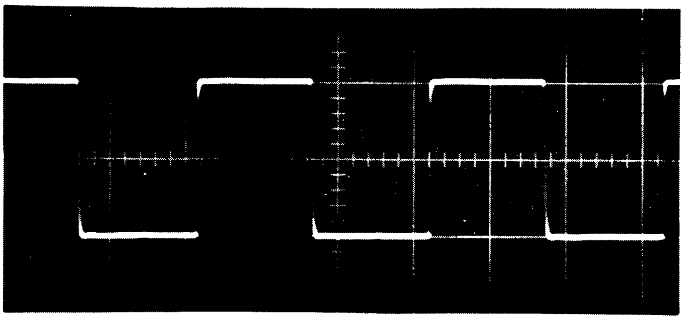
c) 150 ns/2.9 MHz pulse generator (50 MeV)



↑ 5 V/cm

⟶ 100 ns/cm

d) 3.3 µs/150 kHz pulse generator (50 MeV spiraling beam)



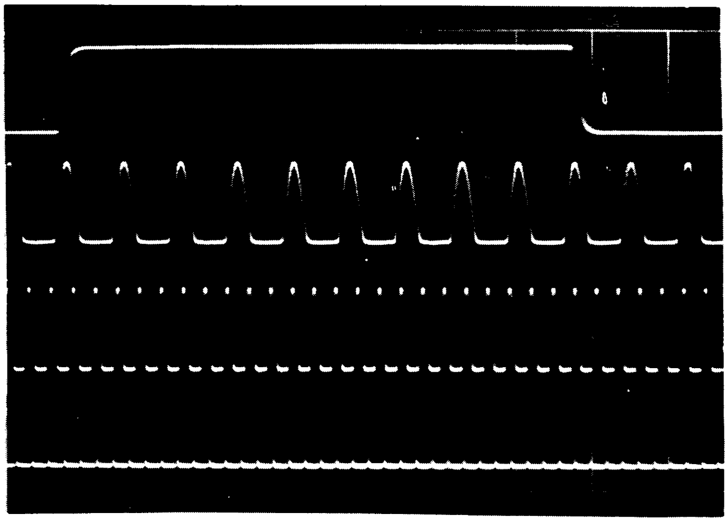
↑ 5 V/cm

⟶ 1 µs/cm

Fig. 11

Signals from the PU Signal Simulator

a) output "DIRECT" (without cable and filter)



b) output "CABLE" (with cable and filter)

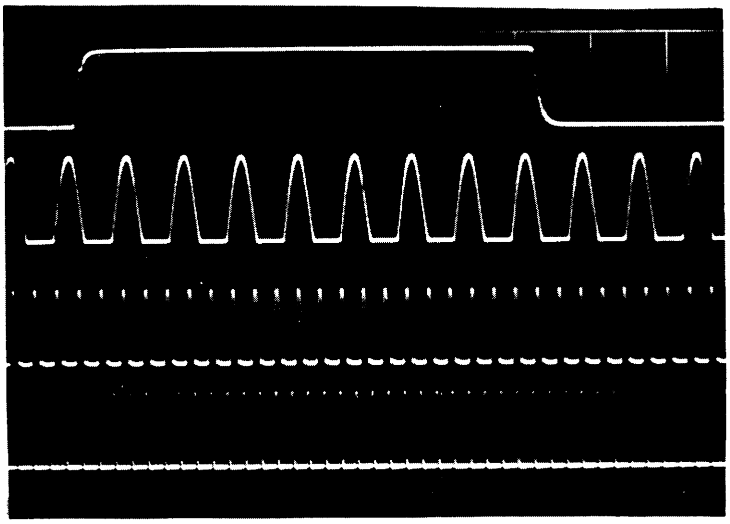


Fig. 12

Front Panel of the PU Signal-Simulator

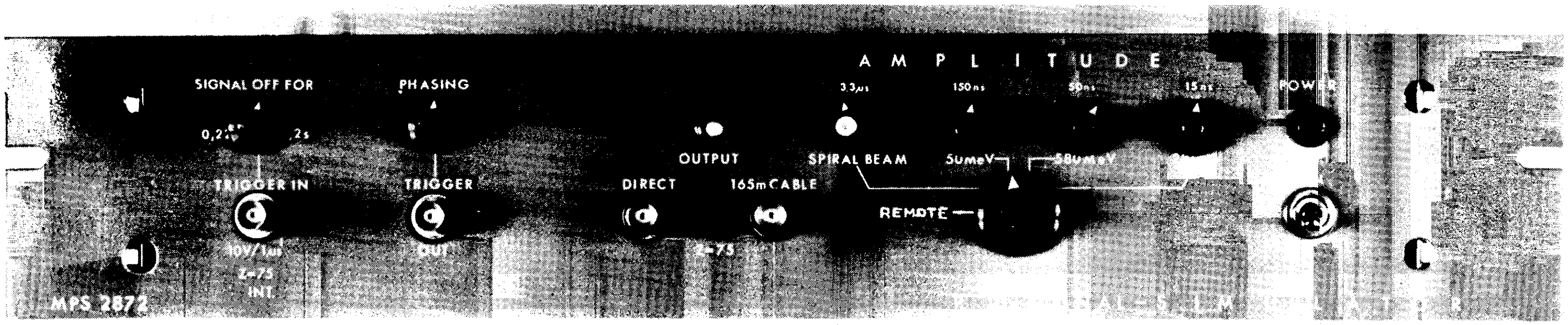


Fig. 13