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A BEAM TRANSFORMER SYSTEM FOR MEASURING FAST EJECTION EFFICIENCIES

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Several beam transformers, connected to a common electronic system, monitor the fast ejection efficiency in the Serpukhov proton synchrotron. Just before ejection, the intensity of each of the 30 circulating bunches is measured; during ejection the same is done for each ejected bunch and after ejection the intensity of the remaining circulating bunches is measured again. All signals are digitalized and go to a minicomputer.

INTRODUCTION

The fast ejection system for the Serpukhov 70 GeV proton synchrotron [1)] was made by CERN as part of the CERN/Serpukhov collaboration. Part of the system is a series of beam transformers for measuring intensities and ejection efficiencies.

At the time of installation, the beam intensity was typically about 10^{12} protons per cycle. The beam is divided in 30 bunches of about 20 ns length, in time, and spaced 165 ns apart. The bunch-form is approximately triangular.

The ejection system must eject single proton bunches, or sequential groups of bunches up to 30, using a magnetic deflecting field. For high efficiency, this field must rise and fall between the passage of two subsequent bunches. In addition to measuring overall efficiencies and intensities, it is therefore interesting, for clean operation, to know whether the first and the last bunches of a group are fully ejected and whether any loss occurs in the adjacent, not ejected, bunches. For this reason, the beam transformer system is made to measure and digitalize each bunch separately.

The fast ejection system can make 3 ejections per machine cycle, each time ejecting a different number of bunches in anyone of the three channels. The whole measurement cycle is then triggered 3 times in each accelerator cycle.

A large beam transformer (BT), mounted around an insulated section of the accelerator vacuum chamber, measures the accelerator bunch intensities. A small BT, mounted on each external beam channel, measures the ejected bunches. When more than one channel is in operation, a coaxial reed switch switches from one small BT to another, between ejection shots.

The 30-bunch intensities are measured before and after each shot in the accelerator and, during ejection, in the external beam channel. The 90 digitalized signals are fed to a minicomputer which calculates intensities and efficiencies for each bunch and overall.

The block-diagram of the system is shown on Figure 1. The signals from the transformers pass first through remote-controlled attenuators. The electronic switch connects the internal BT, except during ejection, when one of the external transformers is connected. Next, the base-line between bunches is accurately reset to zero. This circuit also drives a low-impedance line, to which 30 linear gates are connected, one for each bunch. The gates are controlled by a shift register. A start pulse injects a logical 1, which travels down the register and opens sequentially the gates. The bunch, transmitted through a gate, is processed in an analog-to-time converter (ATC).

The output of the transformer ATC is 30 pulses with a length proportional to the bunch intensities. These pulses are sent, together with a 3 MHz clock-pulse, to the computer interface where they are converted to proportional numbers. To prevent reflections in the distribution line, the whole system has to be very compact (see Photograph 1). The gates and the ATC's are simplified as much as possible.

THE BEAM TRANSFORMERS

These transformers must show the bunch structure of the beam. The beam is the primary winding of the transformers. The secondary winding consists of two parallel sections of 6 turns each. This winding is shielded electrostatically from the beam.

The transformer cores are made of thin tapes of "ULTRAPERM 10" (Vacuumschmelze, Germany), wound in toroidal shape and insulated by magnesium-oxide. The thinnest tape is used for the large BT, in order to make its magnetic characteristics approximately equal to those of the small BT's. A simple network is mounted in parallel with the transformers, to compensate the effect of the transmission cables. This network is calculated to obtain a flat base-line between bunches.

The large transformer is mounted around an insulated section of the vacuum chamber of the accelerator. A low-inductance path is provided around the transformer for the currents which circulate on the vacuum chamber. The small transformer is mounted between the exit window of the accelerator and the entrance window of the beam transport. The main parameters of the transformers are summarized in Table 1.

TABLE 1

	small transformer	large transformer
opening of core (mm)	75	205
opening of transformer (mm)	60	186
cross-section of core (mm^2)	18 x 45	20 x 45
thickness of tape (μm)	30	10
filling factor (%)	72	50
initial μ (minimum)	50000	50000
number of turns	6	6
minimum bandwidth (MHz)	50	50

THE ELECTRONIC SWITCH AND THE BASE-LINE RESET

The circuit diagram is shown on Figure 2. When the "SWITCH" input is low (0 V), transistor T1 is conducting and T2 is cut off. Transistor T3 delivers a constant current of 5 mA. When the voltage on the collector of T1 is higher than - 0.2 V (adjustable with P1), a current flows through T4 and T9 into capacitor C1 and this adjusts the bias current of T1 to 5 mA.

A negative input pulse passes through T1 and D9 into the distribution line. A slightly positive base-line, on the contrary, is brought back to the reference level of - 0.2 V with a time constant of about 50 ns. A too violent reaction to positive parasites is prevented by the current-limiting resistor R1.

When the "SWITCH" is high (+3 V), T2 is conducting and T1 is cut off. Diode D11 clamps the base voltage to a level safe for transistor T1.

THE GATE AND THE ATC

The circuit diagram is shown on Figure 3. The gate is normally blocked. A positive gate pulse, 165 ns wide, opens the gate to let the signal of one bunch through. The gate offset can be adjusted to zero by means of potentiometer P1.

The bunch signal is amplified by T4 and stretched by C1. T5 and T6 form a current amplifier with a high output impedance. Transistor T7 is normally conducting. The amplified bunch brings the voltage on C2 to a negative value, which blocks T7. Capacitor C2 charges again through P2 and T7 starts conducting again when the voltage on C2 exceeds 0.6 V. An output pulse is generated with a duration T_o proportional to the bunch charge. Potentiometer P2 adjusts the gain of the ATC.

The maximum range of the ATC is T_o = 85 μs, or 256 counts with a 3 MHz clockpulse. This corresponds approximately to a charge at the input of 4.10^{-10} C, with P2 set midrange. The offset, of the ATC and the baseline reset circuit together, is then 10±1 counts. This offset is corrected by the computer. The linearity of the system is about 1 %.

RESULTS AND DISCUSSION

At the high frequencies of the bunch wave-form, there are significant losses in the transformer, the cable correction network and the cable itself. These losses change with the bunch-width, making absolute calibration difficult. The transformer cores were designed to obtain equal loss in the large and the small transformers. On the test bench, however, the small transformers were found to have a loss 4 to 6 % higher than the large transformer, the exact value depending on the bunch-width. This error was corrected by the computer by adding 5 % to the reading of the external transformer.

The internal transformer was calibrated by comparing the sum of the measurement of the 30 bunches with the machine intensity. The two values continued to agree within ± 3 % over a period of several months. The full range sensitivity is about 2.5 10^{10} protons per bunch.

The beam loss was monitored independently with several sensitive ionization chambers. When these chambers detect no significant radiation, the fast ejection efficiency is supposed to be 100 %. In these cases, the transformer system measured efficiencies between 96 and 100 %. The differential frequency characteristics explain part of this error but also small ripples on the base-line contribute to the error, because they interfere with the accurate base-line resetting.

The system was also tested with success at CERN, where the bunches are spaced 105 ns apart. With closer spacing, the base-line reset circuit gets into difficulties because the base-line is not sufficiently flat with the long interconnecting cables.

REFERENCE

1) B. Kuiper, B. Langeseth, K.P. Myznikov: Proc. Intern. Confer. on High-En. Accel., Yerevan, 1969, Vol. 1, p. 549.

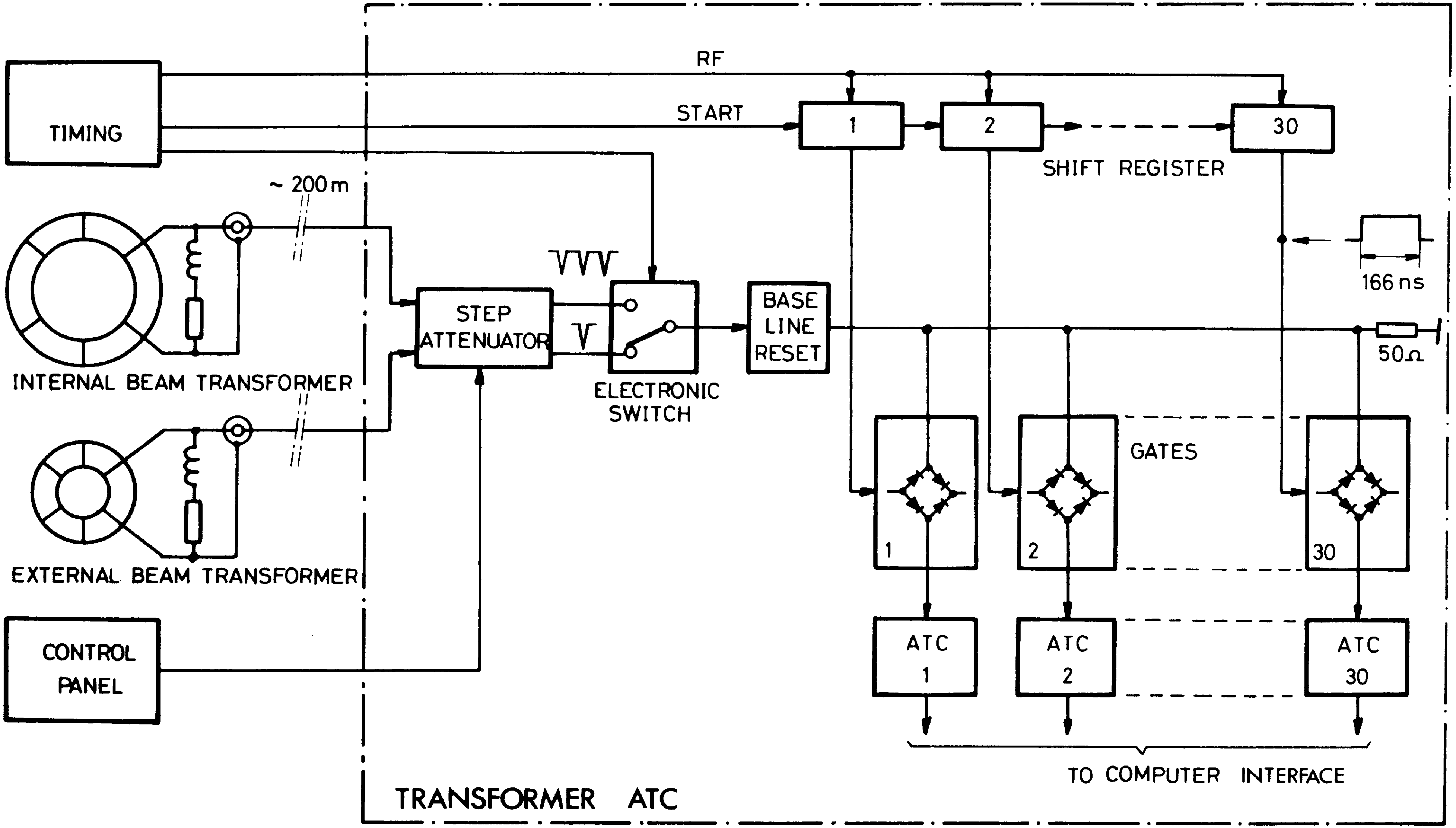

Fig. 1 Block diagram of the beam transformer system

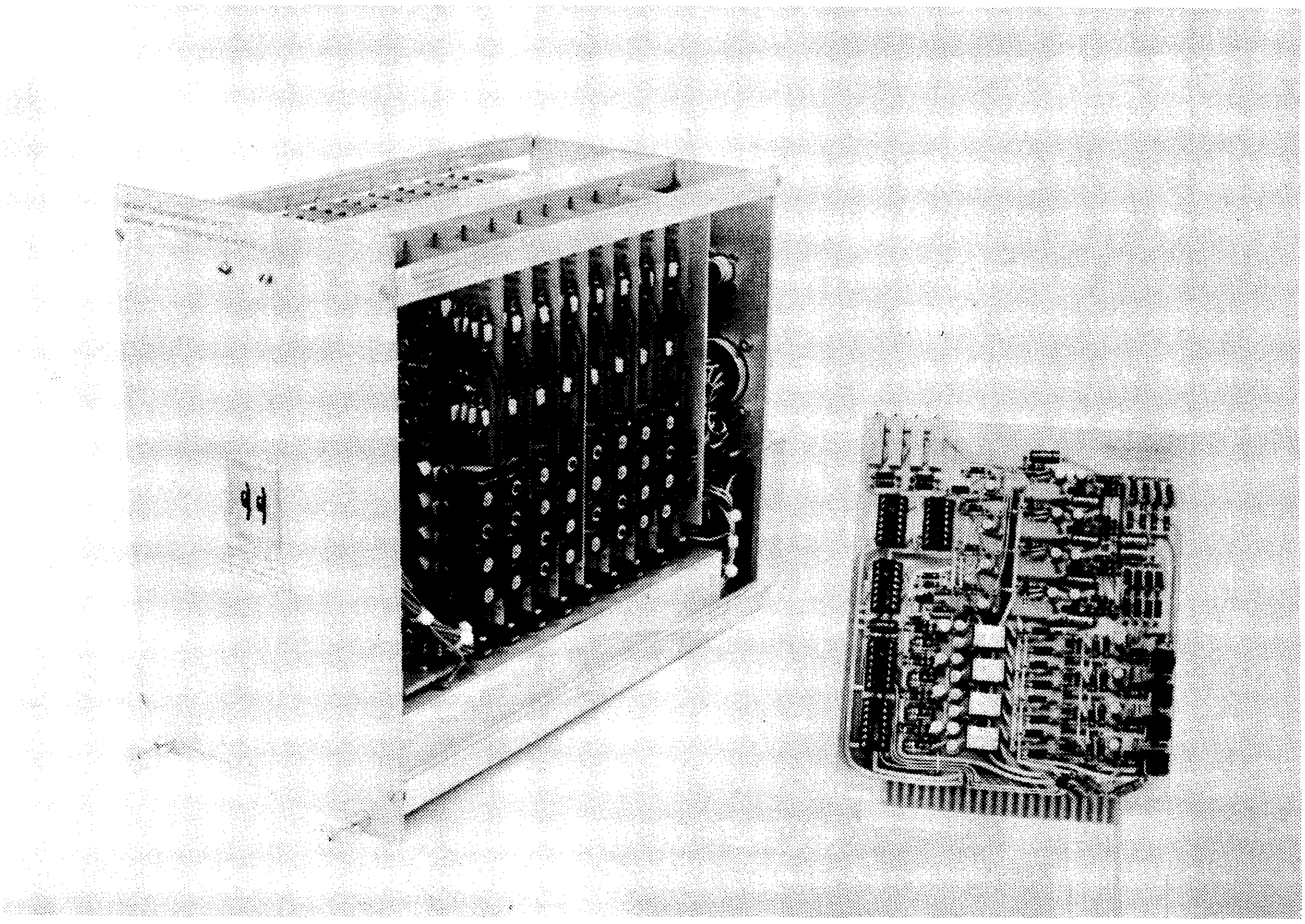

Photo 1 Beam transformer analog-to-time converter. On the right, one of the plug-in cards with 4 gates and 4 analog-to-time converters. The digiswitch on the front panel selects one of the 30 channels for display on a local readout.

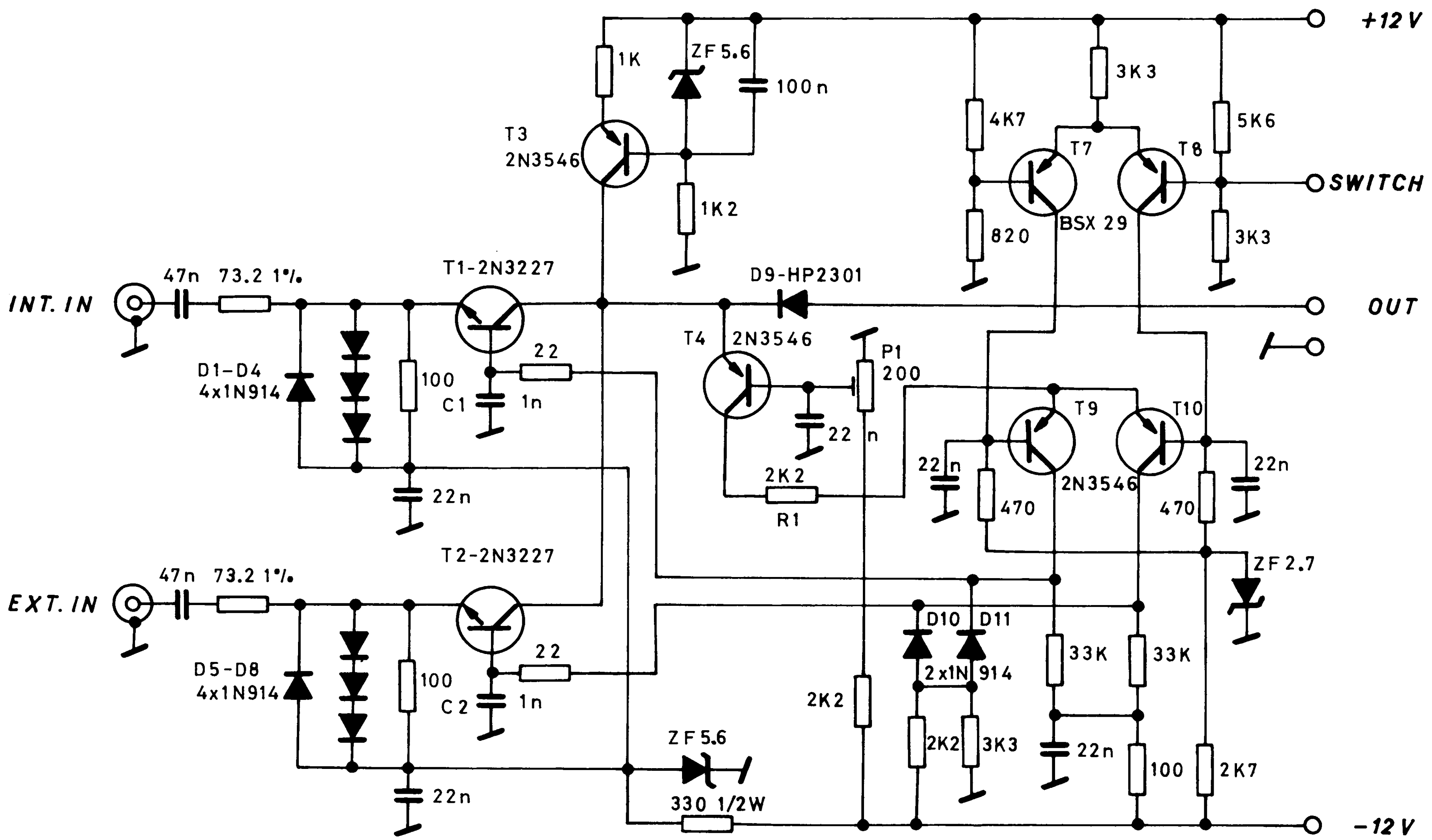

Fig. 2 The electronic switch and the base-line restorer.

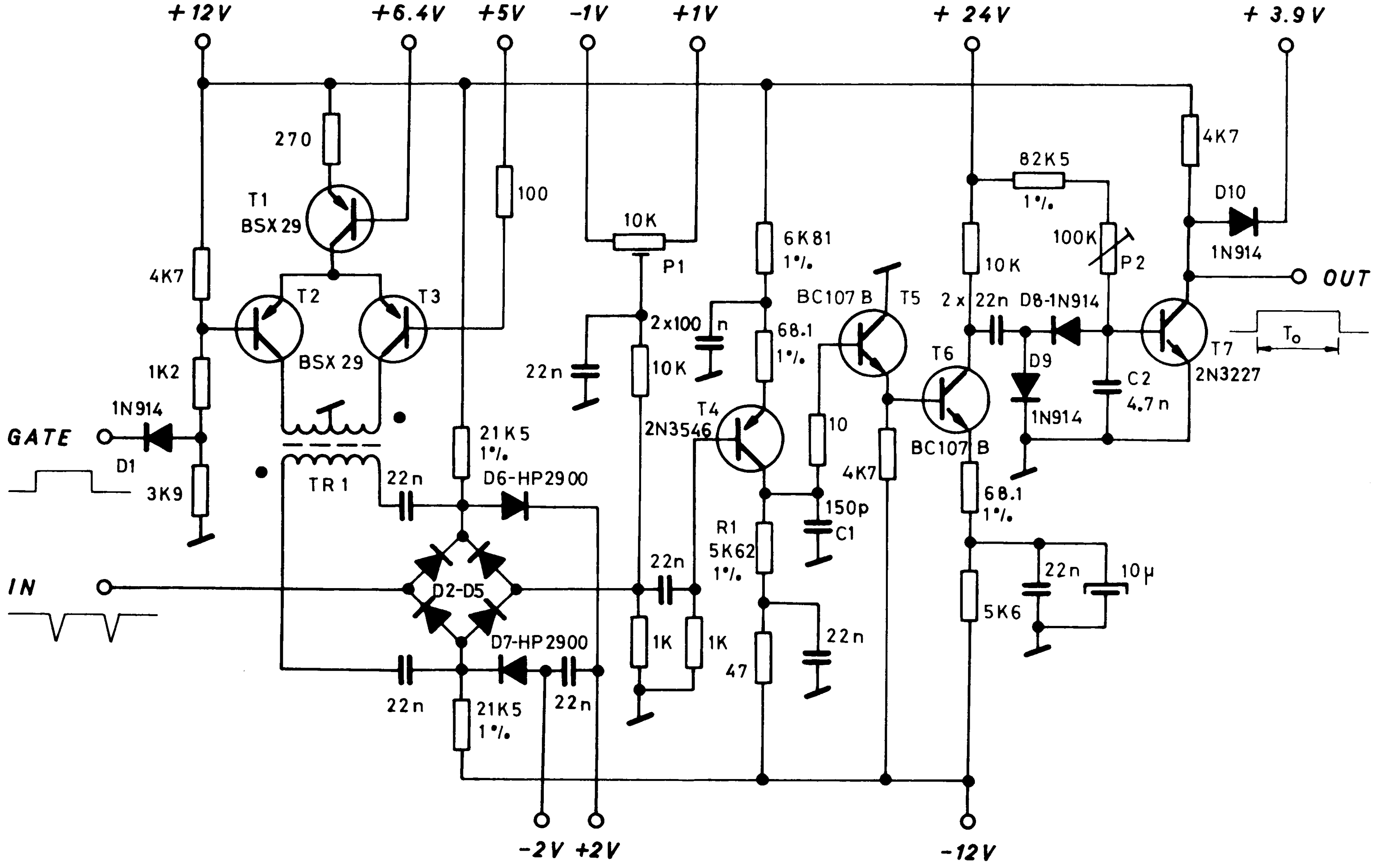

Fig. 3 The linear gate and the analog-to-time converter.