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either undiluted ethylene glycol or plain water. Note that the total attenuation for the chosen concentration is almost twice that for water. The power standing wave ratio, shown in the same figure, is a maximum for pure water and drops to a minimum for ethylene glycol. For the 70 percent–30 percent mixture the maximum standing wave ratio is 1.07 to 1.

The curve for attenuation as a function of position cannot be considered an accurate calibration. The amount of attenuation varies considerably with liquid temperature; the direction of the shift as well as its magnitude depend on the attenuator position.

An interesting property of the liquids used is that the temperature variation of attenuation for water is generally in the opposite direction from that for ethylene glycol. Thus for a particular setting of the attenuator it is possible to choose a concentration of the two liquids which will reduce the temperature coefficient to a very small value. This would obviously be desirable for a high power fixed attenuator or buffer.

In the experiment for which the attenuator was developed, we used auxiliary methods for accurate power level measurement, and did not depend on an accurate calibration of the attenuator. In general, however, with the liquid reservoir maintained at room temperature the attenuator was very reliable and the readings were repetitive. For most measurements a flow rate of 6 cc per sec. was used. Thus for 40 watts input the average temperature rise in the attenuator itself was only 2°C. While 40 watts was our maximum available r-f power there is every indication that 100 watts could be readily handled. By increasing the rate of liquid flow or the size of the attenuator one could increase this power capacity considerably.

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A Flexible High Voltage Square Wave Generator*

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Presented here is the design of a high voltage square wave generator suitable for modulating the absorption cell of a microwave spectrograph. Peak to peak voltages up to 1800 have been produced at 100 kc, feeding into an 800$\mu\mu$f capacitive load. The lower half of the cycle is kept automatically at ground potential and the adjustment of voltage from 0 to 1800 is controlled by a single variable.

THE instrument to be described was developed in response to a demand for a source of high voltage square wave modulation to be applied to a microwave absorption cell as described by Hughes and Wilson.[1]

Specifically, the instrument was required to supply a high (at least 1500V) amplitude square wave, automatically zero-based at all voltages, and amplitude-controlled with a single variable.

Modulation of the absorption cell reduces simply to charging and discharging a condenser at intervals appropriate to produce a square wave of voltage. Conventional amplifiers are unsuitable for the generation of the high voltages desired, and a switching technique similar to that employed in radar systems was devised.[2]

Inspection of Fig. 1 shows that alternately turning on T_1 and T_2 for short intervals will produce a square wave of voltage across the load condenser. Observe, however, that in charging the condenser, T_1 is acting essentially as a cathode follower while T_2 is simply a straight amplifier,[3] to use the term loosely. The result, with equal pulses on the switch tube grids, is an equi-

FIG. 1.

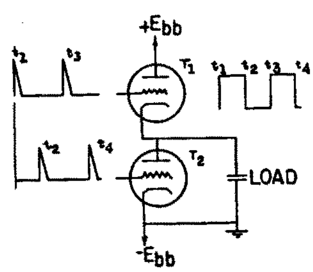
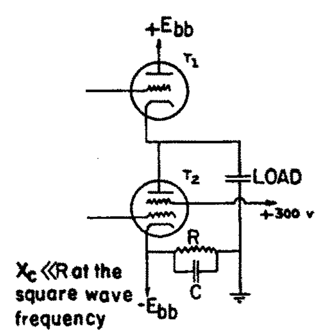


FIG. 2.



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** Now with Baird Associates, Inc., Cambridge, Massachusetts.
[1] D. Hughes and E. B. Wilson, Phys. Rev. 71, 562 (1947).

[2] M.I.T. Radar School Staff, *Principles of Radar*, pp 6–38, 6–39.
[3] Considerations of input admittance of the switch tube grids govern. See F. E. Terman, *Radio Engineering* (McGraw-Hill Book Company, Inc., New York, 1947) pp. 309, 365.

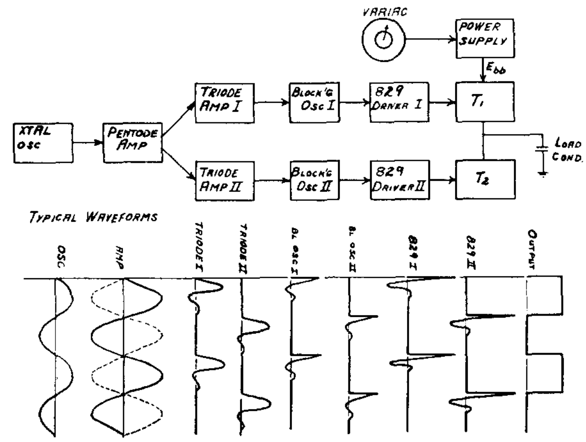

FIG. 3. Block diagram square wave generator.

librium with the bottom of the square wave well above the zero base. Using triode switch tubes, the limitations imposed by the requirements of automatic zero-basing and single dial control of amplitude eliminated, from a practical standpoint, the possibilities of (1) varying the amplitude and duration of the grid pulses so as to return the square wave to zero, or (2) floating the cathode of T_2 below ground sufficiently to produce the desired results.

Substitution of a tetrode for T_2 in Fig. 1 resulted in a significant improvement of the zero-seeking characteristic of the square wave. However, at low values of E_{bb}, the square wave base still drifted considerably above zero. This difficulty was eliminated by (1) tying the screen grid of T_2 to a fixed potential of 300 volts in order to sustain conduction by T_2 at low square wave amplitudes, and (2) reducing the drive to the grid of T_1 by reducing the screen potential on the driver tube for all values of E_{bb} less than 300 volts. Also, as E_{bb} was increased above 300 volts, a progressive drift of the square-wave base to a maximum of 20 volts was considered excessive. This drift resulted from the inability of T_2 to discharge the load condenser completely, regardless of the amplitude of the drive pulse. The use of a tetrode for T_2, however, makes it possible to develop sufficient automatic (negative) bias for the cathode of T_2 to give zero-basing within plus or minus 0.5 volts at all square wave voltages (see Fig. 2).

Figure 3 is a block diagram of the complete unit. Excepting the switch tube circuits, the design is conventional and none of the circuits is critical of adjustment. A crystal oscillator is used as the frequency-stabilizing element, followed by a pentode amplifier tuned to the crystal frequency. The push-pull triodes following the amplifier generate the out-of-phase pulses for synchronization of the blocking oscillators.[4] The precise triggering of the blocking oscillators, alternately every half-cycle, is essential to the stable timing of the rise and fall of the square wave, while the rapid response of the blocking oscillators to triggering is the key to obtaining sufficient drive for the switch tubes.

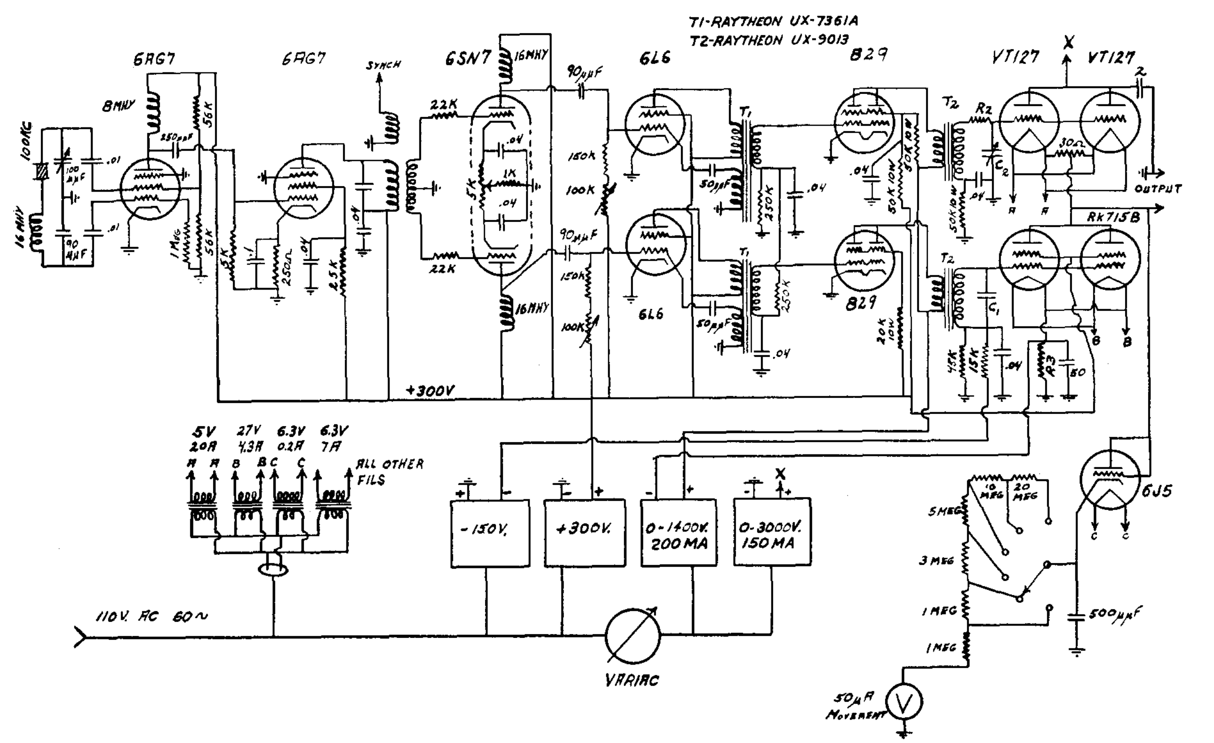

FIG. 4. Square wave generator. Condensers in μf unless otherwise noted; resistors in k = 1000 ohms; power supplies are conventional.

[4] H. J. Reich, *Theory and Application of Vacuum Tubes* (McGraw-Hill Book Company, Inc., New York, 1944), p. 395.

The sharp pulses out of the blocking oscillators are applied to the grids of the 829's (normally cut off). The sudden conduction of the 829's produces a very large voltage across the secondaries of the coupling transformers which triggers the switch tubes. E_{bb} is the variable which controls the amplitude of the square wave. The complete circuit diagram is shown in Fig. 4.

Design features which are important include a very low capacity (secondary winding to primary and ground) transformer for the filament of T_1, and critical adjustment for optimum wave shape of C_1, C_2 and R_2, in the switch tube grid circuits. The fixed and grid-leak components of the bias for T_1 must be adjusted to yield optimum wave shape at both high and near-zero values of square wave voltage, and R_3 must be adjusted for zero-basing.

The transformer driving the VT 127's is overloaded at high voltages. A conventional radar pulse transformer was stripped, rewound, (18 turns No. 14 wire on primary and 42 turns No. 20 wire on secondary) and was found to perform satisfactorily.

Results have justified the efforts in developing this instrument. R_2 and C_2 are adjusted, at maximum square wave voltage (1800 v), to limit the positive overshoot of the voltage rise to 20 volts and C_1 is adjusted to limit the negative overshoot of the voltage fall to 20 volts. With these damping conditions, the square wave rise and fall times are less than 0.2 microseconds at all square wave voltages while the time of the overshoots are less than 0.2 microseconds at maximum square wave voltage so that the top and bottom of the wave are essentially flat.

Currently in use is one unit as shown in Fig. 4, yielding 1800 volts of square wave across a Stark guide of 800 $\mu\mu$f capacity. Also, two smaller units produce 800 volts of square wave while meeting the original requirements. The smaller units use a single 811 in place of the parallel VT-127's, one RK-715B instead of two, and a single 1500 volt power supply for both the 829's and the switch tubes. Otherwise, circuits and construction are identical with the larger unit.

The upper frequency limit of the generators, consistent with good wave shape, appears to be in the region of 500 kc, while those in use and for which the values are specified operate at 100 kc. For frequencies below 100 kc, it is proposed to use a 100-kc crystal oscillator as the control element, dividing by blocking oscillators to twice the square wave frequency, and using an Eccles-Jordan[5] trigger circuit to obtain out-of-phase triggering of the blocking oscillators driving the 829's.[6]

[5] See reference 4, p. 353.
[6] In practice, type 3E29 tubes were used.

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Photo-Tube Input Impedance for a Voltage Stabilizer

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A circuit for stabilizing the voltage of an electrostatic generator is described. A photo-tube under constant illumination is used as an input impedance, eliminating the necessity for d.c. amplification of the error signal. This signal is impressed directly on the control grid of a 5693 pentode that is used to control corona-leakage current to the high voltage terminal of the generator. Convenience of operation and simplicity of construction are features of the circuit.

DURING the course of some recent efforts to improve the circuit used to stabilize the voltage of the open-air electrostatic accelerator at the M. I. T. High Voltage Laboratory, it occurred to the authors that a photo-tube under constant illumination might serve as an advantageous substitute for an input resistor in the first stage. Such a circuit has been constructed and has been in constant use for approximately three months. It has proved to be reliable and convenient in operation and is of very simple construction. Since the employment of a photo-tube in this fashion is not common, but nevertheless presents the possibility of numerous uses, it seems appropriate to give a brief description of its characteristics as applied to a voltage stabilizer.

Figure 1 is a schematic diagram of the circuit. The generator control features are similar to those described previously in the literature.[1] The positive-ion beam from the generator is deflected in the field of a large electromagnet and caused to pass between the jaws of a defining slit. Error signals set up by the beam current spilling onto the slit jaws are amplified and used to control a variable corona load facing the high voltage terminal of the generator. This control is accomplished by varying the potential of the control grid of a 5693 pentode, the plate of which is connected directly to a set of insulated corona needles facing the high voltage

[1] R. M. Ashby and A. O. Hanson, Rev. Sci. Inst. **13**, 128 (1942); A. O. Hanson, Rev. Sci. Inst. **15**, 57 (1944); McKibben, Frisch, and Hush, AEC Technical Information Division, Document MDDC 222 (1946).