NBSIR 78-880

UHF IMPULSE GENERATOR

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Boulder, Colorado 80303

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary

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Jordan J. Baruch, Assistant Secretary for Science and Technology

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UHF IMPULSE GENERATOR

James R. Andrews and Eugene E. Baldwin

This UHF Impulse Generator generates a narrow impulse with a flat spectrum up to 1 GHz. The impulse amplitude is 55 volts and the duration is 365 ps. The maximum repetition rate is 1 MHz. This report describes the generator in detail and includes a complete parts list and printed circuit artwork.

Key Words: Avalanche transistor; impulse; impulse generator; pulse generator; spectrum; spectrum amplitude.

I. INTRODUCTION

The NBS UHF Impulse Generator (IG), figure 1, generates a narrow impulse with a flat spectrum up to 1 GHz. The complete specifications are listed in the next section. The major features are a +55 V, 365 ps impulse and a 1 MHz repetition rate. It was originally designed by the Signal Waveform Metrology Group for the NBS EM Sensing Metrology Group in its time domain testing program for locating buried objects. Additional units have also been built for the EMI-Radiation Hazards Group for use with its TEM cells and for the Signal Waveform Metrology Group's time domain antenna range. This report describes the circuit in detail and gives a complete parts list and a mechanical layout.

Figure 1. NBS UHF Impulse Generator.

II. SPECIFICATIONS

Table 1. Specifications

Impulse Output	
Amplitude	55 V, ±10%, into 50 Ω
Polarity	Positive
Baseline	0 V
Duration (50%)	365 ps, ±10%
Source Impedance	50 Ω, nominal
Spectrum Amplitude, S(f)	90.5, ±2 dBμV/MHz
Spectrum Ripple	±1.0 dB
Frequency Range for S(f) Spectrum	100 MHz to 900 MHz
Repetition Rate, Trigger and Timing	
Internal Repetition Rate	10 Hz to 1 MHz in 5 ranges
Repetition Rate Vernier	0.1 to 1 range
Ext. Sync. Input:	
Frequency	DC to 1 MHz, frequencies in excess of 1 MHz will be internally limited to approximately 1 MHz maximum.
Pulse Required	Standard TTL pulse 0 V < "0" < 0.8 V 2 V < "1" < 5 V
Polarity	Trigger occurs on positive going transition
Input Loading	330 Ω
Trigger Output Pulse:	
Amplitude	0.5 V into 50 Ω
Polarity	Positive
Baseline	0 V
Transition Time (10%-90%)	2 ns nominal
Duration (50%)	80 ns
Timing	Leading edge of trigger pulse is 80 ns in advance of impulse output.
Jitter	∿ 20 ps nominal jitter in the delay between the trigger output pulse and the impulse output
General	
Supply Voltage	117 V, ±10%, 60 Hz
Size	21 cm x 17 cm x 28 cm

III. OPERATION

The operation of the NBS UHF Impulse Generator (IG) is quite straightforward. There are only three controls, figure 1; namely, the power switch, the repetition rate range switch, and the repetition rate vernier. Two signal outputs, impulse and trigger, are provided along with an external sync. input.

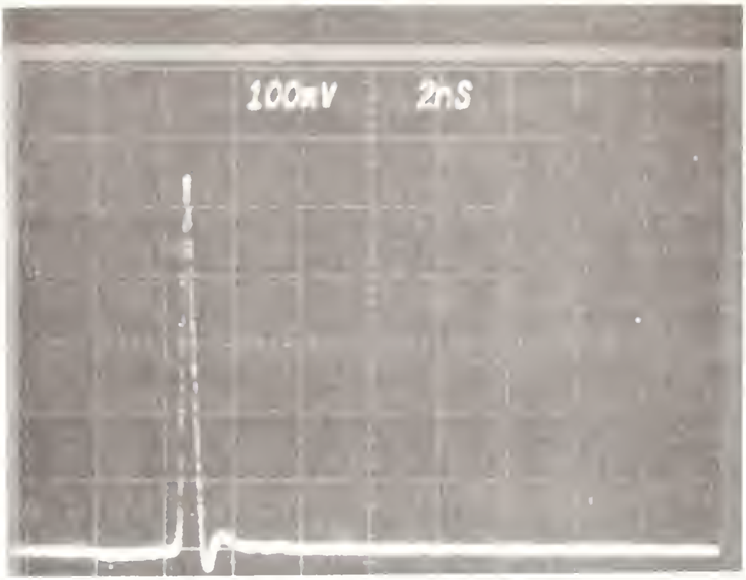
A typical impulse waveform and spectrum for the NBS UHF Impulse Generator are shown in figures 2 and 3. For time domain applications and for verifying the impulse waveform, the auxiliary trigger pulse output is used. This is a positive going 0.5 V pulse that is 80 ns in advance of the impulse. This pulse can be used for triggering a sampling oscilloscope or other instrumentation.

The NBS UHF IG's are calibrated by measuring the impulse voltage waveform delivered to a 50 Ω load connected to the impulse output connector on the front panel. The spectrum amplitude, S(f), at the output is then computed from the waveform using the Fourier transform [1,2]. S(f) can be determined by consulting the calibration report for the particular instrument. For frequencies not included in the calibration report, it is normally acceptable to extrapolate from the nearest calibration frequencies.

The IG can also be used for the calibration of a Field Intensity Meter (FIM). The IG's impulse output is simply connected to the FIM's antenna input. For some FIM's it may be necessary to insert a wideband coaxial attenuator to avoid overloading or destroying the FIM. For FIM's with a preselector-tuned circuit before the first active element (transistor, diode, etc.), an attenuator will probably not be necessary. However, some FIM's use a wideband preamplifier, and some spectrum analyzers have no input preselection but apply the input signal straight to the first mixer. In these cases it is usually necessary to use an attenuator. A preselector filter between the generator and the FIM is also sometimes useful for limiting the peak voltage applied to the FIM. When an external preselector filter is used, it should have padding attenuators on each side. The amount of attenuation required is dependent upon the filter characteristics.

When all connections are made, the power switch is then turned on, and the repetition rate control is set to the desired repetiion rate. The maximum repetition rate is determined by the bandwidth, BW, of the FIM being calibrated,

$$PRR(max) \leq BW/5.$$



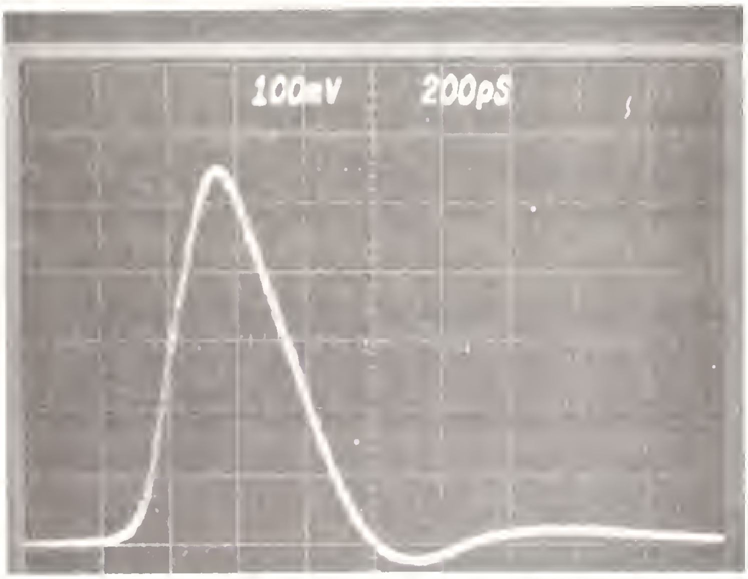


Figure 2. Typical waveform of an NBS UHF Impulse Generator. Vert: 10 v/div.; Horiz.: 2 ns/div. (top) and 200 ps/div. (bottom).

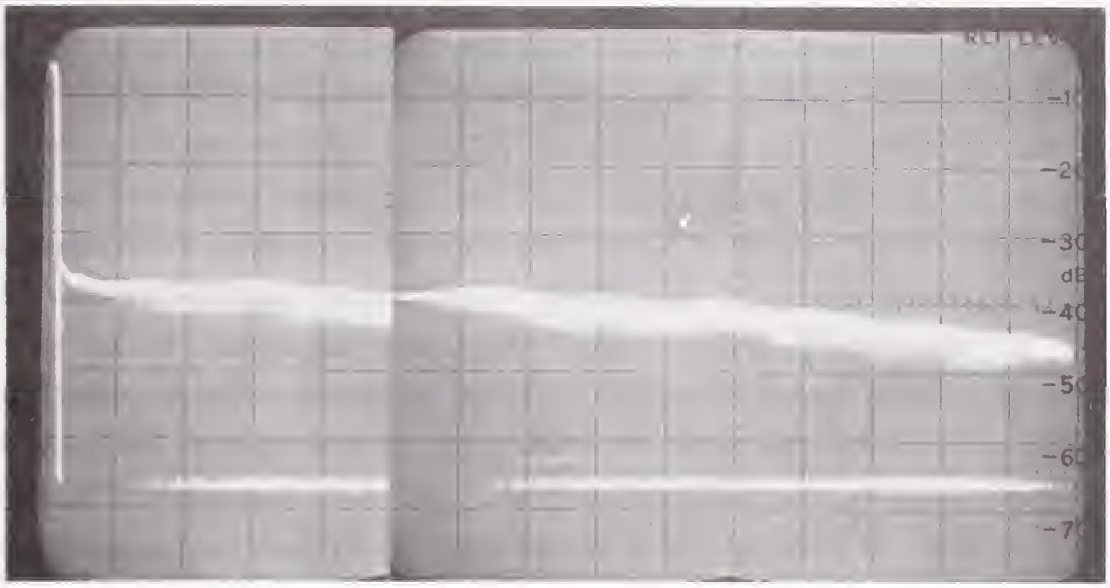


Figure 3. Typical spectrum of an NBS UHF Impulse Generator. Vert.: 10 dB/div., log ref level = +30 dB/div., 3-MHz bandwidth; Horiz.: 100 MHz/div., dc to 1500 MHz.

IV. CIRCUIT DESCRIPTION

This generator forms an impulse using the classical technique of discharging a short transmission line [3]. An avalanche transistor is used as the fast switching element to discharge the line [2,4]. The circuits for the UHF IG are shown in figures 4 through 7. Figure 4 shows the heart of the IG; namely, the avalanche transistor circuitry in which the impulse is formed. Q2 is the output transistor and is operated in the avalanche mode with the base to emitter shorted via RFC1 and with +140 V applied to the collector through 13 kΩ. Delay line, DL1, is charged to the B+ voltage (typically 140 V) through the string of resistors (DL2 and the 4.3 kΩ). A large triggering pulse is applied to the base-emitter junction of Q2. This causes Q2 to go into avalanche breakdown and thus rapidly discharge DL1 into the 50 Ω output load and the internal 50 Ω termination (R2 and R3 in parallel). The waveshape of the output impulse is determined by the length and impedence profile of DL1. The small inductors, L1 and L2, also provide some peaking to increase the impulse amplitude. The B+ feedline, DL2, critically affects the low level perturbations on the impulse baseline and, as a result, the ripple on the impulse spectrum. DL2 is a lossy distributed transmission line made up of six, 1/8 W resistors. It arches up and away from Q2 and the circuit board, figure 11. It also contains RFC2, which is three ferrite toroids slipped over the first resistor. A 150 Ω termination for DL2 is supplied by R6.

The driving pulse for Q2 is generated by Q1, which is also an avalanche transistor. Capacitor C1 is charged to +100 V through the 1 kΩ resistor. The negative 80 ns pulse from IC2a is differentiated by C2. The positive spike from the trailing edge of the 80 ns pulse is used to trigger Q1 into avalanche breakdown. C1 then discharges the 51 Ω resistor and the pulse transformer through Q1. The large (∿ 100 V) pulse from C1 is coupled through the transformer to Q2. The secondary of the transformer is floating with respect to circuit ground. Thus, terminals 1 and 3 produce, respectively, a positive and a negative going pulse which is coupled to the base-emitter junction of Q2 through the 1 kΩ resistors, R4 and R5. This differential drive pulse produces a large turn-on base current for Q2, and yet is well balanced with respect to ground, producing a negligible signal on the impulse output line. R4 and R5 are chosen to be large, compared with R2 and R3, to produce negligible loading of the output impulse.

The clock and delay circuits are shown in figure 5. IC1 and IC2 are Schottky TTL, dual, monostable multivibrators. IC1a and IC1b are interconnected to form an astable multivibrator that functions as the generator clock. Clock frequency ranges from 10 Hz to 1 MHz are chosen by changing the timing capacitors with S2. A 10:1 vernier is supplied by R16a and R16b. The clock output (IC1b, pin 10) is connected to the delay monostable IC2a through S2c. The positive going transition of the clock square-wave triggers IC2a, which then generates an 80 ns pulse. The 80 ns Q pulse drives a 10 mA tunnel diode through a 100 Ω resistor. The tunnel diode shapes it into the 500 mV, 2 ns transition time trigger output pulse. The 80 ns $\overline{Q}$ pulse is used to drive Q1 as described earlier. It also triggers IC2b, which in turn generates a 0.9 μs pulse. This 0.9 μs pulse is applied to the input gate of IC2a, thus inhibiting the generation of any additional trigger pulses during the 0.9 μs hold-off period. This is done to protect the avalanche transistors from damage due to overheating.

Avalanche transistors Q1 and Q2 require stable, high B+ voltages. These are supplied by the high voltage regulator shown in figure 6. From figure 7, +220-V filtered dc is supplied to the regulator. The B+ voltage is sensed by the voltage divider chain R10-R13 and applied to the (+) input of the 741 operational amplifier. This voltage is compared to the 6.8 V reference voltage established by the zener diode. The error signal drives Q3 and Q4. Q4 is a high voltage transistor. The collector output of Q4 controls the series pass transistor, Q6, to establish the regulated B+ voltage. R19 and Q7 are a current limiter. The B+ voltage for Q2 is adjustable from +120 V to +150 V. Q1 requires +100 V. This is obtained from the 100 V zener diode and Q8.

The power supply, figure 7, uses conventional circuits and components. It supplies +5 V for the TTL clock and delay circuit, +12 V for the 741 operational amplifier, and +220 V for the B+ regulator.

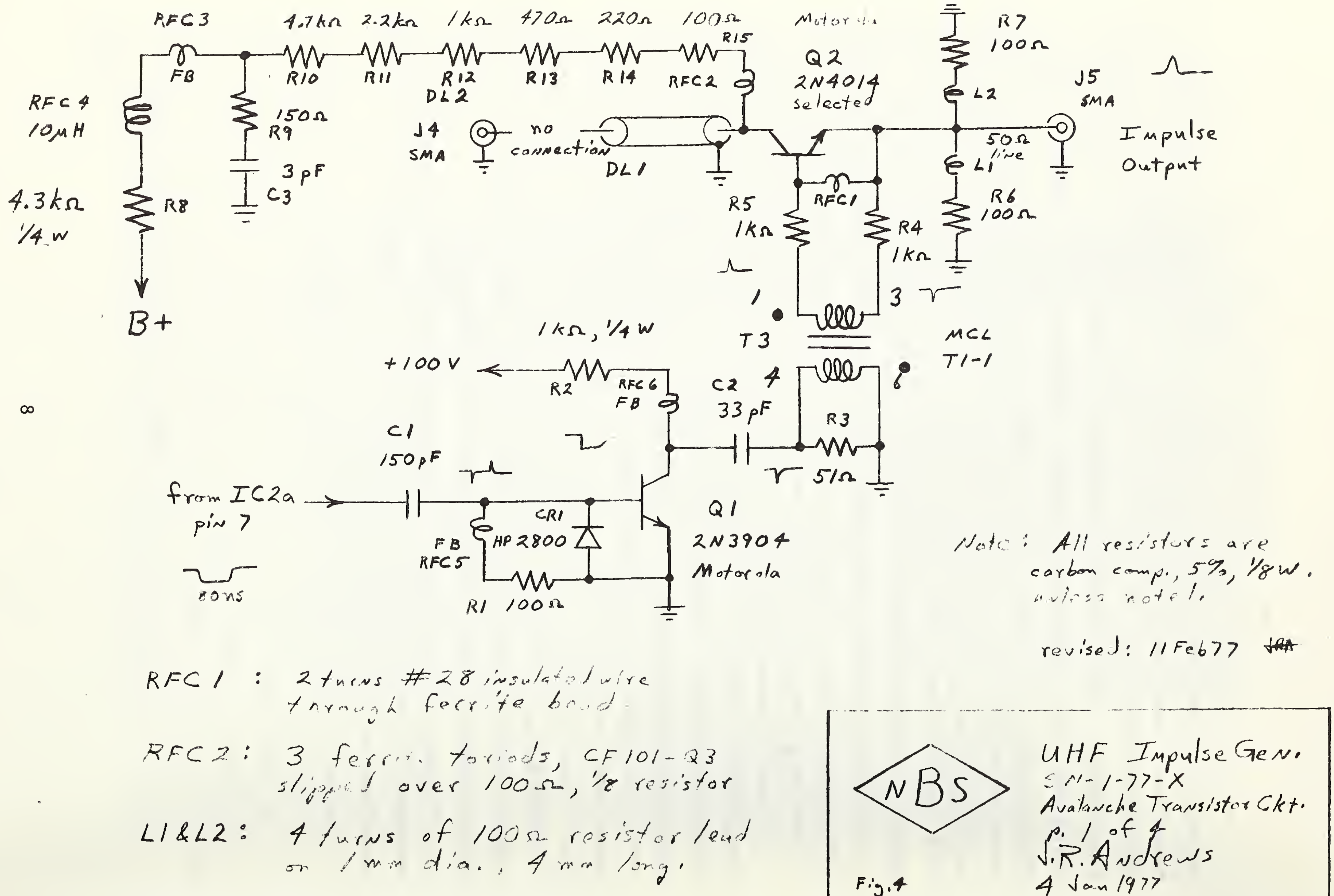


Figure 4. Avalanche transistor circuit.

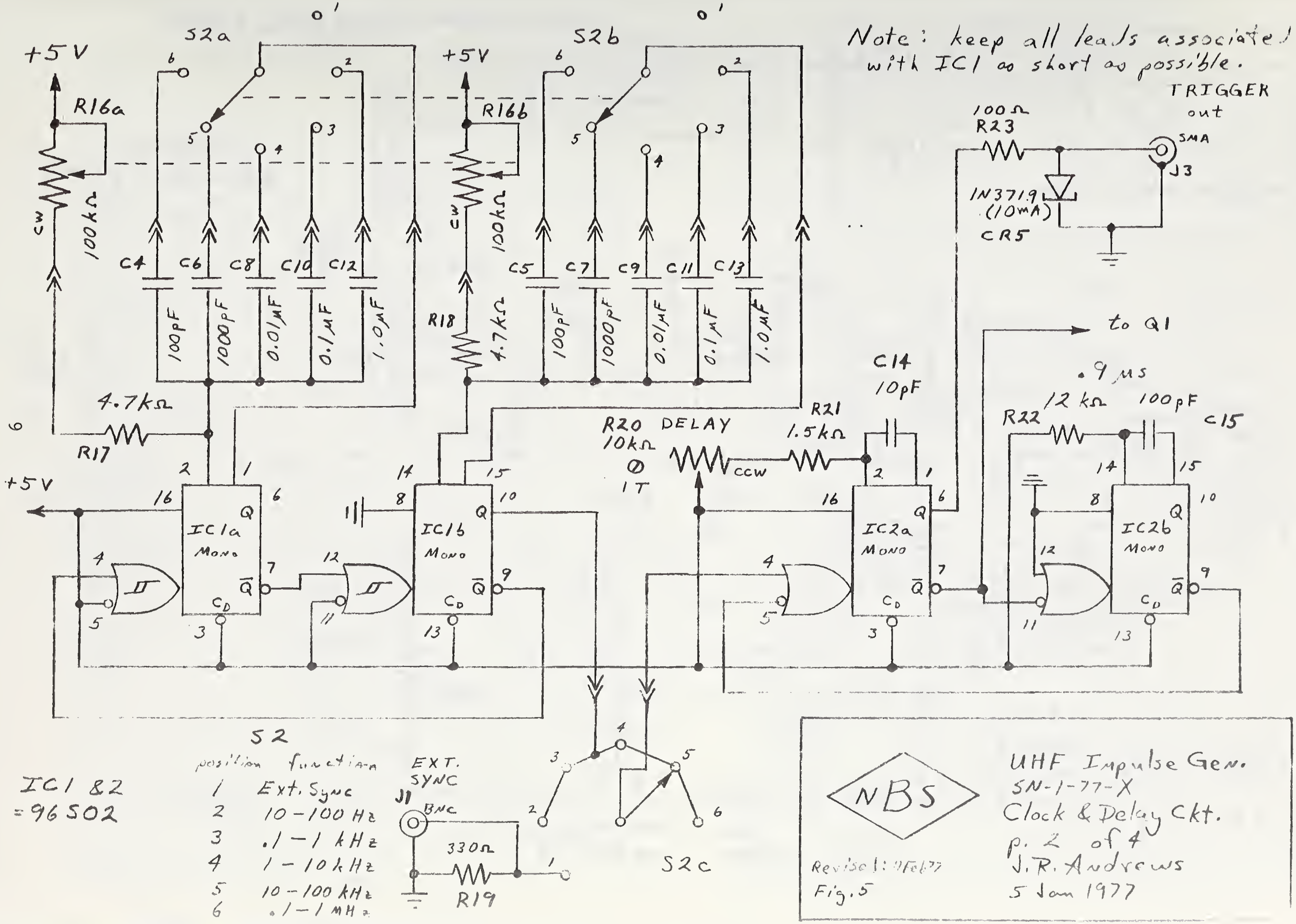


Figure 5. Clock and delay circuit.

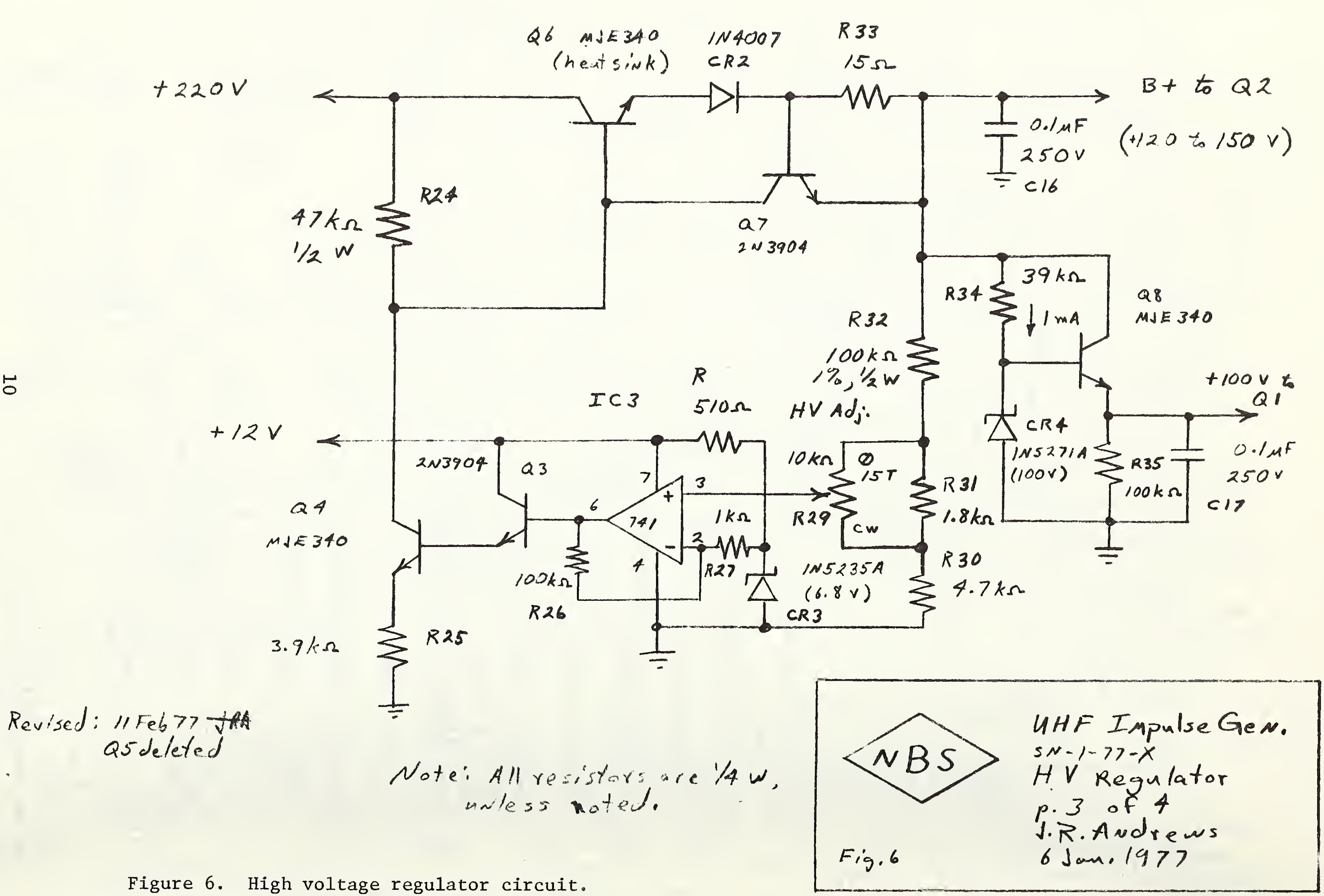


Figure 6. High voltage regulator circuit.

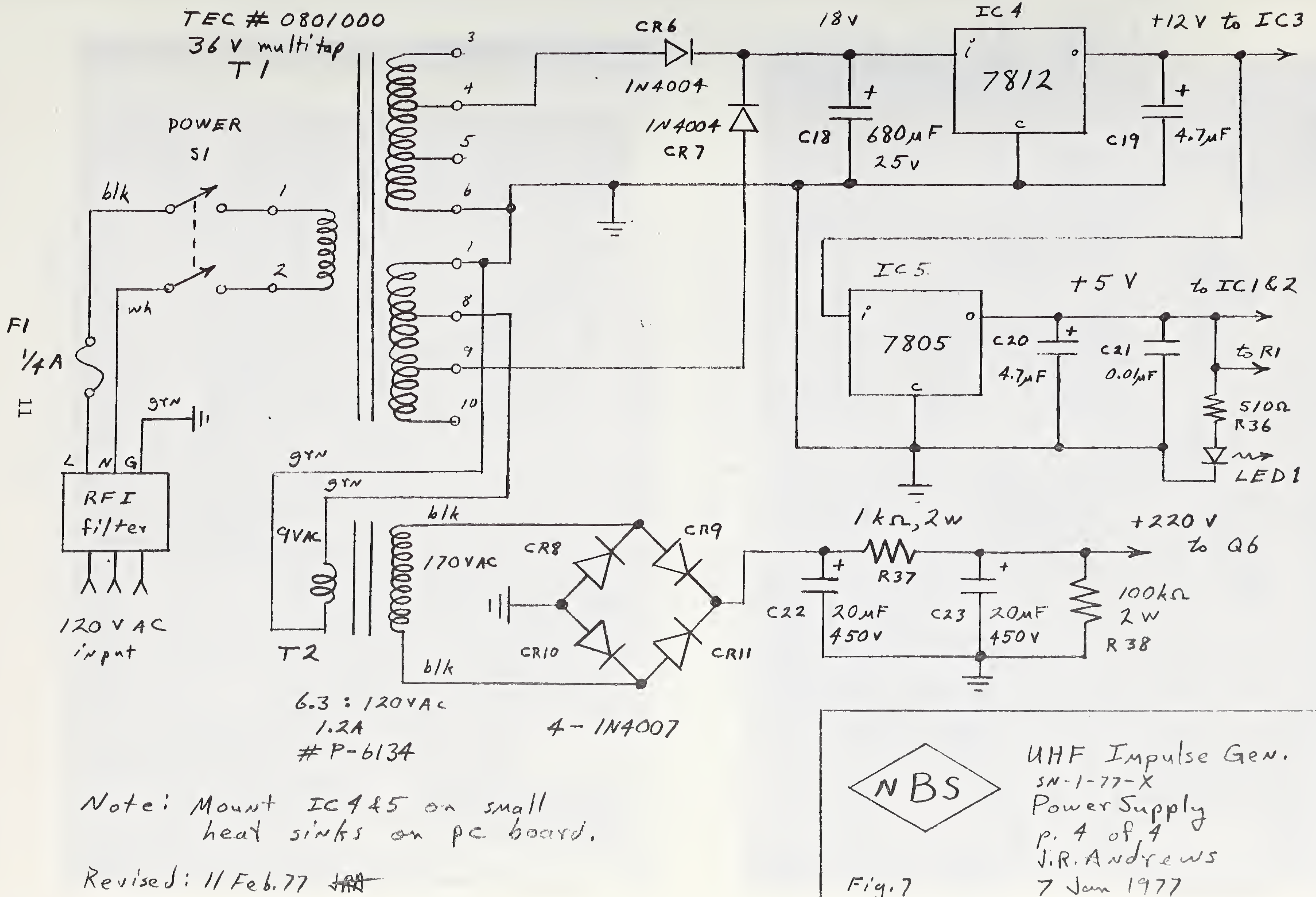


Figure 7. Power supply circuit.

V. CONSTRUCTION

Figures 8 and 9 show the top and bottom internal parts layout of the impulse generator. A 23 x 18 x 5 cm chassis is used to support the various components. A large 14.5 x 12.5 cm hole is cut out for the pc board. The large power supply components are located to the rear of the chassis. The majority of the components are located on the pc board. Figure 10 shows the artwork for the pc board. The board is 1.6 mm, double-sided, copper-clad, G-10 fiberglass-epoxy. The parts layout and assembly are conventional with the exception of the impulse-forming circuit.

The parts layout associated with avalanche transistor, Q2, is very critical. The impulse waveshape and amplitude are highly dependent upon the constructor's duplicating the exact layout. Figure 11 shows several views of the Q2 circuitry. The impulse output from Q2 is routed to the front panel by a short, 50 Ω, 3 mm, semi-rigid, coaxial cable.

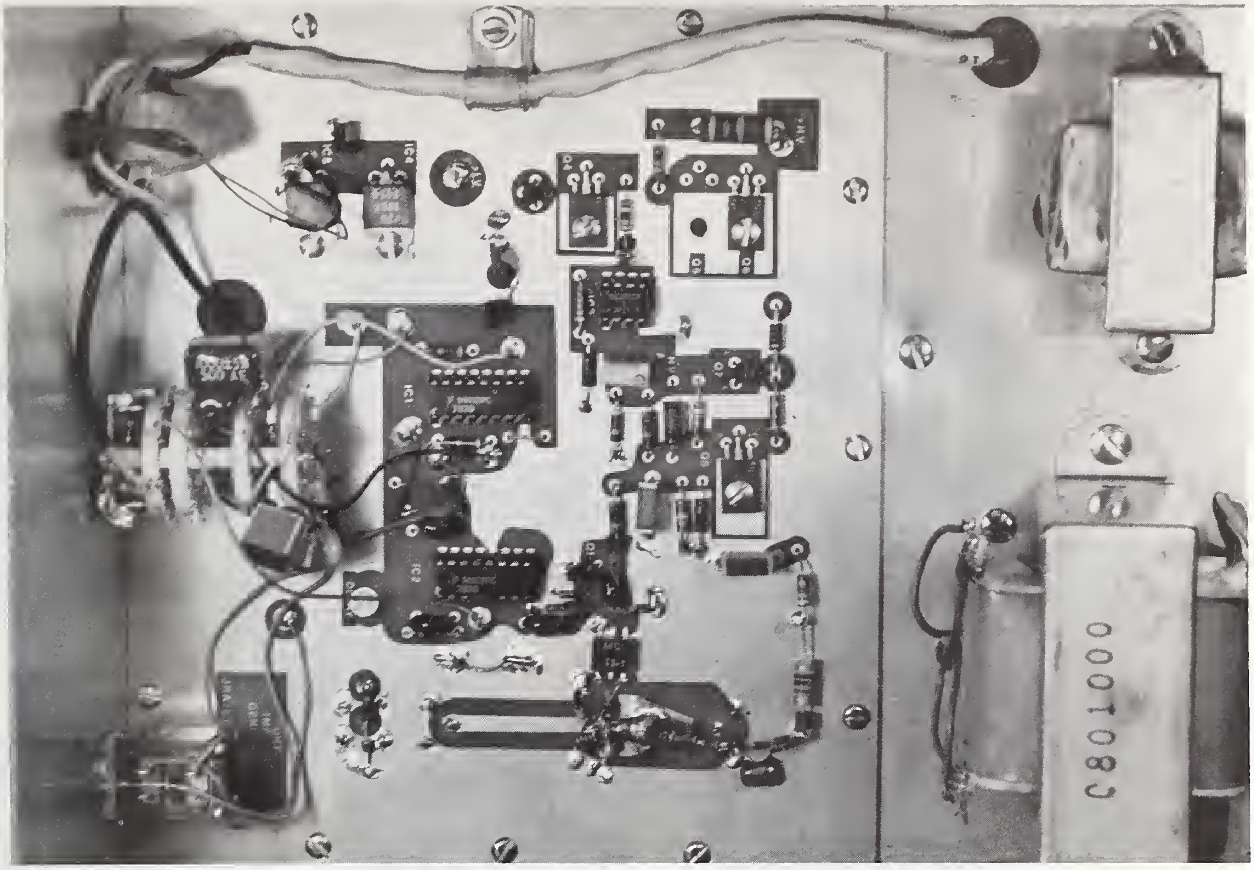


Figure 8. Top view of the chassis.

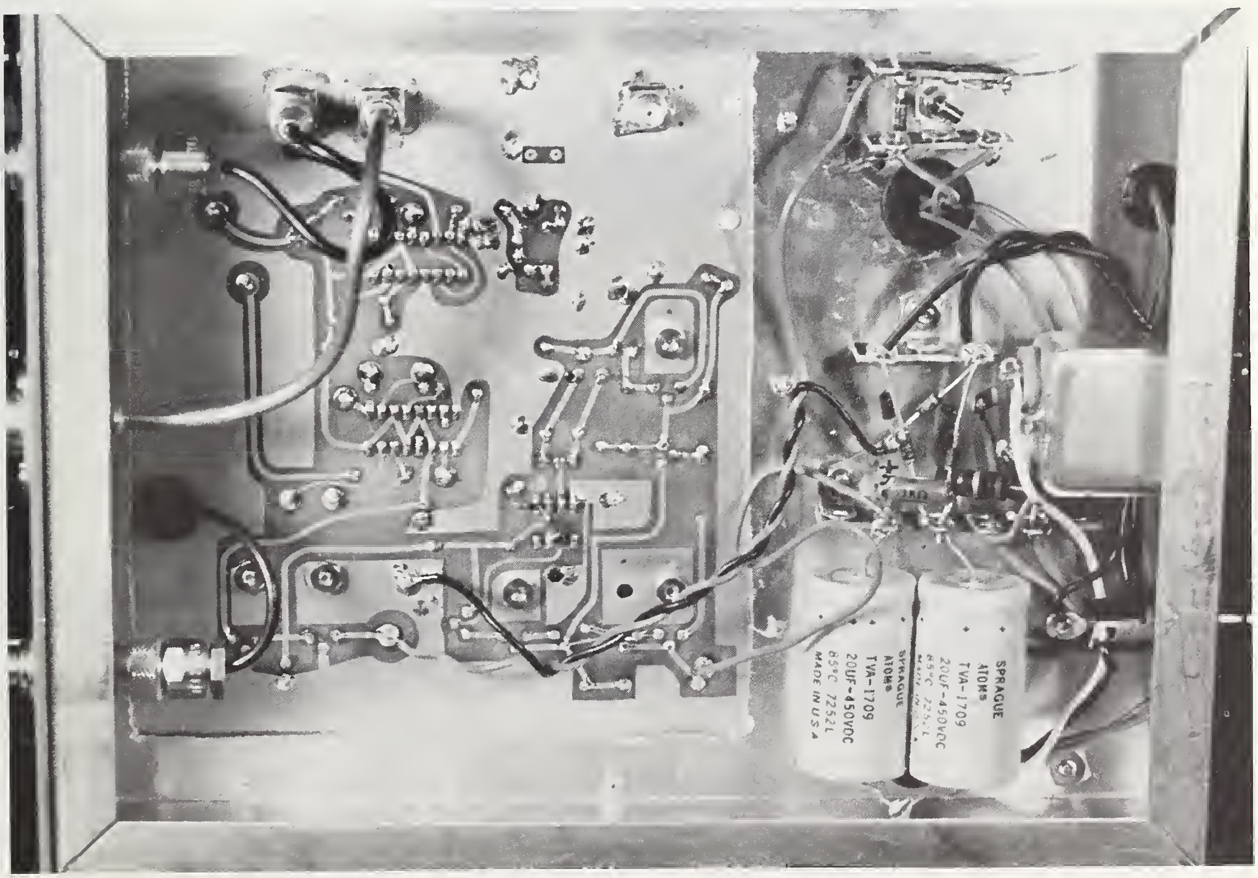


Figure 9. Bottom view of the chassis.

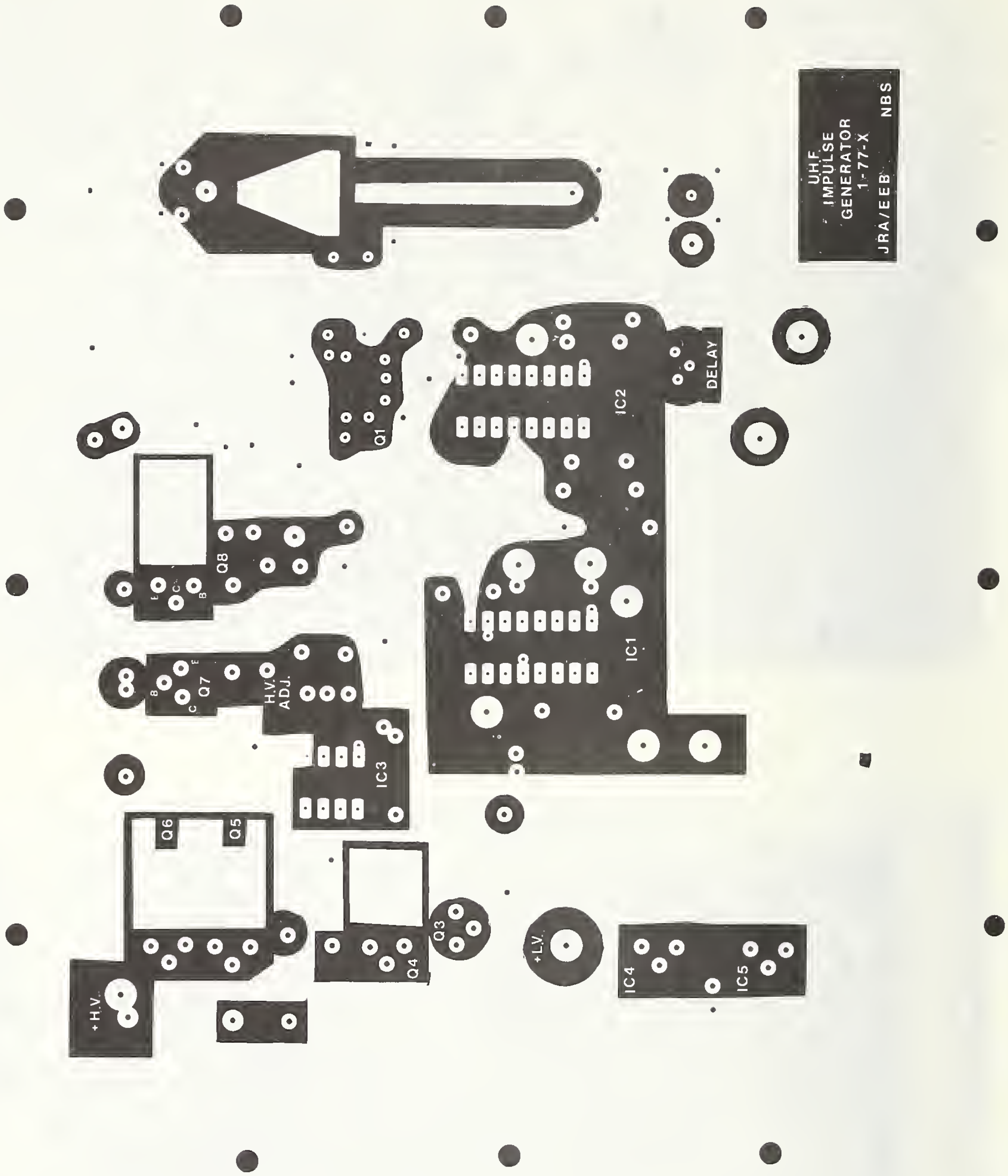


Figure 10. Printed circuit board layout. 1:1 scale. (a) Top side. (b) Bottom side. Double-sided, copper-clad, 1.6-mm thick, G-10 fiberglass-epoxy board. Dark areas indicate regions where the copper cladding is removed. Finished board size is 15.3 cm x 17.8 cm.

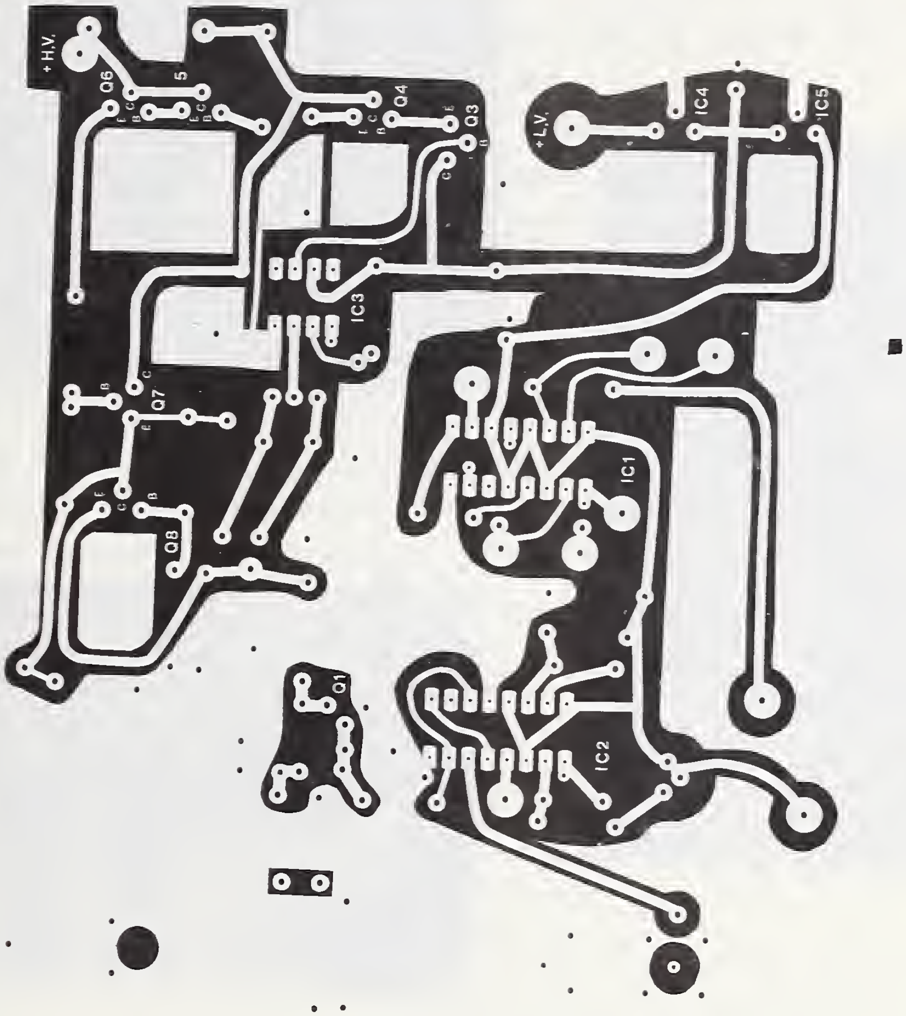


Figure 10. (b) Bottom side.

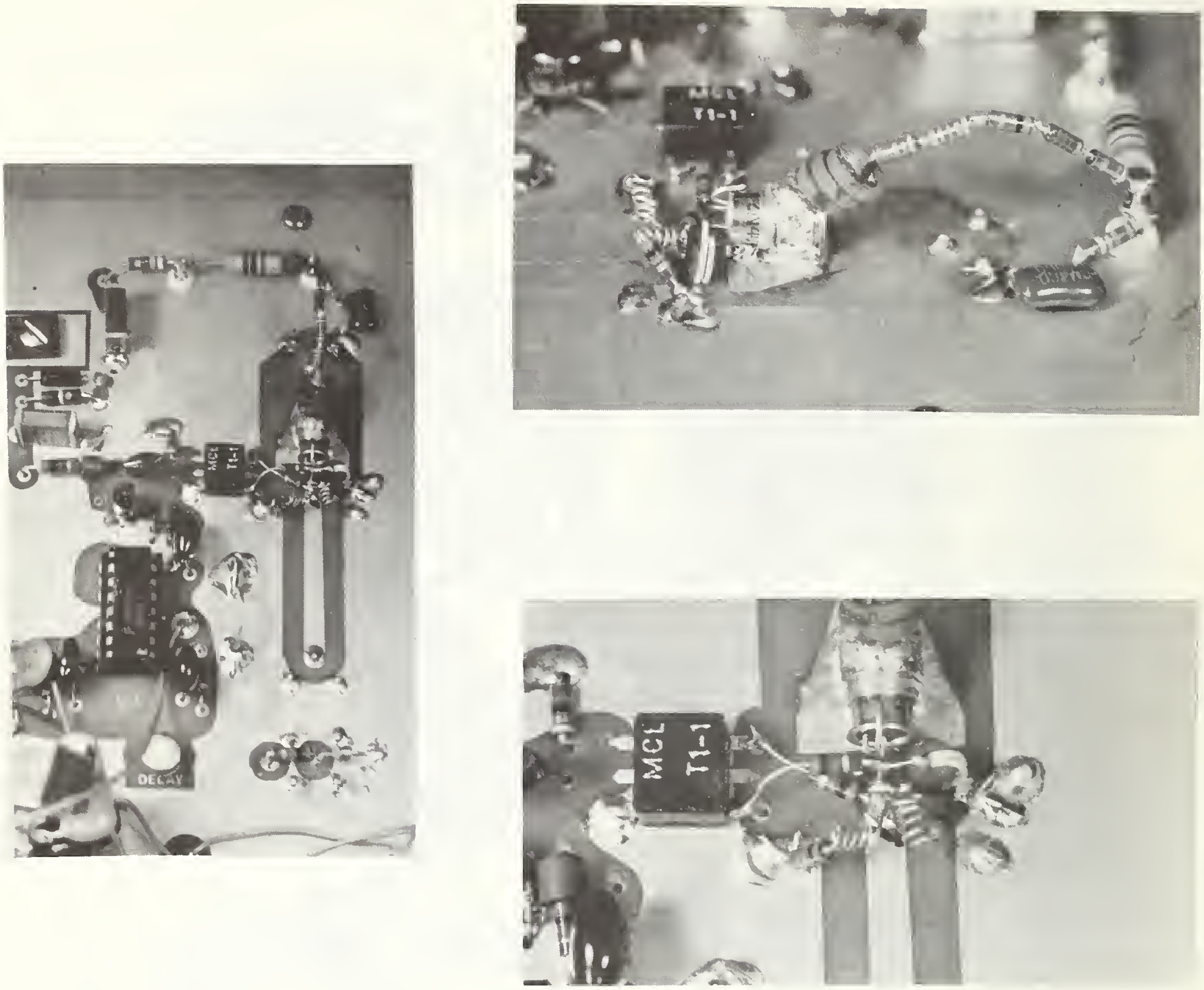


Figure 11. Several views of the component layout of the Q2 impulse forming circui

VI. COMPONENT SELECTION

The majority of the components in this instrument are standard tolerance, off-the-shelf items. The only exceptions are IC2, Q1, and Q2, which must be hand selected for the proper characteristics.

IC2 is either a 96S02 or a 9602 dual, monostable, integrated circuit. The instrument will function with any off-the-shelf 9602 or 96S02. However, it may not meet the 20 ps or less timing jitter specification. It is necessary to select IC2 on the basis of minimum timing jitter between the trigger pulse output and the impulse output.

Q1 and Q2 are ordinary, inexpensive ($.50 and $2 respectively) switching transistors. They are used in this generator as avalanche transistors although they are not specified by the manufacturer as avalanche transistors. The important selection parameter for this application is the collector-emitter breakdown voltage (base-emitter shorted), BV_{CES}. For Q1, BV_{CES} should be 110 V or greater. For Q2, BV_{CES} should be 130 V or greater. In addition, neither Q1 nor Q2 should evidence any sign of instability in the BV_{CES} curve tracer test or in the actual impulse generator circuit.

VII. ADJUSTMENTS

There are only two internal adjustments (DELAY and HV Adj.) within the impulse generator. The adjustment procedure is as follows:

1. Disconnect RFC4 (figure 4) from the 4.3 kΩ resistor and the B+ line.
2. Set the repetition rate switch to 100 kHz.
3. Turn the power on.
4. Connect the trigger output to a 50 Ω input impedance oscilloscope.
5. Set the oscilloscope time base to 20 ns/cm.
6. Adjust the oscilloscope to trigger on the positive edge of the trigger signal.
7. Adjust the DELAY pot, R7, to set the trigger pulse 50% duration to 80 ns. The adjustment range is from 50 ns to 150 ns approximately.
8. Disconnect the trigger output from the oscilloscope.
9. Connect a DVM to the B+ line.
10. Adjust the HV Adj. pot, R13, through its full range and note the upper and lower limits (+120 V to +150 V typical).
11. Set the B+ to the lower limit.
12. Turn the power off.
13. Reconnect RFC4 to the 4.3 kΩ resistor.
14. Connect the trigger output to the trigger input of the oscilloscope.
15. Connect the impulse output to the signal input of the oscilloscope.
16. Turn the power on.
17. Adjust the oscilloscope for a stable display.
18. Slowly increase the B+ (turn HV Adj. CW) and note an increase in the inpulse amplitude.
19. Continue increasing the B+ until instability in the impulse is observed. Note the B+ voltage at which this first occurs.
20. Reduce the B+ voltage 2 V below the level at which instability is noted.
21. The adjustments are now completed.

VIII. MODIFICATIONS

For some special measurement applications, it may be desirable to modify the IG to have a different trigger delay and/or impulse duration. The IG is normally adjusted for 80 ns trigger delay; however, the delay may be changed from 50 ns to 150 ns by simply adjusting the internal DELAY pot, R7.

If a different impulse waveshape is desired, this is accomplished by changing the charge line, DL1. A narrower impulse can be obtained by shortening DL1. However, the price paid will be a reduction in the impulse amplitude. Longer duration impulses can be obtained by lengthening DL1. To facilitate this, an additional SMA jack, J4, is already installed on the circuit board 5 mm from the end of DL1. To use this jack, a short strip of 3.2 mm wide copper tape should be soldered between DL1 and the jack. A longer charge line can then be attached to this SMA jack. A 50 Ω, RG-174/u coaxial cable with an SMA male connector is recommended. The opposite end of the coax is left open-circuited. If this modification is made, the maximum repetition rate limit must be decreased from 1 MHz by increasing the hold-off period set by IC2b. The hold-off period should be increased in proportion to the increased impulse duration. For example, if the impulse duration is increased from 0.36 ns to 3.6 ns, then the hold-off period should be increased from 0.9 μs to 9 μs. R22 and/or C15 should be changed to determine the hold-off period. The impulse duration should not be increased beyond 50 ns.

IX. PARTS LIST*

Resistors

(All resistors are 5% carbon composition unless noted)

R1	100 Ω	1/8 W
R2	1 KΩ	1/4 W
R3	51 Ω	1/8 W
R4	1 KΩ	1/8 W
R5	1 KΩ	1/8 W
R6	100 Ω	1/8 W
R7	100 Ω	1/8 W
R8	4.3 KΩ	1/4 W
R9	150 Ω	1/8 W
R10	4.7 KΩ	1/8 W
R11	2.2 KΩ	1/8 W
R12	1 KΩ	1/8 W
R13	470 Ω	1/8 W
R14	220 Ω	1/8 W
R15	100 Ω	1/8 W
R16A } R16B	100 KΩ Dual Variable Pot., Linear Taper	
R17	4.7 KΩ	1/4 W
R18	4.7 KΩ	1/4 W
R19	300 Ω	1/4 W
R20	10 KΩ, Miniature 1 Turn Pot.	
R21	1.5 KΩ	1/4 W
R22	12 KΩ	1/4 W
R23	100 Ω	1/4 W
R24	47 KΩ	1/2 W
R25	3.9 KΩ	1/4 W

*The inclusion of manufacturers' names in this parts list is not intended as an endorsement. Other manufacturers' products might perform equally as well or better.

R26	100 KΩ	1/8 W	Metalized 1%
R27	1 KΩ	1/8 W	Metalized 1%
R28	510 Ω	1/4 W	
R29	10 KΩ, Trim Pot., 15 Turn		
R30	4.7 KΩ	1/4W	
R31	1.8 KΩ	1/4 W	
R32	100 KΩ	1/4 W	Metalized 1%
R33	15 Ω	1/4 W	
R34	39 KΩ	1/4 W	
R35	100 KΩ	1/4 W	
R36	510 Ω	1/2 W	
R37	1 KΩ	2 W	Wire-wound
R38	100 KΩ	2 W	Wire-wound

Capacitors

C1	150 pF	Silver Mica
C2	33 pF	Silver Mica
C3	3 pF	Silver Mica
C4	100 pF	Silver Mica
C5	100 pF	Silver Mica
C6	1,000 pF	Silver Mica
C7	1,000 pF	Silver Mica
C8	0.01 μF	Plastic
C9	0.01 μF	Plastic
C10	0.1 μF	Plastic
C11	0.1 μF	Plastic
C12	1.0 μF	Plastic
C13	1.0 μF	Plastic
C14	10 pF	Silver Mica
C15	100 pF	Silver Mica
C16	0.1 μF	250 V (Low Leakage Current)
C17	0.1 μF	250 V
C18	680 μF	25 D.C.W.V. Electroloytic, Tubular
C19	4.7 μF	25 V Tant.
C20	4.7 μF	25 V Tant.
C21	0.01 μF	50 V Disc Ceramic

C22	20 μF	450 V Electrolytic, Tubular
C23	20 μF	450 V Electrolytic, Tubular

R. F. Chokes

RFC 1	2 Turns #28 insulated wire through 3 mm ferrite bead
RFC 2	3 ferrite toroid cores (CF-101-Q3 or equal.) slipped over 100 Ω, 1/8 W resistor, R15 and held in place with RTV
RFC 3	3 mm ferrite bead over lead of RFC 4
RFC 4	10 μH, Miniature
RFC 5	Ferrite bead over lead of R1
RFC 6	Ferrite bead over lead of R2
L1 and L2	4 Turns of 100 Ω resistor lead wound 1 mm, dia., 4 mm long, starting at body of resistor.

Diodes

CR1	Diode, hot carrier, H.P. 2800 or equal.
CR2	1N 4007
CR3	Zener diode, 6.8 V, 1N 5235A
CR4	Zener diode, 100 V, 1N 5271A
CR5	Tunnel diode, 10 ma., 1N 3719
CR6	1N 4004
CR7	1N 4004
CR8	1N 4007
CR9	1N 4007
CR10	1N 4007
CR11	1N 4007
L.E.D.1	Light emitting diode, 10 ma

Transformers

T1	Transformer, 36 V, multi-tap T.E.C. 080100 or equiv.
T2	Transformer, 6V, 1.2A, Stancor P-6134 or equiv.
T3	Transformer, Min., Pulse, 1:1, 50 Ω, MCL T1-1

Transistors

Q1	2N3904, Motorola, selected
Q2	2N4014, Motorola, selected
Q3	2N3904
Q4	MJE-340
Q5	Deleted
Q6	MJE-340
Q7	2N3904
Q8	MJE-340

Integrated Circuits

1C1	9602
1C2	9602 or 96S02 selected for min. jitter
1C3	741
1C4	7812
1C5	7805

Miscellaneous

S1	Switch, toggle, D.P.S.T.
S2	Switch, Rotary 3 pole, 6 position
F1	Fuse, 1/4A. SLO-BLO Fuse holder
FL1	Line filter, Corcom 3EF1 or equal.
	Line cord to fit above
J1	Connector, BNC Bulkhead UG-492 A/U
J2	Connector, BNC Bulkhead UG-492 A/U
J3	Connector, OSM P.C. board, E.F. Johnson 142-0298-001 or equal.
J4	Connector, OSM P.C. board, E.F. Johnson 142-00298-001 or equal

J5	Connector, OSM P.C. board E.F. Johnson 142-00298-001 or equal
J6	Connector, Bulkhead, SMA female/N female

Cabinet, BUD BB 1801 RB or equiv.

Chassis, 23x18x5 cm, Aluminum

Large knob, 3.8 cm, 6.35 mm Shaft

Small knob, 1.9 cm, 6.35 mm Shaft

Cables as follows:

12 cm RG-174/U with BNC male on one end and pigtail on other end

6 cm RG-174/U with SMA male on one end and BNC male on other end

12 cm of 3 mm, 50 Ω, semi-rigid coax with one SMA male on each end, bending gently to shape

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

This UHF Impulse Generator generates a narrow impulse with a flat spectrum up to 1 GHz. The impulse amplitude is 55 volts and the duration is 365 ps. The maximum repetition rate is 1 MHz. This report describes the generator in detail and includes a complete parts list and printed circuit artwork.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Avalanche transistor; impulse; impulse generator; pulse generator; spectrum; spectrum amplitude

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