



User Manual **Model DB-2**

Random Pulse Generator

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SECTION 1 SPECIFICATIONS

COUNT RATE:	10 Hz to 1 MHz, continuously adjustable.
MODE:	Random or Repetitive.
RANDOM DISTRIBUTION:	Poisson for intervals greater than 1.4 μ s.
PULSE SHAPE:	Tail pulse with independently adjustable rise and fall times.
PULSE AMPLITUDE (STEP) CHARACTERISTICS: a) Amplitude Shift with Count Rate: b) Jitter (resolution): c) Temperature Coefficient:	Less than $\pm 0.05\%$ from 10 Hz to 100 kHz. 0.01% RMS. $\pm 0.02\%/^{\circ}\text{C}$.
FREQUENCY JITTER (Repetitive Mode):	Less than 0.1%.
EXTERNAL TRIGGER:	Requires 1 V positive pulse. Input impedance 1 K.

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- SPECIFICATIONS -

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TRIGGER OUT:	Positive 3 V pulse, 20 ns rise time, 100 ns width, 50 Ω output impedance.
RISE TIME OF OUTPUT (10 - 90%):	0.1 - 20 μ s, in 8 steps.
DECAY TIME CONSTANT (100 - 37%):	5 - 1000 μ s, in 8 steps. Rise and Decay time independent of each other for Decay Time/Rise Time > 10.
OUTPUT AMPLITUDE RANGES:	Repetitive only, \pm 10 V maximum. Repetitive or Random, \pm 1 V maximum. Adjustable by ten-turn potentiometer from zero to maximum. AC coupled.
NORMALIZE:	Ten-turn control varies amplitude by 60%.
OUTPUT IMPEDANCE:	50 Ω .
ATTENUATION:	4 step attenuators of X2, X5, X10 and X10 for a maximum of X1000.
EXTERNAL REFERENCE INPUT:	+10 V maximum; 10 K input impedance.
POWER REQUIREMENTS:	\pm 24 V at 65 mA, +12 V at 140 mA, -12 V at 40 mA.
MECHANICAL:	Double-width NIM module, 2.70" wide by 8.70" high in accordance with TID-20893 (Rev. 3).
WEIGHT:	3-1/2 lbs. net; 7 lbs. shipping.

SECTION 2

OPERATING INFORMATION

2.1 INTRODUCTION

The Model DB-2 Random Pulse Generator is a precision pulse generator which provides a broad range of calibration and test pulses encountered in the nuclear and life sciences areas. When operated in the random mode, it provides a controlled voltage transition and long decay time constant at average rates up to 1 MHz, allowing accurate simulation of detector signals while retaining a monoenergetic nature. Two or more DB-2's may be connected to a single test point to test overload and pileup response and pulse pair resolution. Typical applications of the DB-2 include:

- rate effect testing including base line shift and analyzer dead time;
- determination of proper gate and coincidence unit timing;
- ratemeter testing for variations between periodic and random inputs;
- linearity measurements of amplifiers and pulse height analyzers at high rates;
- threshold determination of discriminators and single-channel analyzers.

2.2 FUNCTION OF CONTROLS & CONNECTORS

Table 2-1 lists the controls and connectors for the Model DB-2 and describes their function.

Table 2-1. Function of Controls and Connectors.

CONTROL	FUNCTION
FREQUENCY:	Concentric switch and potentiometer control repetition rate of output pulses when the MODE switch is set to REP. When the MODE switch is set to RANDOM, the FREQUENCY controls set the average random rate of output pulses. When the FREQUENCY switch is in the EXT position, output pulses will occur if an external trigger is connected to the EXT TRIG connector.
MODE:	This toggle switch controls the clock mode of the pulse generator. When set to REP (Repetitive), the pulse generator produces output pulses with a fixed time interval between them. With the switch set to RANDOM, the output pulses occur randomly; i. e., the time intervals between successive pulses obey the interval distribution function of a Poisson process.
RANGE:	This toggle switch selects the maximum range of voltage transitions produced by the pulse generator.
AMPLITUDE:	Ten-turn potentiometer controls the magnitude of the voltage transition produced by the pulse generator. This control is disabled when an external reference voltage is used.
NORMALIZE:	Ten-turn potentiometer reduces the upper limit of the AMPLITUDE control by up to 60%. When used in conjunction with the ATTEN (Attenuator) switches, the NORMALIZE control allows calibration of the AMPLITUDE dial in convenient units, such as MeV or keV of energy loss.

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- OPERATING INFORMATION -

Table 2-1. Function of Controls and Connectors (continued)

CONTROL	FUNCTION
POL (Polarity):	This toggle switch selects positive or negative polarity for output voltage transitions.
RISE TIME:	Controls the 10% - 90% rise time of the output pulse.
FALL TIME:	Controls the effective decay time constant, 100% - 37%, of the output pulse.
REF - INT/EXT:	This toggle switch connects the pulse forming circuitry either to an internal DC reference voltage or an external reference. In the EXT (external reference) position, the reference voltage is applied to the EXT REF connector. When an external reference is used, the AMPLITUDE control is disabled.
ATTEN (Attenuation):	These four toggle switches provide attenuation of the pulse generator output in the following amounts: X2, X5, X10, X10. Various combinations may be used to provide attenuation in a 1-2-5 sequence from X1 (no attenuation) to X1000.
PULSE OUT:	The pulse generator output appears at this connector. For best results, the output cable should have a characteristic impedance of 50 Ω and should be terminated with a 50 Ω non-inductive resistor.
TRIG OUT:	This connector provides a synchronizing pulse which precedes the output pulse. The output impedance is 50 Ω , but operation of the pulse generator is not affected if this output is not properly terminated.
EXT TRIG:	<p>This connector is provided to connect an external trigger to control the output rate.</p> <p align="center">----- NOTE -----</p> <p>Signals present at this connector will interfere with operation of the internal clock circuits unless the FREQUENCY switch is set to EXT. Also, when an external trigger is used, the MODE switch should be set to REP. However, if the MODE switch is set to RANDOM, the pulse generator will provide randomly spaced pulses at an <u>average</u> rate approximating the external trigger rate.</p> <p align="center">-----</p>
EXT REF:	This connector allows the use of an external voltage to control the magnitude of the voltage transitions produced by the pulse generator.

The Model DB-2 is a precision instrument and certain care must be taken to obtain optimum performance. The following paragraphs discuss various factors which contribute to this performance.

2.3.1 TERMINATION

The output of the DB-2 should be terminated in 50 Ω whenever long (greater than ten feet) 50 Ω cables are being used. Cables of other impedances may be used if they are properly terminated; however, the reverse termination impedance is designed for 50 Ω . Termination of cables shorter than ten feet is usually not required.

Termination with R ohms will reduce the DB-2 amplitude by a factor N defined by:

$$N = R / (R + 50) \quad (1)$$

For example, if R = 50 Ω , N = 0.5 and the amplitude is half of the unterminated value.

Termination of the trigger output is unnecessary for proper DB-2 operation, but it is recommended if the trigger signal is used with high-speed logic such as electronic counters.

2.3.2 OUTPUT COUPLING

The Model DB-2 is capacitively coupled at its output by a long time constant (0.1 s). Therefore, the output will exhibit base line shift as the frequency is increased. This will have no effect on the output amplitude as each pulse produces a controlled amplitude step regardless of the initial location of the base line.¹

¹Base Line Wander. The base line will wander (hunt-and-see) in a millisecond time range with an amplitude excursion proportional to the decay time. It will be a maximum of 200 mV with a 1 ms tail time as viewed at 10 ms/cm on a scope. This is normal servo operation of the instrument and does not affect the amplitude of the step transition.

Because of this fact, it is not recommended that the DB-2 be connected directly to any device that measures the DC value of the output waveform. Such devices include amplitude discriminators, zero-crossing discriminators, pulse shape analyzers and analog-to-digital converters (ADC's).

The proper method to test these devices is to use the Model DB-2 as a stimulus to either the system preamp test input or the main (shaping) amplifier. The amplifier output waveform is then routed to the unit being tested. Not only does this method allow testing of the devices listed above, but also provides the precise waveform and driving impedance to insure a proper simulation of actual operating conditions.

2.3.3 PULSE PILEUP IN THE RANDOM MODE

Certain combinations of AMPLITUDE, FALL TIME, and FREQUENCY settings in the RANDOM MODE will produce unwanted side effects, a situation analogous to duty factor limitation in ordinary pulse generators. The side effect is saturation of one or more of the internal amplifiers, and occurs for a combination of maximum amplitude pulses, highest average rates and longest fall times. Because the intervals between pulses obey the interval distribution, combinations of these parameters may be calculated which yield certain percentages of distorted or missing pulses. Figure 2-1 is a graph showing the maximum frequency that yields fewer than 1% distorted or missing pulses for combinations of AMPLITUDE and FALL TIME settings. As can be seen from the graph, reducing the AMPLITUDE by a factor of two allows operation at a frequency four times higher.

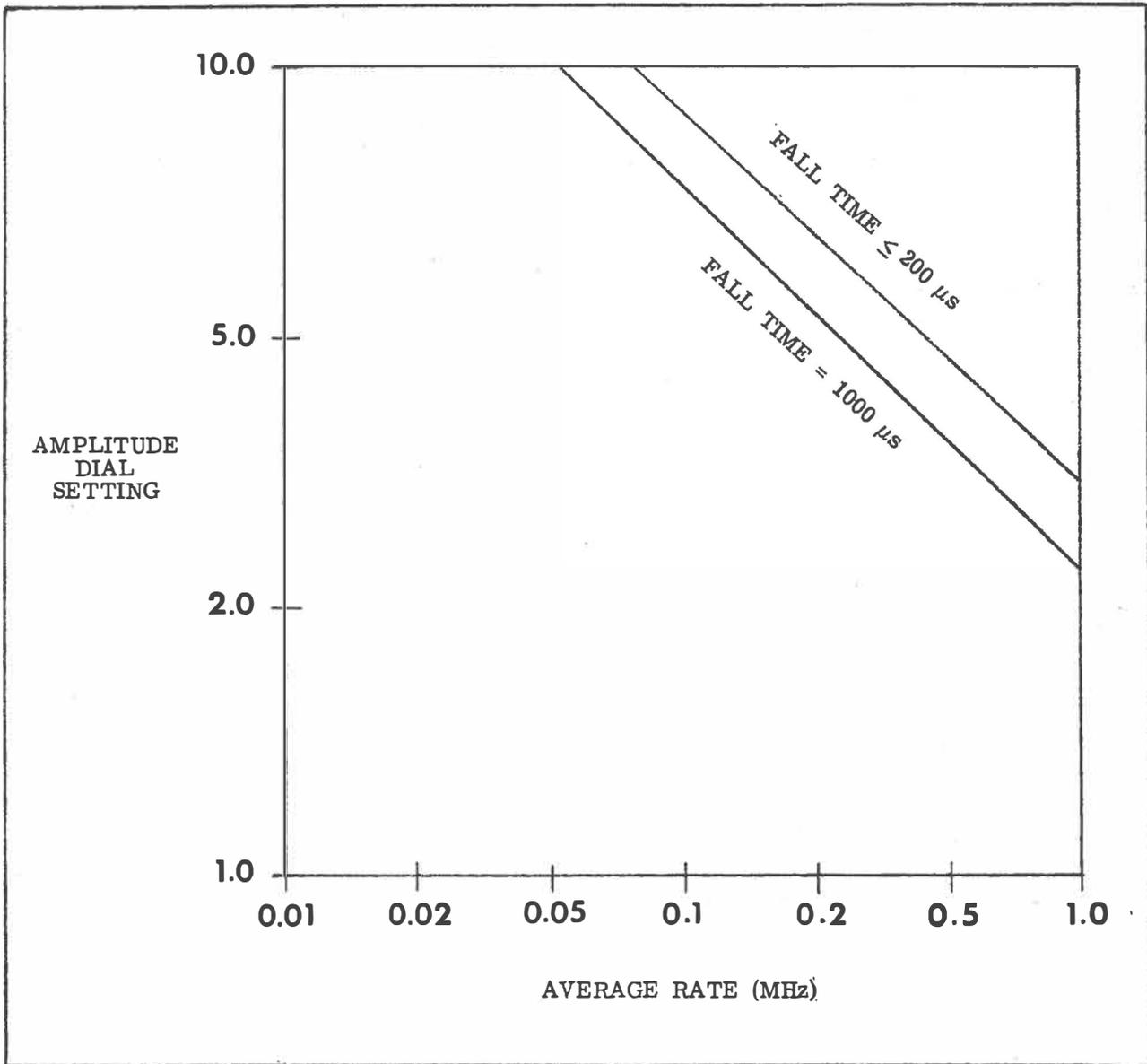


FIG. 2-1. Duty Factor Limitation of the Model DB-2. Amplitude, Rate and Fall Time Settings for less than 1% distorted pulses.

The graph is intended as a guide to indicate those combinations of AMPLITUDE, FALL TIME, and FREQUENCY settings that warrant close monitoring of the DB-2 output by an oscilloscope. Flattened or saturated traces at the top and bottom of the screen indicate that the DB-2 duty factor is being exceeded.

2.3.4 EXTERNAL TRIGGERING

When placed in the repetitive (REP) MODE, the Model DB-2 will produce one output pulse for each external trigger pulse applied to the EXT TRIG connector. Trigger pulses closer together than 120 ns will not produce multiple pulses. If the MODE switch is set to RANDOM,

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the average rate of the output pulses will be within 20% of the external trigger rate.

2.3.5 EXTERNAL REFERENCE

The amplitude of the output pulses may be controlled by an external reference voltage applied to the EXT REF connector by switching the REF switch to EXT. The range of control at the EXT REF connector is 0 - 10 V, but no damage will result from voltages less than ± 25 V.

When used as a sliding pulser (by connecting a Berkeley Nucleonics Model LG-1 Ramp Generator to the EXT REF input), the Model DB-2 exhibits differential nonlinearity less than $\pm 0.25\%$ over the top 85% of the amplitude range. The lower portion of the amplitude range and the ramp turnaround points should be excluded from any differential linearity tests. Computer control of the amplitude may be accomplished by use of a digital-to-analog converter such as the Berkeley Nucleonics Model 9060 DC Reference Programmer.

2.3.6 TRANSIENTS

During the time that pulses are being formed, switching transients will unavoidably be produced. By careful design, these have been reduced so that they will have negligible effect in the majority of applications. However, if the AMPLITUDE control is reduced to near minimum, the transients may dominate the waveform. Consequently, it is recommended that the AMPLITUDE control be operated near maximum and the attenuators (ATTEN) be used to obtain the cleanest small pulses.

2.3.7 NIM POWER SUPPLY

The Model DB-2 is a NIM module and depends upon power from an external source. It is important that the power supply is in good condition and meets all regulation, stability, and ripple specifications of U.S. AEC Report TID-20893 (Rev. 3). If a NIM power supply is inadvertently overloaded, the DB-2 may cease to operate, but will not sustain damage.

SECTION 3

APPLICATIONS

3.1 DETECTOR SIMULATION

The Model DB-2, used in conjunction with the normal charge conversion capacitor at the test input of a preamplifier, simulates the output of a wide range of detector types.

Each detector has a characteristic time or time constant associated with it. For solid state detectors, this time is the charge collection time; for scintillators it is the primary light decay constant. In general, the detector type is simulated by adjusting the DB-2 RISE TIME to be 2.2 times the detector's characteristic time constant (the time required to collect 63% of the detector's charge output).

3.1.1 SOLID STATE DETECTORS, PROPORTIONAL COUNTERS, SPARK CHAMBERS, GEIGER-MÜLLER TUBES and PLASTIC (ORGANIC) SCINTILLATORS

For these detector types, the DB-2 RISE TIME should be set to 0.1 μ s (or to other settings if the charge collection time for individual detector configurations is known to be greater than 0.1 μ s). When the DB-2 is used to simulate detectors with very small (less than 0.1 μ s) charge collection (or light decay) times, the system preamplifier will still collect all of the charge produced by the DB-2; however, the collection time will be longer than if the charge were produced by such a detector. For most applications, the difference will not be noticeable, but systems with ultra-small shaping time constants ($< 0.5 \mu$ s) in the main amplifier will experience a slight amplitude reduction

²Rise time (10%-90%) is equal to 2.2 time constants.

when compared to systems with normal time constants (1 - 3 μ s). The amplitude reduction is termed ballistic deficit³ and also exists when ultra-small shaping time constants are used with detectors having long charge collection times. This effect does not cause problems in most system testing, but does interfere with preamplifier rise time measurements.⁴

3.1.2 INORGANIC SCINTILLATORS

In order to simulate the charge pulse generated by a photomultiplier tube viewing an inorganic scintillator such as CsI(Tl), CsI(Na), or NaI(Tl), the DB-2 RISE TIME control is adjusted to the nearest value equal to 2.2 light decay constants. Table 3-1 lists the primary light decay constants for some popular inorganic scintillation materials.

Table 3-1. Primary Light Decay Constants for Some Inorganic Scintillators.

Material	Primary Decay Constant
CsI(Tl)	1.1 μ s
CsI(Na)	1.0 μ s
NaI(Tl)	0.25 μ s

Intermediate settings of the RISE TIME control may be obtained by replacing one or more of the rise time capacitors (C81 - C87) with different valued capacitors. Consult the Berkeley Nucleonics Engineering Department for details.

³Roddick, R. G., Semiconductor Nuclear-Particle Detectors and Circuits, National Academy of Sciences, 1969, p. 705.

⁴For a further discussion, refer to IEEE Standard No. 301 "Test Procedures for Amplifiers and Preamplifiers", IEEE, 1969.

3.2 PREAMPLIFIER SIMULATION

The Model DB-2 can be used to simulate the output waveform of a system preamplifier in order to test the rest of a system. The output of the DB-2 is connected directly to the main (shaping) amplifier and the FALL TIME is set to approximate the decay constant of the preamplifier being simulated. The RISE TIME is set according to the following formula:

$$\text{RISE TIME} = \left[T_1^2 + 4.84 T_2^2 \right]^{1/2}$$

where T1 = Preamp rise time
T2 = Detector Time Constant

The detector time constant is either the light decay constant (for scintillators) or charge collection time constant (time to collect 63% of the charge). The polarity (POL) should be set, and the FREQUENCY controls adjusted to the desired average rate.

If the main amplifier is equipped with pole-zero compensation, it should be adjusted to compensate for the DB-2 pole simulating the preamplifier decay constant.

3.3 SYSTEM POLE-ZERO CANCELLATION

The Model DB-2 can be used to adjust system pole-zero cancellation for optimum counting at high rates. The DB-2 is connected to the test input of the system preamplifier. The FALL TIME control should be set to 1000 μs , which is long compared to the normal 50 μs - 100 μs decay constant of most system preamplifiers. This insures that the preamplifier output wave-shape is dominated by the preamplifier pole. The RISE TIME control should be set according to the guidelines given in paragraph 3.1 above. The remaining controls are adjusted to the expected system operating parameters.

The system pole-zero compensation is now adjusted while monitoring the data collected on a multi-channel analyzer until the DB-2 peak is as narrow as possible.

It should be noted that the DB-2 introduces non-cancellable poles into the system, but they are sufficiently larger than the preamplifier pole as to not interfere with most systems.⁵

3.4 CHECKING BASE LINE RESTORERS

Operation of a base line restorer may be checked using the Model DB-2 to provide randomly spaced events at the same rate normally experienced by the system. The DB-2 is connected to the preamplifier test input, and the system pole-zero cancellation is checked (see paragraph 3.3).

An oscilloscope is used to monitor the DB-2 output to detect pile-up limitation (see paragraph 2.3.3). A multichannel analyzer is used to monitor the system output with the base line restorer off, then on. A sharp reduction in the DB-2 peak width should be noticed with the restorer on. If the restorer has a choice of time constants, each time constant may be tested to discover which yields the narrowest peak at the counting rate of interest.

3.5 CHECKING RATEMETERS

Ratemeters can be checked for accuracy using the Model DB-2 to provide randomly spaced events at a variety of average rates. The DB-2 is connected to the system preamplifier test input as before (see paragraph 3.3).

An oscilloscope is used to monitor the DB-2 output to detect pile-up limitation (see paragraph 2.3.3). A digital counter is connected to

⁵Nowlin and Blankenship, Review of Scientific Instruments, 36, 1830, 1965.

the DB-2 TRIG OUT connector. The trigger cable should be properly terminated at the counter for best results. The readings of the ratemeter and the digital counter will agree for low repetition rates. As higher rates are measured, the ratemeter will begin to miss pulses due to system resolving time, thus indicating less than true rate.

Operation with periodic and random inputs is easily compared by changing the MODE switch on the DB-2 from RANDOM to REP (repetitive).

3.6 CHECKING PILE-UP REJECTORS

The Model DB-2 allows the operation of pile-up rejectors to be optimized and the rejection interval to be measured. The DB-2 is connected to the system preamplifier as before (see paragraph 3.3). An oscilloscope is used to monitor the DB-2 output to detect pile-up limitation (see paragraph 2.3.3).

Optimization of rejector operation may be performed by monitoring the system output with a multi-channel analyzer as the rejection interval is adjusted to just eliminate the sum peak. If the rejection interval is too short, part of the sum peak will remain; if the interval is too long, events that would have been correctly analyzed will be lost.

The rejection interval may be measured by using the DB-2 in conjunction with a conventional pulse generator. The conventional pulse generator is operated in the double pulse mode to trigger the DB-2 twice in succession. The DB-2 MODE switch should be set to REP, the FREQUENCY switch to EXT, and the RANGE switch to 1 V. The time between the two pulses is increased until the second pulse is being rejected 50% of the time. The time between the pulses is measured on an oscilloscope and is the rejection interval.

3.7 CHECKING PULSE SHAPE ANALYZERS

Operation of a pulse shape analyzer may be checked by using the Model DB-2 to simulate events with various pulse shapes. A typical use of a pulse shape analyzer is to discriminate between CsI and NaI events detected by a photomultiplier. The general techniques given in paragraph 3.1 are used to simulate first CsI events, then NaI events, and the pulse shape analyzer output is monitored with a multi-channel analyzer. Mixtures of events may be simulated by intermediate values of rise time using a single DB-2, or two DB-2's may be slaved to allow any mixture ratio to be simulated. One DB-2 is set for CsI events; the other DB-2 is set for NaI events; and their amplitude ratio varied to simulate different mixture ratios.

SECTION 4

THEORY OF OPERATION

4.1 INTRODUCTION

Section 4 deals with the theory of operation of the Model DB-2 in four parts: Paragraph 4.2 gives an overall view of the instrument and its major block diagram. Paragraphs 4.3 and 4.4 go into greater detail but still deal with block diagrams. Paragraph 4.5 refers to the schematics and discusses the circuit paths through the instrument. (Diagrams are located at the end of this section.)

4.2 BLOCK DIAGRAM

An overall block diagram of the Model DB-2 appears in Figure 4-1. The Clock Generator provides either periodic or random trigger pulses to the Timing Control and to the TRIG OUT connector. The Precision Current Source provides an adjustable precise current to the Timing Control. The Precision Current Source may be controlled by an external reference voltage applied to the EXT REF connector.

The Timing Control switches the current (from the Precision Current Source) to the Charge Sensitive Amplifier for 80 ns each time a trigger pulse arrives from the Clock Generator. This current pulse contains an amount of charge that is directly proportional to the magnitude of the current provided by the Precision Current Source.

The Charge Sensitive Amplifier accepts the charge pulse from the Timing Control, and produces an abrupt voltage transition at its output. An Average Value Subtractor removes the DC component of the Charge Sensitive Amplifier output, thereby increasing its dynamic range.

The Pulse Shape Controls introduce RC pulse shaping allowing the pulse rise time and fall

time to be varied. The Output Buffer Amplifier isolates the Pulse Shaping Controls from the output connector, provides polarity selection, and contains passive attenuators. The Output Buffer Amplifier has a 50Ω output impedance to allow the use of terminated coaxial cables to transmit the pulse.

4.3 CLOCK CIRCUITRY (See Fig. 4-2.)

The Periodic Generator utilizes an Emitter Coupled Multivibrator as the basic timing element. Coarse frequency adjustment in decade steps is realized by switching the emitter capacitor, C_T , while fine adjustment within any decade is accomplished by varying the charging rate via a potentiometer, R_T . One coarse switch position disables the multivibrator, allowing an external trigger to be used. A Comparator detects external trigger signals exceeding 0.7 V and provides a logic signal to the OR gate. The 80 ns One Shot standardizes the pulses from either the multivibrator or the external trigger.

The random portion of the Clock Generator consists of a noise generator, buffer amplifier, variable threshold comparator and cascade one shot. A Differential Ratemeter compares the average frequencies from the Random and Periodic Generators, and adjusts the discrimination threshold level until the two frequencies are the same.

Examining the Random Generator in Figure 4-2, a base-emitter junction operating in the avalanche mode provides a broad band gaussian noise. The high impedance Noise Source is buffered with an amplifier using a Field Effect Transistor (FET Input Buffer). The noise signal is then differentiated, creating a signal with

sharp spikes of varying amplitude. The Comparator detects those spikes exceeding a certain threshold. If the threshold is set to zero, the Comparator will fire on nearly every spike, yielding an average output rate greater than 2 MHz. If the threshold is increased to twice the rms noise voltage, only 2.3% of the spikes will trigger the Comparator, and a lower average rate (~46 kHz) will result. Thus, the average rate of the Random Generator is controlled by the Comparator threshold voltage.

The Comparator output triggers the Cascade One Shot. The first one shot produces a pulse whenever its threshold is exceeded, but its output pulse width varies due to the amplitude and duty cycle variations of the input signal. The second one shot provides output pulses that have little variation in amplitude or pulse width.

The Differential Ratemeter uses two equal diode pumps feeding the same capacitor. The Periodic Generator adds 200 pC (200×10^{-12} coulomb) of charge for each periodic pulse, and the Random Generator subtracts 200 pC for each random pulse. A high input impedance operational amplifier decides whether the Random Generator is subtracting too little or too much charge from the common capacitor. If the voltage on this capacitor is positive, insufficient charge is being removed; therefore, the random frequency is lower than the periodic frequency. The Differential Ratemeter then adjusts the Comparator threshold lower, more noise spikes are counted, and the average random frequency increases. Conversely, a negative voltage on the common capacitor will cause an increase in the Comparator threshold and a decrease in the average random frequency.

The output pulses from the Random Generator and the Periodic Generator are presented to NAND gates, where one pulse source (Random

Generator or Periodic Generator) is selected by the MODE SWITCH, and the other pulse source is blocked.

The selected pulses activate the Trigger One Shot, which standardizes the trigger waveform. One signal path delivers the trigger pulses to the pulse forming circuit, and another path goes to a buffer and then the TRIG OUT connector. The buffering drives 50 Ω loads and isolates the pulse generator from even short circuits at the TRIG OUT connector.

4.4 CHARGE LOOP AND OUTPUT

(See Figure 4-3.)

The basic output pulse is created by allowing a Charge Sensitive Amplifier to sample a carefully controlled current for a precise time interval. The units of current multiplied by time yield charge, thus the magnitude of the voltage transition at the output of the Charge Sensitive Amplifier is proportional to both the controlled current and the precision time interval. The time interval is fixed at 80 ns, with a temperature coefficient that compensates for the thermal coefficient of the Charge Sensitive Amplifier feedback capacitor.

Referring to Figure 4-3, the Precision Current Source utilizes a reference diode and a constant current source to generate a reference voltage that is independent of power supply variations. A portion of this voltage, selected by a ten-turn potentiometer (the DB-2 AMPLITUDE control) is compared to the voltage drop across a series resistor in a FET current generator circuit. The FET gate voltage is adjusted by the Comparator to reduce any difference voltage discovered. Virtually all the current passing through the sense resistor comes through the FET from the Current Switch. An external

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input (not shown) may provide the reference voltage to accommodate programming of the amplitude by external means.

The Current Switch, operated by the Timing Control One Shot, uses Schottky (or hot-carrier) diodes to insure rapid switching and minimum charge storage. Normally D17 is conducting and D18 is reverse-biased. The current required by the Precision Current Source is provided by the Timing Control One Shot. When this one shot is triggered, D17 is reverse-biased and D18 conducts, diverting the current path from the one shot to the Charge Sensitive Amplifier for the duration of the one shot timing interval (80 ns).

The Charge Sensitive Amplifier integrates the rectangular current pulse from the Current Switch to produce a voltage transition proportional to its charge content. A discrete component operational amplifier with a FET input and a slew rate in excess of $350 \text{ V}/\mu\text{s}$ is used in this section. The feedback capacitor and resistor is switched to implement the different output voltage ranges. The decay time constant of the Charge Sensitive Amplifier output pulse is 10 ms, and the leading edge is a linear ramp lasting 80 ns.

The Average Value Subtractor restores the average value of the Charge Sensitive Amplifier output to zero volts in order to reduce the dynamic range requirements for the Charge Sensitive Amplifier. The time constant of the Average Value Subtractor is sufficiently long that the 10 ms tail pulse remains undistorted.

Control of the pulse Rise Time and Fall Time is obtained by passive RC shaping circuits (Pulse Shape Controls) between the Charge Sensitive Amplifier and the Buffer Amplifier.

The Fall Time adjustment controls the time constant of the exponential decay. If a periodic rate is selected such that rate $>10/\text{fall time constant}$, then the output waveform will approximate a linear discharge between pulses because less than the first 10% of the exponential decay is shown. However, the time constant does not change from that originally selected.

Polarity selection and signal buffering occurs in the Buffer Amplifier. The circuit is arranged to amplify the pulse by +4 or -4, depending upon the selected output polarity. A series 50Ω balanced π attenuator (not shown) allows the output pulse to be attenuated by as much as 1000, yet maintains the 50Ω output impedance.

4.5 CIRCUIT DESCRIPTION

Before studying the following paragraphs, it is recommended that paragraphs 4.1 through 4.4 be read to obtain the general concepts.

4.5.1 PERIODIC CLOCK

(Refer to Schematic DB-2-31 in Section 6.)

A free-running multivibrator, Q1 - Q2, generates the Periodic Clock frequency when S1 is in one of the continuous frequency positions. The frequency range is selected by C2 - C6 on S1, and continuous adjustment is provided by R5. The signal at the collector of Q2 is differentiated by C7 - R14 and passes through diode D4 to the input (pins 3, 4) of the periodic one shot, Z1.

External trigger signals exceeding 0.7 V are amplified by Q3 - Q4 and presented to the input (pins 3, 4) of the one shot, Z1. Protection against excessive voltages is provided by D2 - D3.

- THEORY OF OPERATION -

Z1 provides a standard-width, negative-going pulse at pin 6 and a positive pulse at pin 8.

4.5.2 RANDOM CLOCK

(Refer to Schematic DB-2-31 in Section 6.)

The base-emitter junction of Q9 is reverse-biased to provide a source of noise. The noise signal is amplified by Q10, then differentiated by C18 - R34. Q12 and Q13, in conjunction with the input circuit of the random one shot, Z5, form a comparator circuit. This comparator fires Z5 every time the noise signal exceeds the comparator threshold voltage. The output of Z5 is a negative-going pulse and appears at pin 6 of Z5 and is also connected to the input (pin 13) of Z3. Flip-flop Z3 is connected as a one shot.

A negative-going edge at input pin 13 causes a "0" to be shifted into the flip-flop. The Q output, pin 9, goes low and C23 begins to discharge through R40. A short time later, C23 is discharged sufficiently to activate the direct set input, and the flip-flop is set to the "1" state. Pin 9 goes high and C23 is rapidly charged through D11. The negative-going pulse at pin 9 is inverted by gate Z2 and a positive-going pulse appears at pin 3 of Z2. The \bar{Q} output of the flip-flop (pin 8) produces a positive-going pulse.

4.5.3 DIFFERENTIAL RATEMETER

(Refer to Schematic DB-2-31 in Section 6.)

The negative pulse from Z1 pin 6 discharges C10 through D8 to ground. After the pulse is over, C10 is charged in series with C16 through D7. This adds 200 pC (or 0.2×10^{-9} coulomb) to C16 for each periodic pulse. Positive pulses from Z2 pin 3 charge C14 and C15 through D10

to ground. After each pulse, C14 and C15 are discharged in series with C16, thus subtracting 200 pC from C16 for each random pulse.

The voltage of C16 is compared to ground by Q7 - Q8 and Z4. The output of Z4 (pin 10) swings more negative if the voltage of C16 is negative. C12 and R24 integrate the Z4 output so that rapid variations in the voltage of C16 are ignored. The output signal (Z4 pin 10) drives current source Q6 and offsets the base voltage of Q12 from that of Q13. This action effectively varies the threshold voltage of comparator Q12 - Q13, thereby controlling the average rate of pulses that fire Z5.

Because the voltage of C16 can only equal zero if the periodic rate (Z1 pin 6) is equal to the average random rate (Z2 pin 3), the Differential Ratemeter varies the random rate until it matches the periodic rate. C15 adjusts the amount of charge subtracted from C16 by each random pulse, and R25 adjusts the Q7 - Q8 offset voltage.

4.5.4 MODE SWITCH AND TRIGGER ONE SHOT

(Refer to Schematic DB-2-31 in Section 6.)

The Mode switch, S2, provides a low level to Z2 pin 13 when in the REP position. Pin 9 of Z2 is high, allowing the positive pulses from Z1 pin 8 to pass through (and be inverted by) Z2. The positive pulses from Z3 pin 8 are blocked by Z2 because of the low signal on pin 13. Z2 pin 11 is high, keeping D12 reverse-biased, and the negative pulses appearing at Z2 pin 8 pass through D5 to pin 1 of Z3. In a similar manner, when the Mode switch is in the RANDOM position, pulses from Z1 are blocked, and pulses from Z3 pin 8 are passed through Z2, D12 and hence to pin 1 of Z3. When Range switch, S3, is in the 10 V position, the Mode

- THEORY OF OPERATION -

switch is overridden and only periodic pulses from Z1 reach pin 1 of Z3.

Flip-flop Z3 is connected as a one shot as described above (see 4.5.2, Random Clock). The negative-going pulse at pin 5 is inverted by Z2, and the positive pulse at Z2 pin 6 passes through R20 and is routed to the EXT TRIG connector. The positive pulse at Z3 pin 6 passes through R19 to the one shot in the Timing Control.

4.5.5 TIMING CONTROL

(Refer to Schematic DB-2-32 in Section 6.)

The trailing edge of the positive pulse from Z3 pin 6 triggers the Timing Control one shot, Z7. C22 is charged by current from temperature dependent current source Q15 - Q16. R46 adjusts the temperature coefficient, while the one shot interval is set by R45. The Timing Control output is a negative-going pulse at Z7 pin 6.

4.5.6 PRECISION CURRENT SOURCE

(Refer to Schematic DB-2-32 in Section 6.)

Q32 - Q33 form a constant current source for reference diode D16. The fixed voltage across D16 is divided down to a 0V - 2V range (referenced to -12V) by R54 and R56. R60 provides an adjustment of the minimum voltage.

External reference voltages produce a reference current through R48 - R49 to the virtual ground at Z8 pin 4. Essentially, all of that current passes through Q14 to R52, where a fixed fraction (1/5) of the original reference voltage is now referenced to the same -12V as the internal reference voltage. D15 and D25 provide protection against excessive external voltages, and R51 provides an adjustable bias current to set the minimum voltage across R52.

The Reference Select switch, S4, may be set to allow either the internal reference or the external reference to control the output pulse amplitude.

The current flowing through Q17 produces a voltage across R59 and R61. Z9 compares this voltage to the selected (by S4) reference voltage and varies the Q17 current until both voltages (Z9 pins 4, 5) match. For a given voltage at Z9 pin 4, the Q17 current may be adjusted by means of R61 (Normalize Control).

4.5.7 CURRENT SWITCH

(Refer to Schematic DB-2-32 in Section 6.)

The current for Q17 is normally supplied by R105 through D17. Current also flows through D27 and D26. When Z7 fires, pin 6 is forced to ground, and all of the current flowing in R105 is diverted to Z7. The drain voltage of Q17 rapidly drops from 5.5V to 2V, forward biasing D18. The current required by Q17 is now supplied by C37 (10V range) or C37, C36 (1V range). At the end of the time interval for Z7 (80 ns), the voltage at Z7 pin 6 rises to 5.5V (clamped by D26) and D17 is forward-biased again. D18 becomes reverse-biased, and current from C37 or C37 and C36 ceases to flow through D18.

4.5.8 CHARGE SENSITIVE AMPLIFIER

(Refer to Schematic DB-2-32 in Section 6.)

When current flows through D18, the voltage at the gate of Q22 drops slightly, thereby unbalancing the Q22 - Q23 differential pair, and the Q20 - Q21 differential pair. The collector voltage of Q21 rises slightly, reducing the emitter current of Q25. This causes a rise in Q25 collector voltage, and Q26 - Q27 base voltages. The output of the Charge Sensitive Amplifier increases, causing the required current to flow

- THEORY OF OPERATION -

through C36 (or C37 and C36) through D18, and on to Q17. Bias current for Q22 - Q23 is provided by constant current source Q24, while input voltage offset is adjusted by R89. Q18 supplies bias current to Q20 - Q21, and Q19 provides bias current for the output stage, Q26 - Q27. D20 and D21 provide thermal compensation for Q26 - Q27 quiescent current as determined by R94 and R95. High-frequency compensation is provided by C28 and R88, C57.

Each output pulse is 2.5 V in amplitude (10 V range) or 0.25 V (1 V range). Range selection is provided by changing the size of the feedback capacitor with S3.

4.5.9 AVERAGE VALUE SUBTRACTOR

(Refer to Schematic DB-2-32 in Section 6.)

The Charge Sensitive Amplifier output signal is compared to ground by Z10. If the average signal voltage is positive, the voltage on C38 is slowly reduced until the signal averages zero volts. Simultaneously, the voltage on C55 decreases, causing an increase at the collector of Q31, and an increase in emitter current of Q30. The increased current flows through R68 into the feedback capacitor of the Charge Sensitive Amplifier, causing a reduction of the voltage at the output. The long time constant of R78 - C38 insures that this process happens so slowly that individual pulses in the Charge Sensitive Amplifier are not distorted. R75 corrects for Z10 offset current.

If the output of the Charge Sensitive Amplifier exceeds +7.5 V or -7.5 V, either Q28 or Q29 temporarily conducts, changing the voltage on C38 more rapidly than normal. This provides quick return to the null condition (Charge Sensitive Amplifier output = zero average) for sudden changes in rate or amplitude.

4.5.10 PULSE SHAPE CONTROLS

(Refer to Schematic DB-2-33 in Section 6.)

The Charge Sensitive Amplifier output signal (at Q26 emitter) has an 80 ns linear rise time (0% - 100%) and a 10 ms exponential fall time (100% - 37%). The signal is integrated by R152 and a capacitor selected by S6, the Rise Time switch. (Some additional integration is provided by C65 in the Buffer Amplifier and C71 at the output connector.)

The signal, after the integration for rise time, is differentiated by R152, a capacitor selected by S5, and the input impedance of the Buffer Amplifier. This differentiation allows control of the fall time decay constant. The pulse is fully shaped at this point.

4.5.11 BUFFER AMPLIFIER

(Refer to Schematic DB-2-33 in Section 6.)

The Buffer Amplifier is an operational amplifier providing a gain of either +4 or -4 depending upon the Polarity switch (S7) setting. The operational amplifier is nearly identical to that used in the Charge Sensitive Amplifier. Input offset adjustment is provided by R118, and output quiescent current is set by R131.

When the Polarity switch is set to "+", the signal from S5 is routed to the positive input of the amplifier, Q36 - gate, and the negative input is connected to -2.5 V through R155 and R153. The signal from S5 is divided by R152 and R154, then multiplied by the follower-with-gain connection of the amplifier. The net effect is a gain of +4 from the Charge Sensitive Amplifier output to the Buffer Amplifier output. In this configuration, both Buffer Amplifier inputs are referenced to -2.5 V, thus the output average

- THEORY OF OPERATION -

voltage (at R126, R127) is -2.5 V. The output signal is coupled through C69 - C70 and referenced to ground by R135. R133 and R134 increase the output impedance to 50 Ω .

When the Polarity switch is set to "-", the signal from S5 is routed through R155 to the negative input of the amplifier. The positive input is connected through R154 to -2.5 V. Q34 is turned on by connecting R111 through R153 to -2.5 V. In this configuration, the Buffer Amplifier is converted to an inverting amplifier with a gain of -4. The steady current through R113 changes the output average voltage (at R126, R127) from -2.5 V to +2.5 V. Again, the output signal is coupled through C69 - C70

and referenced to ground by R135. R133 and R134 increase the output impedance to 50 Ω .

4.5.12 ATTENUATOR

The output signal passes through four Attenuators, controlled by switches S8 - S11. Each Attenuator is a 50 Ω balanced π type providing either 2, 5, or 10 times attenuation. A noise filter, consisting of two ferrite beads and C71, reduces switching spikes down to the millivolt level.

4.5.13 +5 VOLT POWER

Power for the digital logic (Z1, Z2, Z3, Z5, and Z7) is supplied by Z6 from the +12 V input. The nominal current through Z6 is 100 mA.

SECTION 5

MAINTENANCE

5.1 INTRODUCTION

The Model DB-2 Random Pulse Generator has been designed to provide trouble-free service with minimal preventive maintenance required. However, an occasional operational check using the calibration procedure (paragraph 5.3) can be useful in discovering and localizing minor problems which may not be apparent in normal use. In some cases, recalibration will cure the problem.

5.2 TEST EQUIPMENT

The following test equipment is required to calibrate the Model DB-2. Recommended equipment models are given in parentheses.

- 1) 50 MHz Oscilloscope with a Differential Comparator Plug-In (Tektronix 7504, 7A13, 7B50).
- 2) Regulated NIM Power Supply (BNC AP-2).
- 3) Shaping Amplifier with Bipolar Output (Tennelec TC211).
- 4) Adjustable Regulated DC Power Supply, 0 - 10 V (Hewlett Packard 721A).
- 5) VOM (Triplett 630-NA).
- 6) 50 Ω cables and termination.
- 7) Extender cable for NIM Power Supply.
- 8) Laboratory Oven.

5.3 CALIBRATION PROCEDURE

The calibration procedure should be performed in the sequence given to minimize interaction of adjustments. Any defective components should be replaced prior to calibration. The Model DB-2 and all test instrumentation should be allowed to operate for thirty minutes prior to making adjustments (the initial performance check may be performed during this time).

----- NOTE -----

Location of the calibration trimmers is shown in Figure 5-1.

5.3.1 VISUAL INSPECTION

The exterior of the Model DB-2 should be examined for bent or broken controls or connectors. Remove both side covers and inspect the interior for damage to the circuit board, wires, or components. The remedy for most visible defects will be obvious; however, care must be used if heat-damaged components are encountered. Usually overheating is only a symptom of trouble. For this reason, it is essential to determine the actual cause of the overheating, or the damage may be repeated.

5.3.2 SETUP

Connect the Model DB-2 to the NIM power supply via the extender cable. Monitor the output pulse (PULSE OUT) with the oscilloscope using a 50 Ω terminated line.

Set the controls as follows:

- RANGE = 10 V
- MODE = REP (Repetitive)
- AMPLITUDE = 10.0
- NORMALIZE = 10.0
- FREQUENCY = 1 kHz (fine control fully clockwise)
- RISE TIME = 0.1 μ s
- FALL TIME = 200 μ s
- POL (polarity) = +
- REF = INT
- No attenuation = (All ATTEN switches set to left)

5.3.3 INITIAL PERFORMANCE CHECK

- 1) Apply power to the NIM supply and check for 5 V (approximately) output pulses over all frequency settings (except EXT).
- 2) Return the FREQUENCY controls to the nominal 1 kHz setting (see setup above) and note that the leading edge of the tail pulse is positive in slope.
- 3) Change the polarity (POL) switch and note that the leading edge is now negative in slope.
- 4) Set the RANGE to 1 V and the MODE to RANDOM. Note that the pulses are approximately 0.5 V in amplitude, and are randomly spaced in time.

----- NOTE -----
Allow the Model DB-2 to operate for thirty minutes before continuing the procedure.

5.3.4 RATEMETER OFFSET (R25)

Monitor the cathode of D7 with the oscilloscope using the 0.2 V/div scale. Adjust R25 for zero average volts.

5.3.5 LOOP INPUT DC OFFSET

- 1) Set the FREQUENCY to EXT and the RANGE switch to 10 V.
- 2) Set the MODE to REP.
- 3) Using the differential comparator, monitor the differential voltage from the anode of D28 to the cathode of D29.
- 4) Adjust R89 until the voltage is zero ± 0.1 V.

5.3.6 LOOP OUTPUT DC OFFSET (R75)

- 1) Set the RANGE to 1 V and monitor the junction of C72 - C79 (on the FALL TIME switch).
- 2) Adjust R75 for a DC voltage of -0.5 ± 0.5 V.

----- NOTE -----

Since there are long time constants in the circuit, 30 or more seconds should be allowed for circuit settling. The adjustment range of R75 is 10 V, thus the output offset would only change by 2.5 V for a quarter turn of the pot.-----

5.3.7 RATEMETER CHARGE EQUALIZATION (C15)

- 1) Set the FREQUENCY controls to approximately 1 MHz.
- 2) Monitor Z10 pin 10 with the differential comparator.
- 3) Measure the DC voltage with the MODE set to REP.
- 4) Change the MODE to RANDOM and adjust C15 (using a non-metallic tool) until the DC voltage is within ± 0.01 V of the REP value.

5.3.8 BUFFER AMPLIFIER DC OFFSET (R118)

- 1) Set the FREQUENCY control to EXT and monitor the heat sink of Q45 with the oscilloscope.
- 2) Set the RANGE to 1 V and set POL to '+'.
- 3) Measure the DC voltage to the nearest 0.1 V. It should be negative.
- 4) Set the POL switch to '-' and again measure the voltage which should now be positive.
- 5) Adjust R118 until the magnitudes of the two voltages are the same within ± 0.1 V.
- 6) Repeat both measurements each time R118 is adjusted. The final value should be 2.5 ± 0.5 V.

5.3.9 BUFFER AMPLIFIER BIAS (R131)

- 1) Set the FREQUENCY control to 10 kHz (fine control fully clockwise), RANGE to 1 V, MODE to REP, and POL to '-'.
- 2) Monitor the output (PULSE OUT) using the 50 Ω termination at the oscilloscope.
- 3) Adjust R131 for minimum peaking. Use a non-metallic tool for this adjustment.

5.3.10 OUTPUT AMPLITUDE (R45)

- 1) Set the RANGE to 10V, and verify that both AMPLITUDE and NORMALIZE are set to 10.0.
- 2) Set the RISE TIME to 0.2 μ s and the FALL TIME to 100 μ s.
- 3) Monitor the output pulse (PULSE OUT) with the differential comparator (terminate with 50 Ω) and measure the magnitude of the amplitude step.
- 4) Switch POL to '+' and repeat the measurement.
- 5) Adjust R45 until both amplitudes fall between 5.0 V and 5.1 V (10.0 - 10.2 V un-terminated).

5.3.11 INTERNAL ZERO INTERCEPT (R60)

- 1) Set the AMPLITUDE to 2.00, RANGE to 1.0 V, and POL to '+'.
 2) Connect the output pulse (PULSE OUT) to the input of the shaping amplifier and terminate with 50 Ω .
 3) Set the amplifier for time constants between 0.5 μ s and 3 μ s.
 4) Set the gain to a value between 20 and 40, yielding a signal between 2 V and 4 V.
 5) Measure the signal with the differential comparator.
 6) Set the AMPLITUDE to 1.00 and repeat the measurement.
 7) Subtract the readings to obtain the calculated 1.00 value.
 8) Adjust R60 until the measurement at 1.00 equals the calculated 1.00 value.

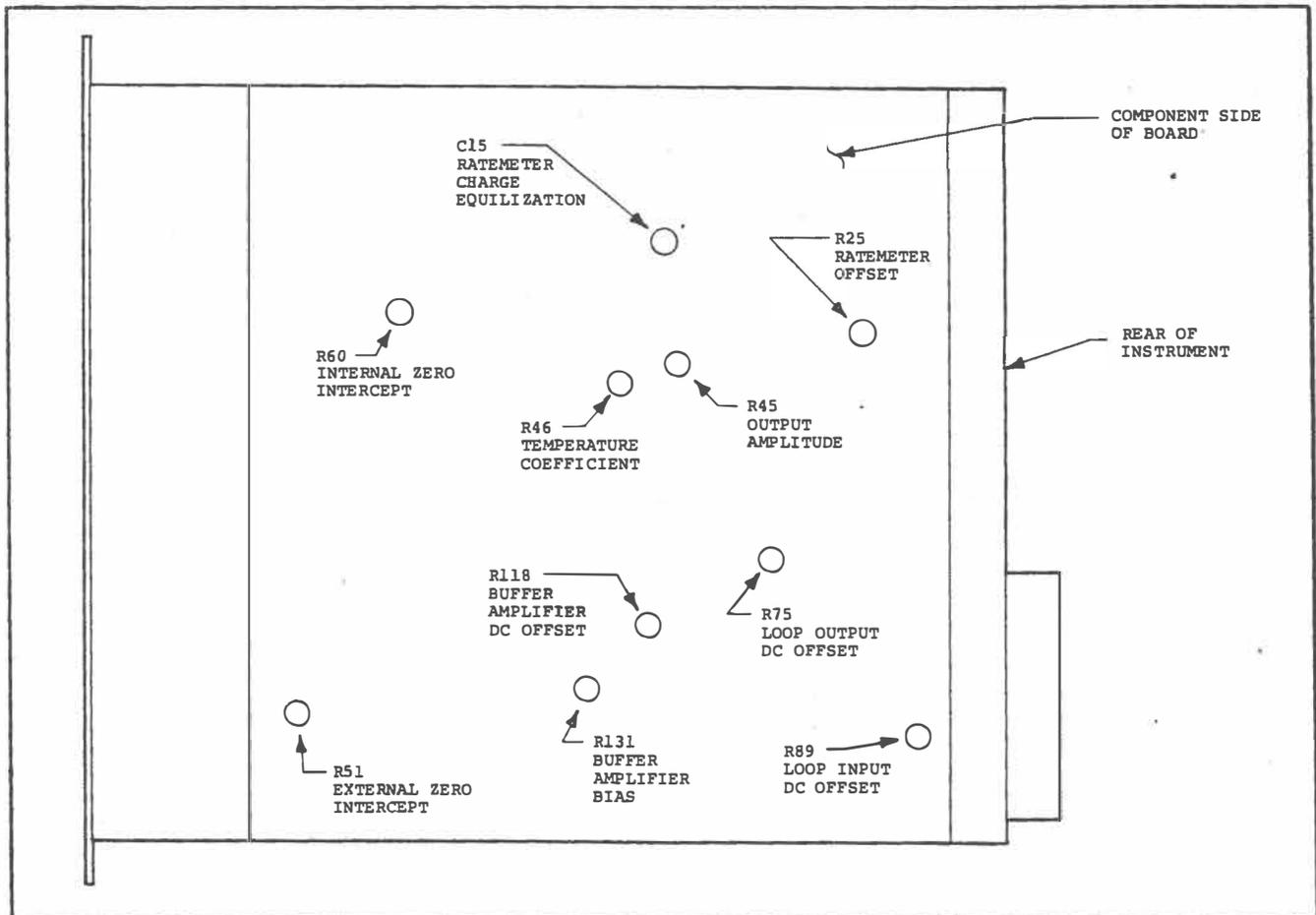


FIG. 5-1. Location of Calibration Trimmers.

- MAINTENANCE -

5.3.12 EXTERNAL ZERO INTERCEPT (R51)

- 1) Properly adjust R60 (see above) before adjusting R51.
- 2) Set REF to EXT.
- 3) Connect the DC power supply to the EXT REF connector.
- 4) Adjust the power supply until it is set to 2.000 ± 0.001 V.
- 5) Measure the output of the shaping amplifier as before.
- 6) Set the supply to 1.000 ± 0.001 V.
- 7) Subtract the readings to obtain the calculated 1.000 V value.
- 8) Adjust R51 until the 1.000 measurement matches the 1.000 value.

5.3.13 TEMPERATURE COEFFICIENT (R46)

The two amplitude ranges have slightly differing temperature coefficients (TC). If either range is adjusted for zero TC, the other range will fall within the stated specification ($\leq 0.02\%/^{\circ}\text{C}$).

- 1) Place the DB-2 in the laboratory oven and set the temperature controller to slightly above room ambient temperature.

- 2) Set the AMPLITUDE to 9.00, the MODE to REP, the RANGE to 10 V.
- 3) Set the RISE TIME to $0.2 \mu\text{s}$ and the FALL TIME to $100 \mu\text{s}$.
- 4) After thermal equilibrium is obtained, measure the wiper arm voltage of R46 using the differential comparator.

----- NOTE -----

Be sure that all probes and cables are removed from R46 after each measurement.

- 5) Record the output voltage, the temperature, and the wiper arm voltage of R46.
- 6) Repeat these measurements at an elevated (room + 15°C) temperature.
- 7) Calculate the thermal coefficient:
 - (a) If the TC is negative, adjust R46 so that a higher wiper voltage is obtained.
 - (b) If the TC is positive, adjust R46 so that a lower wiper voltage results.
- 8) Record the new wiper voltage.
- 9) While monitoring the DB-2 output, adjust R45 until the output voltage returns to the earlier recorded value (room temperature).
- 10) Repeat the temperature test until the TC is set to zero.

SECTION 6

PARTS LIST AND SCHEMATICS

ABBREVIATIONS

cer	ceramic	μ H	microhenry
comp	composition carbon	μ F	microfarad
elec	electrolytic, metal case	pF	picofarad
mic	mica	pos	positions
myl	mylar	tan	tantalum
K	kilohm	V	working volts DC
M	megohm	var	variable
m	milli	W	watts
MF	metal film	ww	wirewound

NOTE

----- NOTE -----
 The last number after each part description is the
 BERKELEY NUCLEONICS part number for reordering.

CAPACITORS

C1	0.05 μ F	cer	500 V		110-015	C36	910 pF	myl		10%	114-032
C2*	470 pF	mic	100 V	5%	112-013	C37	100 pF	poly	50 V	10%	115-001
C3	0.0047 μ F	myl	400 V	10%	114-008	C38	100 μ F	elec	16 V		120-007
C4	0.047 μ F	myl	200 V	10%	114-018	C39	0.33 μ F	myl	600 V	10%	114-016
C5	0.47 μ F	myl	100 V	10%	114-023	C40	0.47 μ F	cer	10 V		110-016
C6	4.7 μ F	tan	35 V	10%	122-004	C41	25 μ F	elec	25 V		120-005
C7	220 pF	cer			110-020	C42	0.05 μ F	cer	500 V		110-015
C8	22 pF	mic	500 V	5%	112-001	C43	25 μ F	elec	25 V		120-005
C9	25 μ F	elec	25 V		120-005	C44	22 pF	mic	500 V	5%	112-001
C10	56 pF	mic	500 V	5%	112-022	C45	0.05 μ F	cer	500 V		110-015
C11	330 pF	mic	500 V	5%	112-010	C46	25 μ F	elec	25 V		120-005
C12	25 μ F	elec	25 V		120-005	C47	0.47 μ F	cer	10 V		110-016
C13	100 pF	mic	500 V	5%	112-004	C48	0.05 μ F	cer	500 V		110-015
C14	68 pF	mic	500 V	5%	112-018	C49	0.05 μ F	cer	500 V		110-015
C15	4.5-50 pF	var			130-003	C50	100 μ F	elec	16 V		120-007
C16	0.05 μ F	cer	500 V		110-015	C51	25 μ F	elec	25 V		120-005
C17	0.05 μ F	cer	500 V		110-015	C52	0.05 μ F	cer	500 V		110-015
C18	100 pF	mic	500 V	5%	112-004	C53	0.05 μ F	cer	500 V		110-015
C19	0.05 μ F	cer	500 V		110-015	C54	68 pF	mic	500 V	5%	112-018
C20	0.05 μ F	cer	500 V		110-015	C55	100 μ F	elec	16 V		120-007
C21	22 pF	mic	500 V	5%	112-001	C56	25 μ F	elec	25 V		120-005
C22	0.05 μ F	cer	500 V		110-015	C57	62 pF	mic	500 V	5%	112-023
C23	390 pF	mic	500 V	5%	112-011	C58	0.05 μ F	cer	500 V		110-015
C24	0.05 μ F	cer	500 V		110-015	C59	0.05 μ F	cer	500 V		110-015
C25	25 μ F	elec	25 V		120-005	C60	100 μ F	elec	16 V		120-007
C26	100 pF	mic	500 V	5%	112-004	C61	100 μ F	elec	25 V		120-008
C27	220 pF	cer			110-020	C62	100 μ F	elec	25 V		120-008
C28	20 pF	mic	500 V	5%	112-025	C63	5 pF	mic	500 V	5%	112-021
C29	0.05 μ F	cer	500 V		110-015	C64	0.05 μ F	cer	500 V		110-015
C30	0.05 μ F	cer	500 V		110-015	C65	4 pF	mic	500 V	5%	112-027
C31	0.05 μ F	cer	500 V		110-015	C66	0.05 μ F	cer	500 V		110-015
C32	100 μ F	elec	25 V		120-008	C67	1000 μ F	elec	15 V		120-018
C33	100 μ F	elec	25 V		120-008	C68	1000 μ F	elec	15 V		120-018
C34	0.05 μ F	cer	500 V		110-015	C69	1000 μ F	elec	15 V		120-018
C35	0.05 μ F	cer	500 V		110-015	C70	1000 μ F	elec	15 V		120-018

. . . continued

- PARTS LIST -

CAPACITORS (continued)

C71	1200 pF	myl		10%	114-031
C72	0.0022 μ F	myl	600 V	10%	114-003
C73	0.0047 μ F	myl	400 V	10%	114-008
C74	0.01 μ F	myl	200 V	10%	114-025
C75	0.022 μ F	myl	100 V	10%	114-014
C76	0.047 μ F	myl	200 V	10%	114-018
C77	0.1 μ F	myl	100 V	10%	114-020
C78	0.27 μ F	myl	100 V	10%	114-030
C79	0.68 μ F	myl	100 V	10%	114-028
C80	0.05 μ F	cer	500 V		110-015
C81	150 pF	mic	500 V	5%	112-005
C82	430 pF	mic	100 V	5%	112-012
C83	0.001 μ F	myl	600 V	10%	114-001
C84	0.002 μ F	myl	600 V	10%	114-002
C85	0.0047 μ F	myl	400 V	10%	114-008
C86	0.01 μ F	myl	200 V	10%	114-025
C87	0.02 μ F	myl	200 V	10%	114-013
C88	25 μ F	elec	25 V		120-005
C89	33 pF	cer	1 KV	10%	110-004
C90	10 pF	mic	500 V	5%	112-016
C91	0.05 pF	cer	25 V	20%	110-019

DIODES

D1	1N4154	411-003
D2	1N4154	411-003
D3	1N4154	411-003
D4	1N4154	411-003
D5	1N270	411-002
D6	1N4154	411-003
D7	1N4154	411-003
D8	1N4154	411-003
D9	1N4154	411-003
D10	1N4154	411-003
D11	1N4154	411-003
D12	1N270	411-002
D13	1N4739	413-004
D14	1N4739	413-004
D15	1N4154	411-003
D16	1N821	412-001
D17	1N5713	415-003
D18	1N5713	415-003
D19	1N4154	411-003
D20	1N270	411-002
D21	1N270	411-002
D22	1N4154	411-003
D23	1N4154	411-003
D24	1N4737	413-003
D25	1N4154	411-003
D26	1N5713	415-003
D27	1N5713	415-003
D30	1N4100	410-001
D31	1N4742	413-005
D32	1N4154	411-003

D33	1N4742	413-005
D34	1N270	411-002
D35	1N270	411-002
D36	1N4154	411-003
D37	1N4154	411-003

INDUCTOR

L1	39 μ H	310-009
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INTEGRATED CIRCUITS

Z1	74122 N	440-145
Z2	MC3000P	440-024
Z3	74S113	440-094
Z4	741C	440-021
Z5	74122 N	440-145
Z6	7805	440-023
Z7	74122 N	440-145
Z8	741C	440-021
Z9	741C	440-021
Z10	741C	440-021

RESISTORS

R1	430 Ω	1/4 W	comp	5%	213-431
R2	100 Ω	1/4 W	comp	5%	213-101
R3	2.2 K	1/4 W	comp	5%	213-222
R4	2.7 K	1/2 W	comp	5%	212-272
R5	75 K		var		610-012
R6	15 K	1/4 W	comp	5%	213-153
R7	2 K	1/2 W	comp	5%	212-202
R8	2.2 K	1/4 W	comp	5%	213-222
R9	1 K	1/4 W	comp	5%	213-102
R10	1 K	1/4 W	comp	5%	213-102
R11	2.2 K	1/4 W	comp	5%	213-222
R12	2.2 K	1/4 W	comp	5%	213-222
R13	470 Ω	1/4 W	comp	5%	213-471
R14	1 K	1/4 W	comp	5%	213-102
R15	4.7 K	1/4 W	comp	5%	213-472
R16	10 K	1/4 W	comp	5%	213-103
R17	1 K	1/4 W	comp	5%	213-102
R18	150 Ω	1/4 W	comp	5%	213-151
R19	100 Ω	1/4 W	comp	5%	213-101
R20	39 Ω	1/4 W	comp	5%	213-390

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- PARTS LIST -

RESISTORS (continued)

R21	10 K	1/4 W	comp	5%	213-103	R71	2.2 K	1/4 W	comp	5%	213-222
R22	27 K	1/4 W	comp	5%	213-273	R72	2.2 K	1/4 W	comp	5%	213-222
R23	270 K	1/4 W	comp	5%	213-274	R73	4.7 M	1/4 W	comp	5%	213-475
R24	1 K	1/4 W	comp	5%	213-102	R74	2.4 M	1/4 W	comp	5%	213-245
R25	1 K		var		244-025	R75	10 K		var		244-025
R26	27 K	1/4 W	comp	5%	213-273	R76	10 K	1/4 W	comp	5%	213-103
R27	1 K	1/4 W	comp	5%	213-102	R77	4.7 K	1/4 W	comp	5%	213-472
R28	27 K	1/4 W	comp	5%	213-273	R78	10 M	1/4 W	comp	5%	213-106
R29	2.2 K	1/4 W	comp	5%	213-222	R79	10 K	1/4 W	comp	5%	213-103
R30	1 M	1/4 W	comp	5%	213-105	R80	2.2 K	1/4 W	comp	5%	213-222
R31	2.2 K	1/4 W	comp	5%	213-222	R81	22 M	1/4 W	comp	5%	213-226
R32	10 K	1/4 W	comp	5%	213-103	R82	10 M	1/4 W	comp	5%	213-106
R33	10 K	1/4 W	comp	5%	213-103	R83	10 Ω	1/4 W	comp	5%	213-100
R34	1 K	1/4 W	comp	5%	213-102	R84	30 K	1/4 W	comp	5%	213-303
R35	1 K	1/4 W	comp	5%	213-102	R85	1 K	1/4 W	comp	5%	213-102
R36	1 K	1/4 W	comp	5%	213-102	R86	30 K	1/4 W	comp	5%	213-303
R37	470 Ω	1/4 W	comp	5%	213-471	R87	2.2 K	1/4 W	comp	5%	213-222
R38	470 Ω	1/4 W	comp	5%	213-471	R88	100 Ω	1/4 W	comp	5%	213-101
R39	4.7 K	1/4 W	comp	5%	213-472	R89	10 K		var		244-025
R40	150 Ω	1/4 W	comp	5%	213-151	R90	2.2 K	1/4 W	comp	5%	213-222
R41	10 K	1/4 W	comp	5%	213-102	R91	10 K	1/4 W	comp	5%	213-103
R42	100 Ω	1/4 W	comp	5%	213-101	R92	1 K	1/4 W	comp	5%	213-102
R43	(not used)					R93	10 K	1/4 W	comp	5%	213-103
R44	620 Ω	1/2 W	comp	5%	212-621	R94	150 Ω	1/4 W	comp	5%	213-151
R45	10 K		var		244-025	R95	15 Ω	1/4 W	comp	5%	213-150
R46	10 K		var		244-025	R96	220 Ω	1/4 W	comp	5%	213-221
R47	1 M	1/4 W	comp	5%	213-105	R97	10 K	1/4 W	comp	5%	213-103
R48	1.54 K	1/4 W	MF	1%	222-043	R98	10 K	1/4 W	comp	5%	213-103
R49	8.45 K	1/4 W	MF	1%	222-040	R99	10 K	1/4 W	comp	5%	213-103
R50	102 K	1/4 W	MF	1%	222-046	R100	10 K	1/4 W	comp	5%	213-103
R51	10 K		var		244-025	R101	1 K	1/4 W	comp	5%	213-102
R52	2.00 K	1/4 W	MF	1%	222-042	R102	10 M	1/4 W	comp	5%	213-106
R53	604 Ω	1/4 W	MF	1%	222-048	R103	2.2 K	1/4 W	comp	5%	213-222
R54	4.22 K	1/4 W	MF	1%	222-041	R104	(not used)				
R55	1.5 K	1/4 W	comp	5%	213-152	R105	4.7 K	1/4 W	comp	5%	213-472
R56	2 K		var		242-007	R106	2.2 K	1/4 W	comp	5%	213-222
R57	5.1 K	1/4 W	comp	5%	213-512	R107	10 Ω	1/4 W	comp	5%	213-100
R58	100 Ω	1/4 W	MF	1%	222-051	R108	2.2 K	1/4 W	comp	5%	213-222
R59	649 Ω	1/4 W	MF	1%	222-047	R109	10 K	1/4 W	comp	5%	213-103
R60	10 K		var		244-025	R110	39 K	1/4 W	comp	5%	213-393
R61	1 K		var		242-006	R111	100 K	1/4 W	comp	5%	213-104
R62	10 K	1/4 W	comp	5%	213-103	R112	270 K	1/4 W	comp	5%	213-274
R63	10 K	1/4 W	comp	5%	213-103	R113	12 K	1/4 W	comp	5%	213-123
R64	3.3 K	1/4 W	comp	5%	213-332	R114	30 K	1/4 W	comp	5%	213-303
R65	10 K	1/4 W	comp	5%	213-103	R115	1 K	1/4 W	comp	5%	213-102
R66	750 Ω	1/4 W	comp	5%	213-751	R116	30 K	1/4 W	comp	5%	213-303
R67	5.6 K	1/4 W	comp	5%	213-562	R117	2.2 K	1/4 W	comp	5%	213-222
R68	5.6 K	1/4 W	comp	5%	213-562	R118	10 K		var		244-025
R69	1 M	1/4 W	comp	5%	213-105	R119	2.2 K	1/4 W	comp	5%	213-222
R70	4.7 K	1/4 W	comp	5%	213-472	R120	10 K	1/4 W	comp	5%	213-103
						R121	1 K	1/4 W	comp	5%	213-102
						R122	2.2 K	1/4 W	comp	5%	213-222
						R123	100 Ω	1/4 W	comp	5%	213-101
						R124	2.7 Ω	1/2 W	comp	5%	212-027
						R125	15 Ω	1/4 W	comp	5%	213-150

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- PARTS LIST -

RESISTORS (continued)

R126	1 Ω	1/2 W	comp	5%	212-010	Q6	MPS5172	430-031
R127	1 Ω	1/2 W	comp	5%	212-010	Q7	2N4360	430-035
R128	15 Ω	1/4 W	comp	5%	213-150	Q8	2N4360	430-035
R129	100 Ω	1/4 W	comp	5%	213-101	Q9	MPS5172	430-031
R130	2.7 Ω	1/2 W	comp	5%	212-027	Q10	2N5485	431-005
R131	200 Ω		var		244-024	Q11	MPS5172	430-031
R132	8.06 K	1/4 W	MF	1%	222-045	Q12	MPSA70	430-032
R133	100 Ω	1/4 W	MF	1%	222-051	Q13	MPSA70	430-032
R134	100 Ω	1/4 W	MF	1%	222-051	Q14	2N4360	430-035
R135	10 K	1/4 W	comp	5%	213-103	Q15	MPSA70	430-032
R136	10 Ω	1/4 W	comp	5%	213-100	Q16	MPS5172	430-031
R137	10 Ω	1/4 W	comp	5%	213-100	Q17	2N5485	431-005
R138	150 Ω	1/4 W	MF	1%	222-049	Q18	MPSA70	430-032
R139	37.4 Ω	1/4 W	MF	1%	222-053	Q19	MPSA70	430-032
R140	150 Ω	1/4 W	MF	1%	222-049	Q20	MPS6522	430-034
R141	75 Ω	1/4 W	MF	1%	222-052	Q21	MPS6522	430-034
R142	121 Ω	1/4 W	MF	1%	222-009	Q22	2N5485	431-005
R143	75 Ω	1/4 W	MF	1%	222-052	Q23	2N5485	431-005
R144	61.9 Ω	1/4 W	MF	1%	222-005	Q24	MPS5172	430-031
R145	249 Ω	1/4 W	MF	1%	222-011	Q25	MPS5172	430-031
R146	61.9 Ω	1/4 W	MF	1%	222-005	Q26	MPS6522	430-034
R147	61.9 Ω	1/4 W	MF	1%	222-005	Q27	MPS6520	430-033
R148	249 Ω	1/4 W	MF	1%	222-011	Q28	MPSA70	430-032
R149	61.9 Ω	1/4 W	MF	1%	222-005	Q29	MPS5172	430-031
R150	10 Ω	1/4 W	comp	5%	213-100	Q30	MPSA70	430-032
R151	10 Ω	1/4 W	comp	5%	213-100	Q31	MPS6520	430-033
R152	1 K	1/4 W	MF	1%	222-044	Q32	MPSA70	430-032
R153	143 Ω	1/4 W	MF	1%	222-050	Q33	MPSA70	430-032
R154	1 K	1/4 W	MF	1%	222-044	Q34	MPS5172	430-031
R155	1 K	1/4 W	MF	1%	222-044	Q35	2N5485	431-005
R156	2.2 K	1/4 W	comp	5%	213-222	Q36	2N5485	431-005
						Q37	MPSA70	430-032
						Q38	MPSA70	430-032
						Q39	MPSA70	430-032
						Q40	MPS5172	430-031

TRANSISTORS

Q1	MPS5172	430-031	Q41	MPSA70	430-032
Q2	MPS5172	430-031	Q42	MPS5172	430-031
Q3	MPS5172	430-031	Q43	MPS6520	430-033
Q4	MPSA70	430-032	Q44	MPS6522	430-034
Q5	MPSA70	430-032	Q45	MPSU52	430-037
			Q46	MPSU02	430-036



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Model Type User Manual

Document Version Number: 1.0
Print Code: 61020221