BROOKHAVEN BIC INSTRUMENTS CORPORATION

INSTRUCTION MANUAL

for

Models 1000 A and 1000 C

Current Integrators

11124 Jollyville Road   Austin Texas 78759   Ph. (512) 345-4282

CONTENTS

INTRODUCTION AND DESCRIPTION

The BIC Models 1000-A and 1000-C digitizing current integrators accept pulsed or continuous currents of either polarity ranging from a small fraction of a nanoampere to 20 milliamperes. They provide a series of digital output pulses whose number is proportional to the accumulated charge. The input current is displayed on a front panel meter and on any desired number of auxiliary meters connected to the meter output terminals.

The Model 1000-A operates in conjunction with a separate external counter (not supplied) while the 1000-C features an integral counter with switchable 4 to 7-decade capacity, a 4-digit, single-plane solid-state (LED) display and a thumbwheel selected preset for the 4 displayed decades. An LED decimal point shifts appropriately for the prescaling factor in use.

Internal logic enables the counter to be controlled locally by push-button or by signals from a remote source. It also provides a versatile combination of pulse and level outputs for the control of external functions by the counter. An optional feature permits the counter preset to be programmed by signals from a computer or other external source(s).

Both models feature an independent electrical system for the current digitizing portion of the instrument. It has its own floating, regulated supplies and is insulated from the chassis. The external ground connection can be made to the chassis or to any other point required to minimize noise pick-up or avoid creating a ground loop in a particular installation. A coupling transformer isolates this system from the chassis-grounded digital electronics and from all input and output connectors except the input current connectors which are insulated from the chassis.

An adjustable offset current supply neutralizes spurious input currents up to ±10% of full-scale and normally requires no readjustment when switching ranges. A unique balancing system facilitates rapid, precise adjustment of the offset current. The offset supply provides an automatically switched test current of approximately 10% of full-scale to check operation on all ranges.

Automatic correction for dead-time effects in multichannel analyzers, etc. is accomplished by applying dead-time signals to a special high-resolution inhibit gate.

The time constant of the input amplifier feedback network may be switch-selected either for rapid response to eliminate time-lag errors on very short preset runs or for a .1 second input charge-storage capability to accommodate pulsed inputs and provide very high noise immunity. Peak currents up to 20 mA even with extremely large peak-to-average ratios will not cause amplifier saturation on any range high enough to accept the average value of the input current.

There is no practical limit to the length of input cable which may be used without fear of causing input amplifier instability or undesirable transient response. Input loading capacitance up to .25 microfarad will not significantly degrade performance.

A digitizing pulse rate of 1000 pps provides excellent resolution of measurement without requiring the use of interpolating meters.

All of the specifications and descriptions in this manual except those relating specifically to the internal counter-logic system of the Model 1000-C apply equally to the Model 1000-A unless otherwise noted.

SPECIFICATIONS FOR BIC MODELS 1000 A/C CURRENT INTEGRATORS

Input Amplifier: Chopper-stabilized, gain 2×10^8. Wire-wound feedback resistors of .01% accuracy, ±10 ppm/deg tempco maintain accuracy indefinitely.

Instrument ground: Isolated from case. Can be externally grounded at any point to avoid ground loops.

Input impedance: Virtual ground, less than 0.1 microvolt drop full-scale.

Current indication: Panel meter, 2% accuracy. Mirror scale, taut-band.

Input bias current: Settable to 0 $\pm 10^{-13}$A.

Max. input loading capacitance for specified performance: .25 microfarad.

Maximum frequency of pulsed or fluctuating input: No limit. Integrator responds only to true time integral (dc component) of input current regardless of waveshape or frequency of ac components.

Offset adjustment: 10-turn potentiometer on front panel. Normal mode supplies 0 to $\pm 2 \times 10^{-10}$A. Allows input bias and small external leakage currents to be set to 0($\pm 10^{-13}$A). Normally requires no readjustment when switching ranges. Special ±10% mode provides stable, adjustable offset to approx. ±10% of current range in use. Useful for balancing out large external error or background currents. A 20 X meter scale expansion facilitates precise adjustment in either mode.

Absolute accuracy of calibration: ±.02%, all ranges.

Linearity: No measurable non-linearity.

Temperature stability: Max. ±30 ppm/deg for ranges 1 through 12, ±60 ppm/deg for ranges 13, 14, 15.

Test current: Approx. 10% F. S. from offset supply. Selected automatically for each current range.

Peak pulse input current: 20 mA on any range. No duty factor limit. Inputs with peak-to-average ratios in the range of millions are integrated with full specified accuracy. No input filter is required.

Digitizing rate: 1000 pps full scale.

External meter output: Will drive as many remote meters as required. Uses economical 0 to 1 mA meters.

Analyzer dead time correction: Output inhibited by positive 2.5 V to 10 V signal. 20 nsec resolution.

Range Identification: Optional. Provides binary coded readout of range switch position, 3.5 V positive logic. Can supply 2.5 mA, sink 100 mA.

Models 1000 A/C Specs. (cont'd.):

Ranges and input smoothing time constant (input averaging time):*

Range	F. S. Range Amperes	Avg. Time (sec) Fast Mode	Avg. Time (sec) Slow Mode
1	2×10^{-2}	$<10^{-3}$	10^{-3}
2	6×10^{-3}	$<10^{-3}$	3×10^{-3}
3	2×10^{-3}	$<10^{-3}$	10^{-2}
4	6×10^{-4}	$<10^{-3}$	3×10^{-2}
5	2×10^{-4}	10^{-3}	10^{-1}
6	6×10^{-5}	10^{-3}	10^{-1}
7	2×10^{-5}	10^{-3}	10^{-1}
8	6×10^{-6}	10^{-3}	10^{-1}
9	2×10^{-6}	10^{-3}	10^{-1}
10	6×10^{-7}	10^{-3}	10^{-1}
11	2×10^{-7}	10^{-3}	10^{-1}
12	6×10^{-8}	10^{-3}	10^{-1}
13	2×10^{-8}	10^{-3}	10^{-1}
14	6×10^{-9}	10^{-3}	10^{-1}
15	2×10^{-9}	10^{-3}	10^{-1}

Method of digitization: Gated-current charge-neutralization. Current pulses controlled by aged, stabilized, temperature-compensated reference diode and precision crystal-controlled oscillator. No drift, no dead time, no linearity adjustments, no dielectric absorption errors. Maintains calibration accuracy for years without adjustment.

Mechanical: Standard 7" x 10" panel. Model 1000-C is 10", 1000-A is 7" deep.

Power: 50-60 Hz, wireable for 115 or 230 V ±10%.

*The averaging time specifies the effective time constant of the R-C feedback network in the input amplifier. It imposes no limitation on the ability to integrate currents with ac components of any frequency. On the Model 1000-A the fast and slow modes are labelled "continuous" and "pulse" respectively.

INTERNAL COUNTER SPECIFICATIONS*

Total capacity: 7 decades.

Display: 4-digit, 7-segment LED.

Prescaling: Divides by 10^0, 10^1, 10^2, 10^3, to extend operating period to 10^4 sec. at F. S. input, LED decimal point automatically shifts as prescaling factor is selected.

Preset: Four-digit, decimal thumbwheel switch provides full preset of the 4 displayed decades.

External function control: "Stop" and "run" states are indicated by separate complementary 5 V logic level outputs. Additional 5 V, 40 microsec pulse occurs at transition to "stop" state. All outputs short-circuit proof.

Controls: Start and stop commands may be introduced by front panel push-buttons or by momentary grounds applied by TTL, relays, switches, etc., to rear panel connectors. Counter is automatically reset to zero by start command.

Computer control: Optional. Provides BCD inputs for programming of counter preset by computer or other remote sources. Positive, current-sinking logic.

BCD output: Optional. Provides readout of the four displayed decades. Open-collector TTL gates with 510 ohm pull-up to +5 V.

*Not applicable to Model 1000-A.

EXTERNAL CONNECTIONS

Input current: BNC receptacles for the input current are provided on the front and rear panels. The connector bodies are connected to the instrument ground (low side of input) which is insulated from the chassis. The instrument ground may be connected to the chassis via the jumper provided on the terminal strip or through the sheath of the input cable to a ground at the current source location. It may be connected to any point which is at nominal ground potential but must not be left floating. The independent instrument ground insures that the instrument may be connected to any current source without creating a ground loop. The isolated instrument system has separate floating power supplies. Its digital output is transformer-coupled to the digital output connector and to the internal counter which, together with its power supply and all the control logic is referred to the chassis ground.

Remote meters: External current indicating meters may be connected to the appropriate terminals on the rear strip. Dc meters of 1.0 mA sensitivity are normally used. Any desired number of meters may be connected in series. To allow for variations in meter resistance depending upon the number and type of meters used, the series resistance is chosen to make the external meters read about 15% high with no additional resistance in the circuit. When external meters are connected a series resistor should be included. The resistance should be adjusted to make the external meter readings agree with those of the meter on the panel. The resistance required will be about 1.5 K. If desired, a 2.5 K potentiometer can be inserted in the circuit and locked when the correct adjustment is reached.

Alternatively, a 0-100 microampere meter may be used with an additional 100 K series resistance. Part of the 100 K resistance may be momentarily shorted to increase the sensitivity without switching ranges for preliminary tuning of accelerators, etc. The external connections for the digital output and counter control functions are described under "Counter Operation."

External counter reset: Terminals on the rear of the 1000-A provide a normally closed circuit which opens when the reset button is depressed. It may be connected to simultaneously reset the external counter when the integrating capacitor is discharged.

Digital output: The digital output from the integrator is available at the rear panel. It can be applied to an external counter, computer, etc. as desired. It is subject to control by the inhibit gate but not by the on-off logic or prescaling function of the internal counter and is therefore always 1000 pps full-scale regardless of the position of the pps switch. It is a 7 volt, 5 microsecond pulse with a source impedance of 75 ohms. It is referred to the chassis ground and can be shorted without disturbing any other function.

If the digital output pulses are observed with an oscilloscope they will appear to occur at random intervals for inputs lower than full-scale. Close inspection, however, will reveal that the intervals between the pulses, though irregular, are always integral multiples of 1 msec. The digital output is derived not from a voltage-to-frequency converter but from a much more stable and precise charge-neutralization system which operates synchronously with a precision crystal-controlled oscillator. The charge-neutralization system is described under "Theory of Operation."

Range identification: The optional binary coded range identification feature provides a 4-bit, 3.5 V positive logic level output to identify the current range being used. Each of the output lines can supply 2.5 mA from a zero-impedance clamped-load source in the high state and sink 100 mA in the low state. Pin assignments are indicated on page 13.

OPERATING PROCEDURE

Averaging time setting: The averaging time switch on the rear panel adjusts the effective time constant of the input amplifier feedback network. Except for a few special cases (see page 7), this switch should be placed in the slow position* which provides strong ac feedback for greatly enhanced noise immunity and protection against amplifier saturation on

*On the Model 1000-A the averaging time switch is located on the front panel, bottom center. The "pulse" and "continuous" positions correspond to the "slow" and "fast" positions respectively of the Model 1000-C.

higher-than-full-scale input current peaks. The latter consideration is especially important in applications such as ion-implantation systems where such current peaks are frequently encountered.

Normal zero adjust: A variable current source is provided to neutralize any spurious input currents which may cause error. These currents arise from thermal effects in the external circuitry which has finite leakage resistance to ground and in the input amplifier which even with the most advanced design can never be perfect. The resulting errors are normally very small and are significant only when extreme accuracy is required on the lowest two or three ranges. The zero adjustment should be made with the external circuitry connected to the input terminal and no current flowing, e.g. the Faraday cup and cable connected and the beam turned off. The toggle switch near the left edge of the front panel should be in the "normal balance" position and the range switch on the lowest range to be used. With the function switch in the "operate" position the balance-offset control should be rotated to make the meter read "zero". The input circuit will now be roughly balanced. Next, the function switch should be set to the zero position. In this position the meter sensitivity is increased by 20 times. A final, precise zero adjustment can be made and the balance-offset control locked in place. It will be noted that the balance-offset control is very sensitive on the lowest range and becomes progressively less so as the full-scale current range is increased. On the higher ranges no effect will be observed and the control may be left at the approximate center of its range. As long as no error is indicated with the function switch in the zero position on the range to be used, the input circuit is adequately balanced and no adjustment is needed. On the lowest two or three ranges small, random fluctuations due to input flicker noise may be observed. In the zero mode a deflection of one division on the bottom meter scale represents a 0.1% offset.

±10% offset: In some cases spurious input currents may be encountered which are beyond the range of the neutralizing current available with the toggle-switch in the normal balance position. Such conditions could result, for example, from insulation leakage when biased targets are used or from electrochemical effects in water-cooled targets. Placing the toggle switch in the ±10% offset position will provide a neutralizing current which is adjustable through at least ±10% of the full-scale current range in use. The balancing operation is performed as described under "Normal Zero Adjust" except that the balancing adjustment will be correct only for the range on which it is made and, therefore, must be repeated each time the range is changed. For operating convenience this mode of operation should be used only when abnormally high error currents make it necessary or when it is desired to subtract a fixed value from the input current in some special situation.

Operate: After the input circuit has been balanced the function switch should be placed in the operate position. The instrument is now ready for operation. The on-off control function is normally performed by the counter logic which is discussed under the title, "Counter Operation."

Test: Operation of the instrument and associated system components may be verified by using the offset supply as a test current source. With the function switch in the operate position and the toggle switch in the ±10% offset position, rotate the balance-offset control to its limit (clockwise for positive current). A current of 10% to 15% of the selected range is now being injected into the input. The meter should indicate the input current and a digital output should be observed. It should be understood that this is not an accuracy test. The offset supply is highly stable but is not designed to provide a precisely determined particular value of current at the maximum setting.

Reset: The reset button on the Model 1000-A provides a momentary short circuit to dissipate any residual charge in the integrating capacitor and resets the external counter (see "External reset" above). The reset function in the Model 1000-C is performed by the counter logic as described below under "Counter Operation.

COUNTER OPERATION

The internal counter and all of the associated inputs, outputs and control logic are electrically isolated from the floating instrument (integrator) system by the blocking oscillator output transformer. The counter-logic system and its 5 V regulated supply are grounded to the chassis regardless of where the instrument system is grounded.

The full-scale count rate is selected by the PPS switch on the front panel (bottom center). The integrator digitizing rate is always 1000 pps, full-scale. Counting rates of 100, 10 and 1 pps are obtained by progressively switching in prescaling decades. As each decade is added, the quantity of charge per unit of displayed count is increased 10 X. The decimal point is accordingly shifted one place to the right to perform the required multiplication.

Counting commences when the start button is depressed and ceases when the stop button is depressed or when the preset count is reached if the preset is turned on. The counter (including the prescaling decades) is automatically reset to zero by the start command for the next counting period. The automatic reset precludes the possibility of data loss due to accidental premature reset. The accumulated charge is given by $Q = N_c I_{fs}$ where N_c is the counter reading (including decimal point), I_{fs} is the full-scale current range in amperes and Q is quantity of charge in coulombs. To preset the integrator to turn off (and perform desired control functions) at a particular value of Q the thumbwheel switches should be set to the number, $N_{tw} = Q/I_{fs}$ and the preset switch turned to on. For the best accuracy and resolution use the lowest current range which will accommodate the current to be integrated and the highest counting rate (pps setting) that will allow N_{tw}, as computed above, to be set in the thumbwheel switches (observing the correct decimal point position).

Control of external functions: Two logic levels and a pulse output are provided for the control of external functions by the integrator. One logic level is high (+5 V) in the "run" state and zero in the "stop" state. The other is low in the "run" state and high in the "stop" state. The level outputs can supply 8 mA to a s. c. load and sink 6 mA. The pulse output delivers a 40 microsecond, 5 V pulse at the transition to the "stop" state. It can supply 100 mA to a s. c. load and presents 1150 ohms to ground in the quiescent state. Any or all of the outputs may be shorted to ground without causing damage or disturbing other functions.

Remote stop-start: The counter may be started and stopped by external command simply by grounding the "start" or "stop" inputs (BNC). The ground may be applied by a transistor, a switch, a relay or any other connection capable of sinking 10 mA from a 5 V source. The ground may be momentary or continuous so long as it is removed at least 0.25 sec. before the control is to be exercised. If the control source is situated far from the instrument, the loading effect of the cable capacitance must be accounted for. The sink must be capable of discharging the cable from +5 V to +0.8 V or below in less than 5 microseconds.

Remote preset: The optional remote preset feature contains a register in which a desired counter preset from an external source may be stored. If the preset switch is placed in the computer position the counter will turn off when the number stored in the register is reached.

The register is loaded via the 24-pin "computer control" connector in the rear. The logic is standard TTL. A logical "one" or open circuit applied to the "read" input will load whatever number is present at the bcd inputs into the register. After the "read" input is grounded the register content will remain unchanged as long as the power remains on. The bcd inputs each present one standard unit TTL load. The "read" input requires its driving source to have at least a six standard TTL load-driving capability.

Counter readout: The optional counter readout makes the content of the four displayed counter decades available in BCD form as TTL gate outputs through a 24-pin connector at the rear of the chassis. Open collector gates with a 510 ohm pull-up to +5 V are used.

SIGNIFICANCE OF AVERAGING TIME

The averaging time switch ("mode switch" on the Model 1000-A) adjusts the input amplifier feedback time constant to the values indicated in the table, page 2.

Slow mode: In the slow (pulse) mode a capacitor is connected directly around the input amplifier to provide in combination with the feedback resistor network an effective feedback time constant of 0.1 sec on all but the 4 highest ranges. In this configuration peak input current values in excess of 20 mA can be accommodated even on the 2 nA range without overloading of the input amplifier. Operation in the slow mode therefore allows very small currents to be integrated precisely even in the presence of ac noise components of many times greater magnitude and allows the integration of pulsed currents with peak-to-average ratios up to 10^9 or even higher.

It should be understood that the 0.1 sec time constant imposes no limitations on the frequency components which may be present in the input current. The smoothing effect simply removes any high-frequency structure from the amplifier output voltage waveform and delays its appearance by 0.1 sec. The filtering process has no effect upon the bounded area under the waveform which still accurately represents the true time integral of the input current.

Time delay effects: Because of the time delay described above, the digital output lags the time integral of the input current by 0.1 sec. The counter content representing a particular value of accumulated charge therefore will be achieved 0.1 sec after that amount of charge has actually been delivered to the input terminal. A few counts will thus be registered after the cessation of the input current. These pulses should be counted because they represent a portion of the input charge.

If the counter preset is used, however, to cut the current off when a preset value is reached, the situation will be somewhat different. The current will be cut off not when the indicated input charge has been achieved but 0.1 sec later when the preset number of counts has actually been registered by the counter. The current will therefore have remained on for an extra 0.1 sec period resulting in a slightly larger dose than that represented by the preset. The relative importance of this effect is, of course, inversely proportional to the length of the operating period, becoming negligible for runs longer than ten to a few tens of seconds depending upon the required accuracy.

For such short runs a simple correction can be made for this effect by setting the preset to a slightly lower value, N' given by:

$$N' = N\left(1 - \frac{.1(\text{sec})}{Tr(\text{sec})}\right)$$

where N represents the normally computed preset number and Tr the estimated duration of the run in seconds.

Fast mode: In the fast (continuous) mode the ac feedback around the input amplifier is greatly reduced, resulting in a time constant and consequent time delay $\leq .001$ sec. Since the maximum digitizing rate is 1000 pps, the time-lag is never greater than the system resolution and may be neglected in all cases.

Operating in the fast mode, the input amplifier is free to follow rapid variations in input current and is therefore deprived of the great immunity to error-producing saturation on high input current peaks which is characteristic of operation in the slow mode. For these reasons operation in the fast mode should be confined to special situations such as where it is necessary to initiate or terminate some action or process without appreciable delay after a predetermined amount of charge has been delivered.

WHEN OPERATING IN THE FAST MODE THE PEAK INSTANTANEOUS CURRENT MUST NEVER BE PERMITTED TO EXCEED THE FULL-SCALE RANGE IN USE. In satisfying this requirement noise peaks as well as the waveform of the input current must be considered.

The fast mode should not be used in applications such as ion-implantation where, because of its periodic interruption (due to overscanning), the input current during part of the cycle may exceed full-scale even though its average value, as indicated by the current meter is well within range.

PULSE INTEGRATION

Pulse input currents generally have peak values greater than the full-scale current range in use. The averaging time switch, therefore, must be in the slow position for pulse integration.

Pulsed currents of unlimited peak-to-average ratio can be integrated with exactly the same technique as continuous current inputs if the following simple conditions are satisfied.

1. The pulse repetition period must be equal to or less than one-fifth of the averaging time shown for the range in use in the slow mode column of the table, Page 2. For the 2×10^{-4} A and all lower ranges, this requirement will be satisfied for pulse rates of 50 pps or higher. Lower pulse rates are acceptable but may require the use of a range higher than that specified by condition #2 below. The optimum range for lower rep rates may be determined by observing the A_1 amplifier output voltage waveform with an oscilloscope while the pulsed input is applied and selecting the lowest range for which the peak A_1 output does not exceed ±10 V. The A_1 output voltage is available at the negative external meter terminal, rear panel when the input polarity switch is in the positive position and at the positive meter output terminal when the polarity switch is in the negative position.

2. The average input current must not exceed the full-scale range in use. This condition can be met simply by selecting the lowest range which will keep the meter on scale.

3. The peak pulse current must not exceed 20 mA. For pulse widths less than 2.5 microseconds, the 20 mA limit may be exceeded if the product of pulse width in seconds and current in amperes is equal to or less than 5×10^{-8} coulombs. Pulses exceeding these limits may be accommodated by the addition of a simple input filter. Consult BIC for specific recommendations.

Input currents of a pulsed or interrupted nature whose peak values do not exceed the full-scale current range in use may be regarded as continuous currents and are exempt from all the special conditions for pulse integration.

AUTOMATIC DEAD TIME CORRECTION

For automatic dead time correction the digital output can be inhibited by a +2.5 V to 10 V signal applied to the inhibit connector. The inhibit input may be connected through 2000 ohms to +5 V and driven by current-sinking logic. The inhibit gate, as all the other logic circuitry, is grounded to the chassis and transformer-coupled to the floating instrument system. Even in a comparatively short integrating period many thousands of output pulses will occur. The fraction of the total digital output that will be inhibited by dead time signals of random length and interval will, therefore, be essentially equal to the fraction of the integrating period that was occupied by dead time signals. If the inhibit signal is present when an output pulse is due to arrive the pulse will be blocked, but if a dead time signal is applied while an output pulse is in progress, that pulse will not be interrupted. Since the time resolution of this gate is less than 20 nsec, dead time periods as short as 1 microsecond will be accurately accounted for.

The actual correction is made at the digital output which lags the input current by the averaging time (see "Significance of Averaging Time"). This method of dead time correction is valid so long as significant changes in beam intensity do not occur frequently or regularly in time periods comparable to or shorter than the averaging time. Most beam intensity fluctuations, e.g., Van de Graaff belt variations, power frequency ripple, etc., occur at rates well within this limit particularly if the fast mode is used.

OPERATING PRECAUTIONS

If a fluctuating current is to be integrated it is important to use a current range higher than the maximum anticipated beam current because input currents in excess of full-scale will not be integrated, resulting in error.

The input circuit is protected by a diode network so that accidental input currents as high as several hundred mA can be tolerated on any range without damage to the instrument. Targets in accelerators and their associated cables can be charged to potentials of many thousands of volts if beams are applied while the cable is open. If the cable is plugged into the input without first being discharged very large transient currents can result, possibly causing damage to the instrument.

THEORY OF OPERATION

Symbols used in the following explanation of operation refer to the block diagram, p. 14. This diagram is provided for explanatory purposes only and is greatly simplified. Provisions for polarity switching are not shown and the explanation except where otherwise noted will assume positive input current.

Chopper-stabilized amplifier A_1, whose feedback network is selected by the range switch, delivers an output voltage which is accurately proportional to the input current. The output voltage is of polarity opposite to that of the input current and is equal to -10 V for full-scale positive input on all ranges. The output voltage of A_1 is applied through appropriate resistors to the panel meter to indicate the input current and to the input terminal of amplifier, A_2.

A_2 and its input resistor and feedback capacitor comprise a Miller integrator which is used to integrate the output voltage of A_1. Since A_2 also is an inverting amplifier, its output voltage rises when positive current is applied to the input of A_1. When the output voltage of A_2 reaches the appropriate level, the amplitude discriminator "enables" gate 1 and the flip-flop is triggered to the "on" state by the next trigger pulse from the frequency divider. The switching diode, D_1, now passes a precisely controlled 2 mA current to the summing junction of A_2. This current, of opposite polarity to that caused by the output voltage of A_1, drives the output of A_2 downward, thereby opposing the effect of the input signal. The neutralizing current persists for the .5 msec interval between trigger pulses. The next trigger pulse switches the flip-flop to the off state. At this time the output of A_2 will be below the discriminator threshold and will begin to rise again if input current is still flowing. Each time the output of A_2 rises to the discriminator threshold the process is repeated. The transition of the flip-flop to the on state triggers the blocking oscillator to produce a digital output pulse for each neutralizing pulse. At full-scale input neutralizing pulses are delivered to the summing junction at the rate of 1000 per second.

Amplifiers A_1 and A_2 are bipolar. Negative input currents result in output polarities opposite to those of the foregoing description. Under these conditions the panel meter, neutralizing current source and switching diodes must be reversed and the amplitude discriminator replaced by its negative counterpart. These operations are performed when the input polarity selector is switched to the negative position.

The comparatively high signal level, 1 mA from a 10 V source, to amplifier, A_2 imposes only modest demands on its performance compared to those imposed on A_1. Since the temperature-dependent and aging-induced drifts in its input bias current and offset voltage are easily 5 orders of magnitude smaller than the signal values and its gain is at least 10^5, it is in this application an extremely close approximation to the theoretical "Ideal Amplifier."

The absolute value of the total quantity of charge which flows into the summing junction must be equal to the product of the duration, current and number of the neutralizing pulses. It is totally independent of dielectric absorption and drifts in the integrating capacitor or changes in amplifier gain or discriminator level.

The calibration stability, therefore, depends only upon the stability of the crystal-controlled oscillator, reference diode and the two resistors at the summing junction of A_2. These components are temperature compensated and aged to provide total, long-term stabilities of a few parts per million.

There is no dead time as experienced with capacitor-discharge type v-to-f converters and the process is inherently absolutely linear.

Balance-offset: When the function selector switch is placed in the zero position, the input of A_2 remains connected through a resistor to the output of A_1. The feedback capacitor of A_2 is shunted by a resistor and the meter is connected to the output terminal of A_2. A_2 and the meter now serve to amplify and display the output voltage of A_1.

A_1 is chopper-stabilized and its input offset voltage is essentially zero. Its output voltage, however, will generally not be equal to zero because of internal leakage and thermal emf's and possible leakage currents from the external current source. The balance-offset control is adjusted to supply a current of proper polarity and amplitude to neutralize these effects.

CALIBRATION ADJUSTMENTS

Meter calibration: The small board on the back of the panel meter contains two pots. The one to the left, viewed from the rear, controls the meter sensitivity. It has equal effect on all ranges.

The pot to the right controls the damping factor of a special noise-suppression circuit. It usually does not require adjustment unless disturbed. It may be re-adjusted by rotating it until the meter neither undershoots nor overshoots when a nearly full-scale test current is switched on or off.

Integrator calibration: The overall instrument drift is typically less than a few hundredths of a percent during several years of operation. If larger errors occur they will almost certainly be the result of a catastrophic component failure and will be immediately apparent.

Recalibration is necessary only when one of the few critical components is replaced and should not be attempted unless means are available to check operation to the desired accuracy.

If the need for recalibration is suspected we recommend that, when feasible, BIC be contacted for advice before proceeding. Factory calibration is available at reasonable cost.

The resistive feedback network mounted on and above the range switch determines the current-to-voltage conversion factor of the input amplifier and, therefore, the relative sensitivity on each range. All of the resistors used on ranges 1 through 12 are aged, stabilized, wire-wound resistors of .01% tolerance and are of such stability that their values will not drift more than a few ppm in years of use. They are not adjustable.

The ± 1%, low-T.C. metal-film resistors used on ranges 13 through 15 are trimmed to the precise values required by additional trimming resistors mounted above the range switch.

The overall sensitivity is determined by the setting of the trimmer R_{4A}. This adjustment affects the sensitivity equally on all ranges. It is extremely critical and should be made in small steps. No calibration adjustments should be attempted. until the amplifier zero adjustments described below have been made.

Calibration adjustments should be made with positive imput currents first. The negative trim pot* should then be adjusted to correct the sensitivity to negative inputs.

Chopper-ripple neutralization: Gate-to-channel capacitance in the chopper-modulator FET, Q_{42} (type 3N138) introduces a spurious signal which can overload the amplifier on the lower ranges. This difficulty is avoided by the injection of an antiphase neutralizing signal into the amplifier input through a small variable capacitor. WHENEVER Q_{42} IS REPLACED THE NEUTRALIZATION ADJUSTMENT MUST BE CHECKED AND CORRECTED IF NECESSARY.

The neutralizing capacitor adjusting screw protrudes from the bottom of the main pc board and is approached through the hole in the shield plate above the input polarity switch. The top cover must be on the instrument when this adjustment is made. An oscilloscope should

---

* On units with s/n(X)529 and lower, adjust the -17V regulator in very small increments to adjust negative sensitivity.

be connected to the A_1 amplifier output. The yellow lead on the averaging time switch (mode switch on 1000 A) serves as a convenient test point.

With the instrument in the slow (pulse) mode and the range switch on the 2×10^{-9} A range the capacitor should be adjusted for a minimum ac signal as indicated by the scope. An insulated screwdriver must be used when making this adjustment.

Amplifier zero adjustments: Since the adjustment of the A_1 amplifier current and voltage offsets depends on the zero balance of the A_2 amplifier the A_2 amplifier must be checked and adjusted before any A_1 zero adjustments are attempted. All of the following adjustments should be made with the instrument in the slow (pulse) mode.

1. A_2 amplifier zero adjust: This adjustment is made via the trimmer labelled A_2 zero adjust on the layout drawing. The range switch should be set to 2×10^{-2} A, the toggle switch set to normal balance,the function switch in the zero position and the balance-offset control set at mid-range. The mid-range setting is not critical and can be made most easily by rotating the 10-turn control 5 turns from one end and locking it.

If the panel meter does not read exactly zero the trimmer should be adjusted for a zero reading. This adjustment should be made as accurately as possible. The electrical zero point can be determined best by switching back and forth between the zero and operate positions and adjusting the trimmer for zero needle displacement, ignoring any transient effects.

2. A_1 offset voltage adjust: Set the range switch to 2×10^{-6} A, leaving all other controls as above. The meter should again be set to zero, this time using the A_1 offset voltage trimmer.

3. A_1 offset current adjust: Set the range switch to 2×10^{-9} A, and the function switch to operate, leaving the other controls undisturbed. The A_1 offset current trimmer should now be adjusted for a zero meter reading. This adjustment is much less critical than those of steps 1 and 2 above. In some cases it may not be possible to reach the zero point within the range of this trimmer. In this case it will be sufficient to set the trimmer to yield the lowest meter reading. The only result of a residual offset current will be to make the available current range of the balance-offset control slighly asymmetric, a totally negligible effect.

After the A_1 offset current has been set to (or near) zero, repeat step 2.

A residual A_1 offset voltage (step 2 above) will not impair accuracy because its effect will be negated when the offset-balance control is adjusted in the normal operating procedure. It will however, make readjustment of the offset-balance control necessary when switching ranges. Such adjustment is normally not required (with the toggle switch in the normal balance position) except for a possible slight zero-shift between the 2 lowest ranges.

MAINTENANCE

Switch cleaning: Care must be taken with the choice of any solvent used to clean the range switch, S-1. Chlorinated hydrocarbons such as carbon tet and its so-called non-toxic replacements, acetone, lacquer thinner and many other common solvents must be avoided because they will attack the polystyrene capacitors mounted on the switch. The use of contact cleaner-lubricants like those used on TV tuners should also be avoided. Their residual lubricating films will trap dust which can absorb moisture, creating leakage paths which will seriously impair accuracy on the low ranges. Ethyl alcohol or Freon degreasers may be used safely. Miller-Stepheson MS-230 Contact RE-NU has been found effective and is recommended. An enclosed switch is not used because the molded bodies of such switches produce leakage paths between the terminals which would cause intolerable errors in an instrument which is so highly accurate at low currents.

Diode replacement: Most of the silicon and germanium diodes may be replaced by types possessing similar characteristics. One important exception is the protective diode network at the integrator input. FD - 300's or FD - 333's may be used interchangeably but no other types should be substituted. These diodes must be shielded from ambient light to avoid effects resulting from photo-electrically induced currents. If they are replaced they should be enclosed within opaque tubing like that provided in the original equipment.

FET replacement: When handling the insulated-gate field-effect transistors (FET), Q_1, Q_{41}, Q_{42} and Q_{43}, precautions must be taken to prevent their destruction by static charges. While the FET's are being removed or replaced, one hand must be kept in contact with the chassis and the power must be off. If any soldering is done on the range switch, or at any point having a direct path to the FET's other than through the diode-protected input terminal, it must be done with a grounded soldering iron which is connected to the chassis or with the FET's removed.

If one or more of the FET's are replaced the A_1 amplifier input offset voltage and current should be checked and adjusted if necessary. In addition, IF Q_{42} IS REPLACED THE CHOPPER RIPPLE NEUTRALIZING CAPACITOR ADJUSTMENT MUST BE CHECKED. These adjustments are described in the preceeding section.

Transistor replacement: With the exception of the FET's and the Q_{14-15}, the dual differential input transistor of the A_2 amplifier, any of the transistors may be replaced without necessitating any circuit adjustments.

If Q_{14-15} is replaced, the A_2 amplifier zero trim should be adjusted. See preceeding section. Failure to make this adjustment can result in integration errors up to about 0.1%.

REPAIRS

Every effort has been made in the preparation of this manual to provide competent personnel with sufficient information to keep the instrument in good operating conditon. If problems arise, however, which cannot be solved in the field, the factory should be contacted for advice.

Repairs under warranty: All BIC instruments are guaranteed to perform within specifications for one year from the date of purchase. Any required repairs not necessitated by abuse will be made free of charge. The charges for non-warranty repairs will be limited to the cost of labor, and materials.

IMPORTANT

To avoid unnecessary delay do not return any instrument without first contacting BIC for shipping instructions.

CONNECTOR PIN ASSIGNMENTS

1000-C "Computer Control" Connector

1	common & chassis	
2	1	1's
3	2	1's
4	4	1's
5	8	1's
6	1	10's
7	2	10's
8	4	10's
9	8	10's
10	1	100's
11	2	100's
12	4	100's
13	8	100's
14	1	1000's
15	2	1000's
16	4	1000's
17	8	1000's
18	"read" line	

19 through 24—spare

Model 1000-A "Range Readout" Connector

A - 8
B - 4
C - 2
D - 1
E - common & chassis

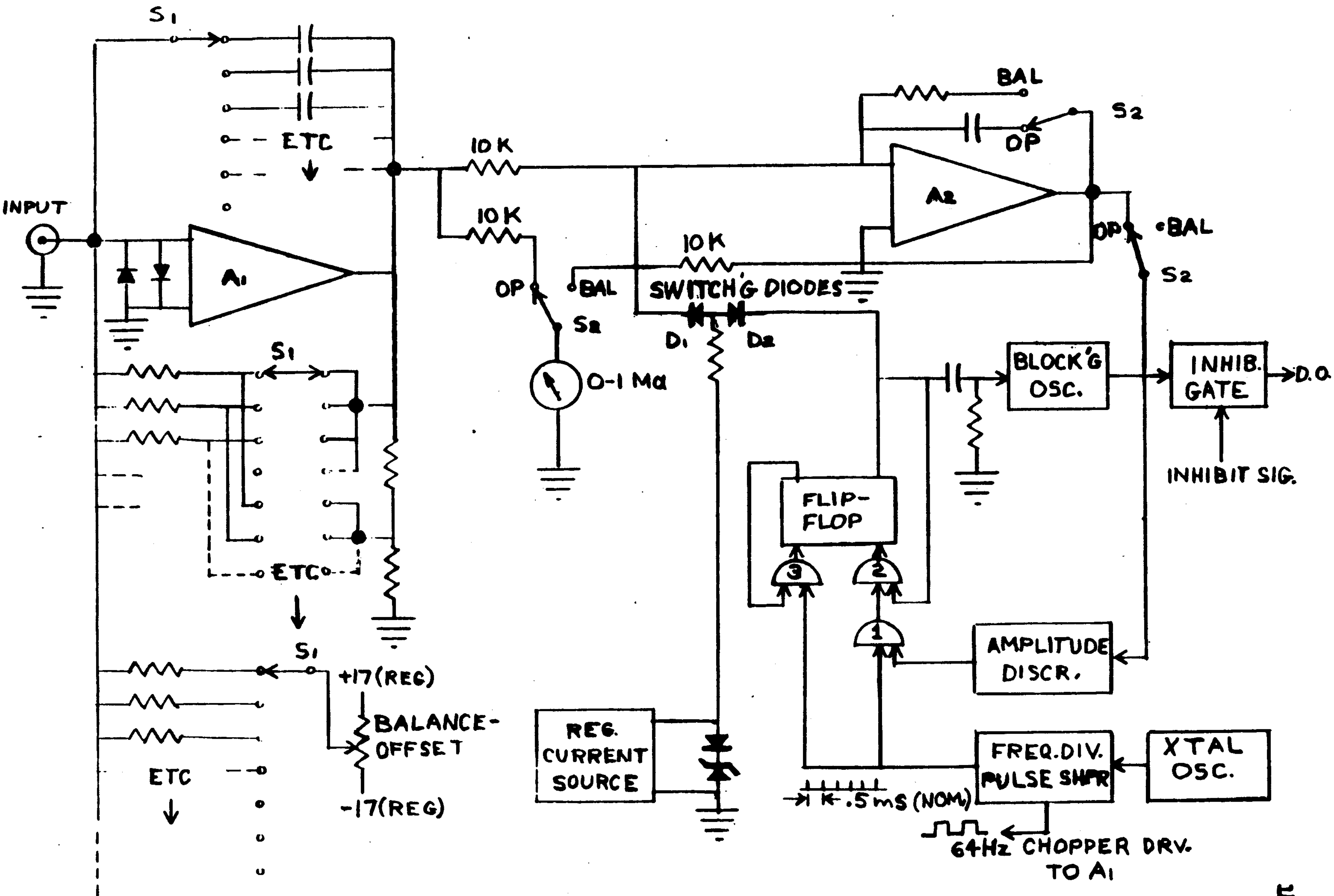
Model 1000-C "Counter-Range Readouts" Connector

19 - 1
20 - 2
21 - 4
22 - 8

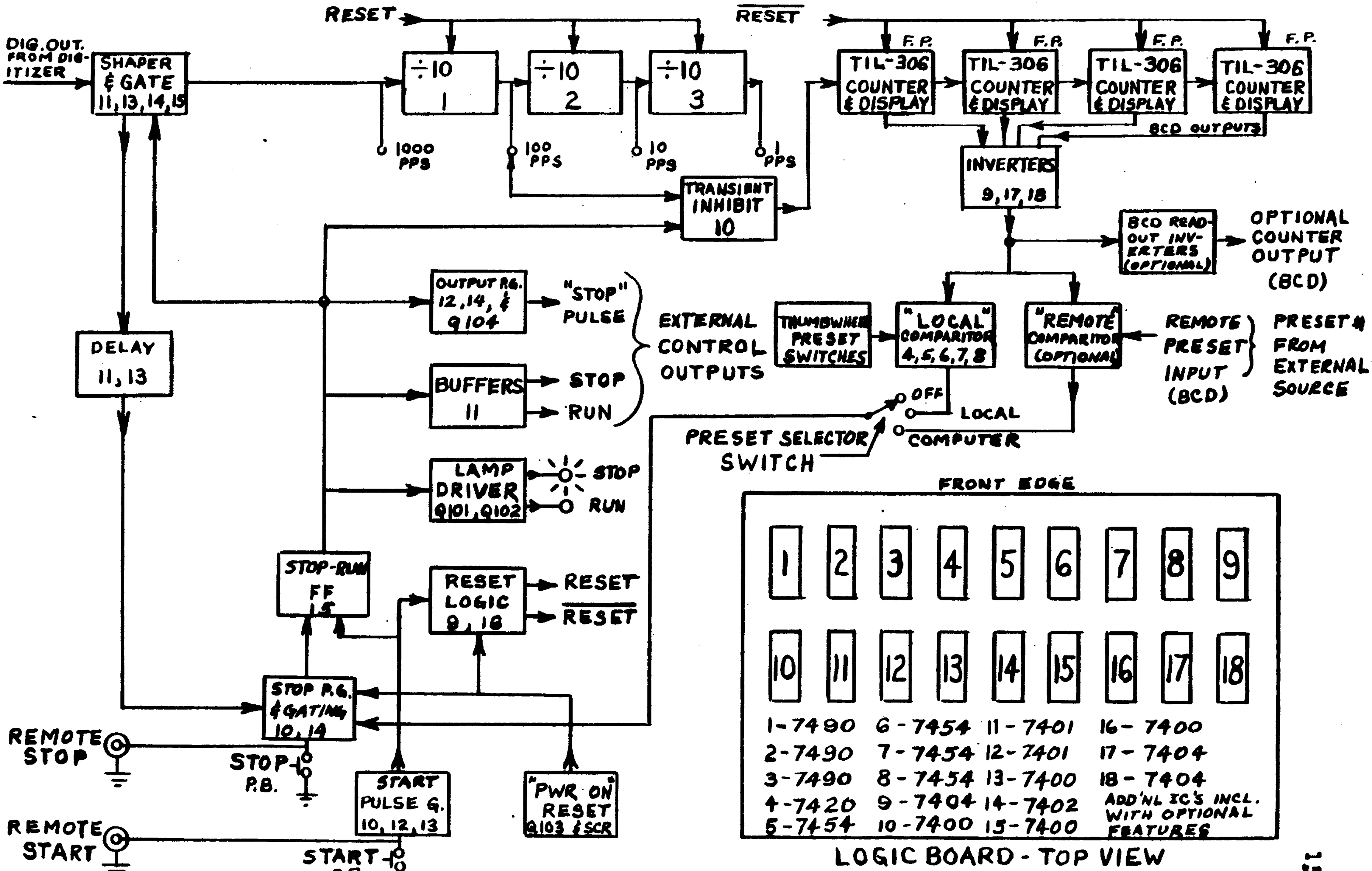
Model 1000-C "Counter-Range Readouts" Connector

1	common & chassis	
2	1	1's
3	2	1's
4	4	1's
5	8	1's
6	1	10's
7	2	10's
8	4	10's
9	8	10's
10	1	100's
11	2	100's
12	4	100's
13	8	100's
14	1	1000's
15	2	1000's
16	4	1000's
17	8	1000's
18	spare	
23	1	pps switch position (binary notation)*
24	2	pps switch position (binary notation)*

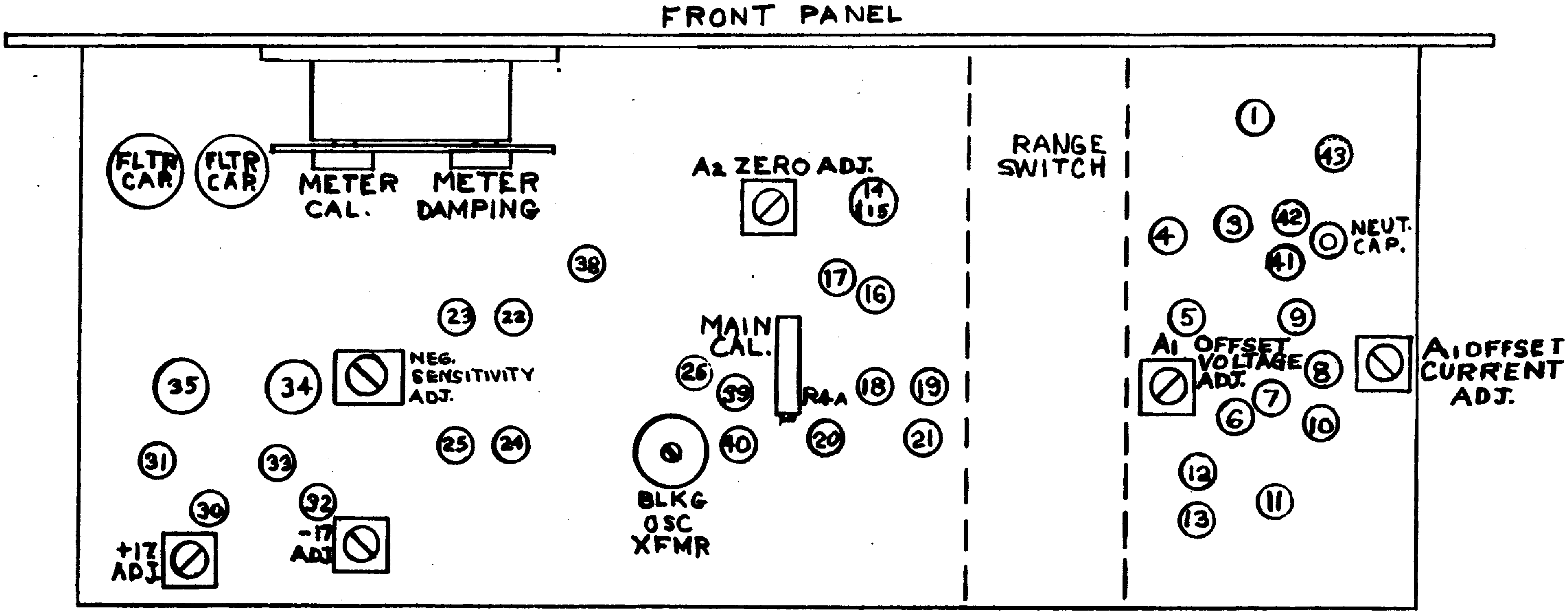
* 0 - 1 pps, 1 - 10 pps
2 - 100 pps, 3 - 1000 pps



SIMPLIFIED BLOCK DIAGRAM-BIC 1000 A/C INTEGRATORS



COUNTER-CONTROL FLOW DIAGRAM & LAYOUT
MODEL 1000 C



CAUTION ! Ground free hand to chassis when handling Q-1, Q-41, Q-42, Q-43. Failure to do so may cause destruction of device by static charges.

MAIN BOARD LAYOUT (TOP VIEW)

BIC MODELS 1000 A/C CURRENT INTEGRATORS