MODEL 164E
AC VOLTMETER
OPERATION MANUAL

KIKUSUI ELECTRONICS CORP.

CONTENTS

1. General

Kikusui Electronics' Model 164E is a transistorized high-sensitivity voltmeter which displays the mean value of the AC voltage measured. Using semiconductor elements in all circuits, Model 164E is compact, lightweight and consuming low power.

Model 164E consists of an impedance converter having a high input impedance, a voltage divider, a preamplifier, an indicator circuit, an output section, and a voltage regulator circuit.

Model 164E measures an AC voltage within a range of 0.1 mV ~ 500 V_{RMS} (-80~56 dBm) whose frequency is 5 Hz~1 MHz.

It has twelve measuring ranges in 10 dBm steps, and the meter scale is graduated in equal divisions by the effective value of sine wave.

Further, Model 164E can give an AC voltage output of approximately 1.5 V in full scale from the output terminal. Therefore, measurement can be monitored or the equipment can be used as a preamplifier.

2. Specifications

Type	AC voltmeter
Model	164E
Meter	105 mm is scale length, two-colored scale, 1 mA full-scale.
Scale	Effective value of sine wave, and dBm value with respect to 1 mW, 600 Ω
Input:	
Input Terminals	UHF-type receptacle and GND terminal, 19 mm (3/4") spacing.
Input Resistance	10 MΩ for each range
Input Capacitance	1.5 mV~500 mV ranges 40 pF or less 1.5 V~500 V ranges 25 pF or less
Maximum Input voltage	1.5 mV~500 mV ranges: AC component ; 150 V in effective value ±200 V in peak value. DC component ; ±400 V 1.5~500 V ranges: AC component ; 500 V in effective value ±700 V in peak value. DC component ; ±400 V
Ranges	12 ranges: On RMS scale 1.5/5/15/50/150/500 mV and 1.5/5/15/50/150/500 V

	On dBm scale	-60/-50/-40/ -30/-20/-10 and 0/10/20/30/40/50 dBm
Accuracy	±3% of full scale at 1 kHz	
Frequency Response	5 Hz - 1 MHz	±10% with respect to 1 kHz
	10 Hz - 1MHz	±5% with respect to 1 kHz
	20 Hz - 200 kHz	±3% with respect to 1 kHz
Stability	Less than 0.5% of full scale against ±10% fluctuation of line voltage	
Noise	Less than 2% by short-circuiting the input terminals.	
Output:		
Output Terminals	5-way type, 19 mm (3/4") spacing	
Output Voltage	Approximately 1.5 V at full scale	
Distortion Factor	Less than 2% at full scale and 1 kHz	
Frequency Response	7 Hz - 250 kHz	$^{+1}_{-3}$ dB
Power Requirement	_______V, 50/60 Hz, approx. 4 VA	
Dimensions	200 (D) x 140 (W) x 190 (H) mm	
(Maximum Dimensions)	(270 (D) x 140 (W) x 205 (H) mm)	
Weight	Approx. 3.2 kg	
Accessories	Type 941B terminal adapter	1
	Operation manual	1

3. Operating Procedure

3.1 Parts on front panel

1	POWER	A snap switch turning on and off power supply. When the switch is pushed upward, Model 164E is energized and the range switch dial is illuminated. For about 10 seconds after the switch is turned on, the meter pointer may possibly deflect irregularly.
2	Range switch	Black dial in the center of the panel. It is illuminated when Model 164E is energized. Markings on the dial denote the following: Outer markings represent full-scale voltages. Orange number mV (=1/1000 V) White number V Inner red marking represents the approximate center value in dBm (details described later). When the range switch is turned clockwise, a higher voltage range is selected; when turned counterclockwise, a lower voltage range.
3	INPUT terminals	Terminals to which the voltage to be measured will be connected. They

consist of a UHF receptacle and a GND (ground) terminal.

For connection, a UHF-type (5/8" - 24) or M-type (16 ϕ 1P) plug, or a standard (spacing: 3/4" = 19 mm) dual banana plug is suitable.

A banana plug may be connected to the center conductor of the receptacle.

Also, by inserting the accessory "Kikusui Type 941B Terminal Adapter," a banana plug, spade lug, alligator clip, 2-mm tip or a lead wire 2 mm or less in diameter can be connected.

The outer conductor of the receptacle and the GND terminal are electrically connected to the panel and chassis.

4 Meter

The meter has the following three scales:

1. "50-scale" This scale is used with 5/50/500 mV and 5/50/500 V ranges.

   The "50" on the scale denotes 5 mV when the 5 mV is selected, and 500 V when the 500 V range is selected.

2. "1.5-scale" This scale is used with 1.5/15/150 mV and 1.5/15/150 V ranges.

   The numeral on the scale denotes a

value similarly to that of the 5-scale.

3. "dBm-scale" This scale is used to read the measured voltage in the dBm value with respect to 1 mW, 600Ω. This scale is used for all 12 ranges, -60∼+50 dBm.

5	Output terminals	Output terminals for using Model 164E as an amplifier. For connection, a standard dual banana plug with a coaxial cable is convenient. A banana plug, spade lug, alligator clip, 2-mm tip or lead wire 2 mm or less in diameter is usable similarly to that for the input terminals. The black terminal is the grounding side.

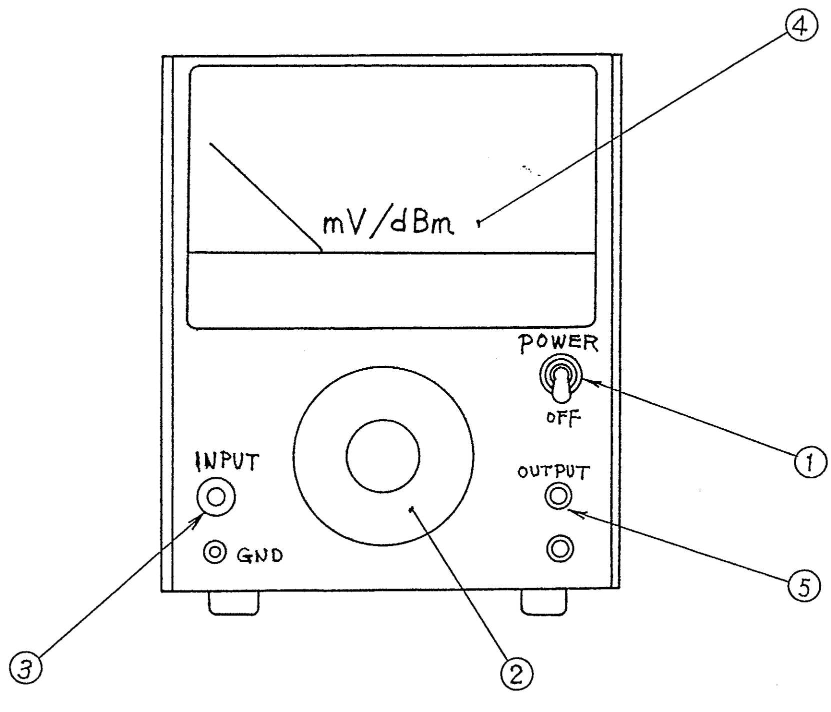

Fig. 3-1

3. 2 Preparation for measuring operation

(1) Turn off the power switch.

(2) Check that the meter pointer is at the center of the zero point on the scale. If not, conduct zero adjustment.
The zero adjustment during use should be effected more than five minutes after the power switch is turned off so that the pointer settle near the zero point.

(3) Connect the power cord to the required power source.

(4) Set the range switch dial to the 500 V range position.

(5) Turn on the power switch, and the equipment will be energized and the range dial illuminated.
For about 10 seconds after the power switch is turned on, the meter pointer may possibly deflect irregularly. This irregular pointer deflection may also occur when the power switch is turned off.

(6) When the meter pointer settles, Model 164E is ready for a measuring operation.

3. 3 Measurement of AC voltage

(1) When the voltage to be measured is low or the impedance of the power source to be measured is comparatively high, use a shielded wire or coaxial cable, considering the frequency, to avoid induction from outside. When the voltage to be measured is low in frequency and high in level or the impedance of the power source is low, the accessory Type 941B terminal adapter can be used conveniently.

NOTE: When using the 1.5 mV range, it is recommended to employ a shielded wire or coaxial cable to prevent the coupling caused by the radiation from the indicator.

(2) To protect Model 164E from an overload, measurement should be started with the maximum voltage range, and then lower voltage ranges will be selected in sequence according to the display on the meter.

(3) Using the 15- and 50-scales of the meter as appropriate, read the display as in Table 3-1.

Table 3-1

Range		Scale	Multiplier	Voltage Unit	Amplification Degree (dB)
1.5 mV	-60 dBm	15	x 0.1	mV	60
5 "	-50 "	50	"	"	50
15 "	-40 "	15	x 1	"	40
50 "	-30 "	50	"	"	30
150 "	-20 "	15	x 10	"	20
500 "	-10 "	50	"	"	10
1.5 V	0 "	15	x 0.1	V	0
5 "	10 "	50	"	"	-10
15 "	20 "	15	x 1	"	-20
50 "	30 "	50	"	"	-30
150 "	40 "	15	x 10	"	-40
500 "	50 "	50	"	"	-50

(4) When measuring a voltage by the dBm value with respect to 1 mW, 600 Ω, use the dBm scale, common to all ranges, and read the display as follows: The "0" marked in the middle of the dBm scale denotes the level the range name represents; therefore, the measured value will be the meter

reading plus the dBm value the range name represents. For example, when the "30" dBm (50 V) range is selected and "2" is read from the dBm scale, the measured value is

$$2 + 30 = 32 \text{ (dBm)}$$

When the "-20" dBm (150 mV) range is used and the meter indicates "1" dBm, then

$$1 + (-20) = 1-20 = -19 \text{ (dBm)}$$

3.4 Measurement of AC current

When using Model 164E for measuring an AC current, let the current (I) flow through a known non-inductive resistance (R), measure the voltage across the resistance, and calculate $I = E/R$, In this case, note that the negative (-) terminal of the input terminals of Model 164E is grounded.

For the convenience of current measurement, Type 921 Shunt Resistors which have standard resistances of 0.1, 1, 10, 100 and 1000 Ω, respectively, are available as optional accessories. Also available are 4, 8, 16 and 600 Ω resistors. Each resistance can be connected to the input terminals of Model 164E by using banana plugs.

Example: To measure the heater current (nominal: 6.3 V, 0.3 A) of a vacuum tube, connect the circuit to Model 164E as in Fig. 3-2 by using Type 921-0.1 (resistance: 0.1Ω) as the standard resistance. If 29 mV is read on Model 164E, the heater current will be

$$1 = \frac{29 \times 10^{-3}}{0.1} = 290 \times 10^{-3} \text{(A)} = 290 \text{ (mA)}$$

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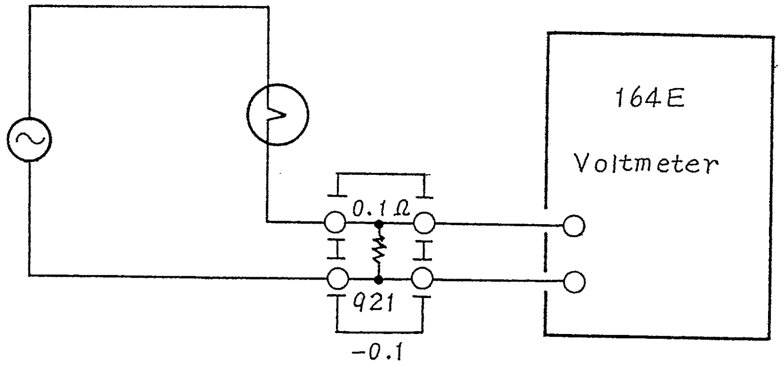


Fig. 3-2

3.5 Use of Model 164E as output meter

By measureing the voltage (E) applied across an impedance (X) the apparent power (VA) of the impedance can be obtained by solving $VA = E^2/X$. If the impedance is ohmic resistance (R) the power (P) consumed in the resistance will be

$$P = E^2/R$$

Since Model 164E has a dBm scale, the power can be read in decibels as it is, provided R=600Ω. If the load resistance is within the range from 1Ω to 10 kΩ, the power can be read in decibels by adding the value obtained from the decibel conversion charts, Figs. 3-3 and 3-4.

Type 921 Shunt Resistors having resistances of 4, 8 and 16Ω, respectively, which are identical with the voice coil impedances of the loudspeakers in general use, are available. They can be utilized as a load resistance of small capacity (0.3W) when using Model 164E as an output meter.

3.6 Waveform error

Model 164E is a "mean value" voltmeter that indicates a value proportional to the mean value of the measured voltage. Since the meter scale is calibrated by the effective value of sine wave, however, the correct effective value may not be displayed, giving rise to an error, when a voltage distorted in waveform is measured. Table 3-2 shows this relationship.

Table 3-2

Measured Voltage	Effective Value	Model 164E Display
100%-amplitude fundamental	100%	100%
100% fundamental + 10% second harmonic	100.5	100
100% fundamental + 20% second harmonic	102	100 - 102
100% fundamental + 50% second harmonic	112	100 - 110
100% fundamental + 10% third harmonic	100.3	95 - 104
100% fundamental + 20% third harmonic	102	94 - 108
100% fundamental + 50% third harmonic	112	90 - 116

3.7 Use of decibel conversion table and charts

(1) Decibel

"Bel" is a logarithmic (common) unit expressing the ratio of two powers. One "decibel" (abbreviated dB) is one-tenth of a Bel. The dB is defined as follows:

$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

That is, how large the power P_2 is in comparison with the power P_1 is represented with 10 times the common logarithm.

If the impedances at the places where P_1 and P_2 exist are equal to each other, the ratio of powers may be expressed with the ratio of voltages or currents as follows:

$$dB = 20 \log_{10} \frac{E_2}{E_1} \text{ or } 20 \log_{10} \frac{I_2}{I_1}$$

Decibel is originally the ratio of powers as explained above. However, the common logarithm of the ratio of other values has also been called "decibel" for a long time.

For example, when the input voltage of an amplifier is 10 mV and its output voltage is 10 V, the degree of amplification is 10 V/10 mV = 1,000 times. This is also expressed in dB as follows:

$$\text{Degree of amplification} = 20 \log_{10} \frac{10 \text{ V}}{10 \text{ mV}} = 60 \text{ (dB)}$$

Also, the output voltage of a standard RF signal generator is expressed in dB to represent how many times of $1\mu V$ the output voltage is. An output of 10 mV, for example, is

$$10 \text{ mV} = 20 \log_{10} \frac{10 \text{ mV}}{10 \mu V} = 80 \text{ (dB)}$$

Such a decibel notation must have the reference, namely, 0 dB, clarified. For example, the output voltage of the above signal generator should be expressed "80 dB ($1\mu V$ = 0 dB)

(2) dBm

"dBm" is abbreviation of dB (mW). This decibel value expresses the power ratio with respect to 1 mW that is 0 dB. Normally "dBm" implies the condition that the power exists in an impedance of 600Ω.

So "dBm" generally means 'dB (mW 600Ω)."

As mentioned before, if the power and impedance are definite, the decibel can express voltage and current as well as power. Therefore, "0 dBm" signifies the following:

0 dBm = 1 mW or 0.775 V

or 1.291 mA

The decibel scale of Model 164E is graduated by the dBm value as explained above. Therefore, when measuring a decibel value that is expressed with respect to other than "1 mW 600Ω, "the reading on Model 164E should be corrected. Because of the character of logarithm, this correction can be effected by adding a value to the reading, referring to Table 3-3 and Fig. 3-4.

(3) ~~Use~~ of decibel conversion table and charts

Fig. 3-3 is used to convert the ratio of values into a decibel value.

Different decibel scales are provided for power (or equivalent) and voltage (or current) ratios.

Example 1: How many decibels is 5 mW with respect to 1 mW? Since this is a power ratio, the left scale is used. From the power ratio of 5 mW/ 1 mW = 5, 7 dB (mW) is obtained as shown with a dotted line in Fig. 3-3.

Example 2: How many decibels are 50 and 500 mW with respect to 1 mW? When the ratio is 0.1 or less, or 10 or more, the decibel value is obtained by using Fig. 3-3 and Table 3-3 as follows:

50mW = 5 mW x 10 = 7 + 10 dB = 17 dB

500 mW = 5 mW x 100 = 7 + 20 dB = 27 dB

Table 3-3

Ratio	Decibel	
	Power Ratio	Voltage or Current Ratio
10.000 $=1 \times 10^{4}$	40 dB	80 dB
1.000 $=1 \times 10^{3}$	30 "	60 "
100 $=1 \times 10^{2}$	20 "	40 "
10 $=1 \times 10^{1}$	10 "	20 "
1 $=1 \times 10^{0}$	0 "	0 "
0.1 $=1 \times 10^{-1}$	-10 "	-20 "
0.01 $=1 \times 10^{-2}$	-20 "	-40 "
0.001 $=1 \times 10^{-3}$	-30 "	-60 "
0.0001 $=1 \times 10^{-4}$	-40 "	-80 "

Example 3: What is 15 mV in dB(V)? Since 1 V is the reference, 15 mV/1 V = 0.015 is calculated first. By using the voltage (current) scale of Fig. 3-3, and Table 3-3,

0.015 = 1.5 x 0.01 = 3.5 + (-40) = -36.5 dB(V)

or

1 V/15 mV = 66.7 x 10 → 16.5 + 20 = 36.5 dB(V)

∴ -36.5dB(V)

(4) Use of decibel addition chart

Fig. 3-4 is used for obtaining the power from the dBm value read out from Model 164E.

Example 1: When the voltage across the voice coil, having an impedance of 8 Ω, of a loudspeaker is is measured by Model 164E, the meter indicates -4.8 dBm. What is the power (more precisely, apparent power) in watts supplied to the speaker? By using Fig. 3-4, the value to be added, corresponding to 8Ω, is obtained to be +18.8 as shown with a dotted line in Fig. 3-4. The power expressed in dB (mW 8Ω) is obtained by adding the +18.8 to the meter reading, as follows:

-4.8 + 18.8 = +14 dB (mW 8Ω)

This 14 dB (mW 8Ω) is converted, by using Fig. 3-3, into the following wattage:

18 dB (mW 8Ω) ⟶ 25 mW

Example 2: What voltage in volts should be applied to supply a power of 1 W to a load of 10 kΩ ?

Since 1 W is 1,000 mW, it is 30 dB (mW); therefore, the voltage corresponding to 30 dB (mW 10 kΩ) is the value being sought.

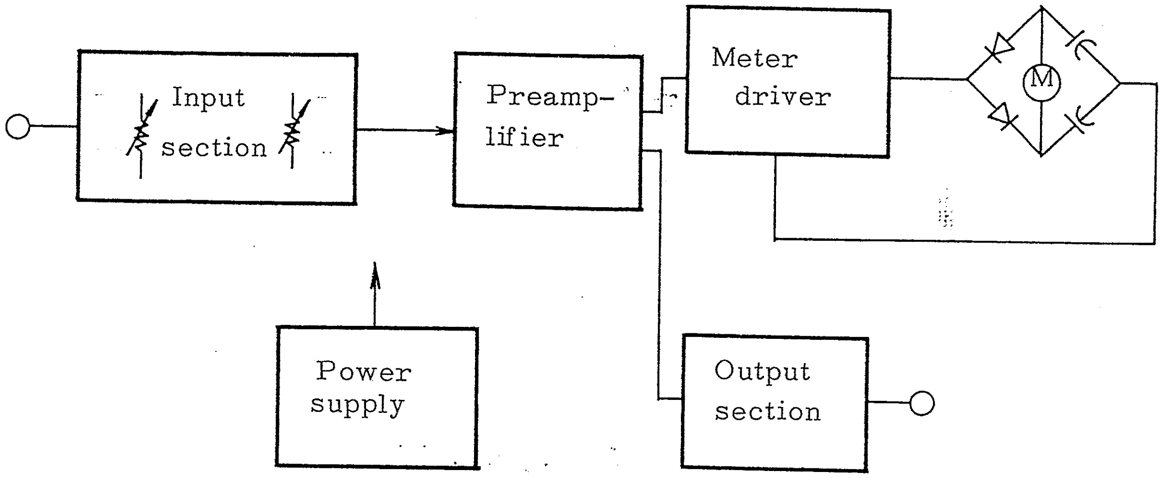
A value of -12.2 to be added for the 600Ω ⟶ 10 kΩ conversion is obtained from Fig. 3-4. Therefore, the meter indication on Model 164E should be 30 - (-12.2) = 42.2 on the dB (mW 600Ω) scale.

The voltage with which Model 164E indicates

42.2 - 40 = 2.2 dBm on the 40 dBm range (0 - 100 V) is the value sought. That is, 42.2 dBm = 100 V.

4. Operation Principle

Model 164E AC Voltmeter consists of an input section, a preamplifier, a meter driver, an output section, and a power supply.



4.1 Input section

The input section consists of a voltage pre-divider (0/60 dB), an impedance converter, and a main voltage divider composed of six ranges in 10 dB steps (0/10/20/30/40/50 dB) as shown in Fig. 4-2.

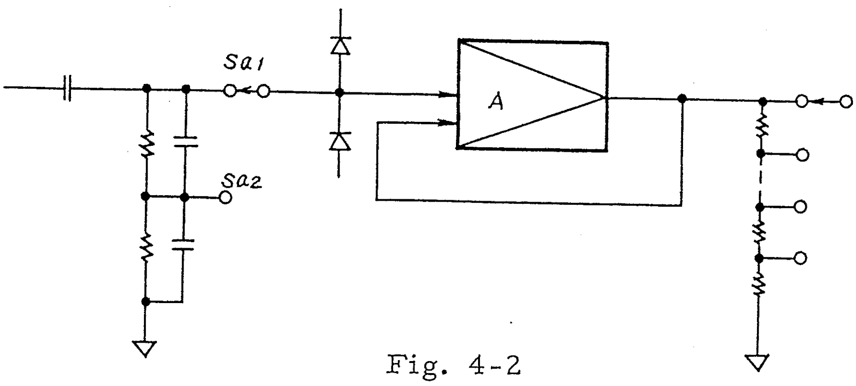


Fig. 4-2

For 1.5~500 mV ranges, the range switch is connected to contact Sa_1; for 1.5~500 V ranges, to contact Sa_2. The input having passed the voltage pre-divider enters the impedance converter. The converter consists of transistors Q_1 and Q_2, with the FET in the first stage. The high-impedance signal is converted into low-impedance output and then supplied to the main voltage divider.

The main voltage divider divides the signal to approximately 1.5 mV according to the signal level.

Diodes CR_1 and CR_2 are provided for protecting an excessive input.

4.2 Preamplifier

The preamplifier is a negative feedback amplifier, consisting of three transistors, for amplifying the faint signal delivered from the input section.

4.3 Meter driver

This is an amplifier using transistors Q_7 and Q_8.

A current feedback is applied from the collector of transistor Q_8 to the emitter of transistor Q_7 through rectifier diodes.

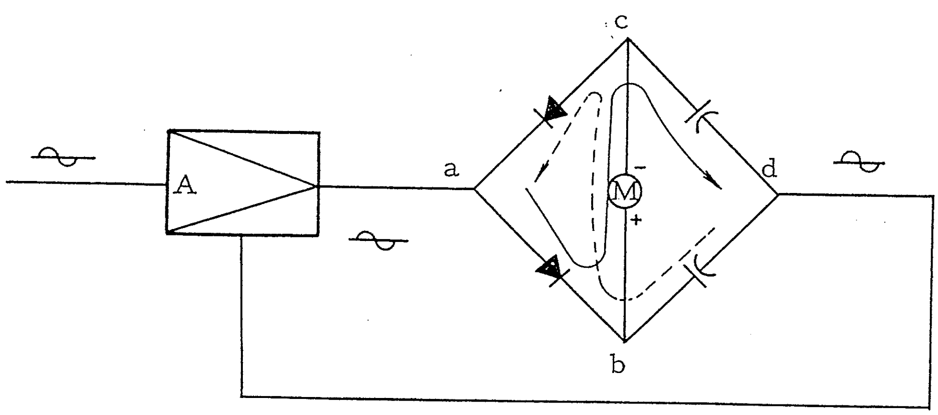


Fig. 4-3

For the above reason, the diodes are driven with nearly constant current, improving the non-linearity of diode and enabling linear meter indication. Fig. 4-3 illustrates the performance. During the positive output voltage cycle of the amplifier, current flows $a \rightarrow b \rightarrow c \rightarrow d$ as shown with a solid line; during the negative cycle, current flows $d \rightarrow b \rightarrow c \rightarrow a$ as shown with a dotted line. This makes the meter be driven according to the mean value of the current flow.

4.4 Output section

The collector voltage of transistor Q_4 in the preamplifier is amplified by transistor Q_6 and taken outside.

The output terminal gives an output of approximately 1.5 V at the full-scale meter indication.

4.5 Power supply

The power supply has regulated +7 and +25 V outputs and an AC 6.8 V output for illuminating the range switch dial.

The +25 V voltage regulator circuit uses the reference voltage produced by utilizing the zener characteristic ~~between the emitter and base of transistor~~ CR_7, amplifies the error by transistor Q_{10}, and conducts series control by transistor Q_9 to obtain the regulated voltage. The regulated 11 V output is obtained by utilizing the reference voltage.

5. Maintenance

5.1 Inspect parts inside the cabinet.

When it is necessary to inspect parts inside the cabinet, remove the four screws located on the rear of the cabinet, and the left and right side panels can be detached. Location of components, with the side panels removed, is illustrated in Fig. 5-1.

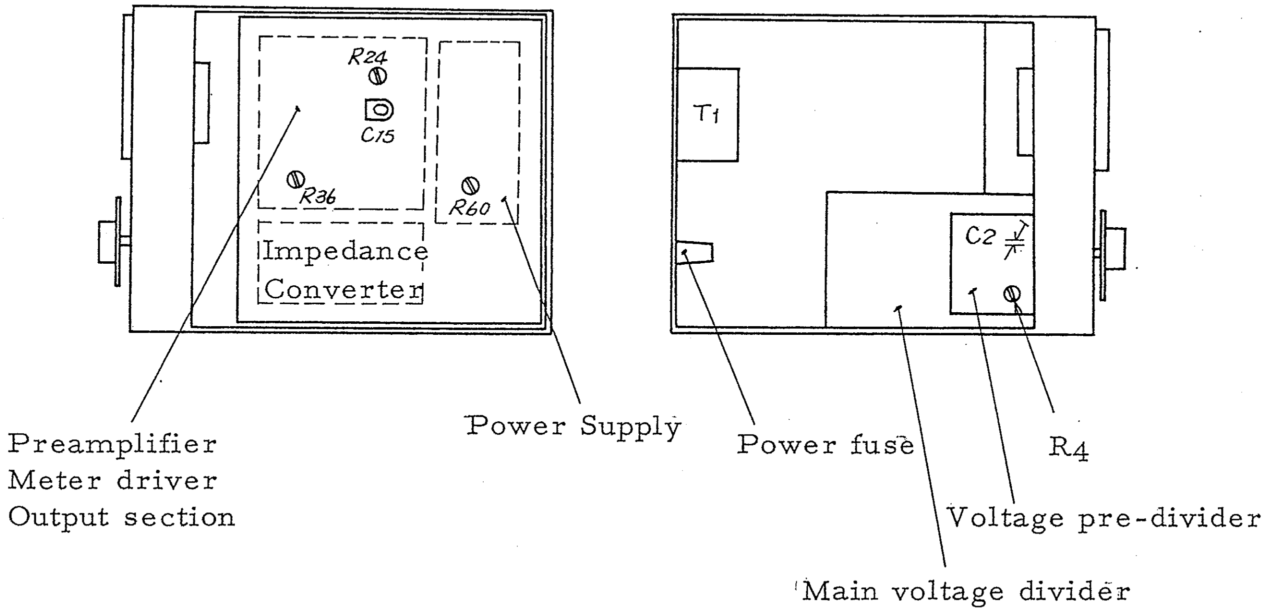


Fig. 5-1

5.2 Adjustment and calibration

When adjustment or calibration is needed during a long period of use or after repair, follow the instructions below:

(1) Adjustment of voltage regulator circuit

Connect a DC voltmeter between the emitter of transistor Q_9 in the power supply circuit, and the ground. Adjust variable resistor R_{60} so that the DC voltmeter indicates +25 V.

(2) Calibration of preamplifier for high and low frequencies

Before calibration, zero-adjust the meter as described in Item 3. 2 (2).

Set the range switch to the 50 mV range, apply a calibration voltage (sine wave of low distortion factor) of 50 mV, 400 Hz, to the input terminal, and adjust variable resistor R_{24} of the preamplifier so that the meter has the full-scale indication precisely.

Change the frequency of the calibration voltage to 1 MHz and adjust trimmer capacitor C_{15} for the precisely full-scale meter indication.

(3) Adjustment of voltage pre-divider

Set the range switch to the 1. 5 V range, apply a calibration voltage of 1. 5 V, 400 Hz, to the input terminal, and adjust variable resistor R_4 of the voltage divider for the full-scale meter indication.

Change the frequency of the calibration voltage to 40 kHz and adjust trimmer capacitor C_2 for the full-scale meter indication.

Repeat the 400 Hz and 40 kHz, 1.5V adjustments two or three times for the complete calibration.

(4) Adjustment of output amplifier

Set the range switch to 1. 5 V range, apply a calibration voltage of 1. 5 V, 400 Hz, to the input terminal, and adjust variable resistor R_{36} so that the voltage at the output terminal is 1. 5 V.

5. 3 Reference voltages for troubleshooting

Model 164E is carefully assembled and adjusted, and then inspected under strict control before shipment. If the AC voltmeter should fail because of an accident or parts life, check the voltage distribution at various points against the following tables.

Tables 5-1, 5-2 and 5-3 show the no-signal voltage distribution measured with respect to the ground by Kikusui Electronics' Model 107A VTVM (input resistance: 11 MΩ).

(1) Impedance converter

Table 5-1

Transistor	Emitter Source (V)	Base Gate (V)	Collector Drain (V)
Q_1 2SK-30	7.2		2.1
Q_2 2SC372	6.6	7.2	2.5

(2) Preamplifier, meter driver and output section

Table 5-2

Transistor	Emitter (V)	Base (V)	Collector (V)
Q_3 2SC372			4.6
Q_4 2SC372	5.4	6	9.7
Q_5 2SA495	5.4	4.6	2.6
Q_6 2SC372	9 8	10.4	2.1
Q_7 "			5
Q_8 "	4.4	5	8

(3) Power supply

Table 5-3

Transistor	Emitter (V)	Base (V)	Collector (V)
Q_9 2SC515	2.5	25.6	42
Q_{10} 2SC372	11	11.6	25.6
Q CR_1 "	33	25	25
~ CR_7 RD11A or 02Z11A	11	0	

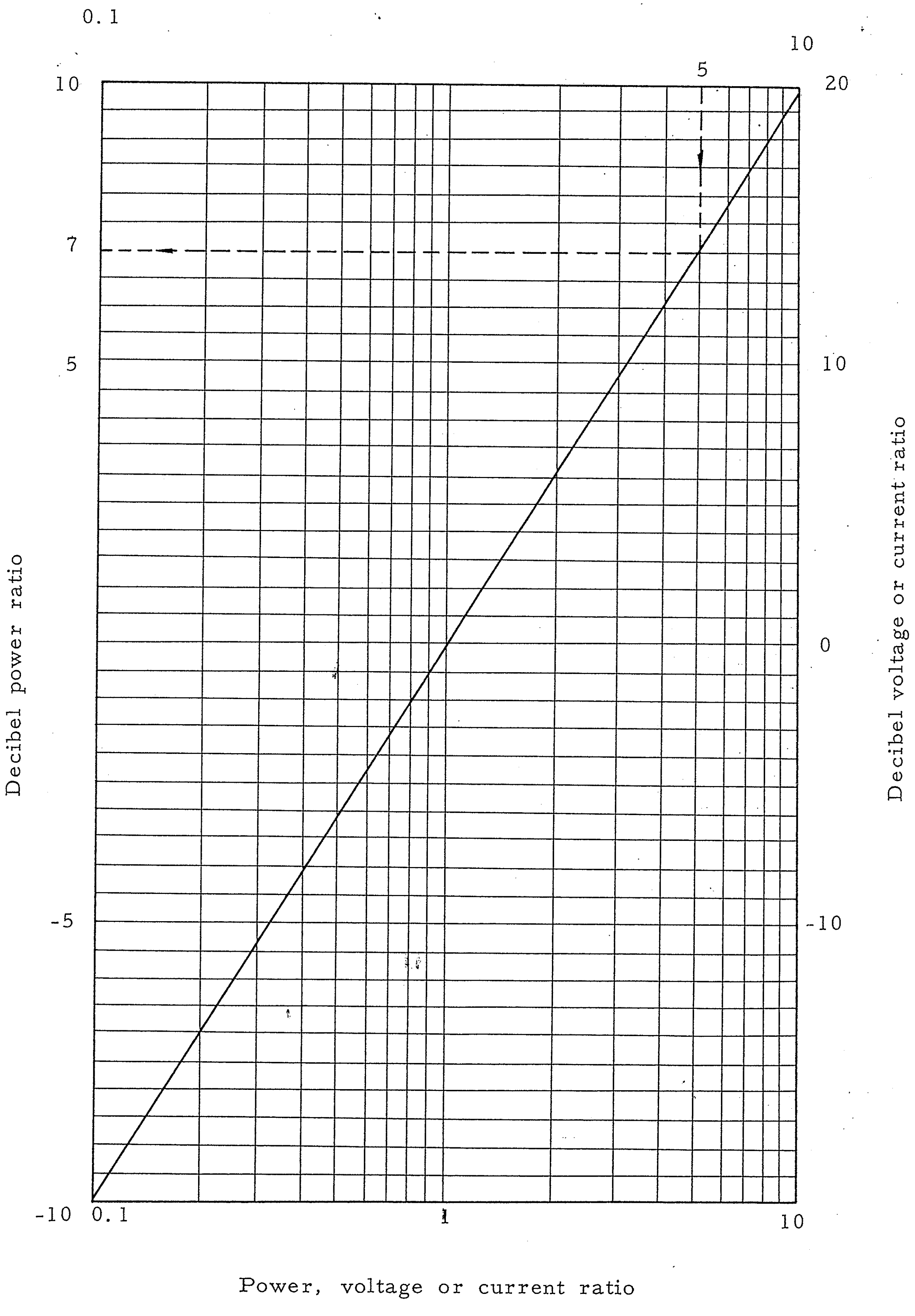
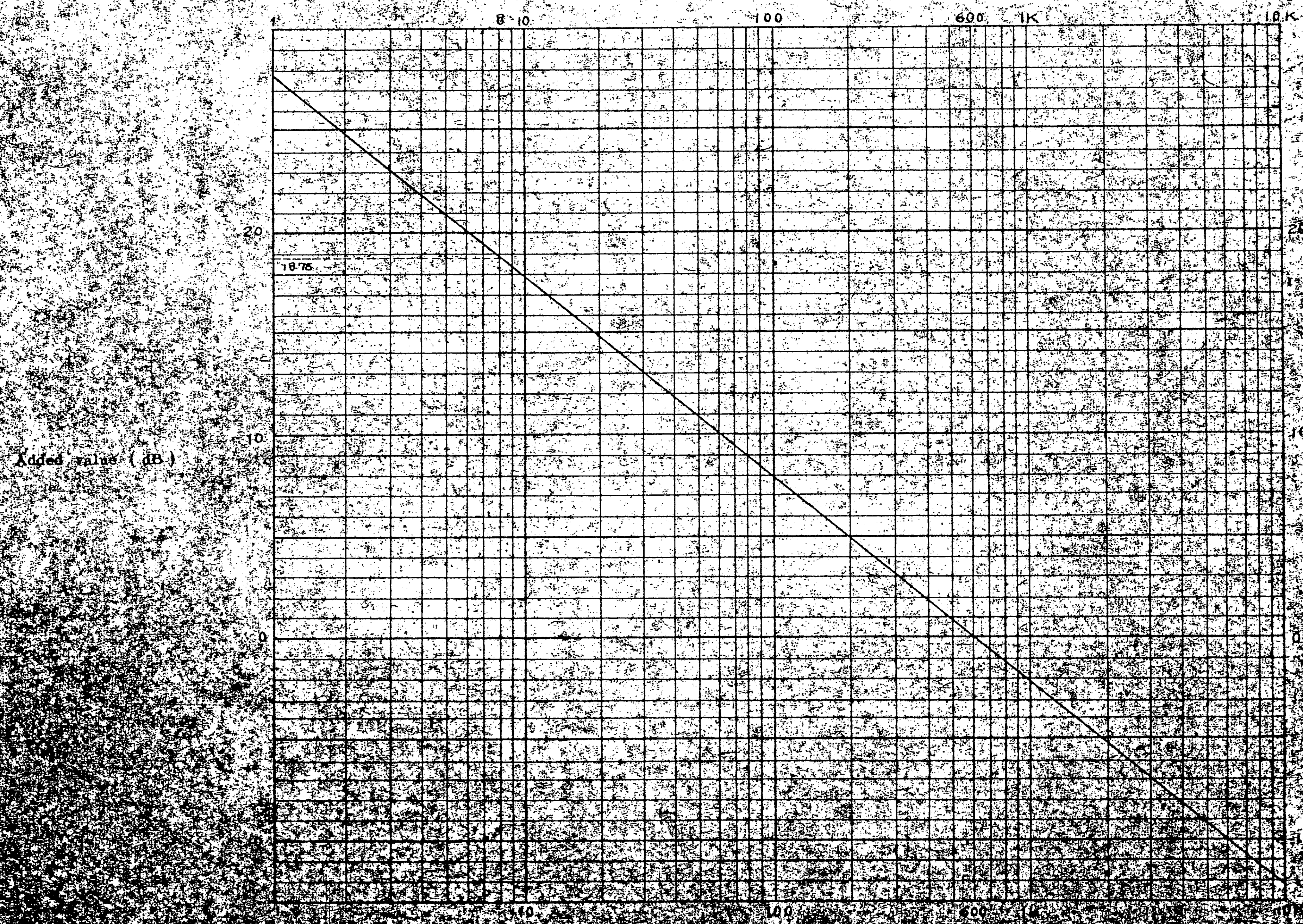

0.1
10
5
20
10
7
5
10
0
-5
-10
-10
0.1
1
10
Decibel power ratio
Decibel voltage or current ratio
Power, voltage or current ratio

Fig. 3-3



1
8
10
100
600
1K
10K
20
18.75
10
0
Added value (dB)