INSTRUCTION BOOK

OPERATING INSTRUCTIONS

MULTI-PURPOSE THRULINE® WATTMETER RF POWER ANALYST® MODEL 4391A

Electronic Corporation
Cleveland, (Solon) Ohio USA

Instruction Book Part Number 920-4391A Rev. A

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Chapter 1
Introduction

The Model 4391A is a multi-purpose Radio Frequency wattmeter designed around a microcomputer. A fairly extensive program stored in permanent memory controls the operation of the instrument at all times, permitting the detection and correction of various error sources and the refinement of the raw data produced by the directional detectors. Thus the instrument can compute VSWR, amplitude modulation, and various decibel variables reducing the odds of error and making such measurements consistent or repeatable regardless of who is making the measurement.

Other benefits include extended range using standard elements in some modes of operation, continuous monitoring of maximum and minimum readings, a peaking aid, and error messages.

Because of its complexity, the proper use of the 4391A is not always obvious. For this reason it is strongly advised that this manual be read in its entirety before using the device.

Purpose and Function

The 4391A RF Power Analyst is an insertion type digital RF Directional Thruline Wattmeter designed to measure peak or average power flow, load match, and amplitude modulation in 50 ohm coaxial transmission lines. It is intended for use with CW, AM, FM, SSB, TV, and Pulse modulation envelopes. The instrument directly reads PEP or CW power in watts, milliwatts, or kilowatts in 9 ranges from 2.5 to 1000 full scale forward power and 0.25 to 100 full scale reflected power depending on the Plug-in Element. In addition it reads SWR directly over the range of 1.00 to 99.99, percent modulation directly over the range of .0 to 99.9, and return loss over the range of 0 to 36.1 dB. For convenience, forward and reflected CW power can be displayed in dBm (dB above 1 milliwatt) from 6 dB above to 24 dB below nominal element range.

Power range and frequency band are determined by the Plug-in Elements used. Two switches on the front panel of the instrument are set by the user to correspond to the nominal power range of the forward element. The reflected element is assumed to have a nominal range one tenth that of the forward element.

In any of the modes of operation described, the instrument can recall from memory the lowest or highest reading taken or tell the operator whether the newest reading is less than, equal to, or greater than the previous reading.

Description

The instrument is housed in an aluminum calculator-style case approximately 4-3/8 inches high by 9-5/8 inches deep by 6-1/4 inches wide (111 mm x 244 mm x 159 mm) including connections, see figure 1. The line section is contained in the case and is not intended for removal. At each end of the line section are Bird Quick-Change type RF connectors which may be easily interchanged with any other Bird QC connector. See Bird Catalog for types available.

Operating power is derived from rechargeable nickel-cadmium batteries inside the unit or from a 115/230 Vac power source connected to the unit through the power cord supplied with the unit.

Specifications

Measuring Medium	RF Transmission in 50 ohm lines
RF Power Range [1]	100 mW to 10 kW full scale using Bird Plug-in Elements. Accuracy not guaranteed with components not supplied by Bird.
Usable Over-Range	To 120% of scale on CW, PEP, SWR and Return loss functions. To 400% of scale (PEP) on dBm and 0% modulation.
Frequency Range [1]	450 kHz to 2.3 Ghz
Sampling Range	2-3 readings per second
Settling Time	10 seconds (worst case) [3]
Accuracy	
Power Readings	±5% of full scale
SWR	±10% of reading
% Modulation	±5% [2]
Return Loss	±0.3 dB to corresponding SWR value
Impedance	50 ohms
Insertion SWR	1.05 max to 1000 MHz
Pulse Parameters (square pulses)	
Pulse Width	0.8 µsec min. [4]
Repetition Rate	25 pps min.
Duty Cycle	0.01% min.
RF Line Connections	
Standard	Bird Quick Change "QC" Female N
Optional	Any Standard AN "QC" type
Temperature Range	
Operating	10°C to 45°C (50°F to 113°F)
Storage	-20°C to 45°C (-4°F to 113°F)
Input Power Requirements	
Voltage	100-130 200-230 Vac (Switch Selectable) or 7.5 Vdc (internal battery)
Frequency	50-60 Hz
Power	6 Watts
Batteries	6-1.25 V Nicad C size
Battery Life	(Reachargable) 8 hours approx.
Weight	5-3/4 lb (2.6 kg)

Specification Notes

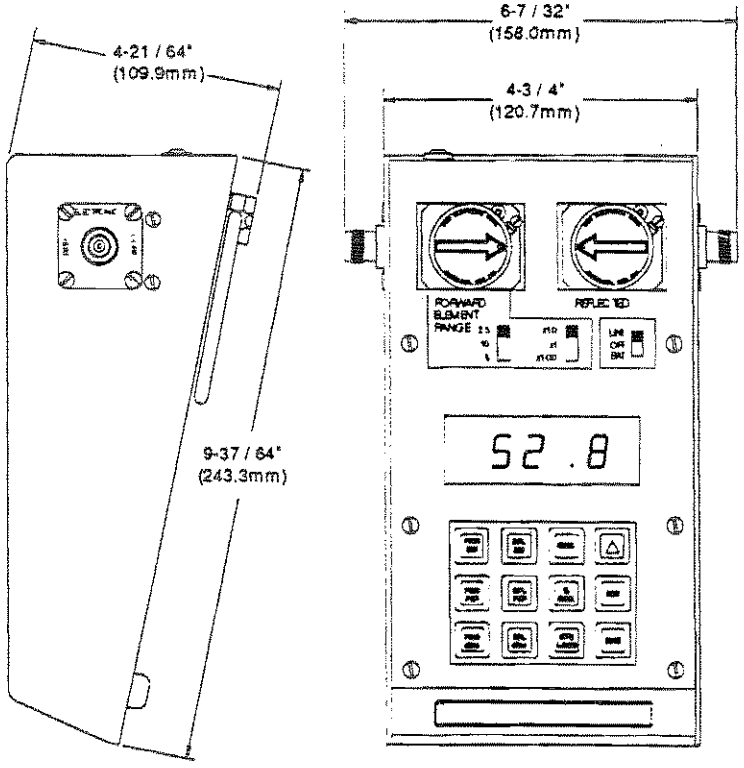
[1] Frequency band and power range is determined by Plug-in Elements selected. See Bird Catalog for availability. Some modes require two elements in a 10:1 power ratio.

[2] For CW power levels greater than one-third of full scale, accuracy of the percent modulation mode is 5% from 0 to 90% and +10% from 90 to 100%. Modulation frequency is 25 to 100,000 Hz; except for "A" and "B" elements: 25 to 20,000 Hz; and "H" elements: 25-10,000 Hz.

[3] VSWR and return loss functions settle in less than 1 second.

[4] For "A" and "B" elements the minimum pulse width is 1.5 microseconds. For "H" elements the minimum pulse width is 15 microseconds.

Figure 1
Outline Drawing



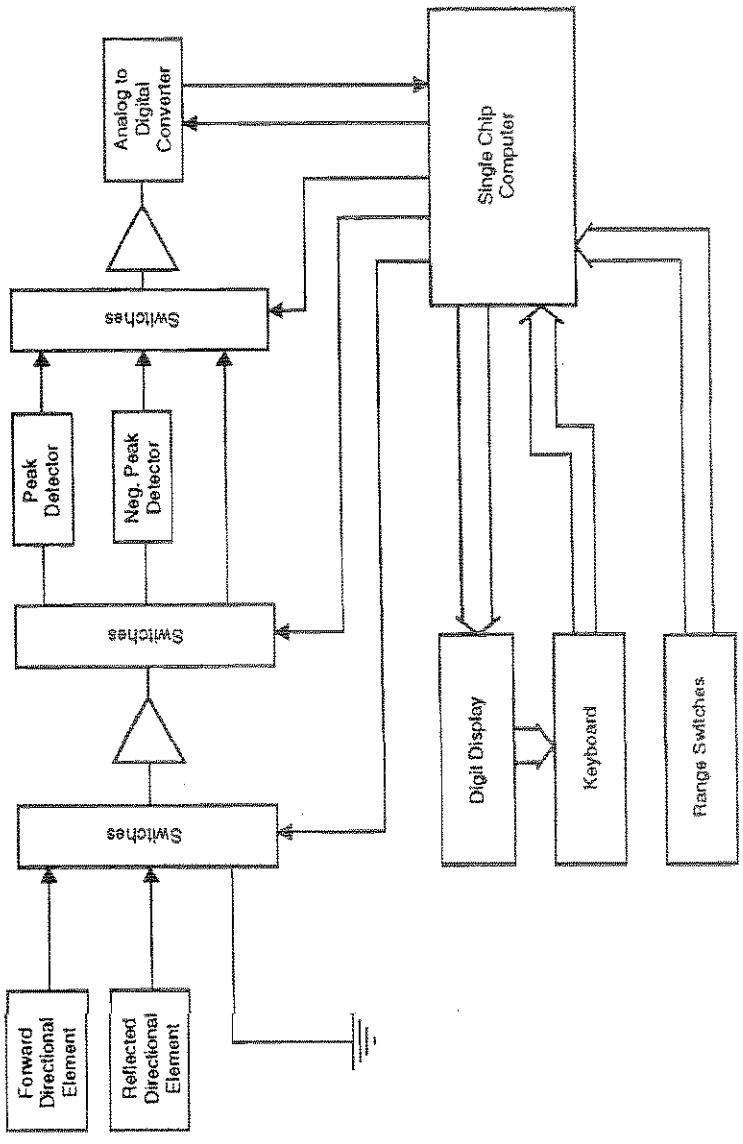
Chapter 2

Theory Of Operation

Description of Operation

Figure 2 is a block diagram of the major functional parts of the Model 4391A RF Wattmeter. The Microcomputer integrated circuit shown, controls all the other portions of the instrument, which fall into two major groups.

Figure 2 Circuit Block Diagram



Keyboard, Range Switches, and Display Group

The keyboard and range switches serve only to pass information to the computer. The display, of course, returns information from the computer to the operator. The display, which is comprised of four seven-segment LED digits, is strobed digit by digit left to right at a rate of approximately one digit per millisecond. This serves to conserve battery power and drive circuitry while providing scanning for the columns of the keyboard. Each time a digit is strobed, the corresponding column of the keyboard is read and if a key is pressed, the computer puts the code for that key into a memory cell. The nine mode keys select which parameter is to be measured. The three modifier keys simply modify the way in which the result is displayed. The range selector switches identify to the computer the nominal full scale values of the elements used. They have no effect on input sensitivity, which is determined by the elements.

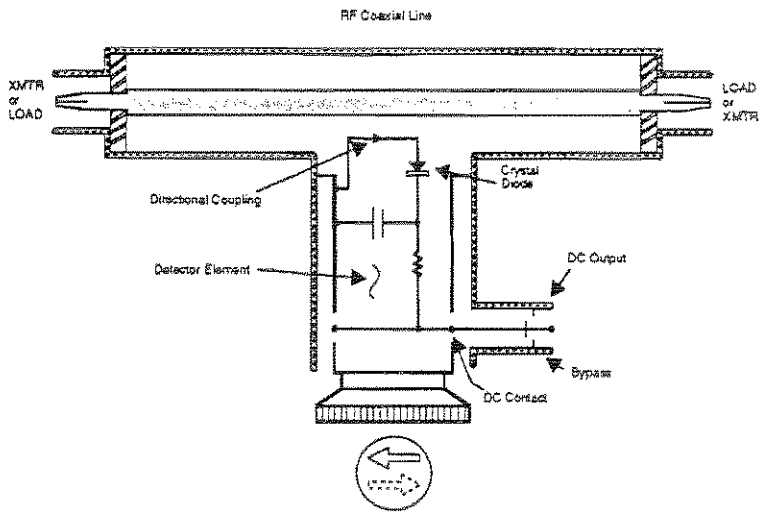
Plug-in Elements, Analog Circuitry, and A/D Converter

These components are controlled by the computer. The Plug-in Elements in the line section provide low level positive voltages related to the instantaneous value of power (see figure 3). The first group of solid state switches selects the forward element, the reflected element, or ground as the input to the preamplifier which boosts these signals to 0.1 to 2.0 volt range. The remaining switches shown as two groups direct the output of the preamp to the analog-to-digital converter either directly or through a peak or negative peak detector. The analog-to-digital converter converts the voltage to a 15 digit binary number.

Each reading output by the display is derived from as many as three different voltage readings using the circuitry described above. Once these voltages are measured, all the remaining operations are performed within the computer chip as follows:

The voltages are corrected for error due to dc drift in the analog circuitry. Each voltage is converted to square root of power using tables of stored data. These values are then combined mathematically to arrive at the final result in binary. This is used to update the registers containing the last value, the maximum value, or the minimum value as required. Finally, the result is converted to a decimal number and placed into a register from which the display driving routine operates.

Figure 3 Plug-In Element Schematic Diagram



The coupling circuit which samples the travelling waves is in the Plug-in Element. The circuitry of the element and its relationship to the other components of the Thruline Wattmeter are illustrated in the schematic diagram. Energy will be produced in the coupling circuit of the element by both mutual inductance and capacitance from the travelling RF waves of the line section. The inductive currents will, of course, flow according to the direction of the travelling waves producing them. The capacitive portion of these currents is naturally independent of the direction of the travelling waves. Therefore, assuming that the Plug-in Element remains stationary, it is apparent that the coupling currents produced from the waves of one direction will add in phase, and those produced from waves of the opposite direction will accordingly subtract in phase. The additive or "ARROW" direction is, of course, assigned to the forward wave.

The electrical values of the element circuits are carefully balanced and so designed that the current produced from the reverse wave will cancel the other almost completely. The resultant is a directivity always higher than 25 dB, which means that the element is highly insensitive (nulled) to the REVERSE direction wave. Being highly directional, the Thruline element is sensitive (at one setting) only to one of the travelling waves which produces standing waves by interference. Thruline Wattmeter measurements are, therefore, independent of position along standing waves.

Figure 4
Readings with Various Envelopes

Transmission Type and Scope Pattern	Frequency Spectrum (C: Carrier)	PEVrms (arbitrary)	PEP = PEV_{rms}^2 / Z_0	Average (Heating) Power	4391 Series CW Mode	4391 Series PEP Mode	4391 Series %MOD Mode	Model 43
CW (100V)	C	$\frac{100}{\sqrt{2}}$ V	100W	100W	100W	100W	0%	100W
AM 100% Mod. (200V)	C	$\frac{200}{\sqrt{2}}$ V	400W	150W	100W	400W	100%	100W
AM 73% Mod. (173V)	C	$\frac{173}{\sqrt{2}}$ V	300W	127W	100W	300W	73%	100W
SSB 1 Tone (100V)	(C)	$\frac{100}{\sqrt{2}}$ V	100W	100W	100W	100W	0%	100W
SSB 2 Tone (100V)	(C)	$\frac{100}{\sqrt{2}}$ V	100W	50W	25W	100W	100%	40.5W
TV Black Level (100V)	C	$\frac{100}{\sqrt{2}}$ V	100W	60W	-	100W	-	9.6W
Pulse (100V; 10% / 90%)	C	$\frac{100}{\sqrt{2}}$ V	100W	0 W	-	100W	100%	-

Z_0 = 50 ohms

PEV: Peak Envelope Voltage. Carrier (or suppressed carrier) PEV was arbitrarily chosen at 100 volts in all examples. $PEV_{rms} = PEV / \sqrt{2}$.

Chapter 3

Installation

The Model 4391A RF Power Analyst is completely portable and very suitable for field or laboratory use. Its power is derived from rechargeable nickel-cadmium batteries inside the unit or from an ac outlet via the power cord supplied with the device.

> CAUTION
> Always be certain the 115/230 voltage selector is set to the proper voltage before ac power is applied.

Connections

The Model 4391A contains a short section of rigid 50 ohm coaxial air dielectric transmission line. To make measurements relating to the travelling waves in a coaxial line, that line must be disconnected at some convenient point to permit the Model 4391A air line to be inserted.

Although the Model 4391A is normally supplied with two Female N-type connectors, a variety of easily interchangeable connectors are available to facilitate connecting to the user's system.

Once the Model 4391A is installed in the coaxial line, a Plug-in Element or a pair of Plug-in Elements must be selected which correspond to the frequency and power levels to be measured.

In order to take full advantage of the Model 4391A's capabilities, two elements in a 10:1 ratio of power range should be used. If only one element is used, the other socket should be filled with a dust plug or a higher power element. Also, for greatest accuracy, the element(s) should be chosen having the lowest possible power range that will not result in over-ranging. Table 1 lists elements required for each mode of operation.

Table 1 Plug-In Elements Required

Mode	Forward	Reflected
FWD CW	✔	
RFL CW		✔
SWR	✔	✔
FWD PEP	✔	
RFL PEP		✔
% MOD	✔	
FWD dBm	✔	
RFL dBm		✔
RTN Loss	✔	✔

*The reflected element must have a nominal power range one tenth that of the forward element.

The higher power element is placed in the socket marked "FORWARD" and its arrow pointed in the direction of forward power flow (toward antenna or load). The lower power element is placed in the socket marked "REFLECTED" and is normally pointed in the direction opposite to forward power flow.

The elements are clamped in place by the hold-down catches on the face of the line section. These catches must be used to avoid error due to the element not contacting the bottom or seating plate of the socket.

With the element(s) in place, set the range switches to correspond with the nominal power range of the elements. For example, if the forward element is a 5 watt element, the switches are set at 5 and x1. For a 250 watt element they are set at 2.5 and x100. Sometimes it is necessary to use milliwatts or kilowatts as the unit of measure. In other words, 1 watt becomes 10 x 100 milliwatts and 2500 watts becomes 2.5 x 1 kilowatts.

Chapter 4

Operating Instructions

Operating Modes

The Model 4391A has nine modes of operation which are selected by pressing the mode keys momentarily. In addition, each mode has three output options selected by pressing the modifier keys. Detailed descriptions of the modes and output options follow.

Reading Forward Power

For this measurement only a forward element is required. Install the meter and element according to the preceding paragraphs and move the power switch to LINE or BAT depending on the power source desired. When powered up, the Model 4391A always goes into the forward CW power mode. If the unit is already operating, the forward CW power mode is selected by pressing the FWD CW key momentarily. If the applied power exceeds 120 percent of the range, two right-facing arrow heads (i.e., "greater-than" symbols) will be displayed. The operation of this error message does not depend on the correct setting of the range switches by the operator, nor will the meter or its elements be damaged if the switches are incorrectly set.

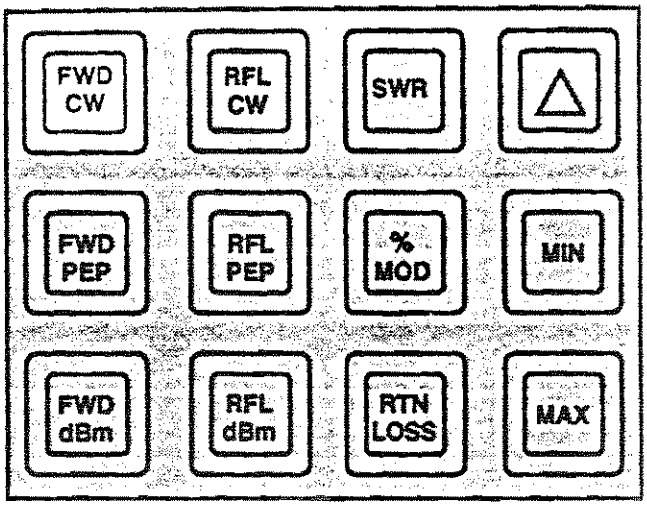
CAUTION

Never apply RF power to the Model 4391A Wattmeter unless both line section sockets are filled with either an element or a dust plug. If an element is used it is advisable to place the element with the arrow at a 90° angle to the coaxial line.

CAUTION

Always disconnect ac power before opening the Model 4391A enclosure. Removal of at least one battery cell is also recommended when servicing the instrument.

Figure 5
Forward Power
(CW)



The Model 4391A arrives at values of CW power by a method quite different from analog meters such as the Model 43, also manufactured by Bird Electronic. While the two instruments will agree when the measured wave is of constant amplitude, AM or SSB waves will result in different indications (in the CW mode). This is because the analog instrument uses the inertia of the microammeter to "time-average" the varying signal coming from the element, whereas the Model 4391A uses peak and negative peak detector circuits to measure peak and minimum square root of power and combines them using the equation:

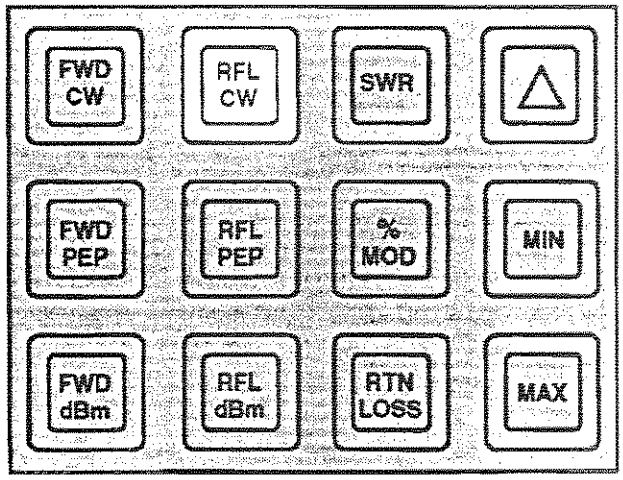
$$\text{CW Power} = \left(\frac{\sqrt{\text{Peak Power}} + \sqrt{\text{Minimum Power}}}{2}\right)$$

Using this technique, operation of the CW mode is predictable regardless of envelope shape (see figure 4).

Reading Reflected CW Power

Operation of the reflected CW power mode is identical to that for forward CW power described above with two exceptions: the readings are taken from the element in the socket marked "REFLECTED" and the range of the element is assumed to be 1/10 the range indicated by the range switches.

Figure 6 Reflected Power (CW)



Reading SWR

Two elements are required for this mode and they must have a 10 to 1 power range ratio. Press the SWR key momentarily. If the average forward power is between 10 percent and 120 percent of the full scale and the average reflected power is less than 120 percent of the reflected element range, SWR will be displayed. If any of the above conditions are not met, an error message will be displayed. Two arrows pointing to the right — or "greater-than" symbols — indicate over-range, while two left-pointing arrows — or "less-than" symbols — indicate under-range or too little power. Refer to table 2.

Figure 7 Standing Wave Ratio

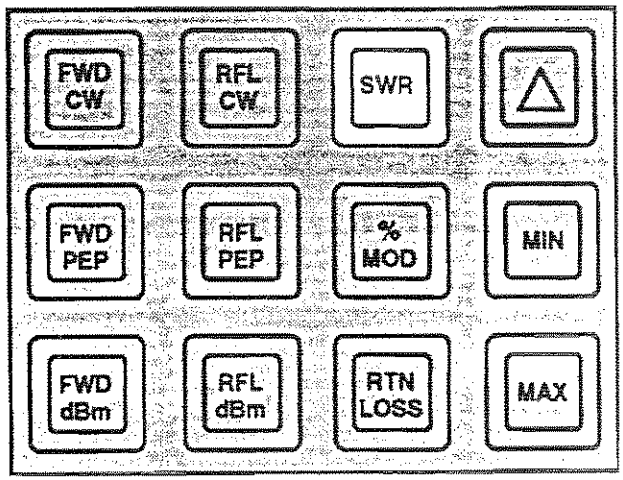


Table 2 Voltage Standing Wave Ratio (VSWR)

VSWR	Return Loss dB	Reflected Power %
1.01	46.1	0
1.02	40.1	.01
1.03	36.6	.02
1.04	34.2	.04
1.05	32.3	.06
1.06	30.7	.08
1.07	29.4	.11
1.08	28.3	.15
1.09	27.3	.19
1.10	26.4	.23
1.15	23.1	.49
1.20	20.8	.83
1.25	19.1	1.23
1.30	17.7	1.7
1.35	16.5	2.22
1.40	15.6	2.78
1.45	14.7	3.37
1.50	14.0	4.00
1.75	11.3	7.44
2.00	9.50	11.11
2.25	8.30	14.79
2.50	7.40	18.37
2.75	6.60	21.78
3.00	6.00	25.00
3.25	5.50	28.03
3.50	5.10	30.86
3.75	4.70	33.52
4.00	4.40	36.00
4.25	4.20	38.32
4.50	3.90	40.50
4.75	3.70	42.53
5.00	3.50	44.44

Measuring Peak Envelope Power

PEP power measurements are made in the same manner as the CW power readings described above, except that the FWD PEP and RFL PEP buttons are pressed and the readings are displayed directly as peak power.

☞ NOTE: The accuracy of measurements made with modulation present which has a frequency, duty cycle, pulse width, or repetition rate outside the range of the instrument cannot be assured in any mode of operation.

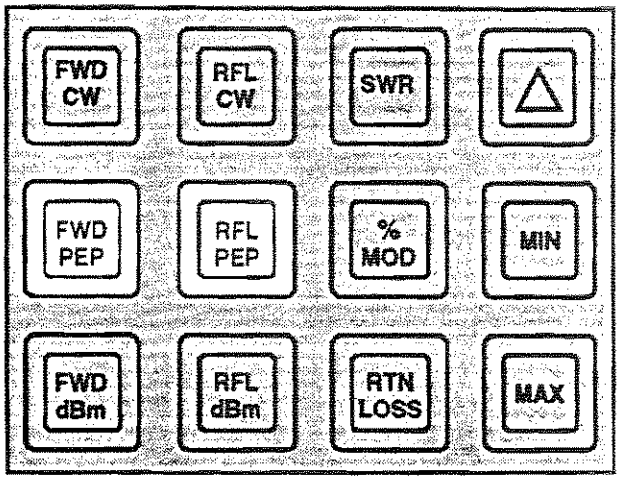


Figure 8 Peak Envelope Power (PEP)

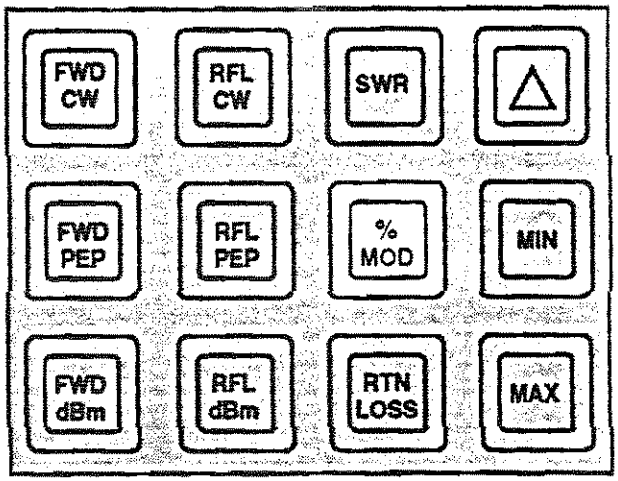
Measuring Amplitude Modulation

Only a forward element is required for this mode. The element should be pointed in the direction of forward power and the % MOD key pressed. Modulation is displayed directly in percent, provided the average signal is above 10 percent and the PEP of the signal is below 400 percent of the element's nominal full scale. For specified measurement accuracy, the average CW power levels must be greater than one-third of full scale. Modulation is calculated as follows:

$$\text{Modulation} = \left(\frac{\sqrt{\text{Peak Power}} - \sqrt{\text{Minimum Power}}}{\sqrt{\text{Peak Power}} + \sqrt{\text{Minimum Power}}} \right) \times 100$$

and is therefore limited to the range of 0 to 99.9 percent. Over-modulation will be indicated as 99.9 percent. Refer to table 3.

Figure 9 Amplitude Modulation %



Because of the threshold of the RF diode, a modulated signal which has a minimum power level below 0.3 percent of full scale will result in high modulation reading with uncertain accuracy.

Table 3 Amplitude Modulation

Peak/CW Power	% Modulation
1.00	0
1.10	5
1.21	10
1.32	15
1.44	20
1.56	25
1.69	30
1.82	35
1.96	40
2.10	45
2.25	50
2.40	55
2.56	60
2.72	65
2.89	70
3.06	75
3.24	80
3.42	85
3.61	90
3.80	95
4.00	100

Measuring Power in dBm

Operation of the forward and reflected dBm modes is identical to the forward and reflected CW power modes, except that the resulting reading is converted to dB above 1 milliwatt before it is displayed. It should be noted that in doing this conversion, the range set on the slide switches is assumed to be watts rather than kilowatts or milliwatts. If it is not, 30.0 must be added to all dBm readings when the range is in kilowatts, or subtracted from all readings when it is in milliwatts. An error message is displayed if CW power is more than 24 dB below, or peak power is more than 6 dB above the nominal element range.

Figure 10 CW Power in dBm

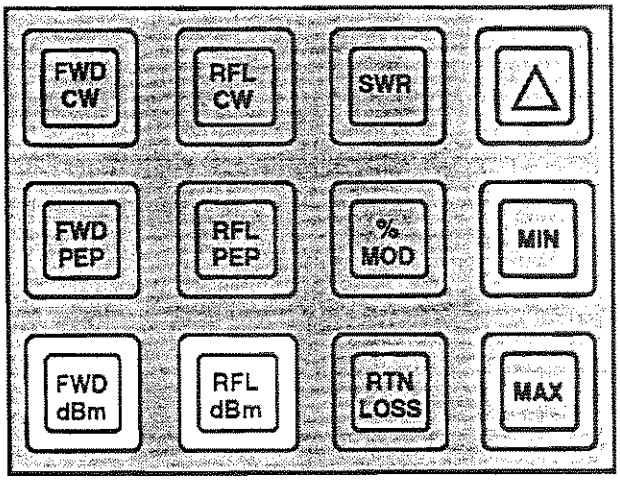


Table 4 Watts/dBm Equivalents

Power	dBm
1 milliwatt	0
10 milliwatts	10
100 Milliwatts	20
1 watt	30
2 watts	33
4 watts	36
10 watts	40
20 watts	43
40 watts	46
100 watts	50

Measuring Return Loss, Insertion Loss, or Attenuation

The measurement of return loss is the same as that of SWR except that the result is displayed in dB. In other words a reading of 21.65 indicates that reflected power is 21.6 dB down from forward power.

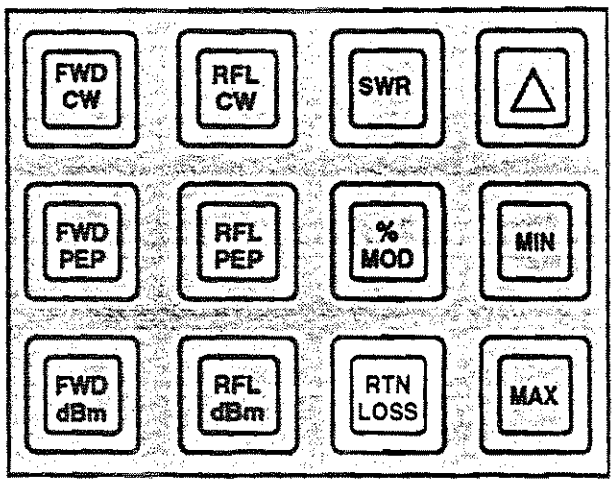


Figure 11 Return Loss, Insertion Loss, or Attenuation

Attenuation or insertion loss can be measured directly using an external single port line section (P/N 4230-006-1), a dc feed-in adapter (P/N 4381-050), and a dc cable (P/N 3170-058-6). The Model 4391A is inserted at the source end of the device being measured. The second line section is inserted at the load end and its dc output is routed by the dc cable to the adapter inserted in the REFLECTED socket of the Model 4391A. Both elements are in this case pointed in the direction of forward power flow. If the two elements do not have a ten to one ratio, a correction factor must be added to or subtracted from the "return loss" reading see table 5, depending on the ratio of the elements.

Table 5 Correction Factors

Ratio of Elements	Added dB	Ratio of Elements	Added dB
1:1	-10	100:1	10
2:1	-7	200:1	13
2.5:1	-6	250:1	14
4:1	-4	400:1	16
5:1	-3	500:1	17
10:1	0	1000:1	20
20:1	3	2000:1	23
25:1	4	2500:1	24
40:1	6	4000:1	26
50:1	7	5000:1	27

Monitoring Maximum and Minimum Readings

While operating in any of the modes described, the Model 4391A will continuously keep track of the highest and lowest reading obtained. This action begins after ten reading cycles to allow time for the peak detectors to settle from the previous mode.

To recall the maximum or minimum reading, depress and hold the MAX or MIN key. When these keys are released, the meter goes back to displaying the current value of the parameter being measured. Recalling maximum or minimum does not stop the meter from continuing to monitor the current value and updating the minimum and maximum registers. To clear the minimum and maximum register, the mode key must be pressed again or a new mode selected. For example, if CW power deviations are to be monitored, the Model 4391A is installed as described at the beginning of this section and turned on, then the power source is turned on and allowed to stabilize. Once the system has stabilized, and the FWD CW key is pressed to clear the MAX and MIN registers. At any time during test the MAX and MIN keys can be used to recall the maximum and minimum values without affecting the test. However, pressing the FWD CW key or changing modes will clear the registers.

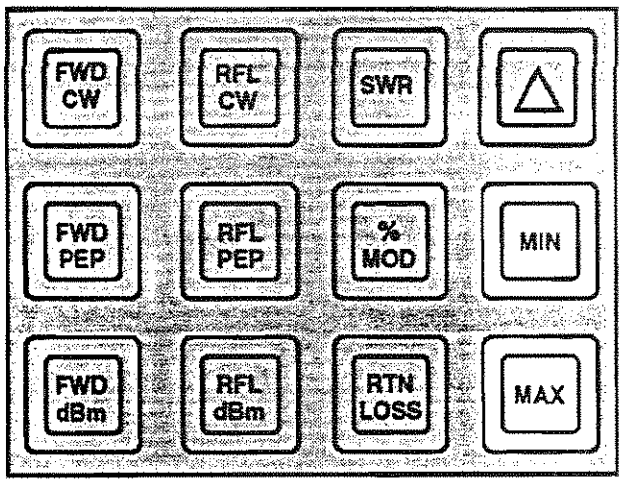


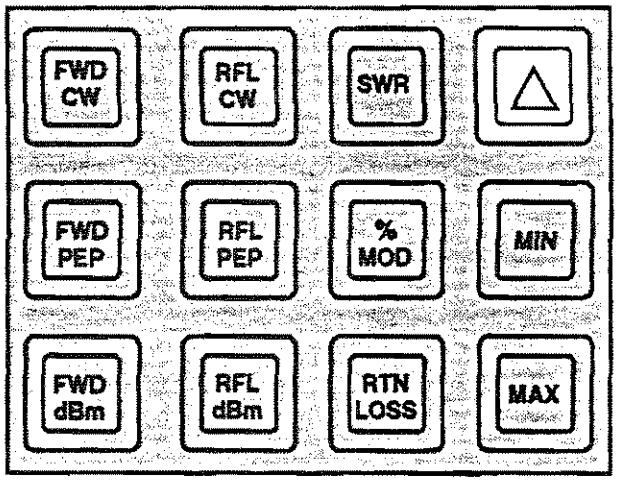
Figure 12 Maximum or Minimum Readings

Using the Peaking Aid

The peaking aid is useful for making adjustments to optimize any of the parameters which the Model 4391A measures. After the mode is selected, the delta (Δ) key is pressed momentarily. This blanks the least significant digit of the display, and replaces it with a right-facing arrow head if the measured quantity is increasing or a left-facing arrow head if it is decreasing. If there is no change, the digit is

left blank. To find a peak, begin making the adjustment in whichever direction produces a right-facing arrow head and continue slowly in that direction until the arrow head turns around. At this point the peak has been reached. To check to make sure the peak has not been passed, press the MAX key to read the highest value read and release it to read the current value. The two should be the same. Desired minimum levels (e.g. of reflected power or of SWR) are found in a similar manner.

Figure 13 Peaking Aid (Δ)



CAUTION
Always be certain the 115/230 voltage selector is set to the proper voltage before ac power is applied.

Operating on AC Power

For ac power operation, the Model 4391A is simply connected to an ac receptacle using the line cord provided. The correct ac voltage is selected via a rear panel switch. The meter may be operated in this manner with the batteries removed if desired. Refer to figure 14.

Figure 14 Rear Panel