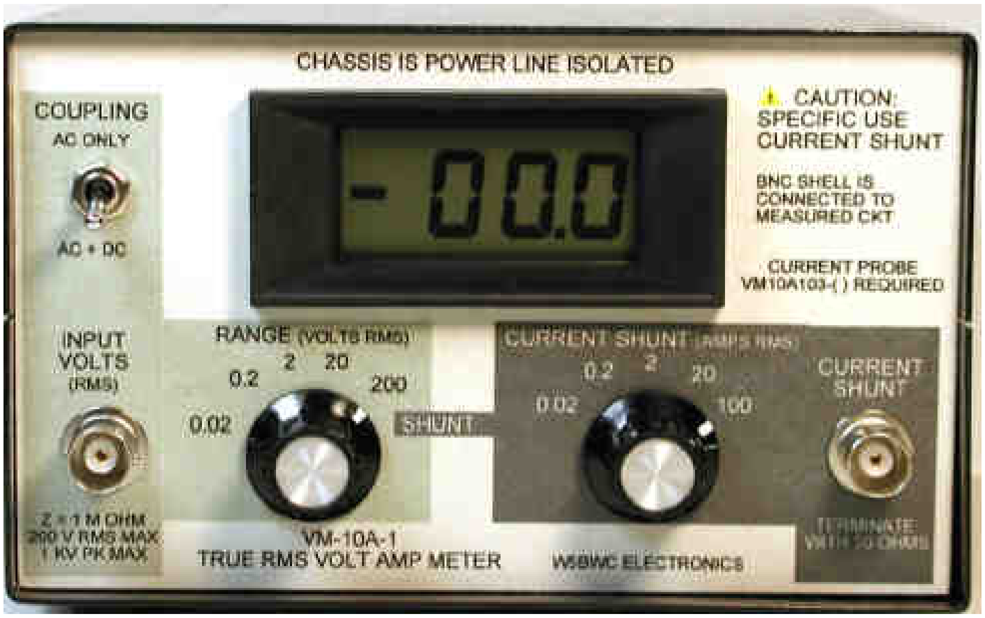
VM-10A-1 True RMS Volt Amp Meter



VM-10A-1
True RMS Volt Amp Meter

The VM-10A-1 is a true RMS Voltmeter implemented with Linear Technology's patented LTC1966 ΔΣ RMS to DC converter. This technology is far superior to the earlier log-antilog converters in terms of stability, accuracy, frequency response, input level linearity, complexity and crest factor dynamics.

A 20 dB amplifier provides 0.02 to 200 VAC RMS range for the converter driving a three and half digit digital panel meter.

A "Specific Use" current shunt measures peak and true RMS current. Five current shunts cover 0.02 to 100 Amp RMS and are ideal for measuring rectifier, transformer and capacitor currents in low voltage DC power supplies. Caution must be used as the current shunt does **not** provide galvanic isolation - the low side shunt is connected to the measured circuit.

Technical Review by Dr. Ken Jenkins, WB6MMV

VM-10A-1 True RMS Volt Amp Meter

Applications and Features:

- Designed specifically for power supply and rectifier testing.
- High allowable crest factor (5:1) for true RMS reading of distorted waveforms
- Ranges of 0.02 to 200 Vrms with 1 kV peak maximum.
- Selection of AC only or AC + DC input coupling.
- Precision 1 M Ohm input impedance allowing accurate division with 10:1 probes.
- 3 ½ digit DPM for 1999 full scale.
- Uses Linear Technology's patented LTC1966 ΔΣ RMS to DC converter for superior accuracy and performance.
- With external, specific use*, current shunts 0.02 to 100 Arms can be measured.
- Current shunts provide high-frequency response terminated into 50 Ohms for peak measurements.

  * Specific use means the shunts are not general purpose "clamp-on" device. **Caution: Current shunt BNC shell is in galvanic contact with the measured circuit.** Intended for measuring current in low voltage rectifier and power supply circuits. **Not suitable for measuring AC line current due to lack of isolation.**

- In "DC Mode", the VM-10A-1 measures DC inputs with higher accuracy and superior linearity than in the AC + DC Mode
- With an external bench power supply, the VM-10A-1 can be used as a Lo-Ohmmeter.
- As a Lo-Ohm meter, resistance can be measured with 10 µΩ resolution - down to 0.00001 Ω.

Comparison of VM-10A-1 to Industry Standards.

The VM-10A-1 is a high accuracy True RMS AC and DC volt/amp meter with 3 ½ digit resolution. To appreciate its' features, compare it to the Fluke 8808A bench DMM (5 ½ digit). The Fluke has better resolution and ultimate accuracy due to the extra digits, but otherwise is a good comparison (and priced away above the VM-10A-1 at around $800).

The Fluke has a minimum AC input of 5% of the range for a similar reason the VM-10A-1 has a minimum AC input level. It also has a 3:1 crest factor limitation for AC also like the VM-10A-1.

However, the VM-10A-1 has a 0.02V vs 0.2V low range. The VM-10A-1 has AC only, DC only or AC + DC modes, the latter of which the Fluke does not have.

Using four wire resistance measurement the VM-10A-1 has 10 µΩ Lo-resistance resolution vs. the 0.001 Ω minimum for the Fluke. Current measurement range for the VM-10A-1 is 0.02 to 100 A vs. 200 µA to 10 A for the Fluke. The low end is easy to achieve by using a precision resistor (safer for over-current) and the 0.02 V range of the VM-10A-1.

The high end is the bigger deal. 10 A is very restrictive in power supply work. Also, the internal shunt resistance of the Fluke is 0.01 Ω plus leads. The VM-10A-1 uses a 0.002 Ω shunt on 20 A range and 0.0002 Ω shunt on 100 A range. Also, the VM-10A-1 shunts are external to the meter and can be located with little or no appreciable lead resistance introduced into the measurement. As well, the external shunts are low inductance SMT resistors connected to the measurement instrument with 50Ω coax allowing accurate pulse and transient measurements.

Comparison with lesser commercial instruments fair even poorer, especially those with "RMS" calibrated average AC functions.

Operation - DC Volts.

DC Voltages are measured in the "DC Mode", selected by the rear panel mounted switch, S4, and the front panel, S1, "AC + DC or AC Only" switch. S1 provides DC coupling and S4 bypasses the RMS to DC converter.

The instrument case is connected to the input BNC shell, and therefore should always be connected to the low side (or ground) of the circuit being measured. In the DC Mode, the meter will display polarity eliminating the need to switch leads.

The DC Mode produces the highest accuracy readings but will not provide any useful information about composite waveforms. The DC Mode should also be used for resistance measurements.

VM-10A-1 True RMS Volt Amp Meter

Operation - AC Volts.

AC + DC voltages are measured with S1 in the “AC + DC Mode” and S4 in the “AC Mode”. The composite signal will be processed by the LTC1966 RMS to DC converter to display the true RMS value of the signal. An example of this function is the output of a shunt capacitor rectifier/filter under load. Usually the DC component is the largest but a substantial ripple rides on it. The heating caused in pass transistors is a function of the total RMS value.

Other times just the AC component is of interest. For example, a power supply’s output noise rides on the DC output voltage, but the artifact of interest is only the AC portion. In this case the “AC Only” mode is used.

Note that both of these examples measure complex (non-sinusoidal) signals that “average” or “peak” reading meters can not accurately do.

Operation - AC or DC Amps.

The choice of AC or DC modes is made the same as with voltage measurements. In addition the “Range” switch is set to “Shunt” and the “Current Shunt” switch is set to the current range of the shunt in use. Figure 1. details the VM-10A-1 connected to a rectifier/filter measuring the forward rectifier current. Figure 2. represents the rectified voltage and forward current pulse typical of this circuit.

The external shunt adds only 0.0002 Ω to the typical 0.040 Ω equivalent series resistance of the circuit. The actual resistance will be slightly higher due to the binding posts and physical connection, but not by much. This is a 0.5% effect on the circuit vs the 25% effect a 0.01 Ω typical shunt would have.

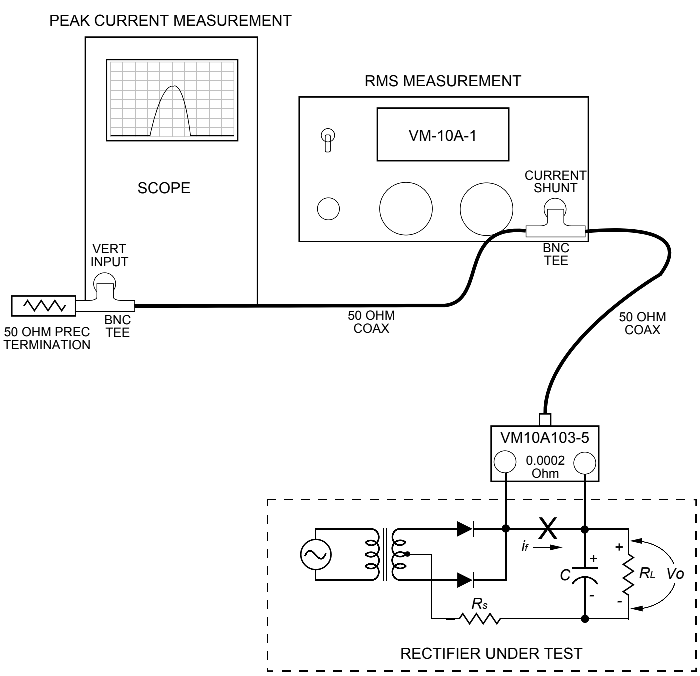


Figure 1. Peak and RMS current measurement using the VM-10A-1.

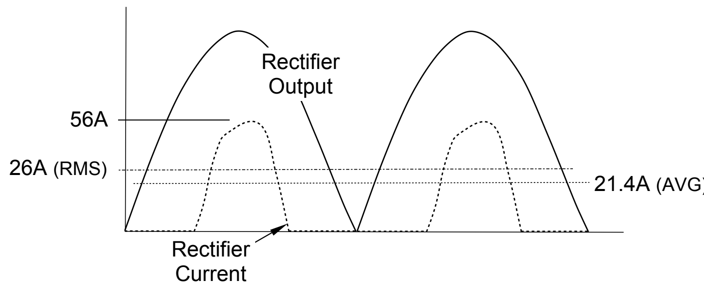


Figure 2. Peak, RMS and Average values of a current pulse typical of a shunt capacitor rectifier circuit.

Also, note the shunt is physically close to the circuit and the measurement is made using 50Ω coax that terminates at the scope. Thus, accurate dynamic current details are viewed as seen in Figure 2.

The current pulse complex shape is apparent when compared to the half-sine rectifier voltage and is typical of a shunt capacitor rectifier/filter. The actual RMS value of 26.0 Amps is erroneously read as 21.4 Amps using a typical “RMS” calibrated average reading DMM. In this case there is **no** simple factor, such as 0.707, that can correct a simple peak or average measurement. The other method, since no equation exists for this pulse, is to perform a tedious graphical integration to mathematically calculate RMS. While this provides a very reasonable approximation it is quite laborious.

Lo-Ohmmeter.

Figure 3. shows the VM-10A-1 set up to measure Lo-Ohms. A bench power supply is adjusted in the constant current mode for 1.000 ADC as measured using the VM10A103-3 Current Shunt and the VM-10A-1 in the “Current” and “DC” modes. The power supply compliance voltage should be set low, around 1 VDC, or just enough to overcome the wiring resistance connecting it to the unknown resistance.

Using the “Input Volts” and 0.02 V_{RMS} Range - still in “DC Mode”, the voltage drop across the unknown resistor is now measured. For 1 ADC current the 0.02 V_{RMS} Range becomes a 0.02 Ω Range, allowing resolution and and measurement of 10 µΩ. For comparison, 12 inches of 10 AWG copper wire has a +23°C resistance of approximately 1000 µΩ.

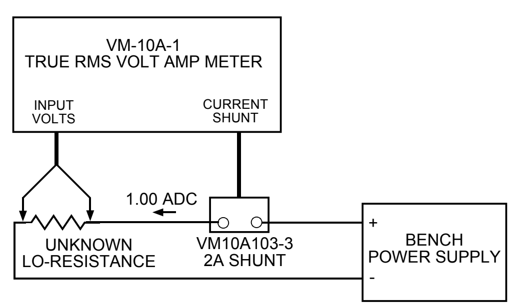


Figure 3. Lo-Ohm measurement using an external bench power supply with the VM-10A-1.

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Characteristics:

Size	5.67”W x 5.30”D x 3.75”H	
Input Voltage	200 Vrms and 1 kV peak Maximum	
Input Protection	1 kV	
Voltage Ranges (Volts RMS)	0.02 0.2 2 20 200	
DC Accuracy	± 0.2% ± 1 Digit	DC MODE
AC + DC Accuracy	± 2% 10 Hz to 2 kHz <4:1 crest factor (see Figures 4. and 5. Performance vs Crest Factors) Input > 5 mV_{rms} on 0.02 V range or corresponding ratio on other ranges	AC MODE Note 1, 2, 3
Input Coupling	AC only or AC + DC	
Input Impedance	1.0 M Ohm ± 0.2%	
Current Shunt (Amps RMS) or DC	Current / Resistance(Ω) / mV/Amp*	VM10A103-( )
	0.02 / 2.0 / 1000	-1
	0.2 / 0.20 / 100	-2
	2 / 0.020 / 10.0	-3
	20 / 0.002 / 1.0	-4
	100 / 0.0002 / 0.1	-5
Termination	*50 Ohm termination required at J2 or at the scope end of coax when peak reading **Caution: Current Shunt BNC shell is connected to measured circuit.**	Note 4, 5
Input Power	NEMA 5-15P cord set. Chassis is isolated from power line ground. 105 to 125 VAC at 5VA	

Notes:

1. In the “DC mode”, DC voltages and currents are measured with greater accuracy than in the “AC + DC Mode” where the measured value will be the composite DC + AC value in RMS. Most DC meters average the AC component and display a value close to the DC value depending upon the symmetry of the AC component.
2. In the “AC+ DC Mode” measurements are processed through the RMS/DC converter. While the RMS value of pure DC is just the DC value, the RMS converter ignores polarity since it has no meaning to the RMS value.
3. Minimum input voltage for RMS converter to function is 5 mV_{rms} on 0.02 V range or corresponding ratio on other ranges.
4. **CAUTION: Current shunt BNC shell is connected to the circuit under measurement.**
5. When measuring complex waveforms for which a scope is used to display the peak waveform, use a BNC tee at the VM-10A-1 “Current Shunt” input and terminate the coax at the scope’s input with 50 Ω.

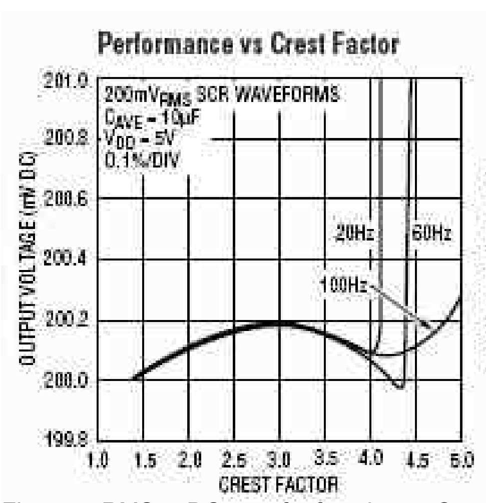

Figure 4. RMS to DC transfer function vs Crest Factor up to 4:1. *Graph from LTC data sheet sn1966*

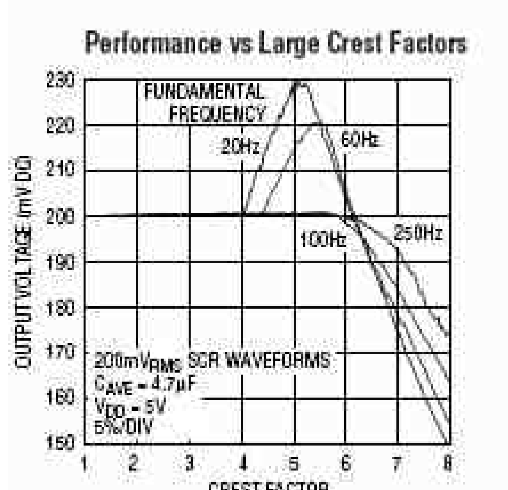

Figure 5. RMS to DC transfer function vs Crest Factor above 4:1. *Graph from LTC data sheet sn1966*

VM-10A-1 True RMS Volt Amp Meter

Basic Operation:

Testing rectifier and power supply designs requires measuring Voltages and currents that contain significant harmonic content. These non-sinusoidal waveforms cannot be accurately measured without using a “true RMS meter”. True RMS meaning an instrument that calculates the actual power of the measured waveform using log-antilog or ΔΣ (LTS patented method) techniques. No form of peak or average reading will yield acceptable results.

For additional details concerning the LTC1966 converter, see Linear Technology web site and specifically the LTS sn1966 document. The LTC1966 is the heart of the VM-10A-1 and provides either AC only or AC + DC measurement of voltages in the 0.02 to 200 Vrms range.

A precision 1 M Ohm input is provided by paralleling a 10 MΩ resistor with the 1.1111 MΩ divider. The divider is comprised of 0.1% resistors with the last 111 Ω set by the 200 V calibration pot. This allows accurate 10:1 division when used with a 10 MΩ scope probe.

For AC only measurements, S1 is open and C1 provides AC coupling. This function allows the non DC portion of a voltage to be analyzed, such as the low level ripple and noise on the output of a linear power supply.

For AC plus DC RMS measurements, S1 shorts across C1 and the converter will calculate the actual RMS value of the composite waveform, such as the output of a rectifier filter capacitor circuit that is basically DC but with a large ripple content.

The “MODE” switch, S4, allows higher accuracy DC measurements in the “DC” position. In the “DC” position, U102 the LTC1966, is bypassed and only DC voltage and current can be measured, but with higher accuracy. S4 is mounted on the rear panel of the VM-10A-1.

R101 and the internal clamp diodes of U101 provide over Voltage protection on all ranges.

U101 is a DC amplifier with a gain adjusted to 10.0 and offset zeroed. This allows a 0.02 Vrms low range to display full scale on the DPM at 19.99 mVrms. The LT1966 has a 50 mV minimum input level for stated accuracy which translates to 5 mV on the 0.02 Vrms range.

The DPM is a 3½ digit LCD with common input and power supply grounds that operates from +5 VDC at 2 mA. The decimal point is selected by the second half of range switch S2. When used with current shunts, S3 selects the decimal point - its’ sole function - with no actual effect on the shunt measurement.

The current shunts are built in small “potting” cases and contain the actual shunt resistor and a divider for a 50Ω termination. The divider provides calibration and a match for 50Ω coax allowing accurate peak waveform analysis using a scope.

2 Watt, 1%, 1225 SMT chip resistors are used as the sense element in the shunts. The VM10A103-5, 100 Amp shunt, uses 5 in parallel totaling 0.0002 Ω and 10 Watts. However, at such low resistance the 1 oz. (1.34 mil) copper foil is insufficient so 0.020” thick copper sheet is attached to the pads lowering each interconnect to 34 μΩ. These same copper sheets are used in the -4, 20A shunt.

All the other shunts use only the foil and one 2 Watt chip resistor. The shunt’s calibration pot compensates for all tolerances, including any connection contribution. This means if the 50Ω termination is removed, the indicated voltage may change by slightly more than 2:1.

Current shunts use the 0.02 V range which determines current measurement accuracy per that range’s AC and DC calibration and linearity.

Calibration.

Basic Meter calibration.

1. Connect the VM-10A-1 to AC outlet (105 to 125 VAC).
2. Allow 30 minute warm-up (not much to warm up, but still a good idea).

In the DC Mode

3. Set the “Range” switch to 200 V, “DC Mode” switch to “DC”, and adjust R105, “zero” for 00.0 on the DPM. Note polarity is not indicated in the AC Mode.
4. With the “AC coupled” switch in the AC+ DC position and the “Range” switch in the 0.02 V position, adjust R109, “20 mV Cal” for a display of 10.00 with a 10.00 mV DC voltage applied to the “Volts In”.
5. With the same set up, but with the “Range” switch set to 200 V and 100.0 VDC input, adjust R116, “200 V Cal” for a display of 100.0.

In the AC Mode

6. If AC Voltage Standard is available, verify the AC accuracy. The LTC1966 RMS/DC converter processes AC and DC identically, so little or no variation should be seen. Beware however, of the limitation on minimum input levels imposed by the LTC1966 - see Engineering prototype notes.

Current Shunts.

In the DC Mode

1. Ensure the shunt is terminated into an accurate 50Ω load.
2. Input a known DC current equal to mid range for each shunt, in turn.
3. Adjust R303, the SMT “Cal” pot in each shunt for an accurate mid range display.
4. If the binding posts loosen with use, the shunt should be re-calibrated after they are tightened.

VM-10A-1 True RMS Volt Amp Meter

Prototype Performance.

Figure 6. VM-10A-1front-side view .

The original design used two back-to-back 1N5228B zener diodes at U101A -3. This provides very robust over-voltage protection, but the diodes also provided a photo coupled input (though the case stopped sufficient light) and a non-linear leakage current. However, the pico-amp range leakage current is sufficient to destroy the meter's accuracy. The diodes were removed and a lower level of protection is now had. U101 can tolerate up to 5 mA input current, so with a 220k R101 the meter can withstand 1100 Volts applied on any range.

Tables 1 through 11 tabulate the engineering prototype measured performance. Notice the DC Mode performance is an order of magnitude better than the AC Mode. Even so, the ± 2% AC accuracy is as good or better than most 3 ½ digit meters, many of which can not even measure true rms.

Figure 7. VM-10A-1rear view showing AC/DC Mode switch.

The LTC1966 requires a minimum input voltage of 5 mV to function and 50 mV to meet its' advertised linearity and accuracy. The VM-10A-1 operates the LTC1966 between 0 and 200 mV on all ranges, as established by U101 gain of ten and the input range switch divider. Therefore, the minimum input on the 0.02 V range is 0.5 mV and on the 200 V range 5V, with the minimum spec compliant inputs of 5 mV and 50 V respectively.

As can be seen by comparing Figure 10. and Figure 11. this requirement effects primarily the low end range accuracy and determines the basic AC accuracy.

Frequency Response.

AC accuracy has an additional error, as seen in Table 1. The meter can measure true rms values into the tens of kHz, but with reduced accuracy - see LTC1966 data sheet for details. However, minimal error is added for fundamental frequencies up to 1000 Hz. The VM-10A-1 is not optimized for wide band, but rather intended for 50 to 400 Hz measurements.

Figure 8. VM103A-2, 0.2 Amp Shunt typical of shunts -1, -2, -3. The -4 and -5 have additional copper sheet and 30 A posts.

Table 1. Frequency Response (20V Range)

Freq (Hz)	Cal Volts	VM-10A Rdg	% Error
5	10.00	10.00	0
10	10.00	10.02	+0.2
60	10.00	10.00	0
100	10.00	10.00	0
1000	10.00	9.92	-0.8
10,000	10.00	9.80	-2.0

Figure 9. VM10A103-( ) Current Shunts.

Prototype Performance.

Range Linearity and Calibration. The engineering prototype AC Mode Range Linearity and Calibration results are tabulated in Table 2. through Table 6. Note ± 1 digit is allowed in addition to conversion accuracy and % error is referenced to the measured value, not full-scale. Many AC meters allow up to ± 4 digits ambiguity.

Table 2. 0.02 V Range Linearity AC Mode

Cal Volts	VM-10A Rdg	Error (mV)	% Error
0.10 mV	0.08	-0.02	-20.0
0.20	0.18	-0.02	-10.0
0.50	0.48	-0.02	-4.0
1.00	0.98	-0.02	-2.0
2.00	1.98	-0.02	-1.0
5.00	5.00	0	0
10.00	10.04	+0.04	+0.4
19.00	19.06	+0.06	+0.6

Table 3. 0.2 V Range Linearity AC Mode

Cal Volts	VM-10A Rdg	Error (mV)	% Error
1.0 mV	1.3	-0.3	-30.0
2.0	2.1	+0.1	-5.0
5.0	5.1	+0.1	+2.0
10.0	10.3	+0.3	+3.0
20.0	20.1	+0.1	+0.5
50.0	50.0	0	0
100.0	100.1	+0.1	+0.1
190.0	190.6	+0.6	+0.3

Table 4. 2 V Range Linearity AC Mode

Cal Volts	VM-10A Rdg	Error (V)	% Error
0.010	0.007	0.003	-30.0
0.020	0.017	0.003	-15.0
0.050	0.047	0.003	-6.0
0.100	0.096	0.004	-4.0
0.200	0.196	0.004	-2.0
0.500	0.496	0.004	-0.8
1.000	0.999	0.001	-0.1
1.900	1.900	0	0

Table 5. 20 V Range Linearity AC Mode

Cal Volts	VM-10A Rdg	Error (V)	% Error
0.10	0.07	0.03	-30
0.20	0.16	0.04	-20
0.50	0.46	0.04	-8.0
1.00	0.96	0.04	-4.0
2.00	1.96	0.04	-2.0
5.00	4.96	0.04	-0.8
10.00	9.99	0.01	-0.01
19.00	19.00	0	0

Table 6. 200 V Range Linearity AC Mode

Cal Volts	VM-10A Rdg	Error (V)	% Error
1.0	0.6	0.4	-40.0
2.0	1.6	0.4	-20.0
5.0	4.7	0.3	-6.0
10.0	9.6	0.4	-4.0
20.0	19.6	0.4	-2.0
50.0	49.8	0.2	-0.4
100.0	100.1	0.1	+0.1
190.0	190.6	0.6	+0.3

Prototype Performance.

Range Linearity and Calibration. The engineering prototype DC Mode Range Linearity and Calibration results are tabulated in Table 7. through Table 11. Note ± 1 digit is allowed in addition to conversion accuracy and % error is referenced to the measured value, not full-scale. Where gross inaccuracies would be suggested, e.g., 0.1 mV error on 2.0 mV, the ± 1 digit ambiguity is included to maintain a monotonic curve.

Table 7. 0.02 V Range Linearity DC Mode

Cal Volts	**VM-10A Rdg**	**Error (mV)**	**% Error**
0.10 mV	0.10 mV	0	<0.05
0.20	0.20	0	<0.05
0.50	0.50	0	<0.05
1.00	1.00	0	<0.05
2.00	2.00	0	<0.05
5.00	5.00	0	<0.05
10.00	10.00	0	<0.05
19.00	18.99	-0.01	-0.05

Table 8. 0.2 V Range Linearity DC Mode

Cal Volts	**VM-10A Rdg**	**Error (mV)**	**% Error**
1.0 mV	1.0 mV	0	<0.05
2.0	1.9	0	<0.05
5.0	4.9	0	<0.05
10.0	9.9	0	<0.05
20.0	20.0	0	<0.05
50.0	49.9	0	<0.05
100.0	99.9	0	<0.05
190.0	189.7	-0.3	-0.15

Table 9. 2 V Range Linearity DC Mode

Cal Volts	**VM-10A Rdg**	**Error (V)**	**% Error**
0.010V	0.010V	0	<0.05
0.020	0.019	0	<0.05
0.050	0.049	0	<0.05
0.100	0.099	0	<0.05
0.200	0.199	0	<0.05
0.500	0.498	-0.02	-0.4
1.000	9.98	-0.02	-0.2
1.900	18.97	-0.03	-0.15

Table 10. 20 V Range Linearity DC Mode

Cal Volts	**VM-10A Rdg**	**Error (V)**	**% Error**
0.10	0.09V	0	<0.05
0.20	0.19	0	<0.05
0.50	0.49	0	<0.05
1.00	0.99	0	<0.05
2.00	1.99	0	<0.05
5.00	4.99	0	<0.05
10.00	9.99	0	<0.05
19.00	18.97	-0.03	-0.15

Table 11. 200 V Range Linearity DC Mode

Cal Volts	**VM-10A Rdg**	**Error (V)**	**% Error**
1.0	0.9V	0	<0.05
2.0	1.9	0	<0.05
5.0	4.9	0	<0.05
10.0	9.9	0	<0.05
20.0	20.0	0	<0.05
50.0	50.0	0	<0.05
100.0	100.0	0	<0.05
190.0	190.0	0	<0.05

Prototype Performance.

Range of Accuracy.

The LTC1966 minimum input level is significant on the lower end of each range. Figure 10. is rather busy, but shows clearly this effect on the five ranges. The top axis identification shows the range linearity in terms of the input as a percent of Full Scale. That is, for ±2% accuracy the input level must be above 10% of Full Scale on all ranges. Above 25% the worst case error is ±1%.

The current shunts use the 0.02 V range which has ±2% maximum error for inputs above 5% of Full Scale.

Figure 11. shows the DC Mode performance which is an order of magnitude better for inputs down to one least significant digit.

Figure 10. can be located near the instrument and referenced for a correction factor when low range end measurements are required.

This low range end error is a small price for true RMS measurements of complex waveforms and AC + DC capability.

The DC Mode is used for Lo-Ohms, DC current and DC voltage measurements with typical accuracy of ± 0.2%. While ± 1 digit ambiguity is expected, the data on the 2 V range is consistent enough to expect a -0.2% error over much of the range, but not the -0.4% data point measured at 0.500 V. The ambiguity factor is applied to that measurement point so Figure 11. shows the expected -0.2% error.

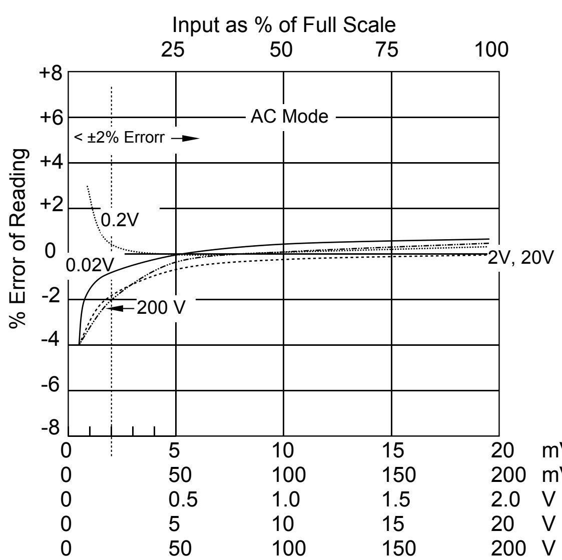

Figure 10. AC calibration and Linearity results for each range of the engineering prototype.

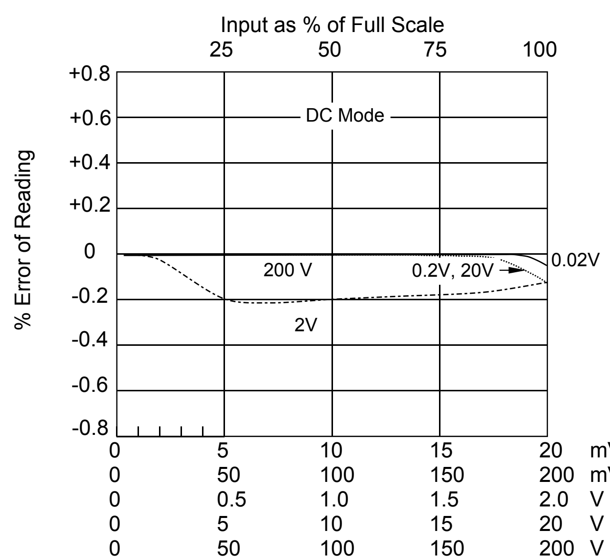

Figure 11. DC calibration and Linearity results for each range of the engineering prototype.

VM-10A-1 True RMS Volt Amp Meter

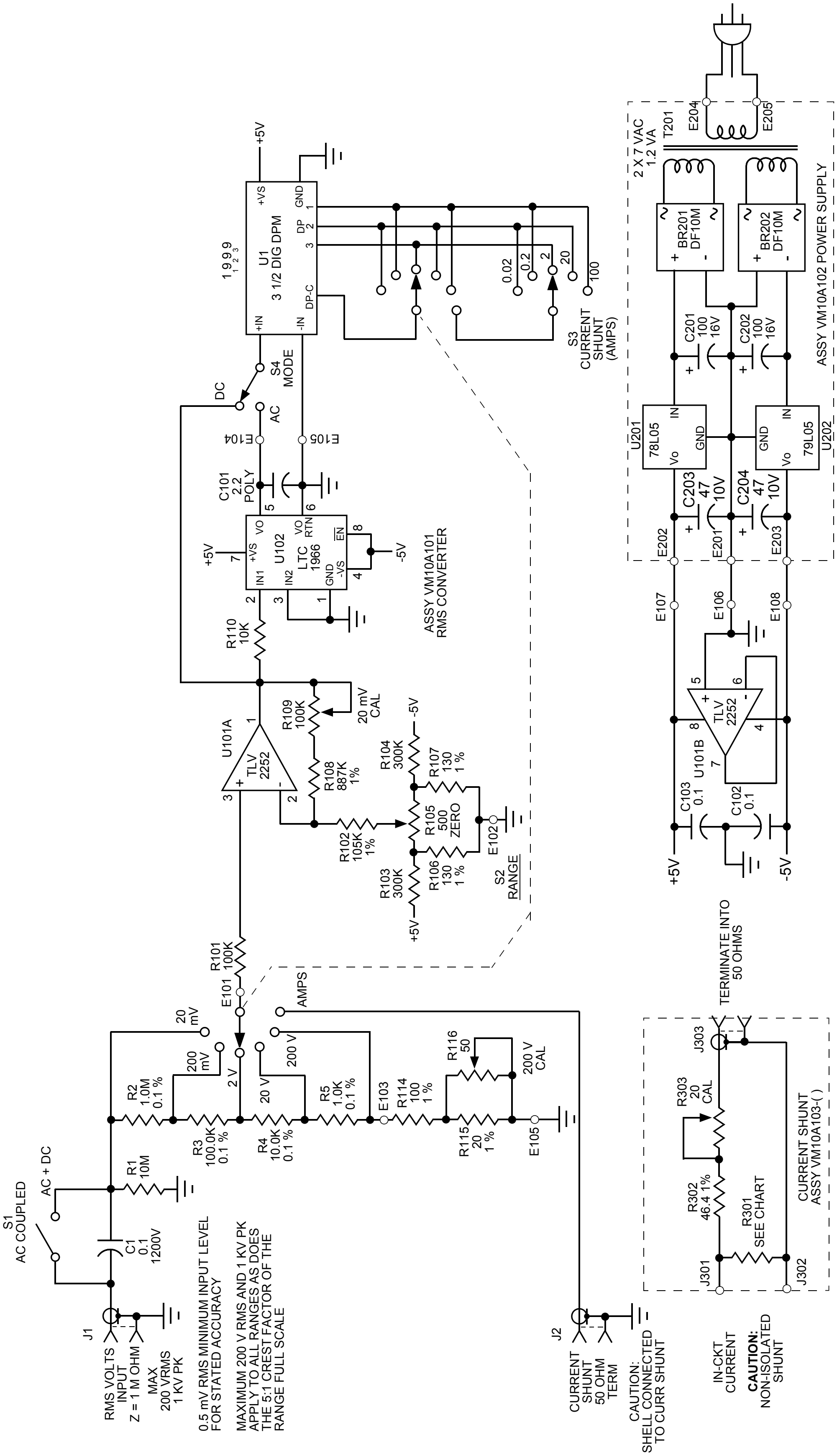

Figure 12. Schematic of VM-10A-1 and Current Shunt VM10A103-( ).

VM-10A-1 True RMS Volt Amp Meter

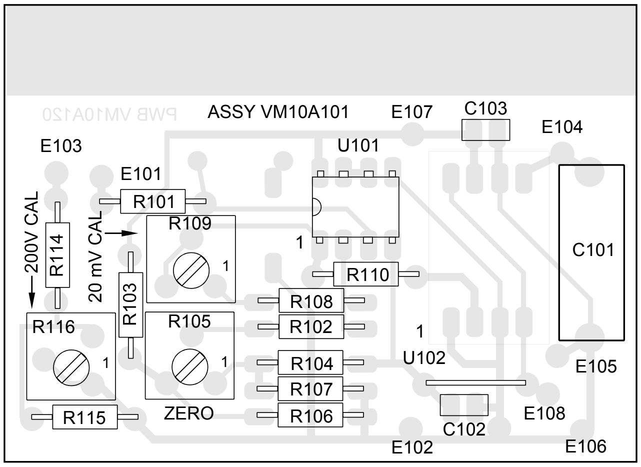

Figure 13. VM10A101 Assembly Component Locator.

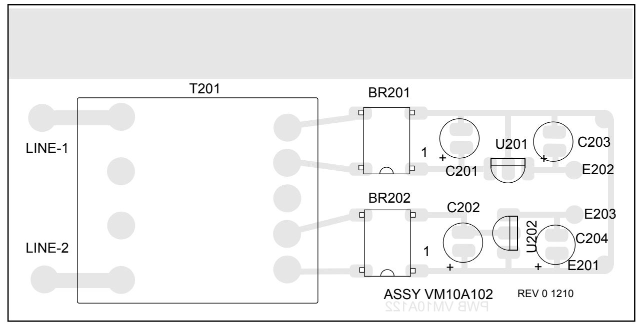

Figure 14. VM10A102 Assembly Component Locator.

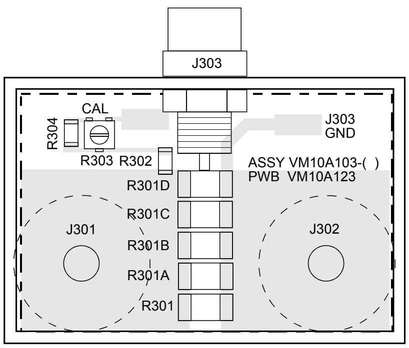

Figure 15. VM10A103 Assembly Component Locator.

Figure 16. VM-10A-1 bottom view .

Figure 17. VM-10A-1 top-front view.

VM-10A-1 True RMS Volt Amp Meter

Material List - VM10A100 Chassis Assembly for VM -10A-1

Qty	Designator	Value/Type	Description	Part Number*	Supplier*
1	C1	0.1 µF, 1.2 kV	Metalized poly	5984-940C12P1K-F	
2	J1, J2	50 Ω BNC	Bulk head jack	523-31-221-RFX	
1	P1	3X18AWG cord set	NEMA 5-15P	562-311007-01	
1	R1	10 MΩ, 5%, 0.25W	CF	291-10M-RC	
1	R2	1.0 MΩ, 0.1%, 0.25W	MF	66-RC55LF-D-1.0M	
1	R3	100.0 kΩ, 0.1%, 0.25W	MF	66-RC55LF-D-100K	
1	R4	10.0 kΩ, 0.1%, 0.25E	MF	66-RC55LF-D-10K	
1	R5	1.0 kΩ, 0.1%, 0.25W	MF	66-RC55LF-D-1.0K	
2	S1, S4	SPDT Toggle switch	Panel mount	1055-TA1130-EVX	
1	S2	6 pos, 2 pole, non-shorting	Rotary switch panel mount	105-SR2511F-26RN	
1	S3	5 pos, 2 pole, non-shorting	Rotary switch panel mount	105-SR2511F-25NS	
1	U1	3 ½ Digit LCD	5V non-iso Panel Meter	15977ME	MPJA**
2		Knobs	0.25" Rd shaft	506-PKA50B1/4	
1		Chassis	Clam shell with brackets		Shop built

Material List - VM10A101 Converter Assembly for VM -10A-1

Qty	Designator	Value/Type	Description	Part Number*	Supplier*
1	C101	2.2 µF, 60V	Metalized poly	5989-100V2.2-F	
2	C102, C103	0.1 µF, 50V	MLC ceramic	581-SR211C104KAR	
1	R101	220k, 5%, 0.25W	CF	291-220K-RC	
1	R102	105k, 1%, 0.25W	MF	271-105K-RC	
2	R103, R104	300k, 5%, 0.25W	CF	291-300K-RC	
1	R105	500, 5%, 0.25W	Cermet trimmer	652-3386F-1-501LF	
3	R106, R107	130, 1%, 0.25W	MF	271-130-RC	
1	R108	887k, 1%, 0.25W	MF	271-887K-RC	
1	R109	100k, 5%, 0.25W	Cermet trimmer	652-3386F-1-104LF	
1	R110	10k, 5%, 0.25W	CF	291-10K-RC	
1	R114	100, 1%, 0.25W	MF	271-100-RC	
1	R115	20, 1%, 0.25W	MF	271-20-RC	
1	R116	50, 5%, 0.25W	Cermet trimmer	652-3386F-1-500LF	
1	U101	TLV2252	Dual rail-to-rail CMOS op amp	595-TLV2252AIP	
1	U102	LTC1966	RMS/DC Converter	LTC1966CMS8#PBF-ND	Digi-Key
1			PWB	VM10A120	
1	XU102	8TSSOP to DIP	Adapter Board	N/A	Far Circuits

Material List - VM10A102 Power Supply Assembly for VM -10A-1

Qty	Designator	Value/Type	Description	Part Number*	Supplier*
2	BR201, BR202	DF10M	1.5A, 1kV bridge rectifier	512-DF10M	
2	C201, C202	100 µF, 16V	Radial Al electrolytic	647-UVR1C101MDD1TD	
2	C203, C204	47 µF, 16V	Radial Al electrolytic	647-UVR1C470MDD1TD	
1	T201	Dual 7 VAC	115 VAC, 1.2VA transformer	838-SB2812-1214	
1	U201	78L05	+5 V regulator	512-MC78L05ACPXA	
1	U202	79L05	-5 V regulator	511-L79L05ABZ-AP	
1			PWB	VM10A122	

Material List - VM10A103 - ( ) Current Shunt Assembly for VM -10A-1

Com Qty	-1 Qty	-2 Qty	-3 Qty	-4 Qty	-5 Qty	Designator	Value/Type	Description	Part Number*
	2	2	2			J301, J302	Binding post	10 A panel mount	164-R109B-EX
				2	2	J301, J302	Binding post	30 A panel mount	164-R126B-EX
	1	1	1	1	1	J303	RCA pnono jack	Chassis mount	161-2052
	1					R301	2.0 Ω, 1%, 2W	2512 SR73 SMT	660-SR733ATTE2R00F
		1				R301	0.2 Ω, 1%, 2W	2512 SR73 SMT	660-SR733ATTER200F
			1			R301	0.02 Ω, 1%, 2W	2512 LR SMT	66-LRF2512-01-R020-F
				1		R301	0.002 Ω, 1%, 2W	2512 ULR SMT	66-ULRB2R002FLFSLT
					5	R301 - R301D	0.001 Ω, 1%, 2W	2512 ULR SMT	66-ULRB2R001FLFSLT
	1	1	1	1	1	R302	46.4 Ω, 1%, 0.25W	1206 SMT	660-RK73H2BTTD46R4F
	1	1	1	1	1	R303	20 Ω, 5%, 0.25W	Cermet SMT trimmer	81-PVG3A200C01R00
						R304	Not used		
	1	1	1	1	1			Potting housing	563-PB-1564
	1	1	1	1	1			Cover	563-PB-1564-C
	1	1	1	1	1			PWB	VM10A123
1						P303	RCA phono plug	Shielded	17PP058
1						P2	BNC Male	50 Ohm	523-31-2-RFX
				2	2	XJ301, XJ302	0.020” Copper sheet	0.70” x 0.70”	Bench stock
	*Unless specified otherwise, supplier is Mouser Electronics ** MPJA Marlin P. Jones and Assoc.								