By George Danavaras

A True RMS Audio AC Voltmeter

This voltmeter design gives you the opportunity to add a useful tool to your workbench.

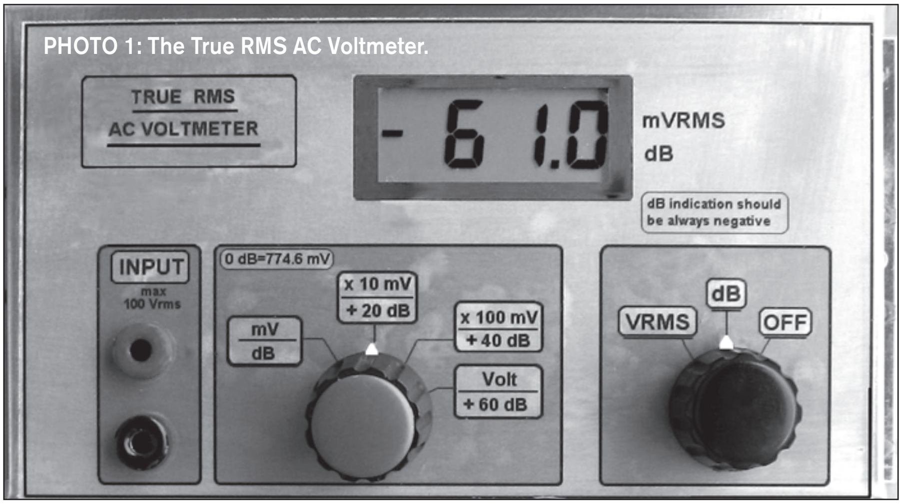


PHOTO 1: The True RMS AC Voltmeter.

The True RMS Audio AC Voltmeter is a portable unit based on the Analog Devices AD636JH true RMS to DC converter and on the ICL7106 A/D converter and LCD driver. It measures the true RMS value of an audio signal up to a level of 100V RMS in four scales: ×1mV RMS, ×10mV RMS, ×100mV RMS, and ×1000mV RMS.

A rotary switch in the front of the meter lets you display either volts or dBs. For the dB measurement, the 0dB level is set at 774.6mV RMS (0dBm = 1mW at 600Ω). The voltmeter is powered by a 9V battery. **Photo 1** shows the complete meter.

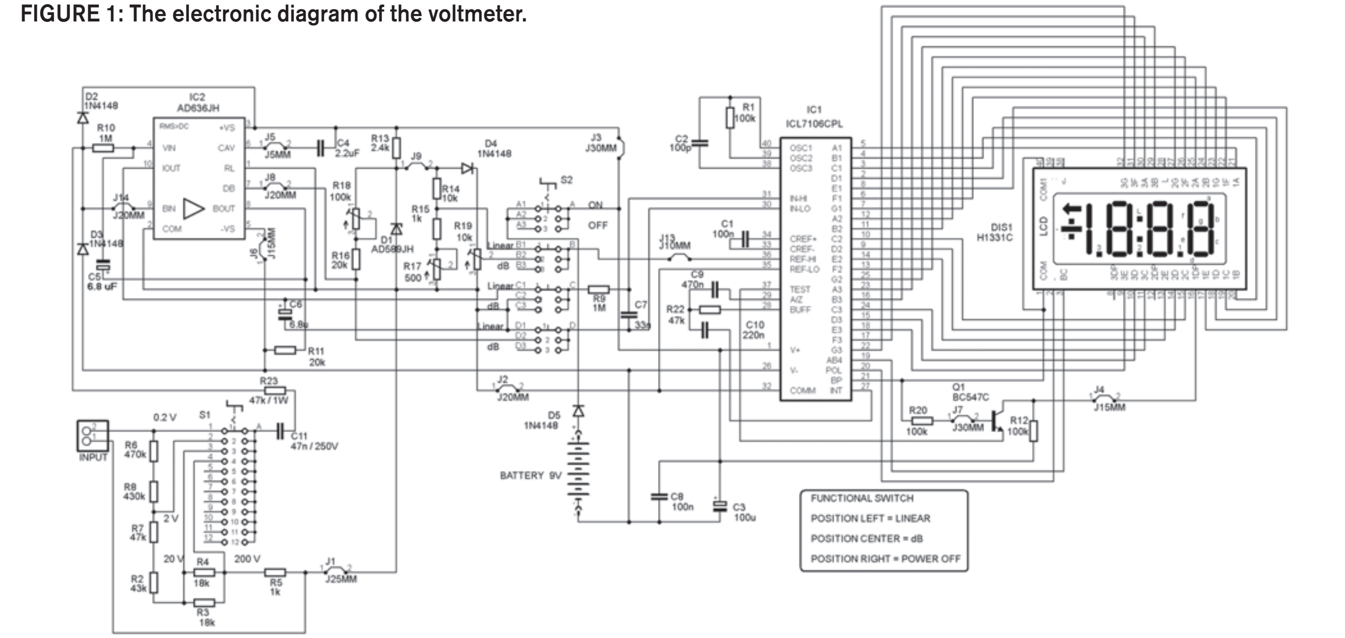
THE AD636JH TRUE RMS TO DC CONVERTER

The Analog Devices AD636JH, on which the voltmeter is based, is a low-power monolithic IC that performs true RMS to DC conversion on low-level signals from 0mV to 200mV RMS. The AD636 includes an auxiliary dB output derived from an internal circuit point that represents the logarithm of the RMS output. An externally supplied current sets the 0dB reference level and corresponds to an input level of 774.6mV RMS. According to the manufacturer, the frequency response ranges from 1.2MHz at 0dBm to greater than 10kHz at –50dBm.

The AD636 computes the true root-mean-square of a complex AC (or AC plus DC) input signal and gives an equivalent DC output level. The true RMS value of a waveform is a more useful quantity than the average rectified value because it measures the power in the signal.

An averaging capacitor is the only external component required to perform measurements to the fully specified accuracy. Its value optimizes the trade-off

FIGURE 1: The electronic diagram of the voltmeter.



between low-frequency accuracy, ripple, and settling time.

The 200mV full-scale range of the AD636 is compatible with many popular display-oriented ADCs. Also, the low-power supply current requirement—typically 800μA—permits use in battery-powered hand-held instruments.

THE INTERSIL ICL7106 AND THE LCD

The Intersil ICL7106 is a low-power, 3½ digit A/D converter with seven segment decoders, display drivers, a reference voltage, and a clock. The ICL7106 is designed to interface with a liquid crystal display (LCD), and for this reason includes a multiplexed back-plane drive. It also features auto zero to less than 10μV, zero drift of less than 1μV/°C, input bias current of 10pA (maximum), and rollover error of less than one count.

The display that I used for the meter is a typical 3½ digit LCD with ½″ character height. I don't have the exact part number of the LCD that I used because I had it in my stock for a long time, but I believe that the LCD available from Digi-Key with the part number 67-1789-ND is suitable.

THE ELECTRONIC DIAGRAM

The voltmeter is based on the block diagram of Figure 17 (*Portable, High-Z Input, RMS DPM and dB Meter Circuit*) of the Analog Devices AD636 datasheet. The complete electronic diagram of the voltmeter is shown in **Fig. 1**.

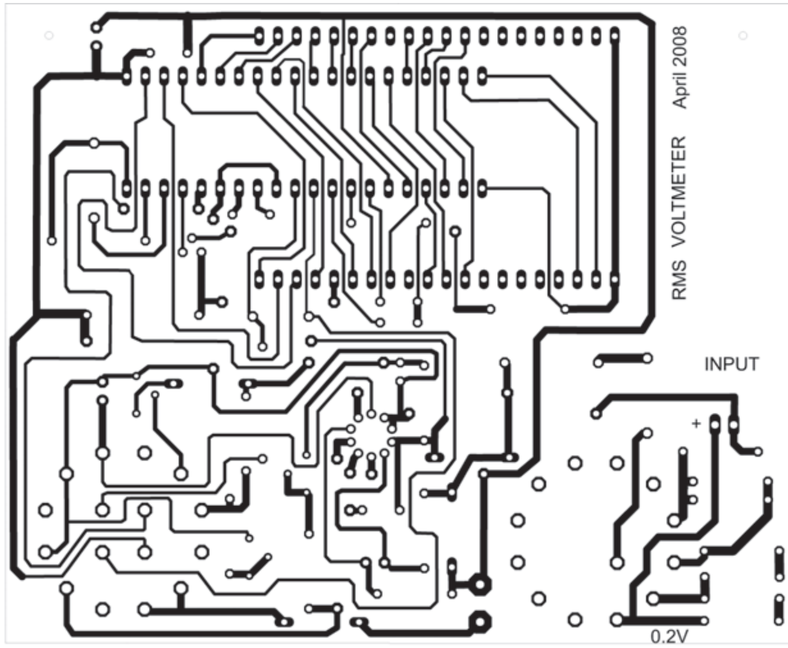
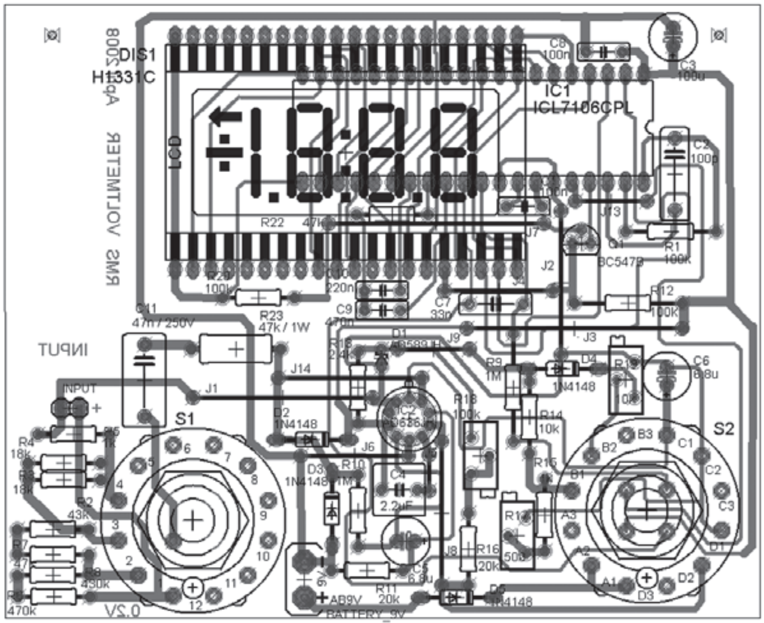


FIGURE 2: PCB.

A brief description of the operation of the meter is as follows:

The 1MΩ input attenuator allows full-scale range for signals up to a maximum of 100V RMS in four positions: ×1mV RMS, ×10mV RMS, ×100mV RMS, and ×1000mV RMS. After the attenuator, the signal is coupled through a 47nF capacitor and a 47kΩ protection resistor to the AD636 buffer amplifier, which is connected in an AC bootstrapped configuration to minimize the loading of the input attenuator by increasing the input impedance of the buffer.



NOTICE: Two cables should be used to connect: a) the pin 2 of the LCD with the pin 20 of the ICL7106
b) the pin 3 of the LCD with the pin 19 of the ICL7106 as shown in photo 3.

FIGURE 3: PCB assembly of the voltmeter.

Then the buffer amplifier drives the 6.7kΩ input impedance of the AD636. The LINEAR or the dB outputs of the AD636 are driven through the S2 switch to the input of the ICL7106. The COM terminal of the ICL7106 provides the false ground required by the AD636 for single-supply operation.

An AD589 1.2V reference diode is used to provide a stable 100mV reference for the ADC in the linear RMS mode by using the trimmer R17 (500Ω); in the dB mode, the trimmer R18 (100k) is used to set the 0dB indication. A diode 1N4148 is inserted in series to provide correction for the temperature coefficient of the dB scale factor. The trimmer R19 (10k) is used to adjust the scale factor of the dB scale.

THE PCB

The construction of the voltmeter is complicated, so I designed a PCB using the demo version of the Eagle Layout editor. You can download this demo version of the program free of charge from the Cadsoft website (www.cadsoftusa.com). The demo version is fully operational, except for a limitation on the maximum dimensions of the PCB, which was not a problem for this project.

The PCB is shown in **Fig. 2**, while the placement of the components on the PCB is shown in **Fig. 3** and **Photo 2**. The two rotary switches (S1 and S2) are placed directly on the PCB to facilitate the construction of the meter. The ICL7106, the resistor R22, the capacitor C1, and the jumper J7 are placed below the LCD. The LCD is not soldered directly to the PCB; two 20-pin sockets are used. This also permits some extra space between the ICL7106 and the LCD.

For the correct operation of the LCD, use two cables to connect pin 2 of the LCD with pin 20 of the ICL7106 and pin 3 of the LCD with pin 19 of the ICL7106 as shown in **Photo 3**. **Figure 4** shows the front plate that I used for the meter. I printed this diagram to a self-adhesive transparent paper, which I then put on the front face of the metallic box of the meter. This gave a very nice look for the meter as shown in **Photo 1**. I used the same diagram as a guide for the opening of the two holes for the rotary switches and the hole for the LCD.

CALIBRATION OF THE VOLTMETER

For the calibration of the voltmeter, I used a Hewlett-Packard HP 3478A multimeter. This digital multimeter offers 3½ to 5½ digit resolution for measuring DC volts, true RMS AC volts up to 300kHz, two-wire and four-wire ohms, and DC and true RMS AC current. The input impedance of the HP3478A is 1MΩ shunted by a capacitance less than 60pF. The accuracy of the HP3478A multimeter for the measurement of the AC voltage as given by the

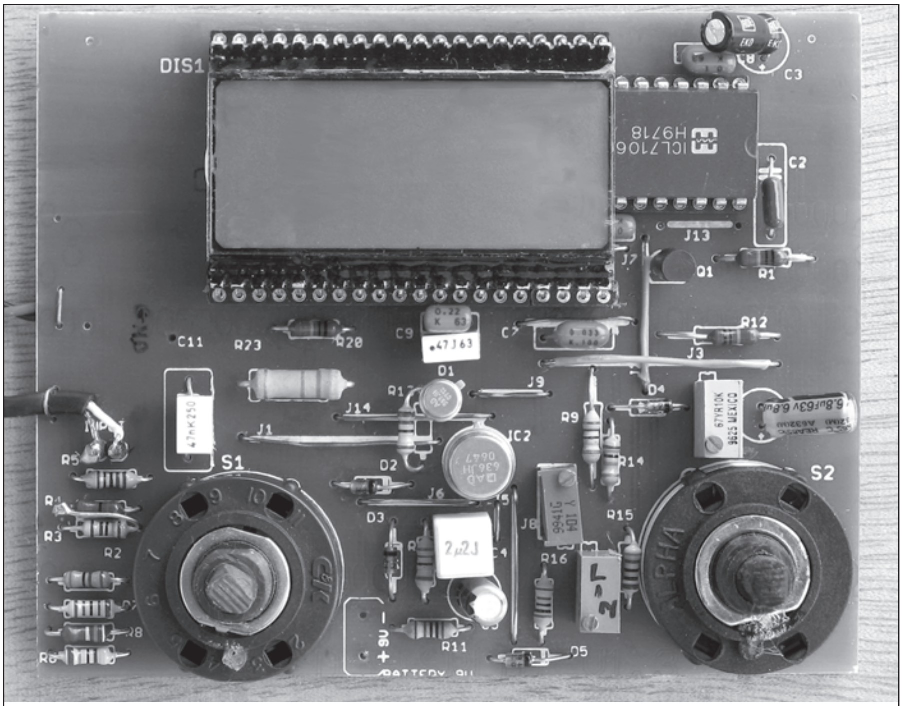


PHOTO 2: The PCB assembly of the voltmeter.

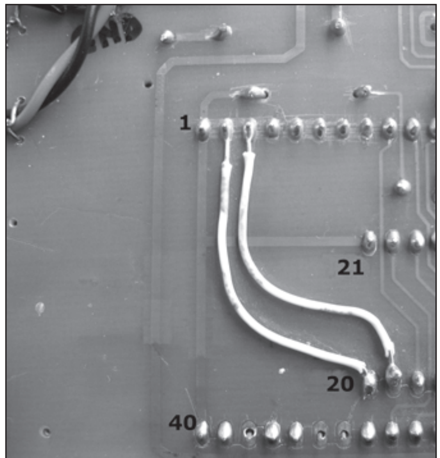


PHOTO 3: The additional connections on the PCB of the voltmeter (see text).

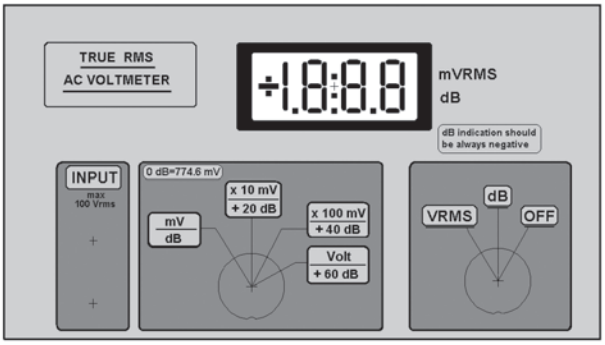


FIGURE 4: The front face of the voltmeter.

manufacturer is shown in **Table 1**.

I performed the calibration of the voltmeter as follows: I connected a sine-wave generator at the input of the RMS voltmeter with the frequency set at 1kHz and the level at 180mV RMS. Then I adjusted the trimmer R17 (500Ω) until the voltmeter display was exactly the same as the HP3478A multimeter display.

For the calibration in the dB range, I set the level of the generator at 774.6mV RMS and adjusted the trimmer R18 (100k) until the meter indicated exactly 0.0dB. Then I reduced the level of the generator to 7.74mV RMS and adjusted the trimmer R19 (10k) until the display indicated -40.0dB. The total battery current required for the operation of the voltmeter is about 2.8mA.

Hewlett Packard HP3478A
AC Volts accuracy (True RMS)

Measurement Accuracy:

±(% of reading + number of counts)
Auto-zero ON. 5½ digit display. Accuracy is specified for sine-wave inputs only, >10% of full scale.
1 Year, Cal. Temp. ±5°C

Input Frequency	Ranges 300mV	3V, 30V	300V
20Hz-50Hz	1.14 + 163	1.14 + 102	1.18 + 102
50Hz – 100Hz	0.46 + 163	0.46 + 103	0.50 + 102
100Hz – 20kHz	0.20 + 120	0.20 + 70	0.24 + 70
20kHz – 50kHz	0.38 + 205	0.26 + 140	0.42 + 140
50kHz – 100kHz	1.20 + 840	0.87 + 780	0.98 + 780
100kHz – 300kHz		10.1 + 3720 (30V Range Only)	

TABLE 1: Accuracy of HP multimeter.

ACCURACY MEASUREMENTS

After the calibration of the meter, I performed some measurements in order to compare the indications of the meter against the HP 3478 multimeter. The accuracy of the HP multimeter as given in its operating manual is shown in **Table 1**. The accuracy is specified only for a sine-wave input with a level greater than 10% of the full scale.

For the accuracy measurements, I used sine-wave and square-wave inputs in the range from 5mV RMS up to about 25V RMS. This was the maximum level that I could have from the power amplifier I used for the tests.

Note that when the meter is set in the dB range, the LCD display should always be kept less than 0dB; otherwise, the accuracy of the meter is not good. When the indication goes above 0dB, the higher voltage range should be used.

I connected both voltmeters to the same signal and checked the voltmeter displays. The results are shown in **Table 2** for the sine-wave and in **Table 3** for the square-wave.

The first column gives the results of the HP multimeter, and the second column shows the AC voltmeter results.

Input ---> SINUS 20 Hz

HP3478 multimeter indication (mV)	VRMS meter indication (mV)	mVrms Relative error with HP (%)	Indication in db by VRMS meter	dB of the HP in reference to 774.6 mV	Error difference (in dB) between HP and Vrms meter
4,997	5,0	0,06	-44,1	-43,81	0,29
10,054	10,0	-0,54	-37,6	-37,73	-0,13
19,920	20,0	0,40	-31,6	-31,80	-0,20
49,455	50,0	1,10	-23,7	-23,90	-0,20
178,350	180,0	0,93	-12,6	-12,76	-0,16
218,750	220	0,57	-10,8	-10,98	-0,18
771,510	775	0,40	0,0	-0,03	-0,03
994,450	1000	0,56	2,3	2,17	-0,13
4947,5	5000	1,06	16,2	16,11	-0,09
24780,0	25000	0,89	30,2	30,10	-0,10

Input ---> SINUS 1 kHz

HP3478 multimeter indication (mV)	VRMS meter indication (mV)	mVrms relative error with HP (%)	Indication in db by VRMS meter	dB of the HP in reference to 774.6 mV	Error difference (in dB) between HP and Vrms meter
5,155	5,0	-3,01	-43,5	-43,54	-0,04
10,185	10,0	-1,82	-37,6	-37,62	-0,02
20,142	20,0	-0,70	-31,6	-31,70	-0,10
50,075	50,0	-0,15	-23,7	-23,79	-0,09
180,040	180,0	-0,02	-12,6	-12,67	-0,07
220,235	220	-0,11	-10,9	-10,92	-0,02
775,700	775	-0,14	0,0	0,01	0,01
999,850	1000	0,02	2,3	2,22	-0,08
4995,0	5000	0,10	16,2	16,19	-0,01
25014,0	25000	-0,06	30,2	30,18	-0,02

Input ---> SINUS 20kHz

HP3478 multimeter indication (mV)	VRMS meter indication (mV)	mVrms relative error with HP (%)	Indication in db by VRMS meter	dB of the HP in reference to 774.6 mV	Error difference (in dB) between HP and Vrms meter
4,921	5,0	1,61	-46,8	-43,94	2,86
10,022	10,0	-0,22	-38,7	-37,76	0,94
20,140	20,0	-0,70	-31,9	-31,70	0,20
50,230	50,0	-0,46	-23,8	-23,76	0,04
180,409	180,0	-0,23	-12,6	-12,66	-0,06
224,301	220	-1,92	-10,7	-10,76	-0,06
788,990	775	-1,82	0,0	0,16	0,16
1016,65	1000	-1,64	2,3	2,36	0,06
4907,2	5000	1,89	16,0	16,04	0,04
24040,0	25000	3,99	30,1	29,84	-0,26

TABLE 2: Sine-wave accuracy measurements.

In the third column, the relative error between the two displays is computed. The fourth column shows the results of the voltmeter when it is set in the dB scale with the same signal as before. In the fifth column I computed in dB the indication of the HP3478 in reference to 774.6mV RMS. The sixth column shows the difference between the fifth and the fourth column.

By examining the results for the voltage range of the meter, you can see that for signals in the frequency range from 20Hz to 10kHz the differences are less than 2%, except in the measurement at a level of 5mV RMS at 1kHz, which is 3%. With the voltmeter set in the dB scale, the differences are very small and below ±0.3dB.

When the frequency is set to 20kHz, the differences are also below 2%, except at the level of 25V, where the difference is about 4%. When the measurements are performed in the dB scale, the results are good except at the 5mV RMS range.

CONCLUSION

This is a very useful piece of test equipment. It measures the true RMS value of an audio signal both in volts and dBs with very good accuracy. It is also portable and very reliable. If you don't have such equipment in your lab, this is a good opportunity to build one. *aX*

Input ---> SQUARE 1kHz

HP3478 multimeter indication (mV)	VRMS meter indication (mV)	mVrms relative error with HP (%)	Indication in db by VRMS meter	dB of the HP indication in reference to 774.6 mV	Error difference (in dB) between HP and Vrms meter
5,113	5,0	-2,21	-43,9	-43,61	0,29
10,210	10,0	-2,06	-37,6	-37,60	0,00
20,133	20,0	-0,66	-31,6	-31,70	-0,10
49,991	50,0	0,02	-23,7	-23,80	-0,10
179,930	180,0	0,04	-12,6	-12,68	-0,08
220,346	220	-0,16	-10,9	-10,92	-0,02
776,481	775	-0,24	0,0	0,02	0,02
1002,20	1000	-0,22	2,3	2,24	-0,06
4960,0	5000	0,81	16,2	16,13	-0,07
24970,0	25000	0,12	30,3	30,17	-0,13

Input ---> SQUARE 10kHz

HP3478 multimeter indication (mV)	VRMS meter indication (mV)	mVrms relative error with HP (%)	Indication in db by VRMS meter	dB of the HP indication in reference to 774.6 mV	Error difference (in dB) between HP and Vrms meter
5,129	5,0	-2,52	-45,4	-43,58	1,82
10,305	10,0	-2,96	-38,4	-37,52	0,88
20,175	20,0	-0,87	-31,7	-31,69	0,01
50,165	50,0	-0,33	-23,7	-23,77	-0,07
180,750	180,0	-0,41	-12,6	-12,64	-0,04
222,850	220	-1,28	-10,8	-10,82	-0,02
783,700	775	-1,16	0,0	0,10	0,10
1011,25	1000	-1,11	-2,3	2,32	4,62
4925,0	5000	1,52	16,0	16,07	0,07
24490,0	25000	2,08	30,2	30,00	-0,20

TABLE 3: Square-wave accuracy measurements.

Parts list for the True RMS Voltmeter

All resistors ¼W

Part	Value
C1, C8	100n
C2	100p
C3	100µ, 16V, electrolytic
C4	2.2µ, MKT
C5-C6	6.8µ, 16V, electrolytic
C7	10n
C9	470n
C10	220n
C11	22n
D1	AD589JH
D2-D5	1N4148
DIS1	3½ digit LCD with ½″ character height (see text)
IC1	ICL 7106CPL
IC2	AD636JH
J1	Jumper 25mm
J2, J8, J14	Jumper 20mm
J3, J7	Jumper 30mm
J4, J6	Jumper 15mm
J5	Jumper 5mm
J9, J13	Jumper 10mm
Q1	BC547C
R1, R12, R20	100k
R2	430k
R3, R4	180k
R5, R14	10k
R6	4.7M
R7	470k
R8	4.3M
R9, R10	1M
R11, R16	20k
R13	2.4k
R15	1k
R17	Trimmer 500Ω, multi-turn
R18	Trimmer 100k, multi-turn
R19	Trimmer 10k, multi-turn
R22	47k
R23	47k/1W
S1	Rotary switch 1 pole × 12 positions
S2	Rotary switch 4 poles × 3 positions
	2 × 20 pin IC socket for the LCD
	2 × 20 pin IC socket for the ICL7106 9V battery with clip