

---

## OBJECTIVE THREE

*When you complete this objective you will be able to...*

Explain and predict using a block diagram, how a true RMS meter processes an input signal (sine and complex waves).

### Learning Activity

*Complete each of the Learning Activities listed below.*

Read the learning material.

### Learning Material

#### True RMS responding voltmeter

Complex waveforms are most accurately measured with a true RMS responding voltmeter. This instrument produces a meter indication by sensing waveform heating power, which is proportional to the square of the RMS value of the voltage. This heating power can be measured by feeding an amplified version of the input waveform to the heater element of a thermocouple whose output voltage is then proportional to  $E_{\text{RMS}}^2$ .

One difficulty with this technique is that the thermocouple is often non-linear in its behavior. This difficulty is overcome in some instruments by placing two thermocouples in the same thermal environment, as shown in the block diagram of the true RMS responding voltmeter of Figure 5-22. The effect of the non-linear behavior of the couple in the input circuit (the measuring thermocouple) is cancelled by similar non-linear effects of the couple in the feedback circuit (the balancing thermocouple). The two couple elements form part of a bridge in the input circuit of a DC amplifier. The unknown AC input voltage is amplified and applied to the heating element of the measuring thermocouple. The application of heat produces an output voltage that upsets the balance of the bridge. The unbalance voltage is amplified by the DC amplifier and fed back to the heating element of the balancing thermocouple. Bridge balance will be re-established when the feedback current delivers sufficient heat to the balancing thermocouple, so that the voltage outputs of both couples are the same. At this point the DC current in the heating element of the feedback couple is equal to the AC current in the input couple. This DC current is therefore directly proportional to the effective, or RMS, value of the input voltage and is indicated on the meter movement in the output circuit of the DC amplifier. The true RMS value is measured independently of the waveform of the AC signal, provided that the peak excursions of the waveform do not exceed the dynamic range of the AC amplifier.



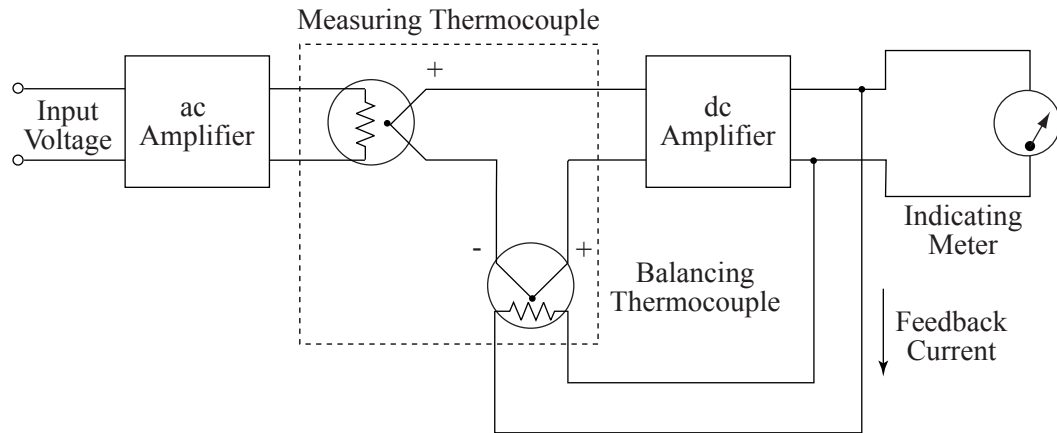


Figure 5-22: Block diagram of a true RMS reading voltmeter. The measuring and balancing thermocouples are located in the same thermal environment.

A typical laboratory-type RMS responding voltmeter provides accurate RMS readings of complex waveform having a crest factor (ratio of peak value to RMS value) of 10/1. At 10 per cent of full-scale meter deflection, where there is less chance of amplifier saturation, waveforms with crest factors as high as 100/1 could be accommodated. Voltages throughout a range of 100  $\mu\text{V}$  to 300 V within a frequency range of 10 Hz to 10 MHz may be measured with most good instruments.

Figure 5-23 shows an IC that converts an input signal to an equivalent DC voltage.

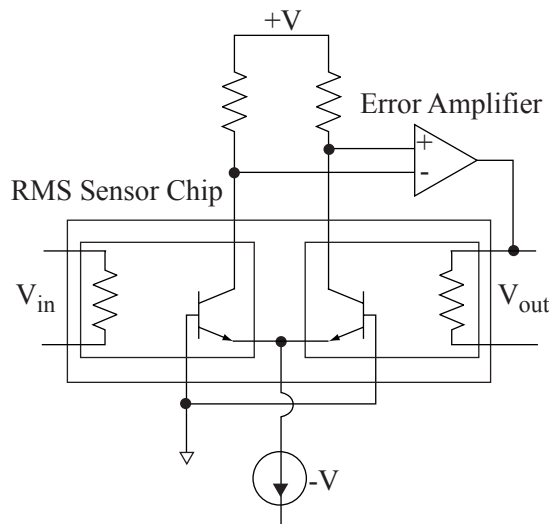


Figure 5-23: Simplified RMS circuit



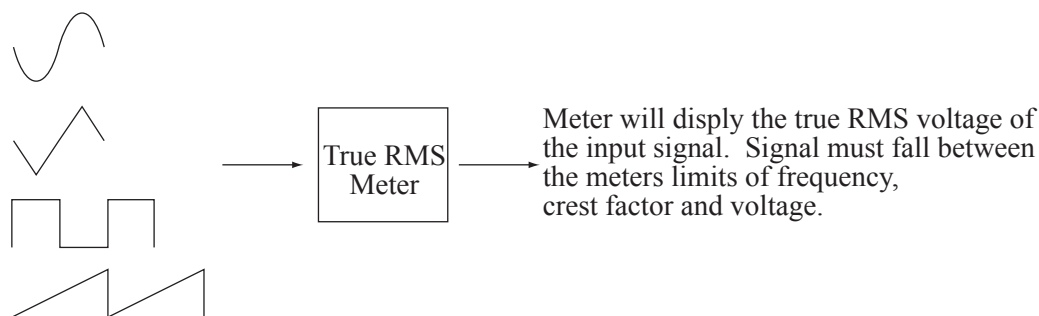
Thermocouple-based thermal elements suffer from the following drawbacks:

- long settling time (the time required for  $V_{out}$  to settle when  $V_{in}$  changes), sensitivity to external temperatures, low output voltages, susceptibility to damage from overload
- The following information refers to the fluke 792A RMS circuit in Figure 5-23: fast settling time, 30 to 60 sec., large output voltage 2 Vdc compared to thermocouples mv's, temperature stability 11 to 35 degrees C, input voltages from 2 mv to 1000 Vac, frequency response 10 Hz to 1 MHz, Hi accuracy 10 PPM to 5000 PPM depending on voltage range and frequency selected

**Explain below how Figure 5-23 operates.**

## True RMS Meters

Only meters that are specified as true RMS can determine the true RMS voltage of waveforms other than sine waves.



*Figure 5-24*

On some true RMS voltmeters (fluke 8010A) the true RMS value must be determined with two measurements.

- 1. Set voltmeter to volts DC and record the value.**
- 2. Set voltmeter to volts AC and record the value =  $V_{ac_{TRMS}}$**

Calculate:  $V_{TRMS} = \sqrt{(V_{ac_{TRMS}})^2 + (V_{dc})^2}$

Some true RMS meters (fluke scope meter, fluke 45) will display the true RMS value directly. The meter measures  $V_{ac_{TRMS}}$  and  $V_{dc}$  then completes the calculation below and displays the true RMS value.



## Average Responding Meters

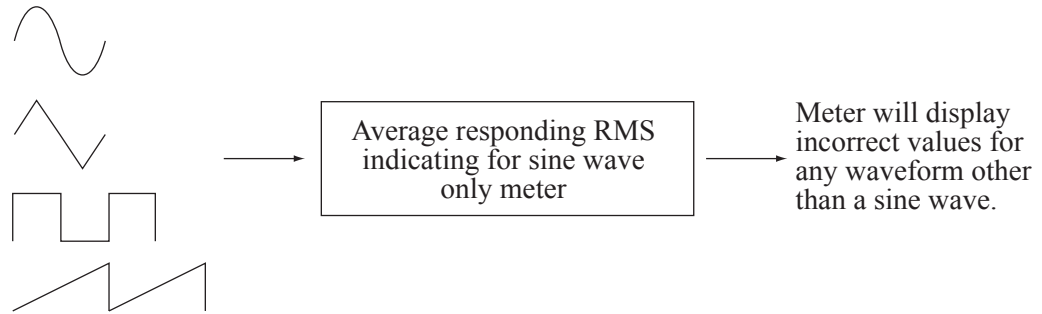


Figure 5-25

Determine the true RMS voltage for the 1/2 wave rectified signal shown below. Also determine what a true RMS meter would display when set to volts DC and volts AC.

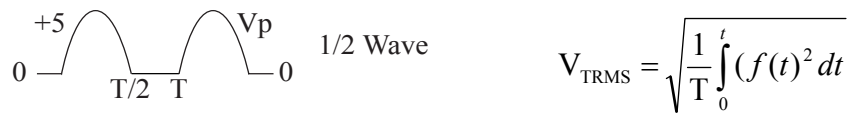


Figure 5-26(a)

$$V_{\text{TRMS}} = \sqrt{\frac{1}{T} \int_0^T (V_p^2 \sin^2 \omega t) dt} = \sqrt{\frac{V_p^2}{T} \int_0^T \sin^2(\omega t) dt}$$

Calculate Vdc for 1/2 wave rectifier sine wave shown in Figure 5-26(b).



Figure 5-26(b)

$$V_{dc} = \frac{1}{T} \int_0^{\frac{T}{2}} V_p \sin \omega t \, dt$$

$$= \frac{V_p}{T} \int_0^{\frac{T}{2}} \sin(\omega t) \, dt = -\frac{V_p}{T} \left[ \frac{1}{\omega} \cos(\omega t) \right]_0^{\frac{T}{2}}$$

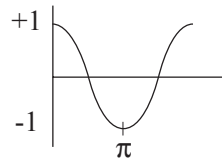


Figure 5-27

$$V_{dc} = 1.59 \text{ V}$$

$$\text{Recall } V_{TRMS} = \sqrt{(V_{ac_{TRMS}})^2 + (V_{dc})^2}$$

$$V_{ac_{TRMS}} = \sqrt{(V_{TRMS})^2 - (V_{dc})^2}$$

Therefore:  $V_{ac_{TRMS}} = \sqrt{(2.5)^2 - (1.59)^2} = 1.93 \text{ V}$ . ← True RMS meter display when set to volts AC.





Determine the  $V_{\text{TRMS}}$  voltage for the signal shown below. Also determine what a true RMS meter would indicate when set to volts AC and volts DC.

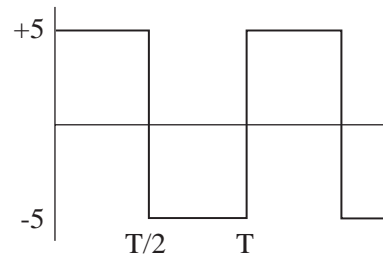


Figure 5-28(a)

### True RMS

$$V_{\text{TRMS}} = \sqrt{\frac{1}{T} \int_0^T (f(t))^2 dt}$$

$$f(t) = \begin{cases} +5; & (0 \leq t < \frac{T}{2}) \\ -5; & (\frac{T}{2} \leq t < T) \end{cases}$$

$$V_{\text{TRMS}} = \sqrt{\frac{1}{T} \left[ \int_0^{\frac{T}{2}} (5V)^2 dt + \int_{\frac{T}{2}}^T (-5V)^2 dt \right]}$$

$$= \sqrt{\frac{1}{T} \left[ 25t \Big|_0^{\frac{T}{2}} + 25t \Big|_{\frac{T}{2}}^T \right]}$$

=

=

$V_{\text{dc}}$  for Figure 5-28(b) = 0 volts.



What would a true RMS meter indicate on volts AC range, using Figure 5-28(b)?

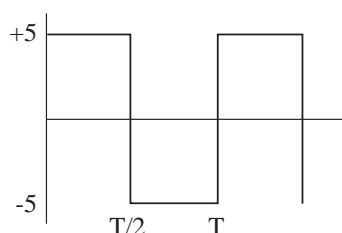


Figure 5-28(b)

$$\text{Recall } V_{\text{TRMS}} = \sqrt{(V_{\text{ac TRMS}})^2 + (V_{\text{dc}})^2}$$

$$V_{\text{TRMS}} = \sqrt{(V_{\text{true RMS}})^2 - (V_{\text{dc}})^2}$$

$$= \sqrt{(5\text{V})^2 - 0^2}$$

$$= 5 \text{ volts}$$

**An average responding RMS indicating meter would display 5.555 volts when set to volts AC. The average responding meter would therefore have a**

$$\frac{5 - 5.555}{5} \times 100 = -11.11 \% \text{ error when measuring the voltage of Figure 5-28(a).}$$

Determine  $V_{\text{TRMS}}$  for signal shown in Figure 5-29.

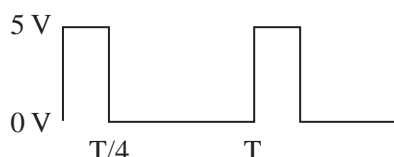


Figure 5-29

Duty Cycle = 25%

$$f(t) = \begin{cases} 5\text{V}; & 0 \leq t < \frac{T}{4} \\ 0\text{V}; & \frac{T}{4} \leq t < T \end{cases}$$

$$V_{\text{TRMS}} = \sqrt{\frac{1}{T} \int_0^{\frac{T}{4}} (5\text{v})^2 dt} = \sqrt{\frac{25}{T} (\text{v})^2 t} \Bigg|_0^{\frac{T}{4}}$$

$$= \sqrt{\frac{25 (\text{v})^2 \left[ \frac{T}{4} \right]}{T}} = \sqrt{\frac{25 (\text{v})^2}{4}} = 2.5 \text{ V}$$

$$V_{\text{TRMS}} = 2.5 \text{ V}$$



Vdc =

=

Vac TRMS =

=

=

Another method to predict what the meter will read on volts AC function, is shown using Figure 5-29 as the input.

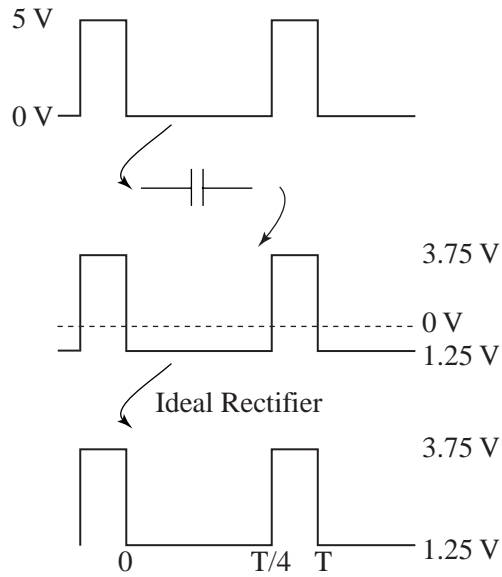


Figure 5-30





$$\begin{aligned}
 V_{\text{AC TRMS}} &= \sqrt{\frac{1}{T} \left[ \int_0^{\frac{T}{4}} (3.75)^2 dt + \int_{\frac{T}{4}}^T (1.25)^2 dt \right]} \\
 &= \sqrt{\frac{1}{T} \left[ 14.0625 t \Big|_0^{\frac{T}{4}} + 1.5625 t \Big|_{\frac{T}{4}}^T \right]} \\
 &= \\
 &= \\
 &=
 \end{aligned}$$

Determine the  $V_{\text{TRMS}}$  voltage of the signal shown in Figure 5-31. Also determine what a true RMS meter would indicate when set to volts DC and volts AC function.

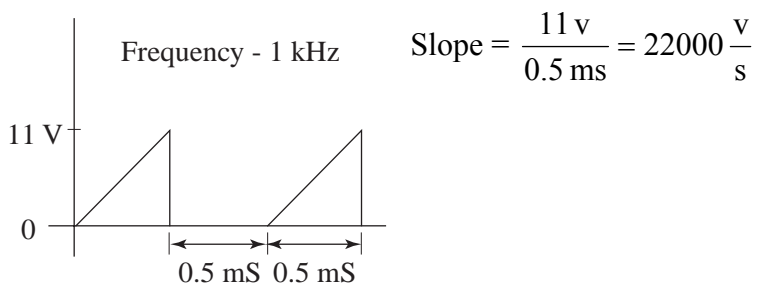


Figure 5-31

$$V_{\text{TRMS}} = \sqrt{\frac{1}{T} \int_0^t (f(t))^2 dt} \quad f(t) = \begin{cases} 22000 \frac{\text{V}}{\text{s}} t & 0 < t \leq 0.5 \text{ ms} \\ 0 & 0.5 \text{ ms} < t \leq 1.0 \text{ ms} \end{cases}$$

$$\begin{aligned}
 V_{\text{TRMS}} &= \\
 &=
 \end{aligned}$$



=

=

=

Determine  $V_{\text{TRMS}}$  voltage of the signal shown below. Also determine what a true RMS meter would indicate when set to volts DC and volts AC function.

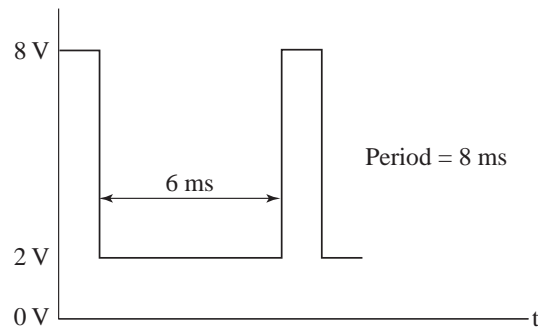


Figure 5-32

$$V_{\text{TRMS}} = \sqrt{\frac{1}{T} \int_0^T (f(t))^2 dt} \quad f(t) = \begin{cases} 8 \text{ v} & 0 < t \leq 2 \text{ ms} \\ 2 \text{ v} & 2 \text{ ms} < t \leq 8 \text{ ms} \end{cases}$$

$$V_{\text{TRMS}} =$$

=

=

=

$$= 4.36 \text{ volts}$$

$V_{\text{dc}}$  = area method =



Vdc calculus method:

$$\begin{aligned} V_{dc} &= \\ &= \\ &= \\ &= \\ &= \\ &= \\ &= \end{aligned}$$

$$\begin{aligned} V_{ac\ TRMS} &= \sqrt{(V_{TRMS})^2 - (V_{dc})^2} \\ &= \sqrt{(4.36)^2 - (3.5)^2} = 2.6 \text{ volts} \end{aligned}$$

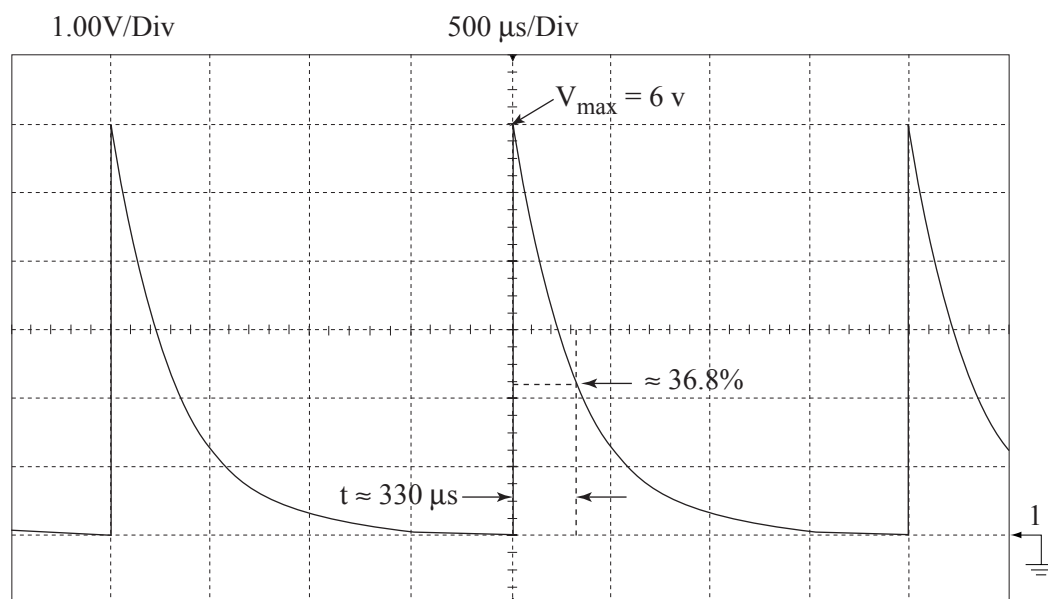


Figure 5-33

Measured Vdc for the signal in Figure 5-33 = 1.03 volts. Measured  $V_{TRMS} = 1.76$  volts.



Determine the equation for the signal in Figure 5-33. The wave form is an exponential fall. Recall 1 time constant  $e^{-1} \approx 0.3679 \approx 36.8\%$  of  $V_{\max}$ . From Figure 5-33, determine the time for the waveform to get to  $\approx 36.8\%$  of  $V_{\max}$ .

$$1 \tau = 330 \mu\text{s}$$

Equation  $v(t) = 6 e^{-t/\tau}$  for waveform in Figure 5-33.

Verify the above equation let  $t=500 \mu\text{s}$ ,  $v(t)= 1.32$  volts

$$\text{Answer: } 1.32 \text{ v} = 6 e^{-\frac{500 \mu\text{s}}{330 \mu\text{s}}}$$

Determine  $V_{\text{dc}}$ ,  $V_{\text{TRMS}}$  and what a true RMS voltmeter would indicate on volts AC ( $V_{\text{ac TRMS}}$ ) for the signal in Figure 5-33.

The exponential fall equation  $Ve^{-x}$  requires five time constants  $\tau$ , for the waveform to decay to approximately 0.

Determine  $V_{\text{TRMS}}$  of Figure 5-33:

$$v(t) = 6e^{-t/\tau}$$

$$\tau = 330 \mu\text{s}$$

$$\begin{aligned} V_{\text{TRMS}} &= \sqrt{\frac{1}{T} \int_0^T (f(t))^2 dt} \\ &= \sqrt{\frac{1}{T} \int_0^T (6e^{-\frac{t}{\tau}})^2 dt} \\ &= \\ &= \end{aligned}$$



---

=

=

=

=

=

=

*Note:* The measured and calculated voltage values are slightly different. One reason for this is the approximation of  $\tau$ .



Determine Vdc of Figure 5-33:

$$v(t) = 6e^{-t/\tau}$$

$$\tau = 330 \mu\text{s}$$

$$\begin{aligned} V_{dc} &= \frac{1}{T} \int_0^T (f(t)) dt \\ &= \frac{1}{2 \text{ ms}} \int_0^{2 \text{ ms}} 6e^{-\frac{t}{\tau}} dt \\ &= \\ &= \\ &= \\ &= \\ &= \\ &= \\ &= \end{aligned}$$

*Note:* The measured and calculated Vdc voltage values are slightly different. One reason for this is the approximation of  $\tau$ .

Vdc = \_\_\_\_\_ (recall Vdc is what a true RMS or average responding voltmeter indicates when set to volts DC.)

$$V_{\text{TRMS}} = \underline{\hspace{2cm}}$$

$$V_{\text{TRMS}} = \sqrt{(V_{\text{dc}})^2 + (V_{\text{ac\_TRMS}})^2}$$

Solve for; Vac TRMS = \_\_\_\_\_