DCC VOLTAGE TESTING EQUIPMENT OVERVIEW

By Charles E. Kinzer – This document may be used by modelers for their personal use.

CONTENTS

INTRODUCTION

This document is for:

- Those who may not know much about electronics but want to measure their DCC track voltage or understand why they are having trouble measuring it.

- Those who may have electronics knowledge and are curious about low-cost DCC track voltage measurement offerings.

What is presented:

- Mostly low-cost options from light bulb testers to multimeters to oscilloscopes.
  This is only a small sampling of what is available but is at least a gathering in one place.

- Basic performance tests. Not full reviews. Also, some items are shown that don't work – and why.

- Appendices with further information for "inquiring minds" yet still summary in nature.

And a few notes:

- DCC voltage measurement here is between the rails. Digitrax has another method (their KB909 article) which makes it easier for many multimeters by measuring a pulsating DC voltage. This is done by setting to analog channel 00 and setting to speed 00 measuring from one rail to a ground on a booster terminal or case. This method is not as convenient as rail to rail, nor will it work with all DCC systems.

- The market is crowded with choices. You must look closely at specifications. Something high-priced may not measure DCC track voltage well. Or something low-priced might work surprisingly well.

- There is vastly more information about most equipment online, especially YouTube reviews.
  However, some are from the inexperienced, and others from the truly knowledgeable.

- Many web sites and YouTubes are "reviews" like "10 Best Low-Cost Multimeters" or "5 Best beginner Oscilloscopes". Most are merely sales promotions for certain models. And the YouTubes are often only a computer narrated regurgitation of a manufacturers' brochures.

- The technology, availability, and pricing of test equipment can change quickly.
  What is shown here may change before the ink dries.
  But the general principles are not likely to change.

- Voltage notations used:

Vrms	RMS AC voltage
Vp	Peak AC voltage
Vpp	Peak-to-Peak AC voltage
Vav	Average AC voltage
VDC	DC voltage
V	"Voltage" in context of bulbs, etc.

This paper does not use VAC or Vac (often used for AC RMS voltage) to avoid ambiguity.

LIGHT BULB TESTERS

Most DCC voltage testing probably only needs to answer, "is it on or off." Typically, you either have the DCC voltage, or you have nothing. "Nothing" can mean the DCC voltage is not present or is shorted.

A homemade light tester can answer the question and is easy to make. It is handy for a quick test even if you have other measuring devices. An advantage is that you can see a light out of the corner of your eye while still focusing on where you are placing test leads such as working around switch points and frogs.

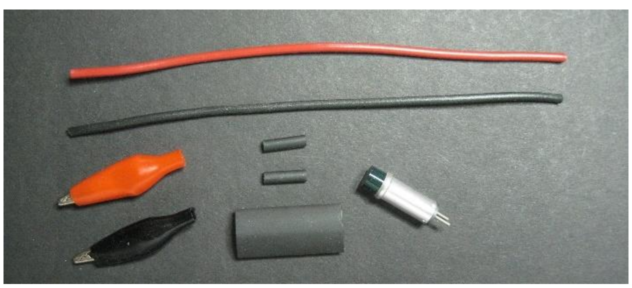
Note: None of the bulb-based testers shown here are suitable for large scale where the DCC voltage is too high. You would need to use bulbs rated for a higher voltage.

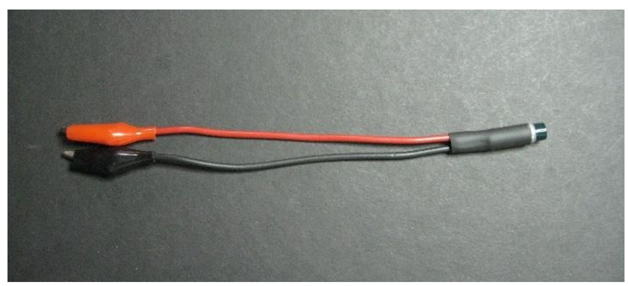
Note: DCC voltage is higher than the 12.8 VDC rating typical for incandescent auto bulbs. This can shorten the bulb life to about one fourth of the estimated hours of lifetime. But since the bulb is not on continuously, this should not be an issue.

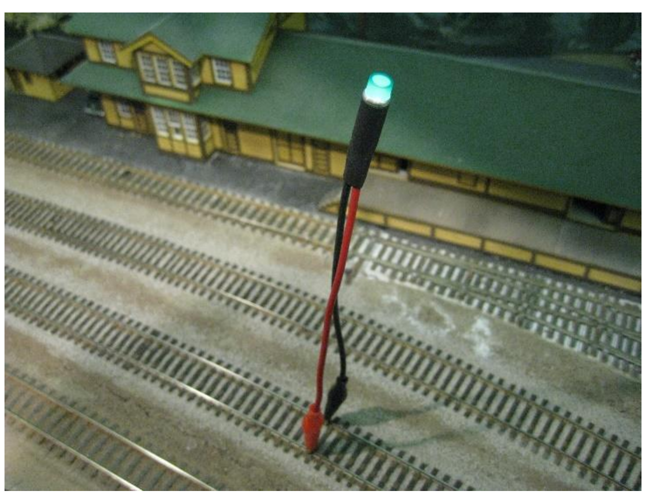
Homemade Test Light – Panel Lamp

The panel lamp is fairly small. Reasonably large, stranded wires will hold their shape well and be easy to handle. But you can use smaller more flexible wires if you want. This lamp draws 80 mA which will be a little over 1 watt so it will get quite warm. Since it is an incandescent, it also has high "inrush" current, perhaps 14 times higher which is 1.12 amps. So, so the load might very briefly be about 1 amp and very quickly drop down to 80 mA. This should not be enough to look like a brief short to the DCC system, but if there are already a lot of loads (engines) on the track, it could be enough to exceed current limiting.

Parts: Dialight panel mount lamp, green, 14V, 80 mA (Mouser #645-50739141472-600F, $9.94 each)
Uxcell Alligator Clips ($7.49 for 50 at Amazon)
Hook up wire, 16 gauge. Color and length as desired.
Shrink tubing (3/32" - 3/64" and 3/8" - 3/16") (Amazon has a Gardner Bender assortment, $11.99.)


Parts


Assembled

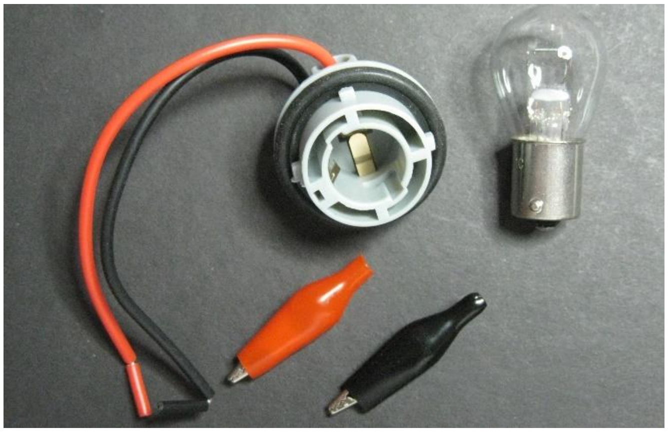

Connected to DCC rails with ~14 Vrms.

Homemade Test Light – 1156 Auto Incandescent Bulb

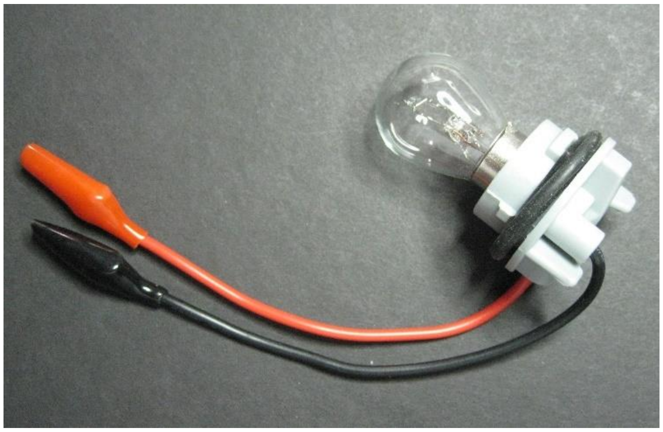
Some blogs mentioned making a test light from an 1156 incandescent tail lamp bulb. (There are other discussions of this bulb for short circuit protection. That is an unrelated issue.) This draws a relatively high current, gets quite hot, and has a high inrush current (higher current when first turned on and cold). You could also consider more tame incandescent bulbs. Here are some comparisons of common auto bulbs:

Bulb	Base	~Amps at 12.8V	~Inrush current, Amps	~Watts at 12.8V
1156	BA15s Bayonet	2.1	29	27
1141	BA15s Bayonet	1.4	19	18
912	For W5S Socket	1.0	14	13

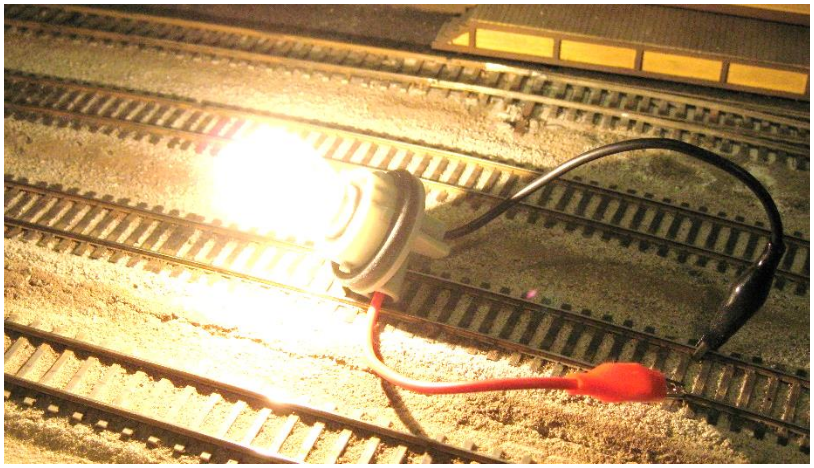
Parts: Eiko 1156 Light Bulb, Pack of 10 ($6.90 at Amazon) or from any auto parts store.
Standard 1156 Bulbs Socket Holder (2 for $7.66 at Amazon).
Uxcell Alligator Clips (50 for $7.49 at Amazon)



Parts before assembly.



Assembled. (You could solder wires directly to the bulb base, but the socket is convenient for handling.)



Testing on a layout. Very BRIGHT. Very HOT. Sometimes the inrush current was so high that the system powered off (assumed a short). When it kept trying to power back on, you would see a very dim brief glow but then the system saw it as a short and power went off again. If you want something that draws a lot of current (and especially inrush current), and can perhaps burn your fingers, this is a good option. Lower wattage incandescents or LED bulbs may be better. ~ 14 Vrms

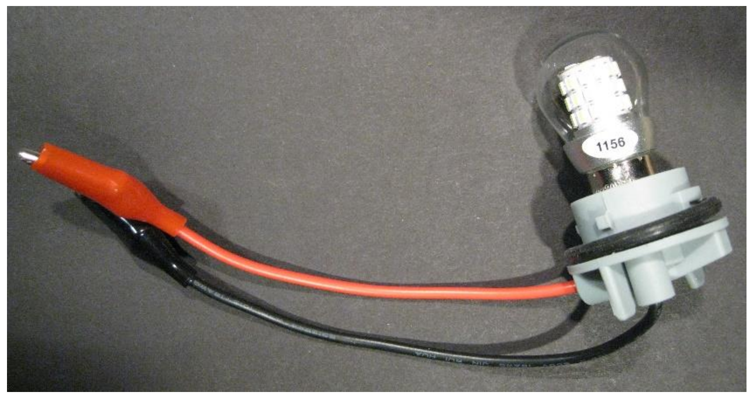
Homemade Test Light – 1156 Auto LED Bulb

This is the assembly from the previous page but with an 1156 LED version bulb installed. These come in many forms, and a few are inside a glass bulb just like an incandescent style. Due to the handling a tester gets, the glass bulb form is better than the versions with exposed LED's and exposed circuitry. Also, it will only get warm to the touch where exposed LEDs can get too hot to touch. The bulb is nominally 3 watts, 1/4 amp, at 12 volts.

On a DCC voltage, it drew 265 mA with an inrush current of about 1 amp.

Parts: ALOPEE 9V-30V DC 1156 LED Bulb, Non Polarity (2 for $15.89 at Amazon)
Standard 1156 Bulbs Socket Holder (2 for $7.66 at Amazon).
Uxcell Alligator Clips (50 for $7.49 at Amazon)

LED version of 1156 auto bulb with glass cover.



Assembly of tester with LED version of 1156 auto bulb with glass cover.

Testing on a layout. Very bright. Only warm to the touch. ~14 Vrms

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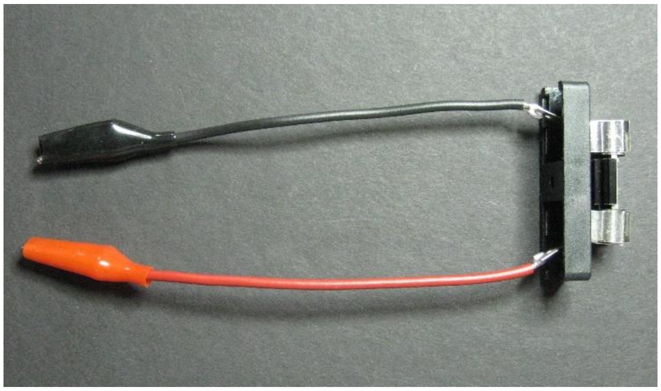
Homemade Test Light – DE3022 Auto LED Bulb

Some blogs mentioned making a test light from DE3022 LED auto bulb. This is a “festoon” style often used for automobile dome lamps and such. The one procured had exposed LEDs on one side, and a heat sink on the other. The LEDs quickly get too hot to touch, and shortly after, so does the heat sink. The bulb is nominally rated at 2.4 watts, 0.2 amp, at 12 volts.

On a DCC voltage, it drew 240 mA with an inrush current of about 750 mA.

Parts: ALOPEE DE3022 LED Bulb 31mm, Non-Polarity (4 for $10.99 at amazon)
3x 31MM Festoon Bulb Socket Base Holder (3 for $9.98 from eBay seller allalighting)
Uxcell Alligator Clips (50 for $7.49 at Amazon)
Hook up wire, 16 gauge. Color and length as desired.

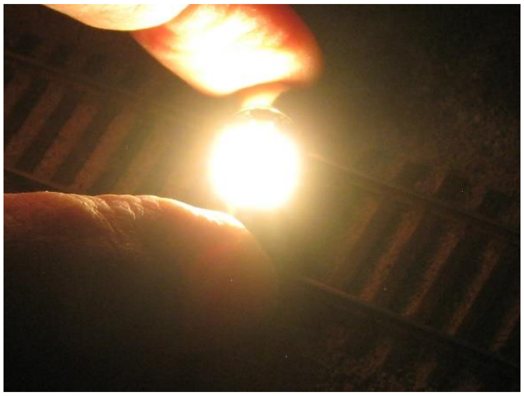
Parts before assembly.



Assembled. (You could put heat shrink on the solder tabs, but with the metal bulb socket exposed anyway, it probably isn’t worth it.)

This socket is adjustable, and contacts must be moved. You first straighten the tabs, and then bend out the plastic part to release detents to pull the contacts free. Then reinsert in the innermost positions. It is a bit difficult.

Testing on a layout. Very bright. LEDs and heat sink quickly get too hot to touch. OK to handle by the socket. ~ 14 Vrms



You can even use a bare festoon style bulb across the rails. It is best to hold by the ends since they don’t get hot very quickly. Face up, like in the photo, is uncomfortably bright. Probably better to have the LEDs face down.

Commercial Auto Voltage Light Tester

Many automotive voltage light testers are available at auto parts stores, Amazon, etc. These typically handle higher voltages (such as up to 28 VDC or more) so should be fine with DCC voltages including for large scale.

One is a Lisle 24550 from an O'Reilly Auto Parts store for $18. Rated at 3 to 28 volts it draws 21 mA at 12 volts, so it is a small load. It has a green/red bidirectional LED that glows red for positive voltage, green for negative. (If assembled correctly. If you reverse the glass tube inside end for end, this behavior reverses.) For the DCC voltage, the LEDs alternate but the green is brighter, so the result is mostly a green color. It handles the DCC frequency just fine. In fact, it operated up to 10 MHz before brightness started to drop off.

The LED just starts to glow at about 4 VDC and becomes reasonably visible at about 6 VDC and gets brighter from that point on up.

This has an alligator clip on a wire for one contact and a handle with a sharp point for the other. The sharp point is for poking through auto wire insulation to test voltage. You could dull the point for model railroad use and still be able to probe around switch frogs and points. Many of these have much larger clips on the wire up to the type you see on jumper cables. If you get one with an overly large clip you can replace it with a smaller alligator clip. The big advantage of this type of tester is that all you have to do is take it out of the package.

Inside is a glass tube with the dual LED and a series resistor. You can just see the end of the resistor at the right end of the tube. The spring just holds it in place with a positive electrical connection.

Connected to the track output of a Digitrax DCS52 Zephyr Express (in dimmed room lighting).

Testing on a layout. The large alligator clip provided with the tester has been replaced with a smaller one.
~ 14 Vrms

Commercial Auto Voltage Digital Display Tester

There are auto voltage testers that have digital displays. They are not really designed to work with AC much less up to 10 kHz AC like the DCC voltage. Still, they seemed worth a try.

Three “Premium Digital LED Automotive Circuit Testers, DC 2.6V-32V” from Amazon from seller WINAMOO all immediately failed on DCC voltage. It is unknown why this happened. (The same component failed in each such that the tester became a near short circuit to a negative voltage.)

A higher voltage range tester worked. It is the “AWBLIN Automotive Test Light 3-60V DC Digital LED Circuit Tester” for $21.99 on Amazon. It is heavy duty. The large ground clamp was replaced with a small alligator clip. The instructions say DC only and not to use with AC and not over 60 volts. But it seems fine with the DCC voltage. (Perhaps they are steering people away from measuring house voltage.)

DC accuracy was within 0.1 VDC tested from 4 to 15 volts. A red LED indicates positive, green LED negative.

For a 10 kHz square wave, it also read within 0.1 Vp from 4 to 15 volts. Surprisingly accurate (and sometimes this is the result of two kinds of errors canceling each other out as a happy accident). On AC, only the green LED seems to light. It read accurately from 10 Hz to 300 kHz. Current draw is about 12 mA which is low.

Connected to a Digitrax DCS52 Zephyr Express track output DCC voltage, it read very accurately.

AWBLIN Automotive Tester comes with a large ground clamp. The molded item on the cord at the left in the photo is a needle guard to cover the sharp point when not in use. (The sharp point is for poking through wire insulation to take a reading. You can dull the point and still be fine for touching small track areas like switch points and frogs.)

Output of DCS52 read by automotive tester and Fluke 8060A multimeter which is True RMS with accuracy of +/-(0.5% of reading + 20 counts) for this voltage range and frequency.

Testing on a layout. ~ 14 Vrms

COMMERCIAL DCC VOLTAGE TESTERS

DCC Specialties RRampMeter

Version II shown.

5.6 x 2.0 x 1.2 inches

Version I and II Track powered

Version III and IV track powered or 9 VDC battery

About $60 to $110

The DCC Specialties “RRampMeter” is designed for measuring DCC track voltage and current. There are four versions: I, II, III, and IV. Importantly, they measure True RMS AC voltage. There are number of ways to use this for testing, and it is best to review their online manual.

RRampMeter I Bare board, no enclosure. Track powered. 10 amps.

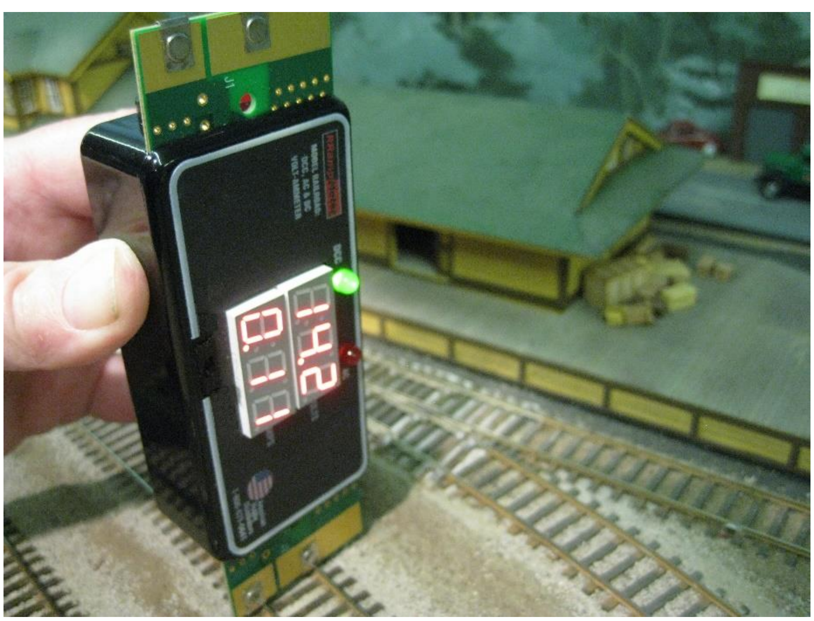
RRampMeter II In enclosure. Track powered. 10 amps.

RRampMeter III In enclosure. Track powered and also battery if track voltage too low. 10 amps.

RRampMeter IV Same as III but rated for higher 20 amp current.

For just measuring track voltages, you hold the RRampMeter directly on the track and do not need test leads.

The RRampMeter also has banana jacks for making connections to measure current.



Reading track voltage ~ 14 Vrms as 14.2 Vrms. This is version III with a battery and an ON-OFF switch although it is also track powered if enough track voltage is present.

PROSES Track Voltage Tester

The PROSES track voltage tester shows voltage level with three LEDs. Bachmann also sells this tester. It measures DCC track voltage or regular DC.

1.6 x 1.3 x 0.3 inches

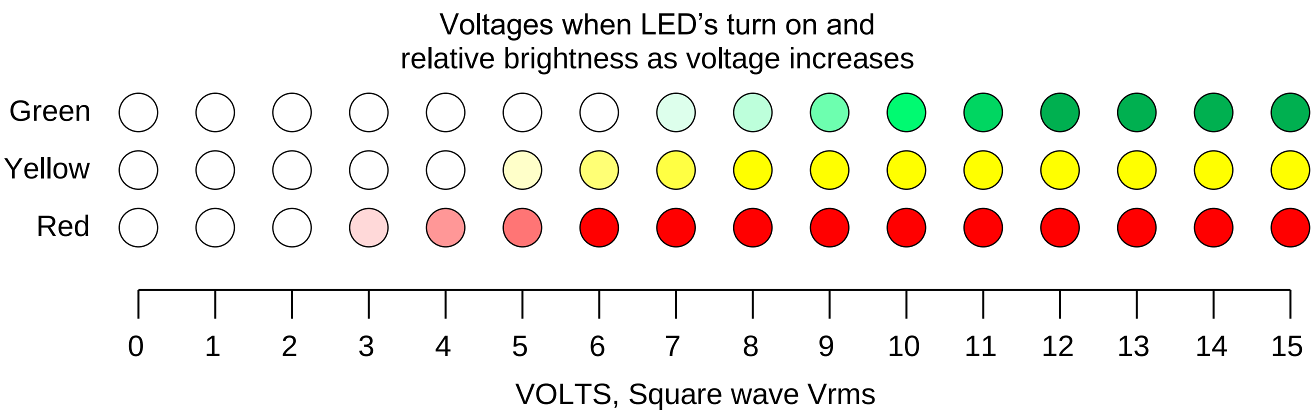
Track powered

About $23

It has red, yellow, and green LED lights for “Low,” “Medium” and “High.”

It is quite small, and you simply hold it down onto the rails. There are no test leads to deal with and its small size makes it easy to work amongst scenery, etc. Even if you have another means to measure voltage, one of these can be handy for a quick test. (You can ignore the DC + and – rail notations for DCC testing.)

Their specification says, “Red LED comes on between 5-9Volts, Yellow LED add for 9-12, Volts, Green LED lights up for voltage over 12V”. But those are nominal values. LEDs started to glow dimly at somewhat lower voltages than specified. The following graphic tries to show when each started to light and when it got to full brightness. Also, note that they are cumulative. At full voltage, all will be on.



Full DCC track voltage present.

No DCC track voltage present.

ANALOG MULTIMETERS

Assorted

There are many inexpensive analog multimeters ($5 to $15) with meter movements. They are sold under many brand names. These do NOT read True RMS for anything but a sine wave. A square wave will read about 11% too high as compared to a sine wave. But readings also get lower as frequency increases. You might get lucky with a meter where the two error sources offset each other at the DCC frequency and produce, by coincidence, a fairly accurate reading. They otherwise inherently may not be very accurate and may read differently whether vertical or lying on their back. Also, while designed mainly to read 60 Hz AC, they will typically handle the DCC frequency to some degree of usability, or at least repeatability. Examples:

SUNWA

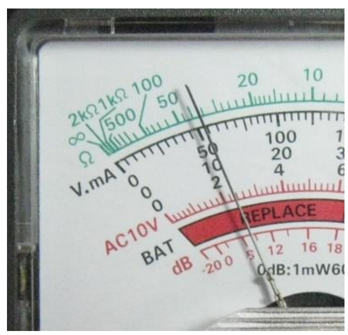
10 kHz 20 Vpp sine.
7.07 Vrms reads 8.0 Vrms.

10 kHz 20 Vpp square.
10 Vrms reads 14.0 Vrms

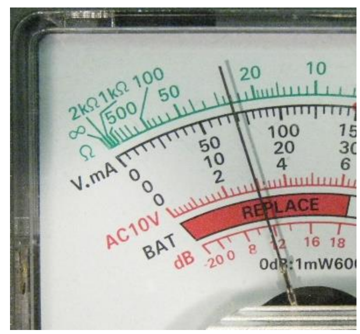
~ 14 Vrms DCC track voltage reads 18.0 Vrms

Commercial Electric

10 kHz 20 Vpp sine.
7.07 Vrms reads 6.3 Vrms

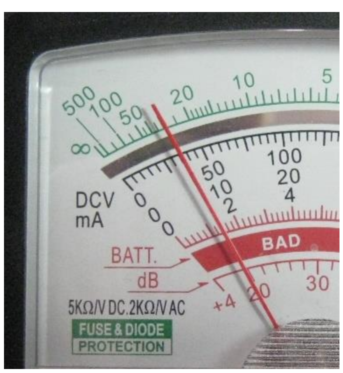


10 kHz 20 Vpp square.
10 Vrms reads 10.9 Vrms

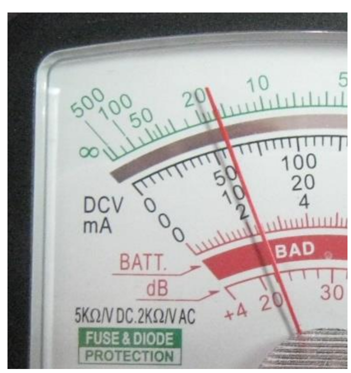


~ 14Vrms DCC track voltage reads 13.9 Vrms

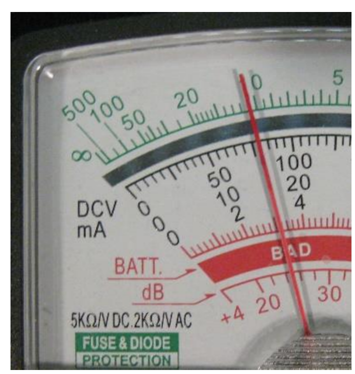
Radio Shack



10 kHz 20 Vpp sine.
7.07 Vrms reads 7.1 Vrms



10 kHz 20 Vpp square.
10 Vrms reads 12.0 Vrms



~ 14 Vrms DCC track voltage reads 15.9 Vrms.

Simpson 260 Multimeter

It is unlikely any model railroader would opt for this style of meter nowadays. This is old school. Really old school. Or is it? While first introduced in 1939 (and yes, thousands helped win WWII), Simpson still manufactures it today. It was the industry standard for decades and still is for some niche activities. Of course, it has gone through many model variations and feature improvements as well as the number and types of batteries used. Something like ten different models are available today.

Also, while called a "multimeter" today, long ago the term was "VOM" for "Volt-Ohm-Milliammeter." (Pronounced Vee-Oh-Em.)

The model tested here is a 260-5P from about 1966 (priced $79.95 then or $688 in 2022 dollars). This was their first model with improved "protection." This is also after they upgraded from a leather strap handle to the Adjust-A-Vue handle in 1955. They still use that Adjust-A-Vue name today. These are big and bulky and Bakelite (but newer ones are a different phenolic). And they have a large 4 1/2 inch meter.

Testing showed this is clearly of the design that averages the AC input voltage and then scales it to display as RMS for a sine wave. The square wave reading about 11% high indicates this. The AC frequency response is excellent and works fine for sine or square up to well beyond 100 kHz.

Also, there are other multimeters of similar form such as the Triplett 630 (still sold today and described by them as "Classic") and the Radio Shack Micronta 22-214 (which doesn't seem to be sold anymore).

7.0 x 5.3 x 3.2 inches

Powered by one 9VDC and one D battery (newer models)

About $365 for a new 260-8
About $440 for a new 260-8P (has relay protection)
(There are also other specialized models)

Used from $20 to $200 depending on model/condition

10 kHz 20 Vpp sine wave.
7.07 Vrms is ideal. Reading
7.0 Vrms on 10 volt range.

10 kHz 20 Vpp square wave.
10.0 Vrms is ideal. Reading
11.0 Vrms on 50 volt range.

~14 Vrms DCC track
voltage reads 15.6 Vrms

DIGITAL MULTIMETERS

Digital multimeters are common and in many price ranges. You need “True RMS” and AC voltage frequency response up to 10 kHz to measure DCC voltage accurately. Meters without “True RMS” will have the error of indicating a square wave about 11% too high. Insufficient frequency response will have the error of indicating too low. Sometimes these errors might cancel each other out for a specific frequency. Other details are the other features provided, how they do input protection, and build quality.

OWON B41T+ Digital Multimeter

7.2 x 3.5 x 1.4 inches

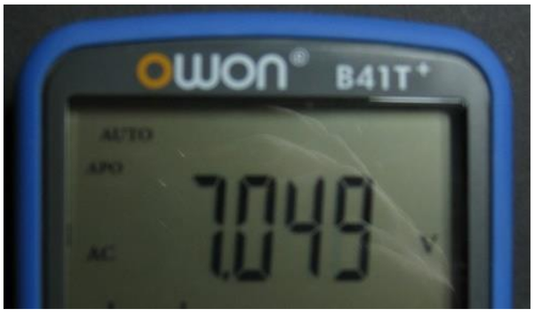
Powered by two AA batteries

About $78

This is a True RMS multimeter with 40 to 10,000 Hz frequency response. For the DCC voltage range, the specification is +/- (1.2% + 50 digits). This is good enough to measure DCC voltage well. OWON has other multimeters for slightly less cost, but the AC voltage frequency range is too low for DCC. The B35T+ is nearly identical but with insufficient frequency response and was selling for $61 when the B41T+ was $78.

Its display is “4 1/2” digits meaning it can display numbers up to 19999.

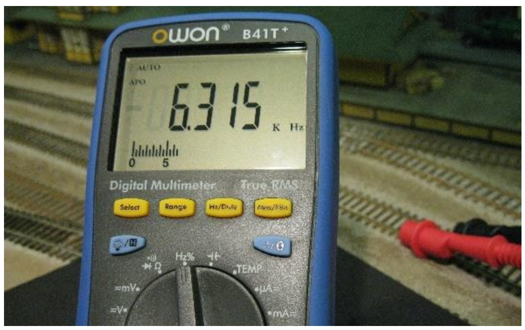
The True RMS capability tested very well at 10 kHz with both test voltages and on a layout. This meter can also read frequency. Readings below are well within the meter’s tolerance.



10 kHz 20 Vpp test sine wave.
7.071 Vrms is ideal.

10 kHz 20 Vpp test square wave.
10.000 Vrms is ideal.

DCC track voltage at ~14 Vrms



DCC frequency averaging a bit over 6 kHz.

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Cen-Tech 98025 Digital Multimeter

This is a multimeter with an AC frequency response specification of 45 to 450 Hz. However, it performed considerably better than this specification would suggest.

A 60 Hz 20 Vpp sine wave displayed 7.1 Vrms (correct as7.07 Vrms rounded) and a 60 Hz square wave displayed 11.3 Vrms (should be 10.0 Vrms). The square wave reading so high indicates it is NOT a "True" RMS meter and instead just averages AC voltage and multiplies it by the 1.11 scale factor that applies to sine waves (Vrms / Vav).

(Refer to table below.) The readings dropped off fairly gradually as frequency increased. For the square wave, which was reading too high at lower frequencies, this drop off improved overall accuracy at higher frequencies. At 10 kHz, by happenstance, the square wave voltage reading was excellent. The nominal average DCC frequency of perhaps 6 to 7 kHz will only read a few percent high.

Harbor Freight sells these, but they also seem to have promotions giving them away with a purchase. It is certainly quite usable for measuring DCC track voltage, but it does have a very low build quality and is not very robust.

4.9 x 2.6 x 0.9 inches

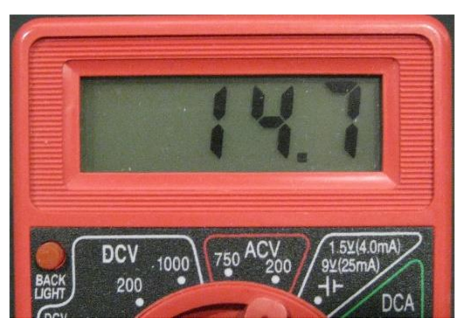
Powered by 9 VDC battery

About $7 or Free

10 Vp SINE WAVE		10 Vp SQUARE WAVE	
kHz	**7.07 Vrms**	**kHz**	**10.00 Vrms**
1	7.1	1	11.2
2	7.1	2	11.0
3	7.0	3	10.9
4	7.0	4	10.7
5	6.9	5	10.6
6	6.9	6	10.4
7	6.9	7	10.2
8	6.8	8	10.1
9	6.8	9	10.0
10	6.7	10	9.9

10 kHz 20 Vpp sine wave.
7.07 Vrms is ideal.

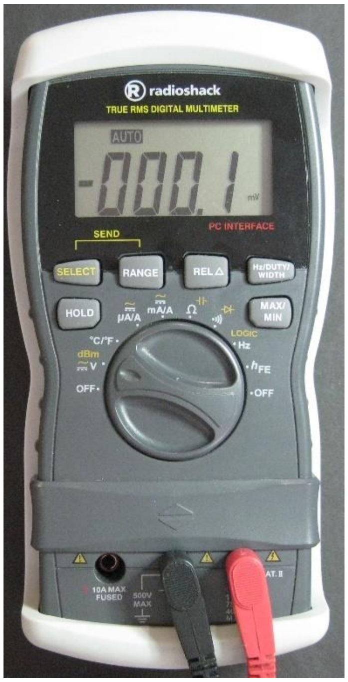
10 kHz 20 Vpp square wave.
10.000 Vrms is ideal.



~14 Vrms DCC track voltage
reads 14.7 Vrms

Radio Shack 2200087 Digital Multimeter

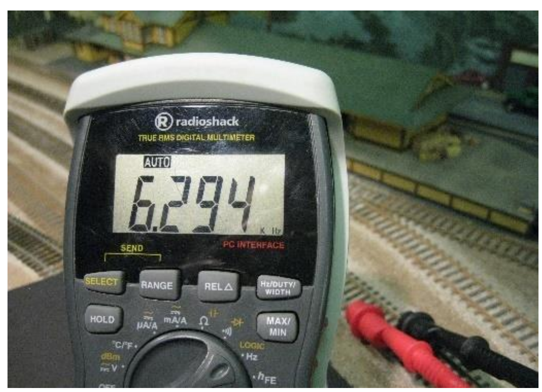
This is an older out of production multimeter (original selling price estimated at $75). It is NOT usable for reading DCC track voltage and is presented here as an example. It has True RMS AC measurement, but its frequency response is not high enough. The AC voltage frequency specification is 25 Hz to 1 kHz. It performed well within its specification but read extremely low at nominal DCC frequencies. This is an example where a meter reading exceptionally low probably has insufficient frequency response. See table below for test results.



Frequency	Displayed voltage with 20 Vpp Sine Wave. 7.07 Vrms is ideal.	Displayed voltage with 20 Vpp Square Wave. 10 Vrms is ideal.
60 Hz	7.07 Vrms	9.96 Vrms
400 Hz	7.07 Vrms	9.73 V rms
1 kHz	7.07 Vrms	9.32 Vrms
2 kHz	6.83 Vrms	8.71 Vrms
5 kHz	1.37 Vrms	1.75 Vrms
10 kHz	0.0126 Vrms	0.0126 Vrms

DCC track voltage at ~ 14 Vrms but meter showing only 369.2 mVrms.

This is useless for measuring DCC voltage.



DCC frequency at nominally a bit over 6 KHz. This is correct. It also illustrates that if a meter includes a frequency counter function, that range is NOT related to the upper frequency of its AC voltage measurements.

Fluke 115 True RMS Digital Multimeter

Quite a few blogs refer to a “Fluke meter.” But there are about 22 models and some variations on those. The 115 is True RMS but is not specified for a frequency above 1 kHz.

In January, 2022, Fluke’s Inside Sales Account Manager for the Pacific Coast answered my question, “What is least expensive Fluke True RMS meter that can measure 10 kHz square wave?” Here is the response:

> “The Fluke 115/117 series DMM will make that measurement without any trouble, but in the 10 kHz range there is no accuracy specification as shown in this image from the manual.”
>
> “The closest accuracy spec stops at 1 kHz and is ± 2% + 3 counts. I would not expect the accuracy to deviate substantially at 10 kHz but it is unspecified at that range.”

Testing showed this was NOT true and I include it here as an example that some (even somebody at Fluke) might incorrectly think it could measure DCC voltage. It will not. It is a superb meter otherwise, however.

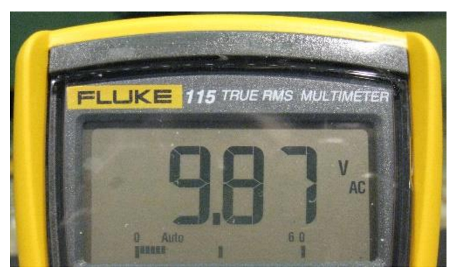
6.6 x 3.3 x 1.8 inches

Powered by 9 VDC battery

About $195 on Amazon.
Used ones on eBay for sometimes half that.

10 kHz 20 Vpp sine wave. 7.071 Vrms is ideal. Not usable at this frequency.

10 kHz 20 Vpp square wave. 10.000 Vrms is ideal. Not usable at this frequency.



~14Vrms DCC track voltage reads 9.87 Vrms. Reading far too low because frequency is too high for it.

Frequency reading of DCC track voltage in kHz.

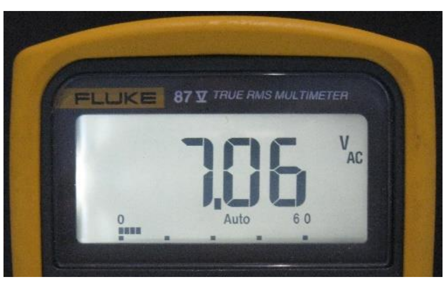
Fluke 87-V True RMS Digital Multimeter

The model 87-V is the lowest cost currently manufactured by Fluke that is True RMS with an AC bandwidth high enough for the DCC AC voltage. Its bandwidth is 20 kHz where many of the less expensive models (the 115 for example) are only 1 kHz.

7.4 x 3.4 x 1.3 inches

Powered by 9 VDC battery

About $420 on Amazon.
Used ones on eBay for sometimes half that.



10 kHz 20 Vpp sine wave.
7.071 Vrms is ideal.

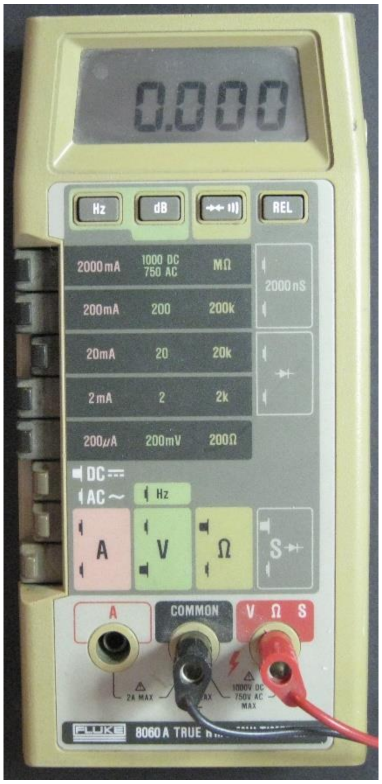
10 kHz 20 Vpp square wave.
10.000 Vrms is ideal.

~14 Vrms DCC track voltage reads 13.84 Vrms (This is within its accuracy specification which for the DCC frequency range is ± (2% + 20 counts). Assuming 14 Vrms is the truth, this specification allows a reading of 13.52 Vrms to 14.48 Vrms.

Frequency reading of DCC track voltage in kHz.

Fluke 8060A True RMS Digital Multimeter

This is an example of a very old, but very good, meter such as you might buy used. Fluke introduced it in 1982 and it was a dominant multimeter in industry for many years. It originally sold for $400 which is $1156 in 2022 dollars. The specification for AC voltage frequency is 20 Hz to 100 kHz with somewhat less accuracy specified for the higher end of that range. For the DCC frequency range it is 0.2% of reading +/- 20 counts of display. A quick test showed this old meter was still doing fine.



7.1 x 3.3 x 1.4 inches

Powered by 9 VDC battery

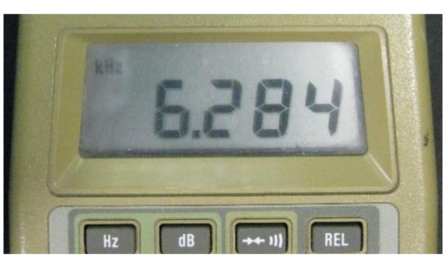
About $40 to $100 on the used market

Frequency	Displayed voltage with 20 Vpp Sine Wave. 7.071 Vrms is ideal.	Displayed voltage with 20 Vpp Square Wave. 10 Vrms is ideal.
60 Hz	7.076 V rms	10.016 V rms
1 kHz	7.086 V rms	10.031 V rms
10 kHz	7.092 V rms	10.015 V rms
100 kHz	7.145 V rms	9.967 V rms

10 kHz 20 Vpp sine wave.
7.071 Vrms is ideal.

10 kHz 20 Vpp square wave.
10.000 Vrms is ideal.

~14 Vrms DCC track
voltage reads 13.911 Vrms



Frequency reading of DCC
track voltage in kHz.

MPJA 35042 ME Talking Digital Multimeter

Yes, a talking multimeter. This MPJA multimeter (Marlin P. Jones & Assoc. Inc., purveyor of a lot of electronic stuff) was mentioned in the January 2022 NMRA Magazine "Tool Car" column. This is included to highlight this unusual feature, because this meter is not usable for reading DCC voltage.

A talking multimeter has a serious side. It can be useful to keep your eyes on the test probes to avoid slipping and making a short (especially if measuring high voltages.) Another current model is the ANENG Q60. Their Q60S (or Zoyi ZT-922s) also listens to voice commands. And there have been others in the past such as the Radio Shack Micronta 22-164 and the TOPHAND LK-10, but they both require pushing a button on one of the probes to make it say the reading. (The MPJA talks automatically.) Talking meters are also useful for the blind and the National Federation of the Blind stocked the TOPHAND LK-10 at one time.

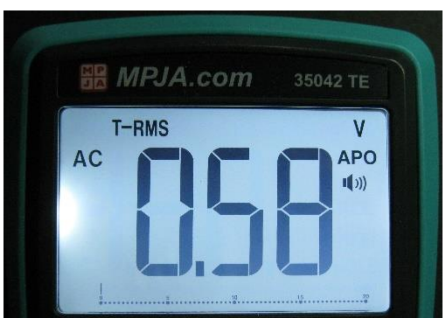
Of all the meters reviewed here, the MPJA was the most up front about AC volt frequency response. Their online description says, "Frequency Response: Sine/Triangle: 40Hz-1KHz, Other Waveform: 40Hz-200Hz".

Talking Multimeter

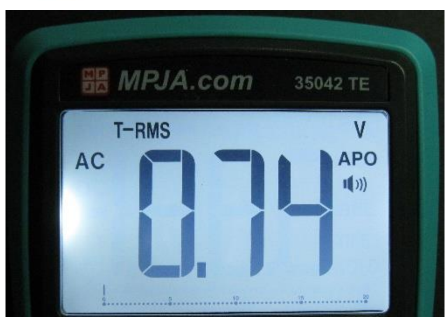
7.3 x 3.5 x 1.8 inches

Powered by 9 VDC battery

About $40 from MPJE Online

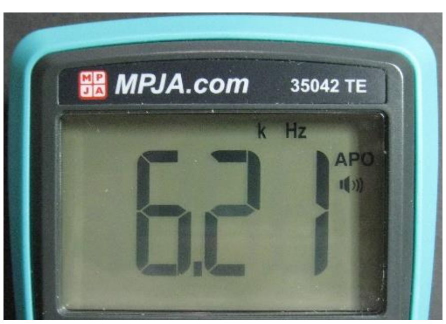


10 kHz 20 Vpp sine wave. 7.071 Vrms is ideal. Not usable at this frequency.



10 kHz 20 Vpp square wave. 10.000 Vrms is ideal. Not usable at this frequency.

~14 Vrms DCC track voltage reads 6.81 Vrms. Not usable.



Frequency reading of DCC track voltage in kHz.

DIGITAL STORAGE OSCILLOSCOPES

Unlike older analog oscilloscopes, these take samples (usually millions of samples per second or MSa/s) and then process that data to display a waveform and provide other information. Sampling rate is an important specification because the higher it is, the higher the frequency that can be shown. Many also provide a square wave signal output that can be used to test the oscilloscope and to adjust probe compensation.

Some of these use “BNC” connectors (large and rugged) and some use much smaller “MTS” RF connectors. You can buy various adaptors to connect one type to the other.

These oscilloscopes typically can also show data such as voltage, frequency, duty cycle, and more.

These models are all portable, handheld, and battery operated. Battery operation provides isolation from earth ground which is important for measuring DCC voltage. (Test equipment that plugs into an AC outlet typically does not have that isolation.)

Specifications for these oscilloscopes may tend to exaggerate usable bandwidth even for a sine wave. And the bandwidth for a square wave will be even lower.

DSO211 by SainSmart

The DSO211 (also DS211) is a 1 channel, 200 kHz (1 MSa/s rate) Mini-DSO (also sold under other names).

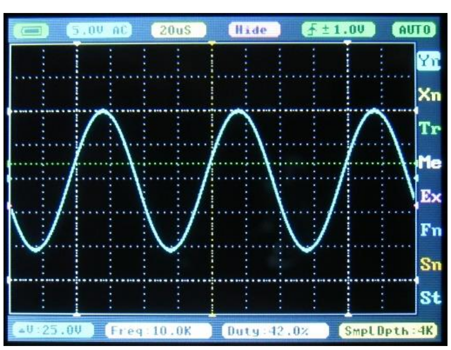
It has a great many menus and features, but a minimal number of controls to access them. It has four arrow buttons with a center “enter” button, plus two other buttons. It has a plastic case.

4.2 x 2.2 x 0.3 inches

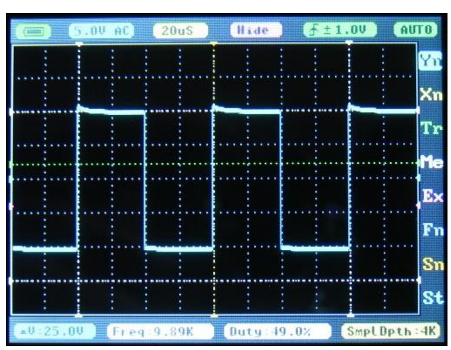
Rechargeable battery
(4 hours at 50% brightness)

Practical bandwidths: 75 kHz sine, 50 kHz square

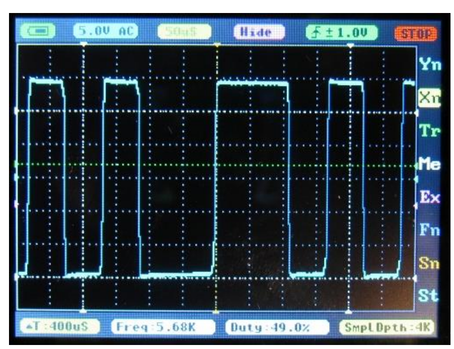
About $70



10 kHz 20 Vpp test sine wave. Time base grid seems wrong or notated wrong. Indicates 20 uS per division, should be 25 uS.



10 kHz 20 Vpp test square wave. Time base grid seems wrong or notated wrong. Indicates 20 uS per division, should be 25 us.



~14 Vrms DCC track voltage.

DSO212 by SainSmart

The DSO212 (also DS212) is a 2 channel, 1 MHz (10 MSa/s) Mini-DSO (also sold under other names).

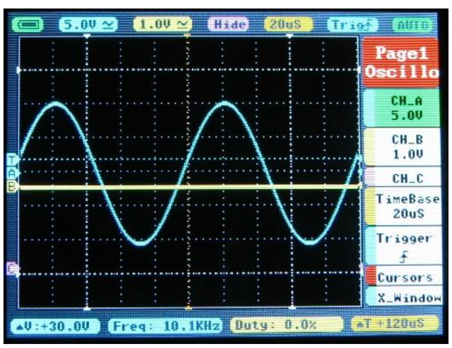
It has a great many menus and features, and a small number of controls to access them. It has two rotary encoder dials that are also push buttons for selecting menus and navigating within them plus a couple of other buttons. It has an aluminum case.

4.9 x 2.3 x 0.3 inches

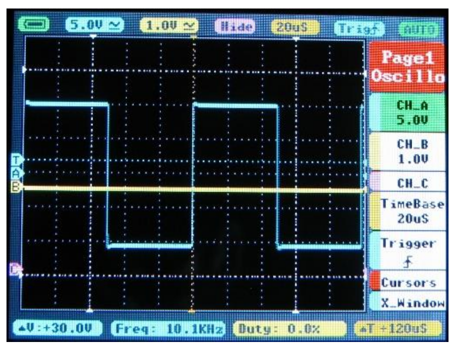
Rechargeable battery
(3 hours at 50% brightness)

Practical bandwidths: 200 kHz sine, 100 kHz square

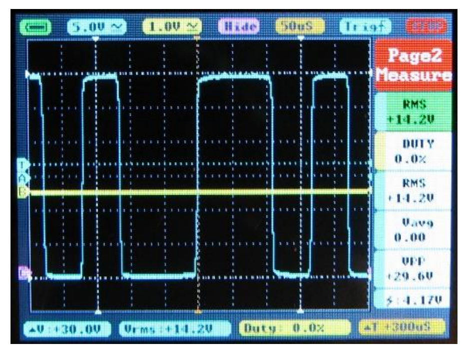
About $110



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



~14 Vrms DCC track voltage.

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DSO213 by SainSmart

The DSO213 (also DS213) is a 4 channel, 15 MHz (100 MSa/s) Mini-DSO (also sold under other names). The four channels are two analog and two digital. This means two of the channels can display varying voltages conventionally. And the other two channels only show if a voltage is on or off.

It has a great many menus and features, and a small number of controls to access them. It has two spring loaded left/right switches for navigating menus and they also press downward as push buttons. And there are a few additional buttons. It has an aluminum case.

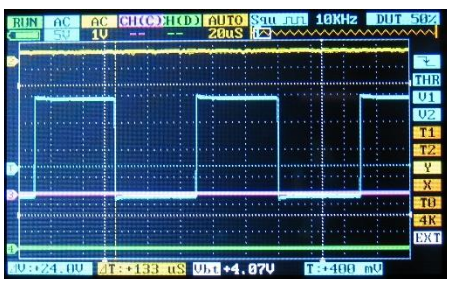
3.9 x 2.3 x 0.5 inches

Rechargeable battery
(4 hours at 50% brightness)

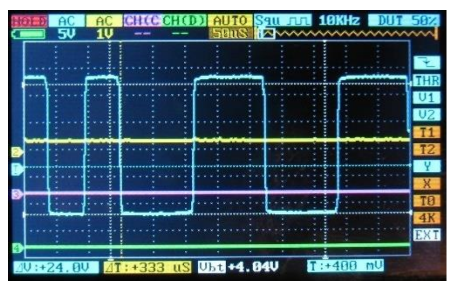
Practical bandwidths: 6 MHz sine, 1 MHz square

About $230

10 kHz 20 Vpp test sine wave. Waveform height displaying slightly low.



10 kHz 20 Vpp test square wave. Waveform height displaying slightly low.



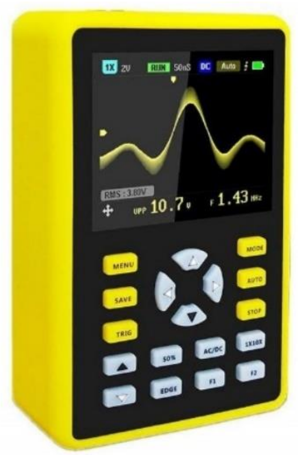
~14 Vrms DCC track voltage.

ADS5012H by Yeapook

The ADS5012H is a 1 channel, 100 MHz (500 MSa/s) Mini-DSO by Yeapook (and also sold under other names). It is a bit larger than the other "Mini" scopes. It has an unusually high sample rate and bandwidth for this class and price. It's slightly larger size, especially depth, allows it to have a larger battery and a long operating time. It has a BNC connector (large and robust) instead of the small "MTS" RF connectors used on many of these small oscilloscopes.

It is notably different from most other Mini-DSO's which have few controls and many menus. Instead, it has few menus and many buttons to make changes more directly. And the buttons are for the most commonly used features. So, you don't have to do a lot moving through menus with the cursor buttons like most other small scopes. It has a plastic case and a thin rubberized wrapper to make it easier to grip.

As a point of amusement, it came with a case with the printed slogan, "A hardy tool make a hardman." On the Amazon page the slogan was "A Handy Tool Makes a Handyman."

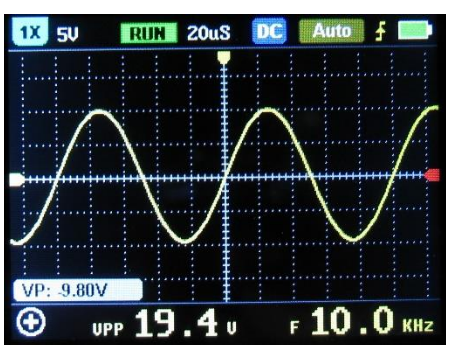


4.5 x 3.0 x 1.3 inches

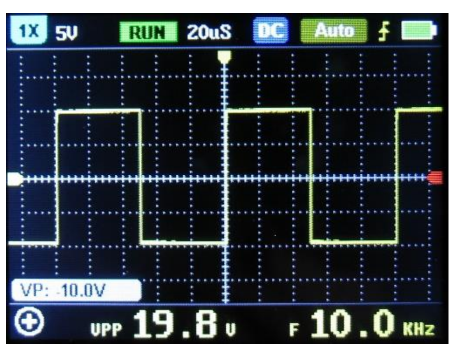
Rechargeable battery
(14 hours at 50% brightness)

Practical bandwidths: 25 MHz sine, 25 kHz square

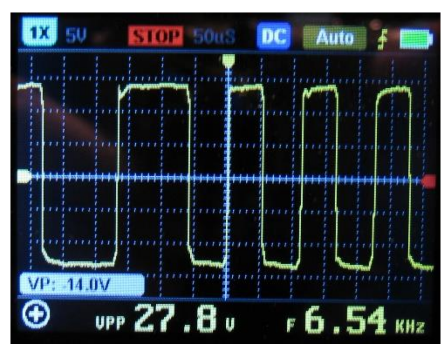
About $90



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



~14 Vrms DCC track voltage.

DSO112A by WisTek

The DSO112A is a 1 channel, 2 MHz (5 MSa/s) Mini-DSO by WisTek (and also sold under other names such as JYTech). The 2 MHz claim seems to be especially exaggerated on this one. At 2 MHz a sine wave has noticeably different heights for alternate cycles. But it is adequate for the DCC voltage.

This is different from the others because you operate it with a touch screen. The only physical control is one push button used to turn it off and on, and if on, to start or stop the trace. There is also a battery disconnect switch hidden behind a tiny slot near where you connect the battery charging cord. The screen shows the waveform or shows various menus. If you tap “menu” you get a main menu. If you tap some other item, you get a menu related to that item. Y position is by vertically swiping anywhere on the left half of the screen, trigger level by vertically swiping on the right half. X position is by swiping horizontally anywhere.

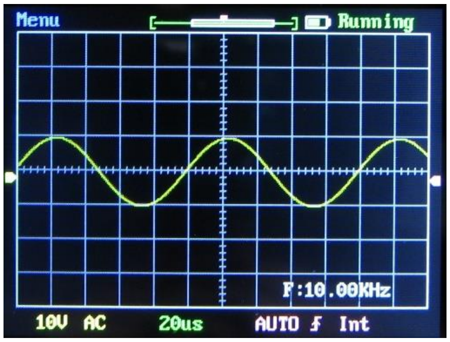
The particular scope tested read double what it should on the 5 V/div and 50mV/div ranges. A search online found that some others had the same experience believing it was likely a wrong resistor value installed somewhere. And the lowest handful of ranges read about 20% high. There may be a software calibration means but did not find one. The test results below use the 10V/div vertical range instead of the more desirable 5V/div range which could not be used.

3.1 x 2.8 x 0.7 inches

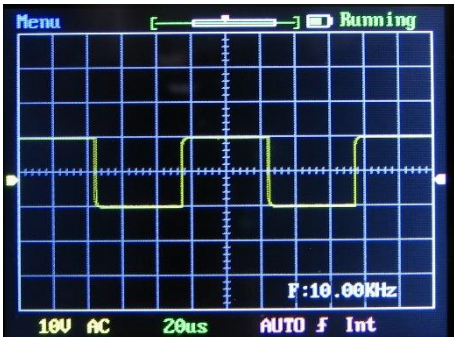
Rechargeable battery
(5 hours at 50% brightness)

Practical bandwidths: 500 kHz sine, 100 kHz square

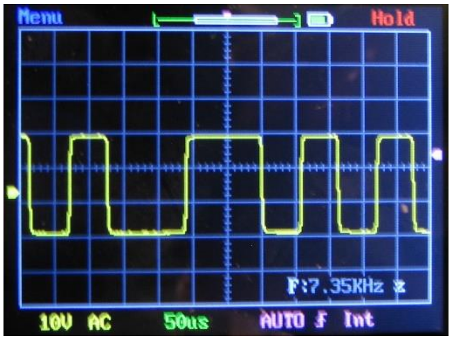
About $70



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



~14 Vrms DCC track voltage.

LOW-COST DIGITAL STORAGE OSCILLOSCOPE KITS

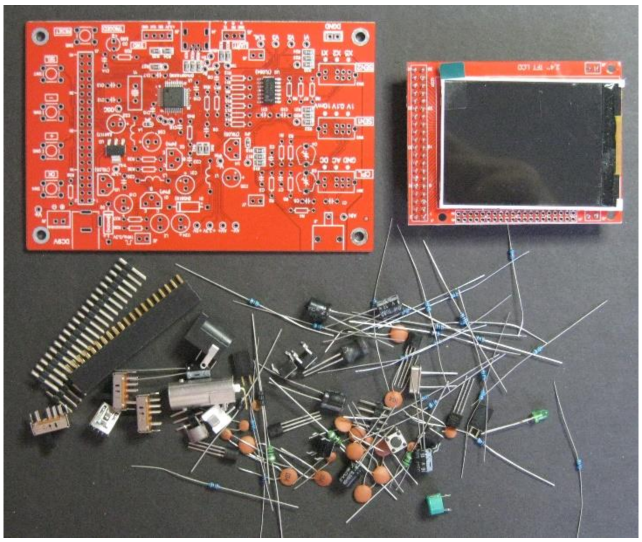
If you REALLY want to spend the minimum there are mini-scope kits. Some electronics experience, especially soldering, is helpful. They are sold under various names but JYTech seems to be the manufacturer.

These do not have menus, just basic functions. Some functions are accessed by having selected some item and then pressing the OK button for 2 seconds. You must read the operating instructions to know the little secrets. The vertical sensitivity is via slide switches, and you change the time base via "+" and "-" buttons. It remembers time base with power off, so these should power on and display with previous settings. This may be useful if you want a permanent fascia mounted display. Instructions are surprisingly good and well-illustrated but have some differences with the reality and some omissions. Optional "enclosures" are available which are cobbled together pieces of clear acrylic.

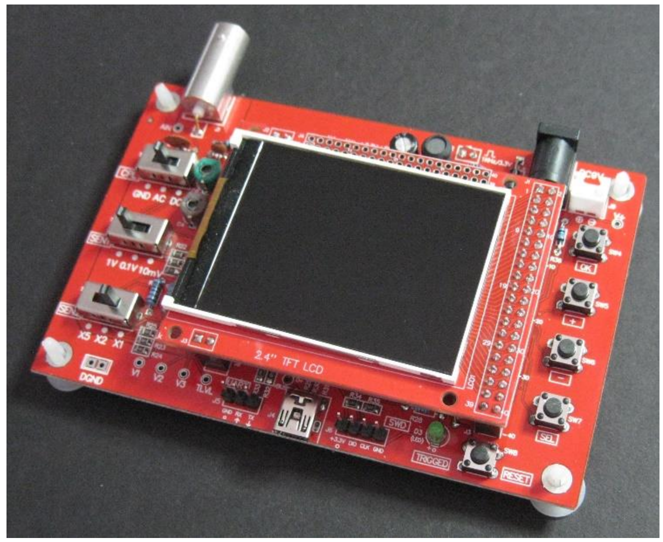
TIP: Increase the values of R6, R7, and R8 (a voltage divider that can excessively load the preceding amplifier) by ten times to prevent some raggedness on the display waveform with a high input signal. Applies to the regular or "Mini" version of the DSO138.

DSO138 Oscilloscope

This is 200 kHz with 1 MSa/s sampling rate. It has a BNC probe connector and a test waveform output.



PARTS They stuck the display on crooked.
(Did not want to risk prying it loose to straighten.)



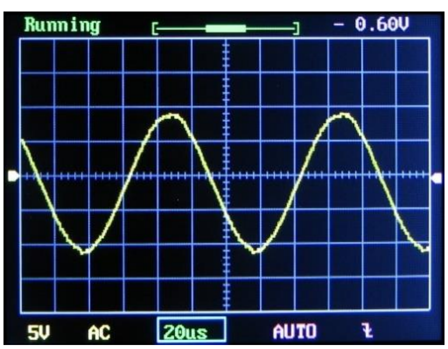
ASSEMBLED (took about 5 hours).

4.6 x 3.0 x 0.7 inches

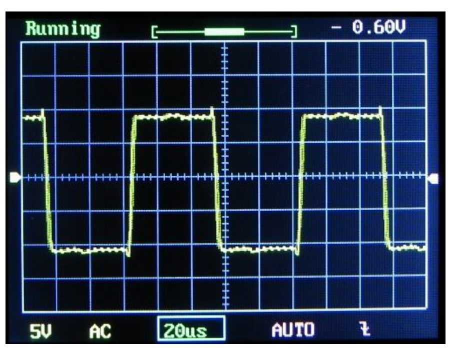
No power source. You must supply separate 9 VDC supply or 9 VDC battery

Practical bandwidths: 100 kHz sine, 30 kHz square

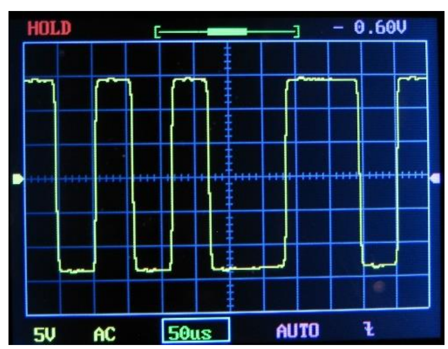
About $27



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



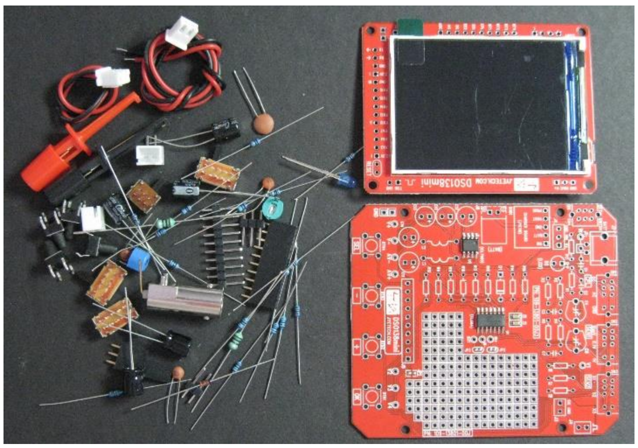
~14 Vrms DCC track voltage.

DSO138 “Mini Version” Oscilloscope

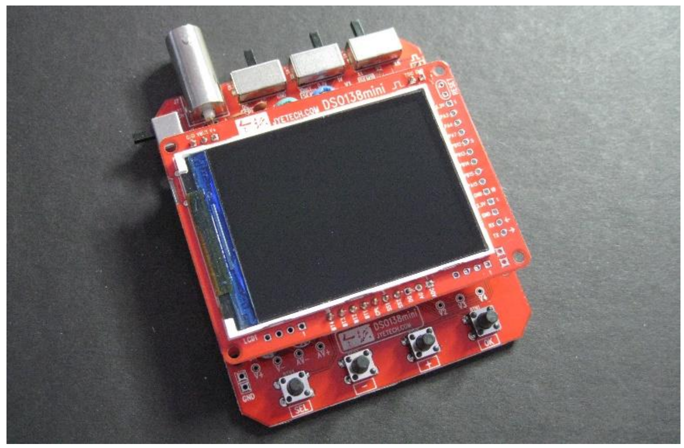
This kit assembles into an even smaller version than the regular DSO138. Also claimed as 200 kHz with 1 MSa/s sampling rate. The input connector can be either a simple 2-pin or a BNC connector (both were included). The instruction sheet had some mismatches, and omissions, with reality. It said to short certain jumpers, but they already had zero ohm resistors installed. They said one jumper was pre-shorted, but it was still open (and prevented it from working until shorted). The instructions do not discuss how to use the battery input, and the need to short at least one other jumper for that. Knowing at least some electronics can be helpful with such a kit.

Plenty of supporting documentation can be found online for these DSO138 oscilloscopes.

Optional “enclosures” are available which are cobbled together pieces of clear acrylic.



PARTS



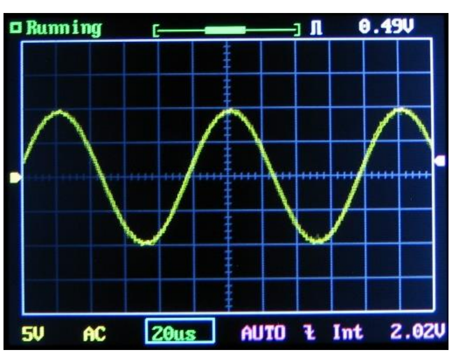
ASSEMBLED (took about 3.5 hours). BNC connector installed.

3.5 x 2.8 x 0.6 inches

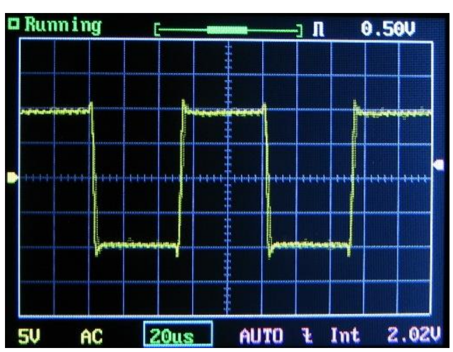
No power source. You must supply USB voltage or 3.7 VDC lithium battery yourself.

Practical bandwidths: 100 kHz sine, 30 kHz square

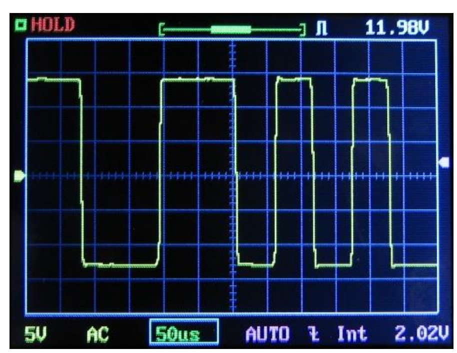
About $22



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



~14 Vrms DCC track voltage.

OSCILLOSCOPE MULTIMETER COMBINATIONS

These are “2 in 1” instruments providing both an oscilloscope and a multimeter. Since a square wave is being measured, it is best if it can read “True RMS.” But not everything that claims “True RMS” performs accurately for all wave shapes.

There are many offerings. Hantek and OWON are two that seem prominent and Liumy has a somewhat lesser model. Some versions also have a waveform generator making them a “3 in 1” and there are also choices for the bandwidth where more bandwidth costs a little more.

HANTEK 2C42 Oscilloscope - Multimeter

This is a 2 channel 40 MHz (250 MSa/s if using single channel, 125 MSa/s if using dual channel) oscilloscope and a digital multimeter. Oscilloscope BNC jacks are on the top and multimeter banana jacks on the front. This does NOT read “True RMS” and the AC voltage frequency is rated for only 40 to 400 Hz. But it worked pretty well up to 10 kHz.

7.8 x 3.9 x 1.6 inches

Rechargeable batteries
Two replaceable 18650 type
(15 hours at 50% brightness)

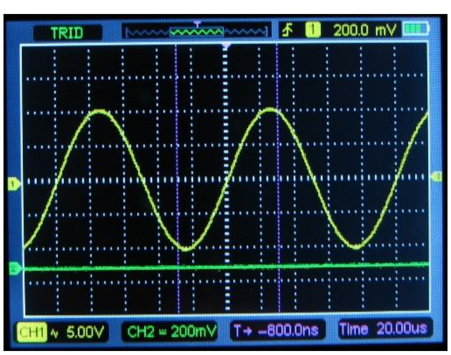
Practical bandwidths: 40 MHz sine, 2 MHz square

About $126

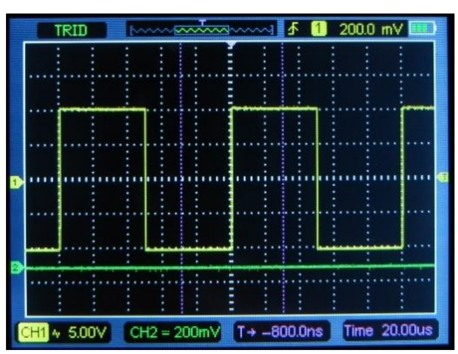
10 kHz 20 Vpp test sine wave.
7.07 Vrms is ideal.

10 kHz 20 Vpp test square wave.
10.000 Vrms is ideal.

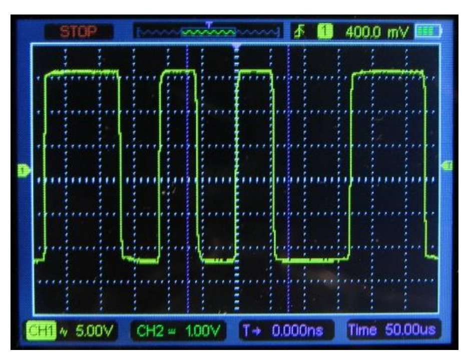
~14 Vrms DCC track voltage.



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



~14V DCC track voltage.

LIUMY LM 2020 Oscilloscope - Multimeter

The Liumy LM2020 (also sold under other names) is 1 MHz (at 2.5 MSa/s) claimed for the scope function. For DCC voltage range and frequency the accuracy specification is ± (5.0%rdg + 10dgt).

6.2 x 3.2 x 1.2 inches

Powered by three AA batteries

Practical bandwidths - oscilloscope: 250 kHz sine, 50 kHz square

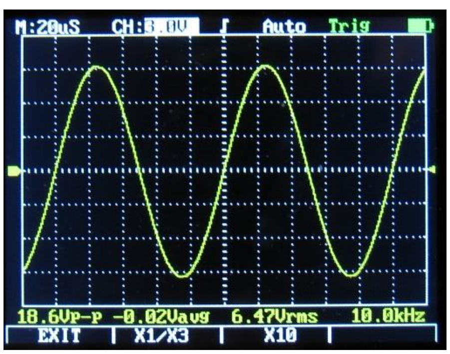
About $100

The RMS is correct ONLY for sine waves. At 10 kHz, sine wave reading is fairly accurate, square too high (indicating it is merely taking the average voltage of the waveform and scaling it). Also, the sine wave had a nearly perfect reading at 1 kHz, so the readings are further lower overall at 10 kHz. Uses test lead inputs for oscilloscope reading instead of a shielded connector type. Voltages indicated on oscilloscope display not particularly accurate and change with different vertical ranges.

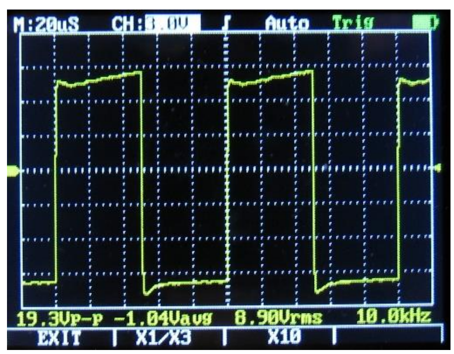
10 kHz 20 Vpp test sine wave. 7.071 V is ideal.

10 kHz 20 Vpp test square wave. 10V is ideal.

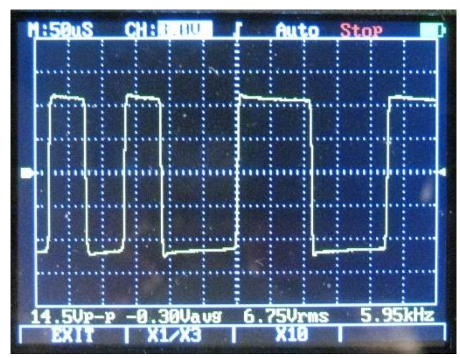
~14 Vrms DCC track voltage.



10 kHz 20 Vpp sine wave.

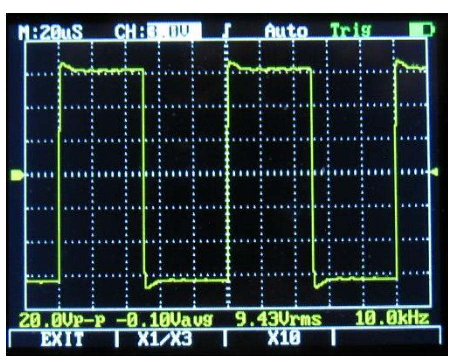


10 kHz 20 Vpp square wave with meter test leads.



~14 Vrms DCC track voltage.

The LM2020 does not have a shielded jack for oscilloscope readings and just uses the meter lead inputs. The square wave (above middle) is with meter leads and is quite distorted from lead capacitance. The one to the right is with a banana to BNC adapter and BNC cable and is less distorted.



10 kHz 20 Vpp square wave with banana to BNC adapter.

DCC track voltage frequency.

OWON HDS1021M-N Oscilloscope - Multimeter

The OWON HDS1021M-N is a 20 MHz (100 MSa/s) single channel Oscilloscope-Meter. (They have others in the same format with 2 channels and higher frequency ranges.) The scope probe connection is a BNC connector on the side.

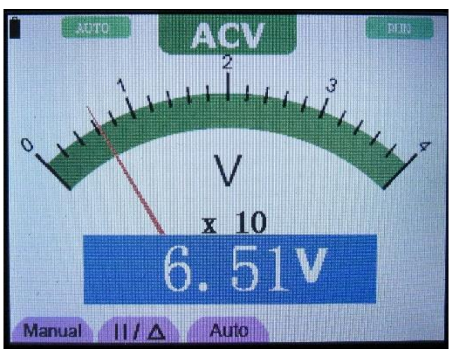
The meter function emulates a needle meter format as well as numeric display. AC frequency specification is 40 Hz to 400 Hz. But, like some others, will operate usably far above that albeit with some error. Also, at 60 Hz a 20 Vpp sine wave displayed 7.08 Vrms which is nearly the perfect 7.07 Vrms. A 60 Hz square wave displayed 11.2 Vrms instead of the correct 10 Vrms. This is a sure sign that is it NOT True RMS and instead is averaging the waveform and using the scaling factor for a sine wave. In such meters, square waves read about 11% too high. But AC frequency range for the meter is only 40 to 400 Hz so it would be expected that readings would be lowered at higher frequencies. At the DCC frequency, it seems the frequency limitation is just about cancelling out the 11% high reading producing, by luck, a fairly reasonable result.

7.1 x 4.5 x 1.6 inches

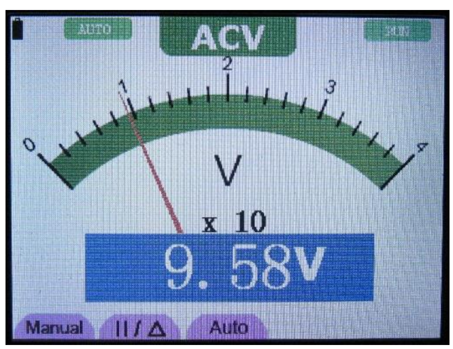
Rechargeable battery
6 hours at 50% brightness

Practical bandwidths - oscilloscope: 40 MHz sine,
5 MHz square

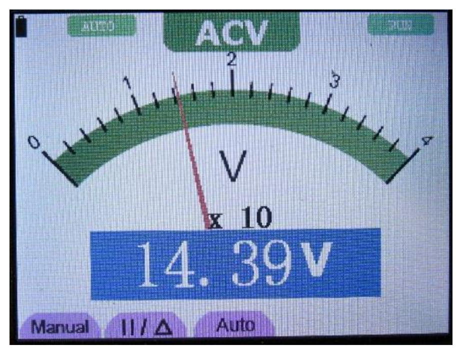
About $219



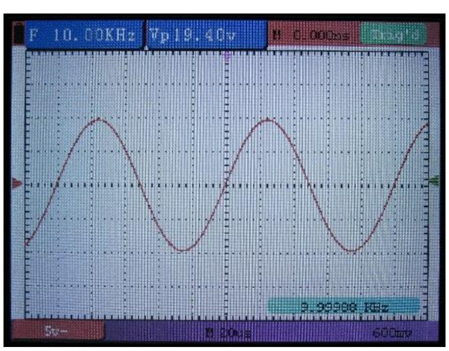
10 kHz 20 Vpp test sine wave.
7.07 Vrms is ideal.



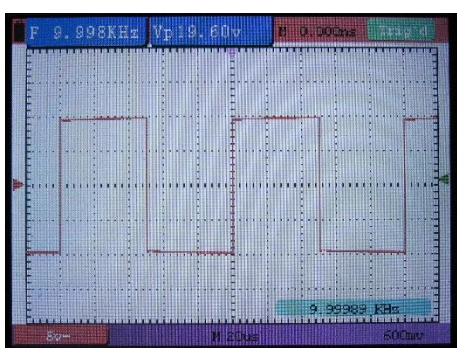
10 kHz 20 Vpp test square wave.
10.000 Vrms is ideal.



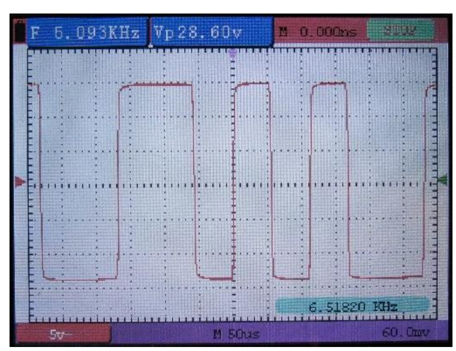
~14 Vrms DCC track voltage
reads 14.39 Vrms.



10 kHz 20 Vpp test sine wave.



10 kHz 20 Vpp test square wave.



~14 Vrms DCC track voltage.

TABLET OSCILLOSCOPES

None were tested. This information presented merely to let you know this is another option.

These are like a larger version of the mini-oscilloscopes. And like them, the same model may be offered under different names. Besides the obviously larger screen, on average they generally also have better performance specifications. And they also have the advantage of being battery powered and very portable. Costs range from about $150 to $800.

Yeapook ADS1013D Digital Tablet Oscilloscope, 100 MHz, 1 GSa/a sampling rate, 2 channels. 7.3 x 4.9 x 2.0 inches. About $150.

Micsig TO1104 Digital Tablet Oscilloscope, 100 MHz, 1 GSa/s sampling rate, 4 channels. 9.9 x 7.9 x 2.2 inches. About $570.

USB OSCILLOSCOPES

None were tested. This information presented merely to let you know this is another option.

This is a small device that uses your computer (usually a laptop) for the display and operator controls. The idea is to provide good performance at lower cost by using your computer as the user interface and power supply. This is “battery powered” (by the computer) so long as your computer is not plugged in to AC power. (You do not want the oscilloscope probe ground referenced to AC ground for DCC measurement.) Cost ranges from about $65 to $330.

While these have a good cost to performance ratio, they are the least handy for working around a model railroad because you need the device, computer, cable to connect them, and the probe cable to connect to track. That’s a lot of clutter. Also, you must install software on your computer which is another step just to get started.

LOTO OCS482 Digital USB Oscilloscope, 20 MHz, 50 MSa/a sampling rate, 2 channels. 6.0 x 3.7 x 0.9 inches. About $65.

OWON VDS1022I Digital USB Oscilloscope, 25 MHz, 100 MSa/s sampling rate, 2 channels. This has isolation for the USB port so it probably could be used with a computer plugged into the wall and still be isolated. 6.7 x 4.7 x 0.7 inches. About $120.

PicoScope 2204A Digital USB Oscilloscope, 10 MHz, 1 GSa/s sampling rate, 2 channels. 5.6 x 3.6 x 0.7 inches. This also has “serial decode” feature and has the DCC protocol built into their software. (Some other scopes also have serial decode, but typically only for industry standard protocols.) About $150.

Hantek 6254BD Digital USB Oscilloscope, 250 MHz, 1 GSa/a sampling rate, 4 channels. 6.9 x 4.1 x 1.0 inches. About $330.

At left: Compocket Minis Digital mini USB Oscilloscope, 2 MHz, 10 MSa/s sampling rate, 2 channels. Works with smart phones or computers and they provide “an app for that.” Phone shown NOT included. It is the little red square brick in front of the phone. 2.8 x 2.8 x 1.7 inches. About $150.

BENCHTOP OSCILLOSCOPES

None were tested. This information presented merely to let you know this is another option.

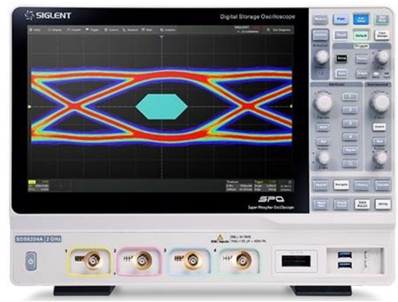
Benchtop (or “laboratory”) oscilloscopes are what you might find on the work bench of an electronic technician, engineer, or enthusiast. They are AC powered and not generally used as portables. However, they are fairly small and easy to carry someplace to set up. There is vast range of features and prices. Usually, if you move up just a few steps above the minimum model, you get considerably more with very little more cost.

Shown here are only a very few models of dozens of models offered by three manufacturers and there are many more manufacturers. Many that are more than enough for DCC work are under $500. But just for fun, a few VERY top of the line models are shown just so you can see what very high performance can cost.

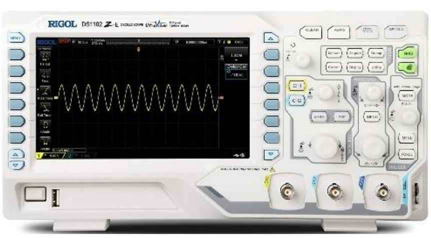
Also, you do not want the oscilloscope probe ground referenced to AC ground for DCC measurement. So, you need to power the oscilloscope with an isolation transformer, or use an isolated or differential probe, or feed two channels of an oscilloscope where you can add the channels (while not connecting any probe grounds).

Siglent 1052DL+, 50 MHz, 500 MSa/s, 2 channels. Lowest model in their lineup. About $259.

Siglent SDS1202X-E, 200 MHz, 1 GSa/s, 2 channels. Example of a lot more performance for a little more cost. About $359.



Siglent SDS6204A, 2 GHz, 5 GSa/s, 4 channels. Top model in their lineup. About $9,990.



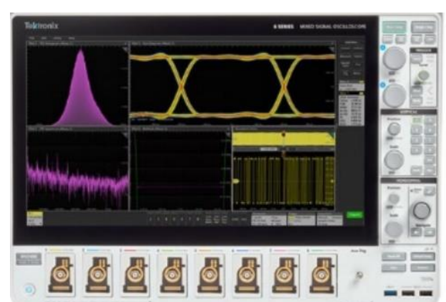
Rigol DS1102Z, 100 MHz, 1 GSa/s, 2 channels. Lowest model in their lineup. About $249.

Rigol DS1202Z-E, 200 MHz, 1 GSa/s, 2 channels. Example of a lot more performance for a little more cost. About $299.

Rigol MSO8204, 2 GHz, 10 GSa/s, 4 channels. Top model in their lineup. About $9,999.

Tektronix TBS1052C, 50 MHz, 1 GSa/s, 2 channels. Lowest model in their lineup. About $504. (Accessories, like probes, extra.)

Tektronix TBS1202C, 200 MHz, 1 GSa/s, 2 channels. About $1870. (Accessories, like probes, extra.)



Tektronix MSO68B, 10 GHz, 50 GSa/s, 8 channels. Top model in their lineup. About $46,900 (base price, no options).

ESR METER – USEFUL FOR FINDING SHORT CIRCUITS

This is not something for reading a DCC voltage, but useful for finding the location of a short circuit. It is an "ESR" meter, and this is a model MESR-100 by Signstek (and also sold under other names.)

5.7 x 3.1 x 1.2 inches

Powered by two AA batteries

About $70

NOTE: Higher resolution is not the same thing as higher accuracy.

However, higher resolution will make it easier to see small relative changes in readings.

"ESR" is related to measuring capacitors and means "Equivalent Series Resistance." But we don't care about this in relation to a capacitor. Instead, we care about its sensitive ohmmeter capability. It can read to 0.001 Ω resolution or THOUSANDTHS of an ohm.

Track rails and wiring all have resistance. Not much resistance, but some. You can try to read this with a regular multimeter, but the typical 0.1 Ω resolution is too low to reliably read subtle differences. Some better multimeters, like the Fluke 87V in "high resolution" mode or the OWON B41T+ can read to 0.01 Ω resolution which might be adequate, but 0.001 Ω resolution is even better for finding shorts.

You take resistance readings up and down the track (power MUST be disconnected) to locate where the lowest resistance is. And that is where the short will be. Or if the lowest resistance isn't very low, you know you are getting closer to the short which may be at the other end of some wiring.

This shows the capability by reading the resistance of a short test lead with alligator clips at each end. It reads 0.453 ohms and not "zero." That is because there is the resistance of the test lead wire and possible resistance in connecting to ESR meter test lead alligator clips. The ESR meter's test leads and connections to the meter don't apply because those were "zeroed out" before taking the reading.

(continued on next page)

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Example 1: An obvious short has been placed on the track. A quarter was placed on the track to make a "short," but it didn't make good enough contact just under its own weight for an extremely low resistance short. So, a large steel weight was placed on the quarter to hold it tight to the rails so the "short" would be close to zero ohms. A series of resistance readings were taken between the rails up and down the track.

0.333 ohms a couple of feet to the left of the short.

0.040 ohms about 6 inches to the left of the short.

0.020 ohms a couple of inches to the left of the short.

These lowest resistance measurements indicate the short is in this area. Which is obvious in this example with the heavy weight resting on a quarter.

0.040 ohms a couple of inches to the right of the short.

1.126 ohms about a foot to the right of the short.

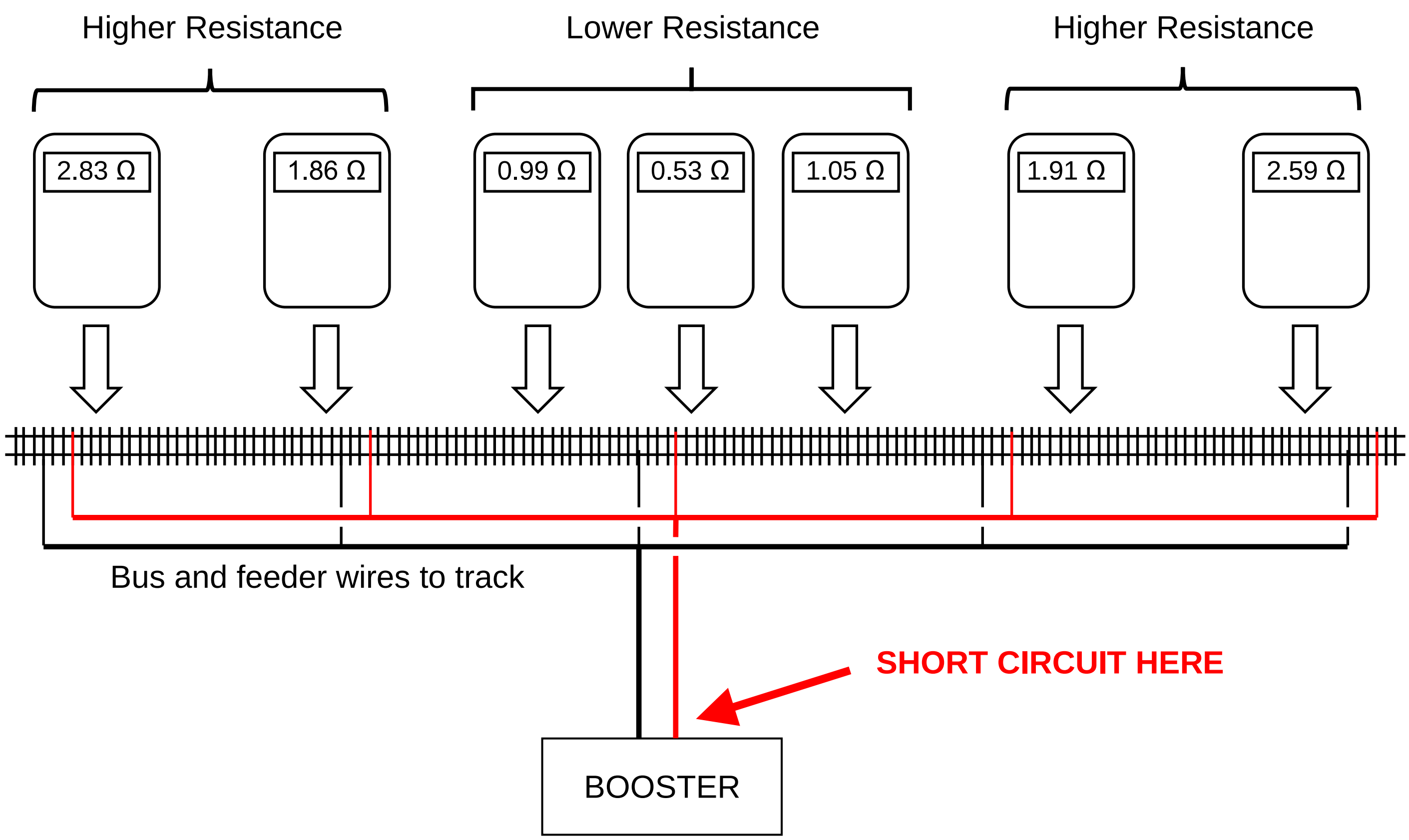
1.67 ohms several feet to the right of the short.

(continued on next page)

Example 2: One power block on the Central Coast Model Railroad at the San Luis Obispo Railroad Museum seemed to be shorted. A test similar to the above was done. However, it did not find a track short. But it did find a point of lowest resistance which was about 0.5 ohm. This suggests that if there is a short, it is still some distance away, but not via the track.

That point on the track was a place with track feeders soldered to the rails. The assumption was made that the short would be at the other end of the track feed wiring. The resistance being measured was the resistance of those lengths of hookup wire from the power source to the track. The short was at the other end of those wires. It turned out that an error was made in some temporary re-wiring and a short existed where the wires were connected at the power booster. (And as a troubleshooting hint: Also, be suspect of the last thing that was worked on, tampered with, installed, or touched.)

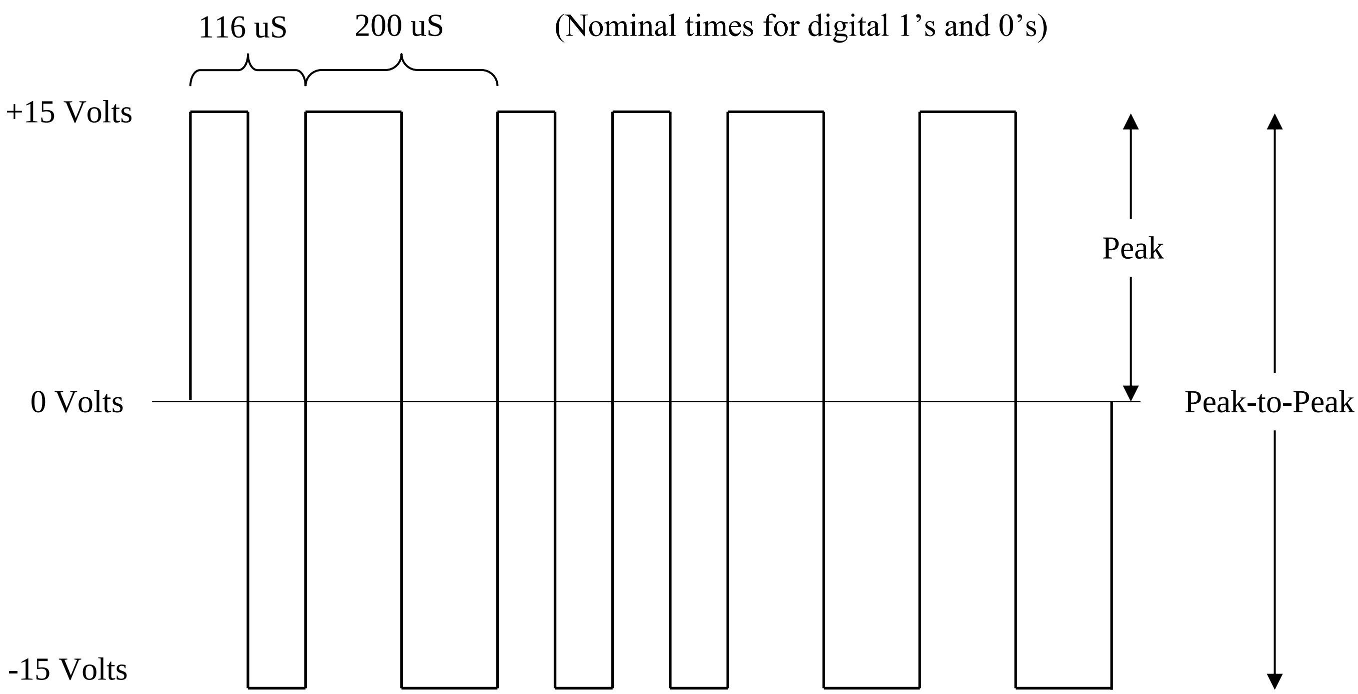
Using the ESR meter, this problem was located in just a minute or two.



APPENDIX A: WHAT IS THE DCC VOLTAGE WAVEFORM?

The National Model Railroad Association (NMRA) defines the DCC track voltage in Standard S-9.1 "Electrical Standards for Digital Command Control" as an alternating current that provides both power AND data. A table in the standard shows nominally 15 Volts for HO, S, and O scales, 12 Volts for N scale, and 18 Volts for large scale. A graph there seems to show 14.5 volts for HO, S, and O. This doesn't matter because a wide tolerance is also specified. An actual application could certainly be different, such as 14.0 Volts (for HO, S, and O).

There are various ways to denote AC voltage: Peak (Vp), Peak-to-Peak (Vpp), RMS (Vrms), and average (Vav). We can ignore the average since it will be the same as peak. A numerical average would be 0 Vav of course. But in the context of AC voltage as a source of power, we ignore the sign of the voltage and only care about the absolute value of each half cycle.



So, the nominal DCC waveform (for HO/S/O) is:

30 Vpp
15 Vp
15 Vrms (The square wave is a special case where Vrms is the same as Vp.)
(Appendix D discusses RMS and "True RMS" voltages if you want to know more.)

The frequency is not constant because the square wave has varying widths representing 1's and 0's. Theoretically, if they were all 1's, the frequency would be 8.621 kHz or 8,621 cycles per second (Hz is for Hertz which means cycle. kHz or kilo Hertz is thousands of cycles.) If all 0's, the frequency would be 5 kHz. But since there is mixture of 1's and 0's, average frequency varies. It might typically average 6 to 7 kHz.

This is a rather low frequency as it is in the audio range. But it is still too high for many multimeters. And being a square wave, it has fast "rise and fall" times and high frequency harmonics.

But all we need to keep in mind is that it is a square wave with varying widths and is nominally 15 Vrms (or Vp) and a bit under 10 kHz on average.

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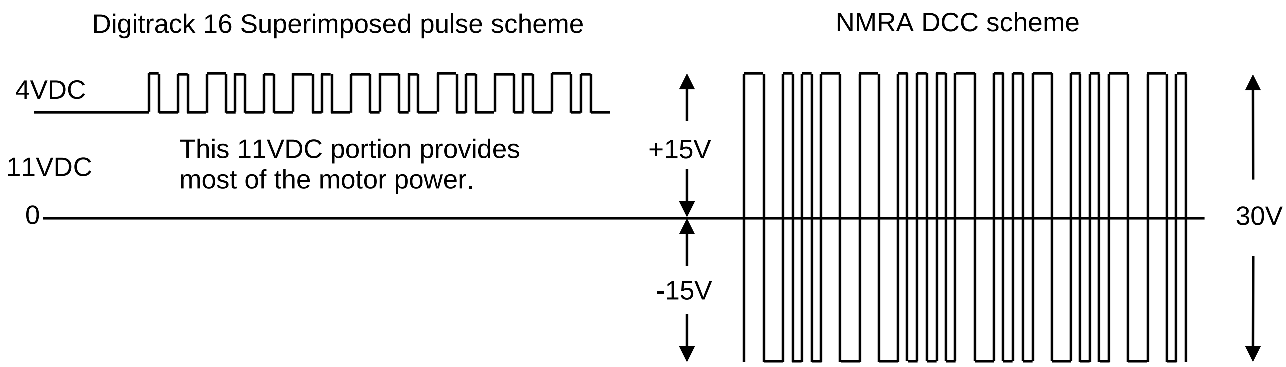
The DCC waveform is quite resistant to interference by design. This is because it is a relatively huge voltage level compared to any likely level of interference from elsewhere.

As a little background, there was an earlier approach called the Digitrack 16 in the early 1970's (the design later presented as the CTC-16 in a Model Railroader article). It superimposed a 4-volt pulsed DC voltage onto an 11 VDC voltage putting the peak at 15 volts. The pulses were not digital data, but a pulse for each channel where its width denoted direction and speed. The 4-volt high pulses worked pretty reliably.

For DCC, NMRA specified that the entire power waveform also act as the signal so it is a whopping 30 volts peak-to-peak and usually pretty near that in actual applications. The diagram below compares the two schemes.



Where does interference come from – and more details

Capacitive coupling is the transfer of an alternating electrical signal due to capacitance. A capacitor is merely conductive items separated by a dielectric (an insulator). Wires separated by their insulation and by air inherently have capacitance. The wires are conductive and the insulation and air between them are the dielectric. Now, this usually isn't very much capacitance, but it is some. And the higher the frequency, the more that can be coupled.

Electromagnetic coupling is based on one of the most fundamental aspects of electricity. That an electric current in a conductor creates a magnetic field and a changing current creates a changing magnetic field. And a changing magnetic field causes a changing current in a conductor. This is how transformers and motors and much more work. Current in one item can interfere with something else by inducing current in it.

Direct injection means a signal is directly connected to a circuit. One such path can be the AC power wiring in a building. Something could put noise on that line, and it could then be seen by other equipment connected to that same AC power circuit.

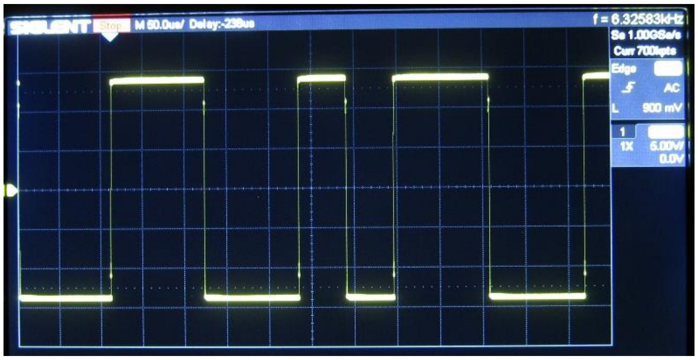
Reflections are another nuance from "transmission line theory" since the power bus is acting as a transmission line. This is probably seldom an issue in DCC. It is a complicated topic, but the solution, should one be needed, is a simple resistor-capacitor circuit called a "snubber" at the end of the line. Some think this is important and some manufacturers suggest it.

Rejection is in the NMRA standard and is a good thing. It says decoders must reject frequencies above 100 kHz. So even if the big antenna of the rails and wiring picks up some interference like your local golden oldies AM radio station, most should be ignored (electrically "filtered out") by the decoder anyway.

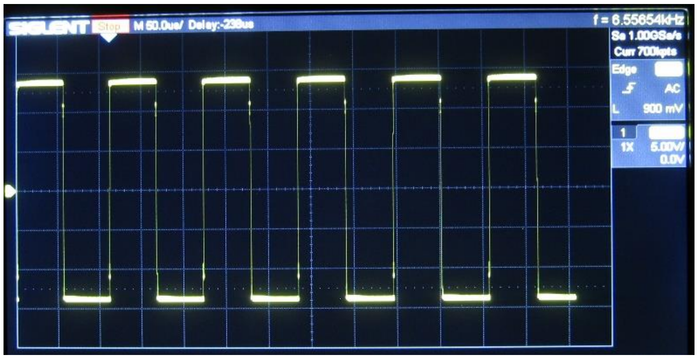
What about signals other than track voltage: There can be other signals involved in a DCC system such as the vastly higher frequencies on data lines (in the 2.4 GHz range using those "RJ" style plugs and jacks) and then there are radio throttles if you are using those. These things have the same susceptibility to interference issues as any similar equipment. Interference can be from something as mundane as a garage door opener.

APPENDIX B: WHAT DOES THE DCC WAVEFORM LOOK LIKE?

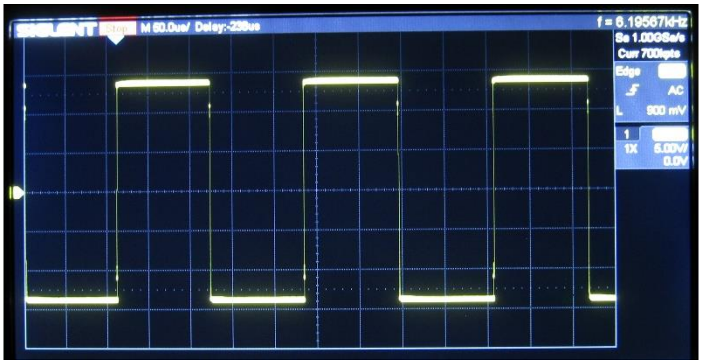
The following are screen shots from a 200 MHz bandwidth digital storage oscilloscope. All but the last one are the output of a Digitrax DCS52 Zephyr Express. This is not a tutorial that includes oscilloscope terminology. It assumes you know the basic terms such as vertical sensitivity, time base, and triggering modes.



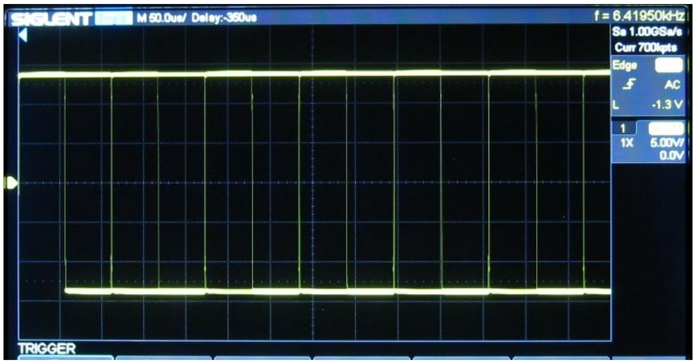
Single trace happening to catch 0's and 1's.



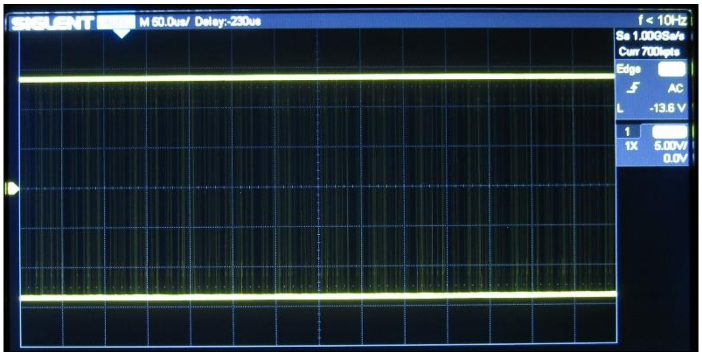
Single trace happening to catch all 1's.



Single trace happening to catch all 0's.

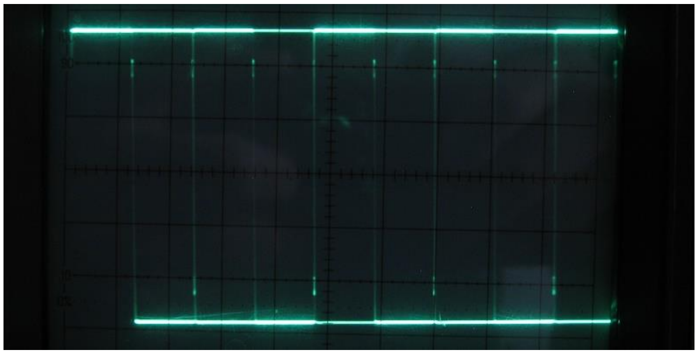


With a good trigger in AUTO or NORM, you are going to see 1's and 0's on top of each other.



This is with the AUTO trigger mode but no trigger. So, the traces start randomly. You see all those faint rising and falling waveform edges occurring randomly all across the screen.

One other possibility is a blank screen. This is if the trigger mode is NORM or SINGLE and there is no trigger, or perhaps the voltage is disconnected.



Here is the expected appearance with good triggering in AUTO on an analog oscilloscope (A Hitachi V-212 where there is no means to capture a single trace.) As in the DSO image above, note that initially no bottom edge shows because after triggering, the waveform will not go low for at least 58 uS. After that, the different 1's and 0's widths will cause overwriting on each other.

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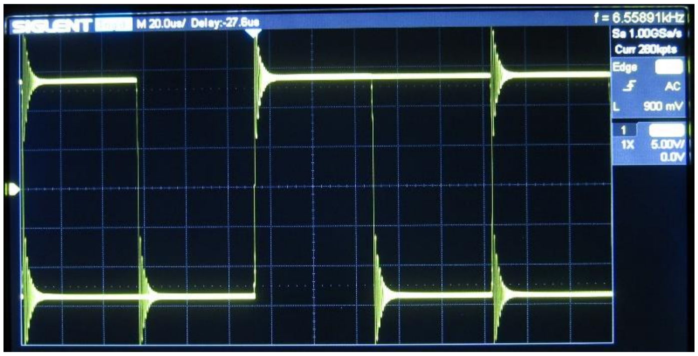
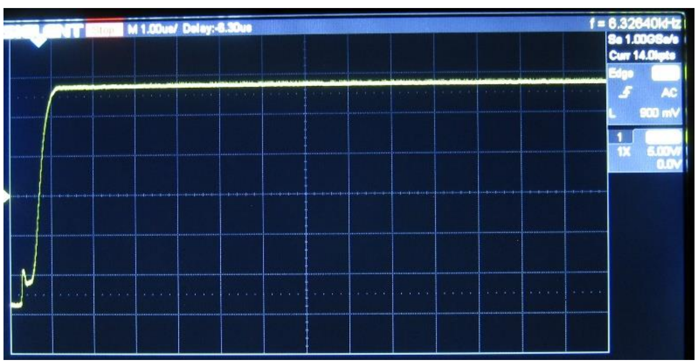
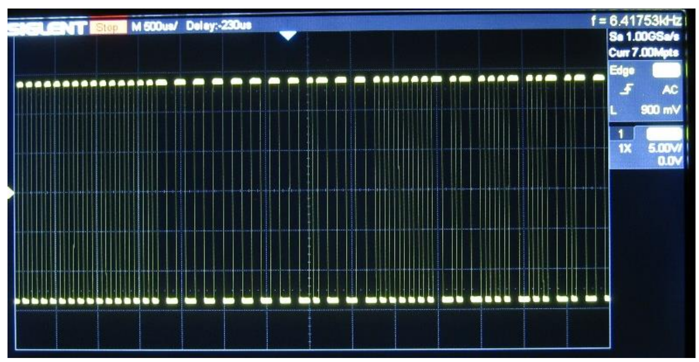


It is highly unlikely you will see anything this bad. This trouble has been artificially introduced into the “wiring.” The current is passing through a spool of hookup wire which is acting as a coil. There is overshoot and ringing. “Ringing” means there is a resonant circuit that has been created and it “rings” like a bell. But it also decays like a bell.

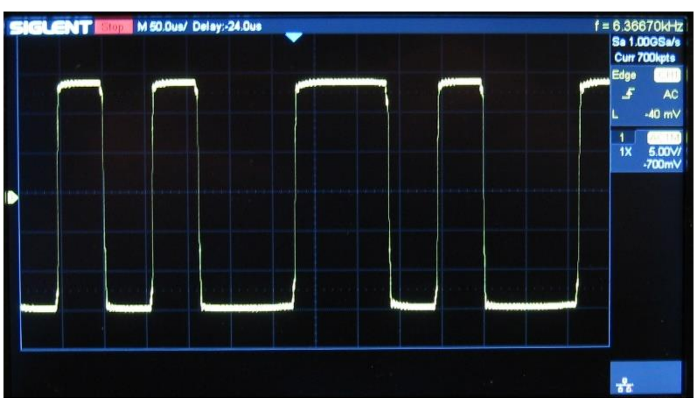
Here is what it looks like at a faster sweep rate of 1 uS/Div. It looks like the frequency is a little over 1 MHz. Actual wiring scenarios might have very small amounts of this sort of thing, but nothing like this. This is to illustrate that the wiring and its associated capacitance and inductance will exist. But even this example should not be an issue because decoders are supposed to have a band pass filter that rejects anything above 100 kHz. That’s part of the robust DCC design.



Here is the exact same setup back to normal with the spool of wire removed. Still at the 1 uS/Div sweep speed. Some interesting little glitch is occurring at the start of the rise time, but it is not important. This also shows that the rise time is roughly 1 uS.



This is the DCC voltage at a slower sweep speed so you can see more cycles and the 1’s and 0’s nature is more apparent.



At left is an actual DCC track voltage measured with the same oscilloscope on the rails at the Central Coast Model Railroad at the San Luis Obispo Railroad Museum. The long wires and long rails (which are also wires as far as electrons are concerned) introduce some capacitance which results in slightly rounded off corners and slightly slower rise and fall times of the waveform. Not as square and fast as the DCS52 with short wires on a test bench. This is expected.

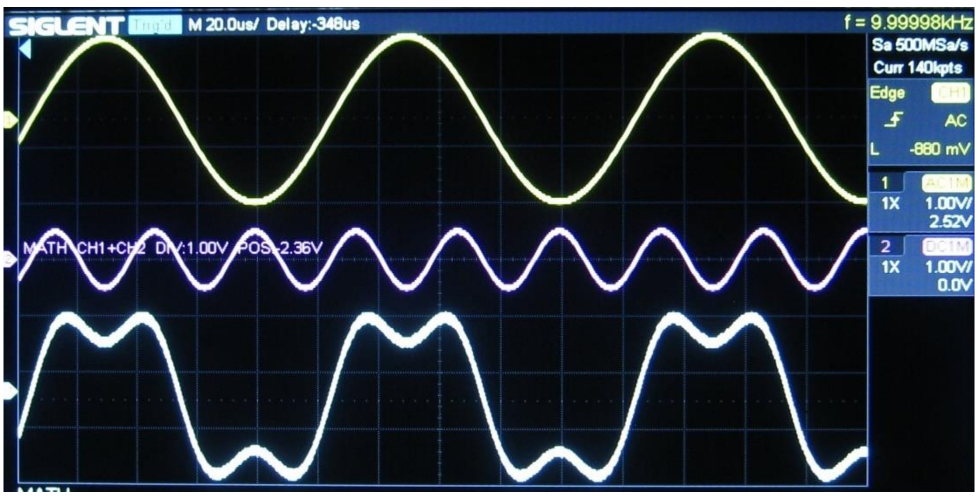
APPENDIX C: WHAT IS A SQUARE WAVE – WHY DO WE CARE

We refer to a square wave as being some frequency. But that is only the fundamental frequency. It has many more and higher frequencies within it.

There are complex equations to describe square waves, but we can skip all of that and still understand what they are in a practical sense.

A typical description is “a square wave is the sum of the fundamental frequency and its odd harmonics.” A harmonic is any frequency where a number of cycles will fit evenly into one cycle of the fundamental. The possible harmonics for a 10,000 cycle per second frequency (10 kHz) would be 20,000, 30,000, 40,000, 50,000, etc. And the odd harmonics are 30,000, 50,000, 70,000 etc. Also, higher and higher harmonics must have specific lower and lower amplitudes.

To see how multiple sine waves can add up to a square wave, the below example involves only a fundamental frequency and its 1st odd harmonic. That 1st odd harmonic which is 3 times the fundamental must be 1/3rd the amplitude of the fundamental. (The next odd harmonic would be 5 times the fundamental and must be 1/5th the amplitude. After that is 7 times the fundamental and 1/7th the amplitude. And so forth.)



The top waveform is the fundamental frequency and is 10 kHz at 3 Vpp.

The middle waveform is the first odd harmonic at 30 kHz and 1 Vpp (1/3rd of the fundamental’s amplitude).

The bottom is the resulting waveform from adding the first two.

(Siglent SDS1202X-E oscilloscope with two input channels and a third “math” channel doing the adding.)

You can see that even with just the first odd harmonic added to the fundamental we are well on our way to making a square wave. Each additional odd harmonic added will 1) make the sides of the waveform more vertical, 2) increase the number of wiggles at the top and bottom and 3) lower the height of the wiggles. With enough harmonics, theoretically, the sides become completely vertical and the top and bottom completely flat.

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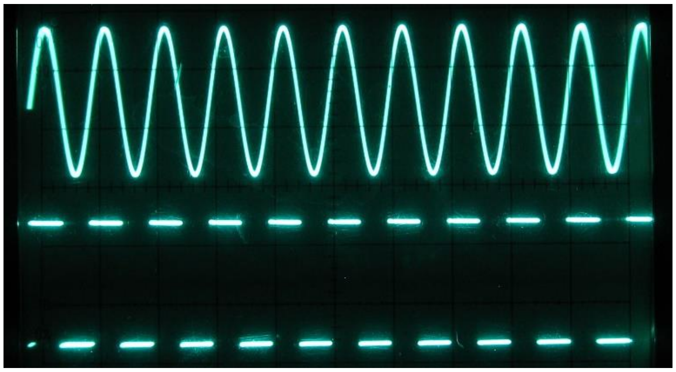
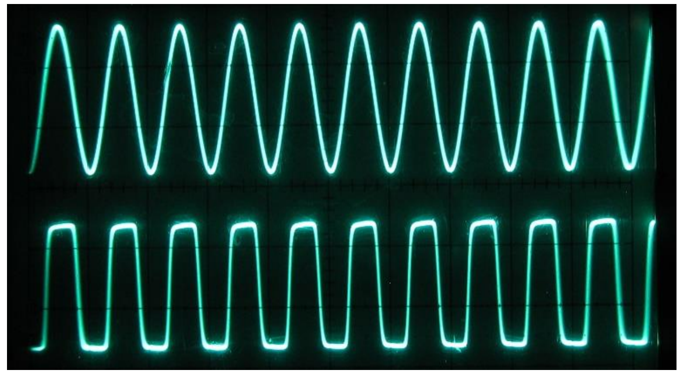
An oscilloscope will typically show sine waves better than square waves at higher frequencies. That's because a sine wave (a pure sine wave anyway) only contains its fundamental frequency. A square wave contains many higher frequencies. Oscilloscope specifications tend to describe how well they can handle a sine wave.

For an analog oscilloscope, the frequency limitation is due to response of analog input circuitry. At some point it just can't pass the frequency along (not unlike the upper limitation you have in your hearing). When this happens with the sine wave, the height of the wave diminishes. For a square wave, its shape first changes as it loses higher frequency harmonics. And then eventually its amplitude diminishes if the fundamental frequency is increased even further.

The examples below are 5 kHz and 5 MHz sine and square waves on a 20 MHz analog oscilloscope.

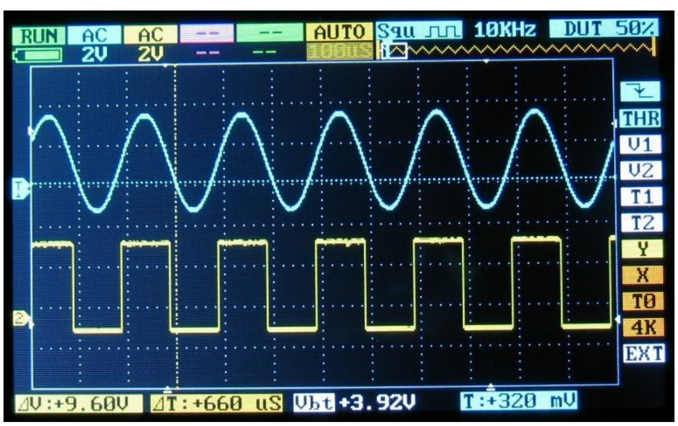


5 kHz sine and square waves.
Both display very well.
The rising and falling edges of the square are too fast to light up the screen phosphor.
(Hitachi V-212 20 MHz analog Oscilloscope.)

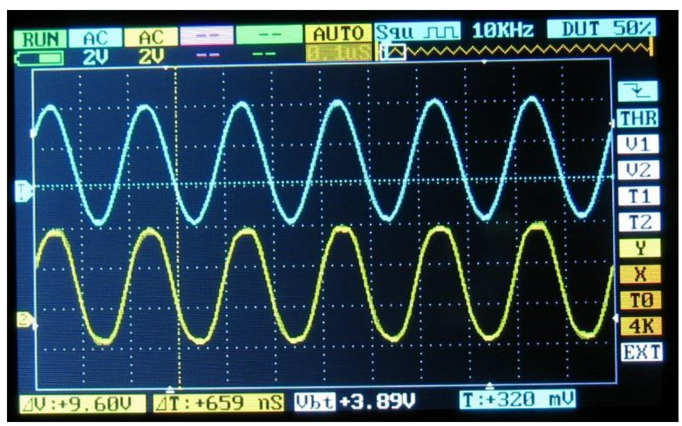


5 MHz sine and square waves.
Sine wave good. Square wave not very square because many of its higher harmonic frequencies can't get through.
(Hitachi V-212 20 MHz analog Oscilloscope.)

For digital oscilloscopes, there will also be some frequency response limitation in the analog input circuitry at some point. But a more significant limitation is more likely the maximum sampling rate possible. Also, algorithms tend to try and "connect the dots" and to "think" in terms of sine waves unless there is enough data to think otherwise.



5 kHz sine and square waves.
Both display very well.
Digital scopes know you would like to see rising and falling edges, so they show them regardless of how fast they are.
(DSO213 15 MHz digital Oscilloscope.)



5 MHz sine and square waves.
Sine wave good. Square shows nearly as a sine.
Not enough samples to do better.
An unrelated issue is that the vertical height is now incorrectly showing about 6 Vpp when the waveforms are actually 5 Vpp.
(DSO213 15 MHz digital Oscilloscope.)

(continued on next page)

However, a multimeter, depending on its design, might not see much difference between a sine wave and a square wave. If it is a design that initially converts the AC waveform to a DC voltage to then display, there may not be much difference in the readings. Or the square wave might actually display as a higher voltage.

Regarding noise from square waves interfering with other items: A square certainly can create more “noise” due to its high frequency harmonics which are absent in the sine wave. But remember that the higher the harmonic, the lower the level. So even though a square may look like it should be radiating interference noise horrifically, it will usually be much less than imagined.

And how is a square wave usually made? Well, you could generate a great many sine waves at the correct frequencies and levels and then add them together. But the easy way is to simply alternately turn a voltage on and off, or alternately turn a voltage positive and negative. The result will be all of those harmonics magically existing as part of the waveform. (Well, not quite all. There are practical limits, and you can never create a perfect square wave.)

This is where you may have to take a leap of faith. You may be asking “How can just turning something on and off create a big collection of sine waves?” However, they really are there. One practical way to illustrate this is to send the square wave through a “low pass” filter. The filter could just be filtering out some of the higher frequencies and the resulting waveform will start to be distorted. If you keep lowering the point above which frequencies can’t pass through, the waveform becomes more and more smoothed. If you lower that point all the way below the first odd harmonic, you are left with a sine wave of the fundamental frequency showing. You might say it was hiding in there all the time.

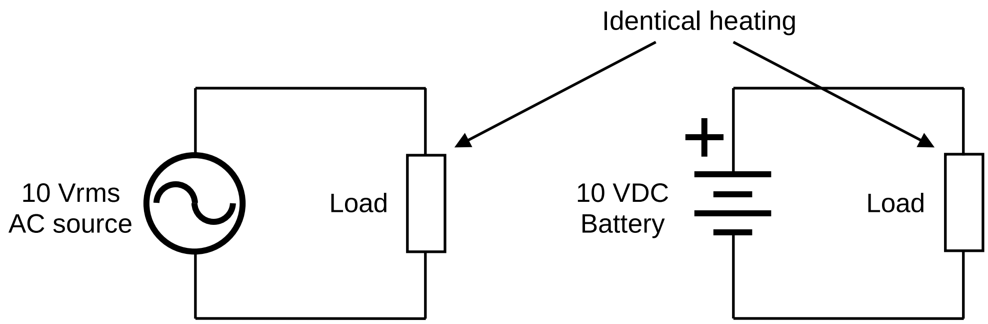
APPENDIX D: WHAT IS RMS VOLTAGE?

RMS Defined

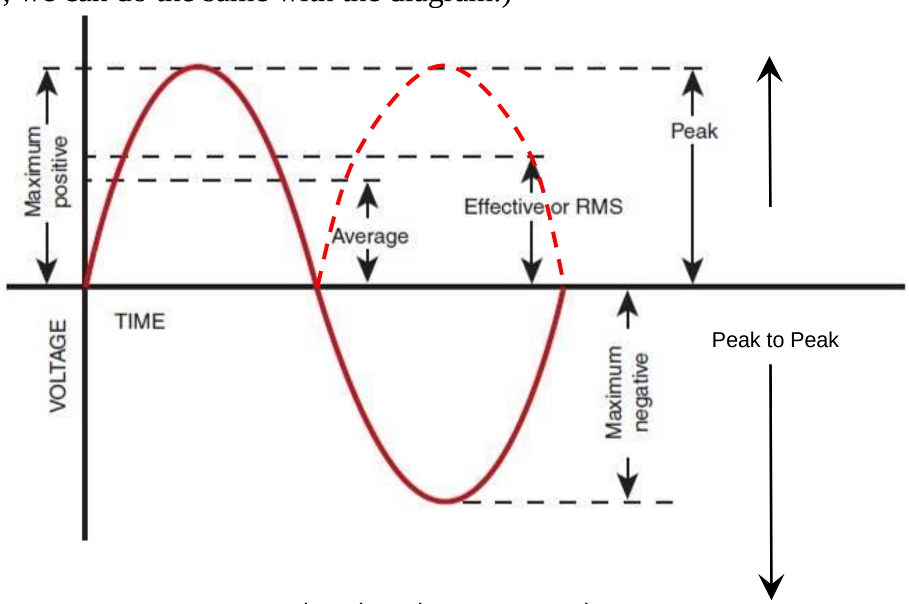
RMS means "Root Mean Square." This suggests there could be a heap of math involved and there is. We'll just skip most of that. There are many online treatises describing RMS voltage and YouTube lectures abound. Whether you crave calculus or just want step by step diagrams, they are all there. The approach here is to provide only enough as relates to the DCC voltage and trying to read it with multimeters.

RMS voltage describes the "effect" the AC voltage waveform is over time. An AC waveform (or most of them anyway) is more effective at some instants than at others. The typical sine wave has a positive and negative maximum effect during one cycle. And also points where it is zero with no effect.

It is easy to see the "effect" of a DC voltage because it is constant. RMS is way to express an AC voltage with the same effective value as if it were DC. The following is a standard sketch showing this involving heating. In the example, 10 Vrms and 10 VDC are equally effective. But how do we calculate it?



Consider the figure below. The AC sine wave varies between zero, where it is providing no power, the positive peak where it is providing maximum power, and the negative peak where it is also providing maximum power. The numerical "average" voltage is zero. But that is meaningless in this context because both the positive and negative cycles provide power. The easy way to start understanding this is to flip the negative half cycle to the top as shown with the dotted half cycle. (The squaring of values in the RMS equation will also make all negatives positive. So, we can do the same with the diagram.)



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There is an imposing equation for the general case that covers any repetitive waveform, but for just a sine wave it reduces to this quite simple one.

$$V_{rms} = V_p / \sqrt{2} \qquad \text{or} \quad V_p / 1.414 \qquad \text{or} \quad 0.7071 \times V_p$$

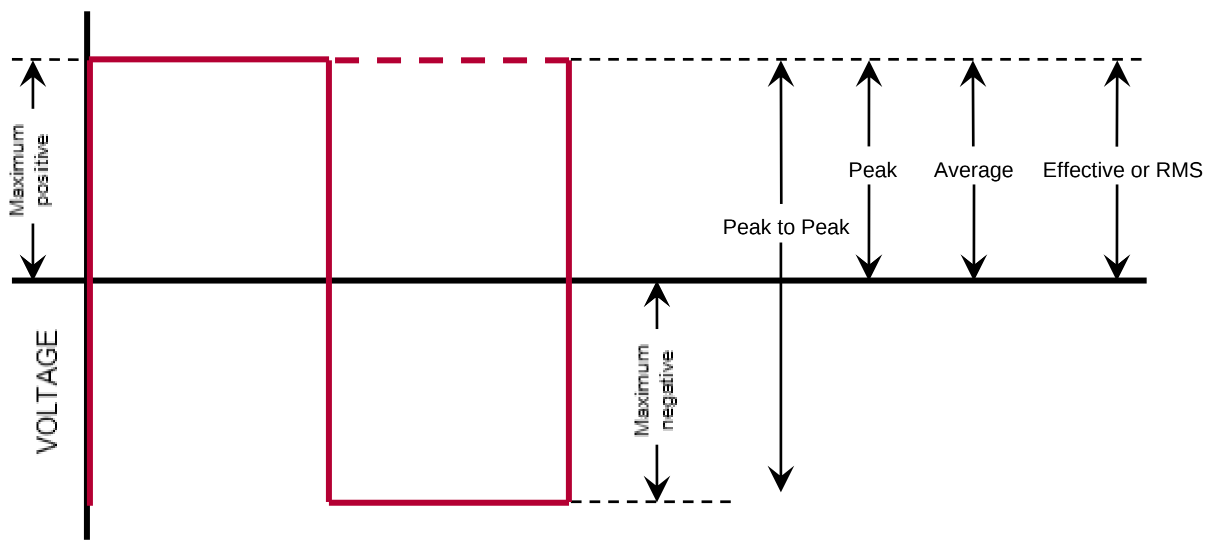
The RMS voltage of a sine wave is 0.7071 peak (often just shown 0.707 to three places) and is a common factor known to many involved in electronics. But that equation doesn't work out so well for other waveforms. Also, the average voltage of a sine wave is 0.637 times the peak. We won't bother to explain that average calculation here. We'll just accept it. And average voltage (for most waveforms) does not represent the "effective" DC voltage. And we won't bother to explain that here either. Note that for a sine wave the RMS and average voltages are different. These sine wave related constants will be good to know later when understanding how some multimeters work.

The square wave is good example, and the easiest, to show that the sine wave RMS equation and average equation do NOT apply to all other waves. For a square wave, we can skip the math and see "by inspection" how things work. This is worth knowing since the DCC voltage is a square wave.

The chart below is the same way of viewing the waveform with the negative half cycle moved to the top (dashed line) as the sine wave on the preceding page. Notice that the result is now a constant unchanging voltage. And that is exactly what DC voltage is. They are equally "effective" (provide the same power).

Therefore, with no math, we can see that the peak, RMA, and average voltages are the same for a square wave.

$$V_p \;=\; V_{rms} \;=\; V_{av} \qquad \text{(for a square wave)}$$



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RMS Voltage and Meters

Note: The diagrams shown below are extremely simplified.

There is more than one way meters measure RMS. It is important to remember several things when dealing with meters. This is especially true in the context of trying to read DCC voltage.

RMS for a sine wave is DIFFERENT from average voltage.

For a sine wave:

Vrms = 0.7071 x Vp
Vav = 0.637 x Vp

To convert average voltage to RMS for a sine wave you multiply by 0.7071 / 0.637 which is 1.11

RMS is not the same relationship to peak voltage for all waveforms.

For a sine wave, we know Vrms = 0.7071 x Vp and also that Vrms = 1.11 x Vav.
For a square wave, we know Vrms = Vp = Vav, certainly different from a sine wave.

Therefore, a meter designed to display RMS voltage properly for a sine wave, and ONLY a sine wave, will not read a square wave accurately.

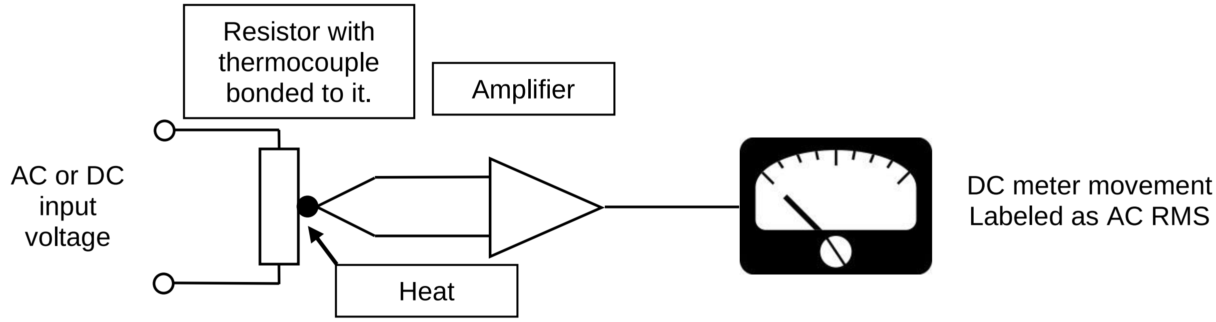
The meter will multiply Vav by 1.11 just like it does for the sine wave. But Vav for the square is already the same as Vrms. So, the reading will end up 1.11 times too high or 11% too high. This is the easy way to spot that a meter is not "True RMS" but plain old RMS for a sine wave.

All meters have some frequency limit beyond which they are inaccurate.

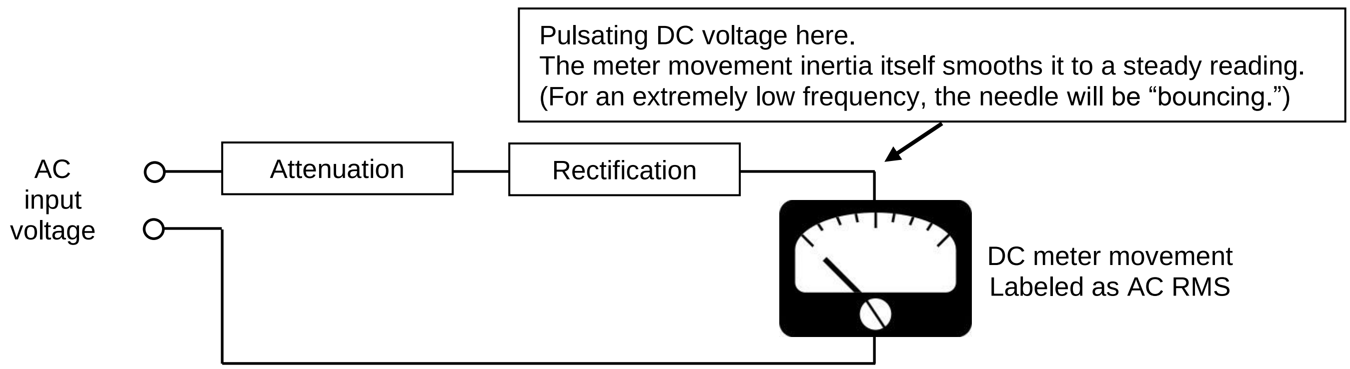
Pretty much all meters can handle low frequencies like 60 Hz AC house voltage. 40-400 Hz is a common rating. 40-1000 Hz less common. Not many meters work well above 1000 Hz. Usually, if you try to measure above the rating, the readings will get lower and lower with higher and higher frequencies.

(continued on next page)

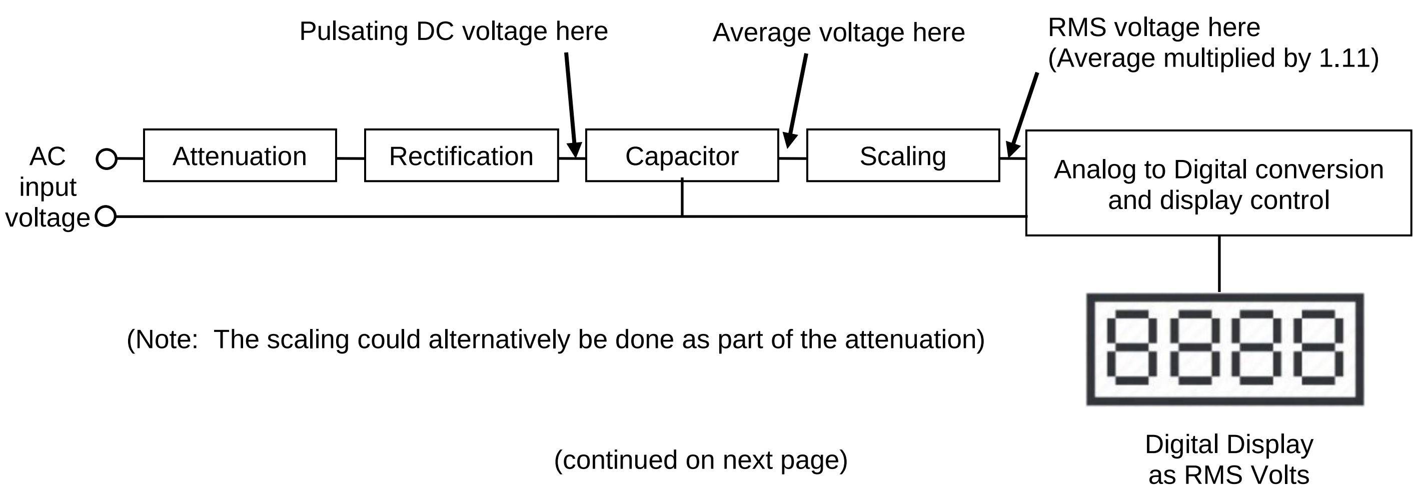
Heat Measuring Meters: (Just for historical perspective.) A very early method that actually produced "True RMS" took the direct approach. The voltage under test heats a resistor and the meter reads the resistor's temperature. More modern versions (Fluke 8506A for example) have also been made, typically for high precision or laboratory work. These are accurate for DC and also AC of any wave shape.



Simple "RMS" Meter Movement Meters: Pretty much all meters with meter movements read RMS accurately only for a sine wave. This is because they simply design attenuation, and meter markings, to make it display as RMS. The "conversion" of the AC voltage to an RMS reading is simply done with resistances to make things work out for whatever small current is required to move the meter movement.



Simple "RMS" Digital Meters: These are NOT "True RMS." These have slightly more circuitry, but not much. It is easy to get an actual average voltage with just a capacitor and not much more. But the average is NOT the RMS. This is scaled up to be represent RMS voltage. The digital display portion then displays that resulting voltage.



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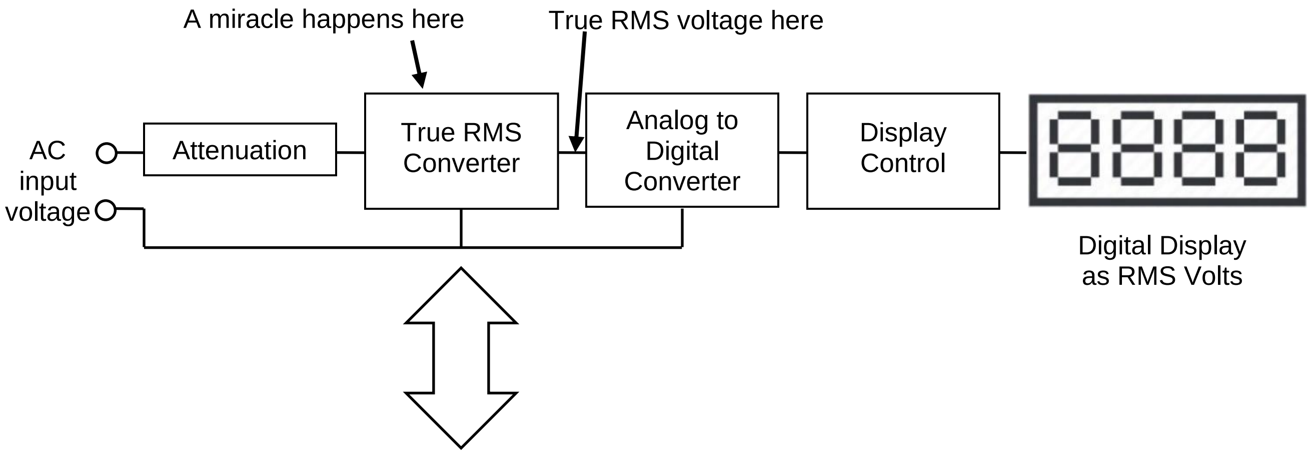
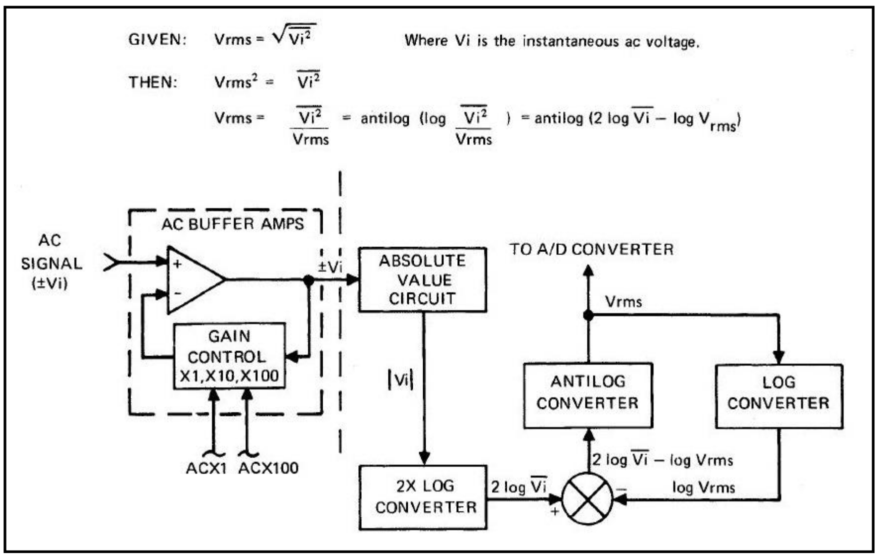
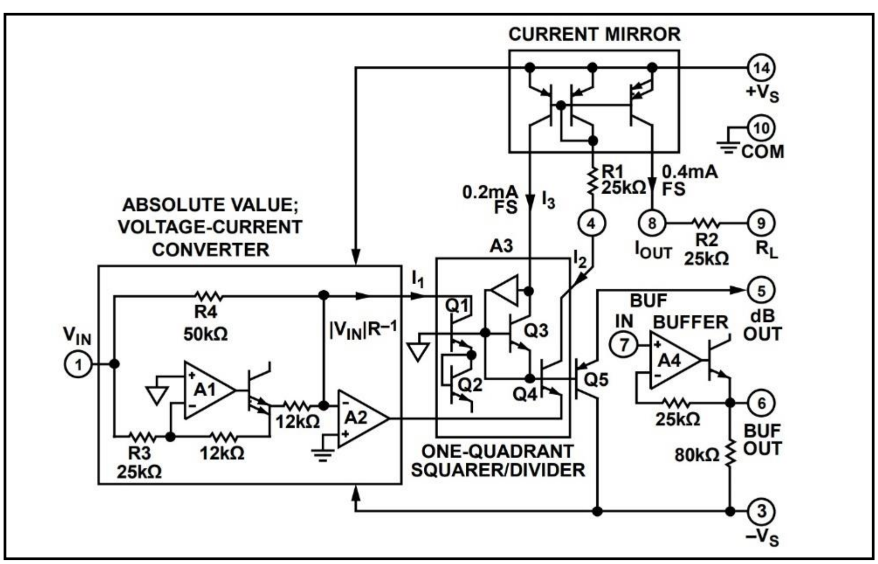
"True RMS" Meter with Analog Calculation: These accurately display the AC RMS voltage for any waveform. That is what "True" means. Not just for a sine wave. This is an earlier approach before today's meters that do digital processing. They use analog circuitry called a "True RMS Converter" to do the RMS calculation. The converter is an analog computer of sorts.



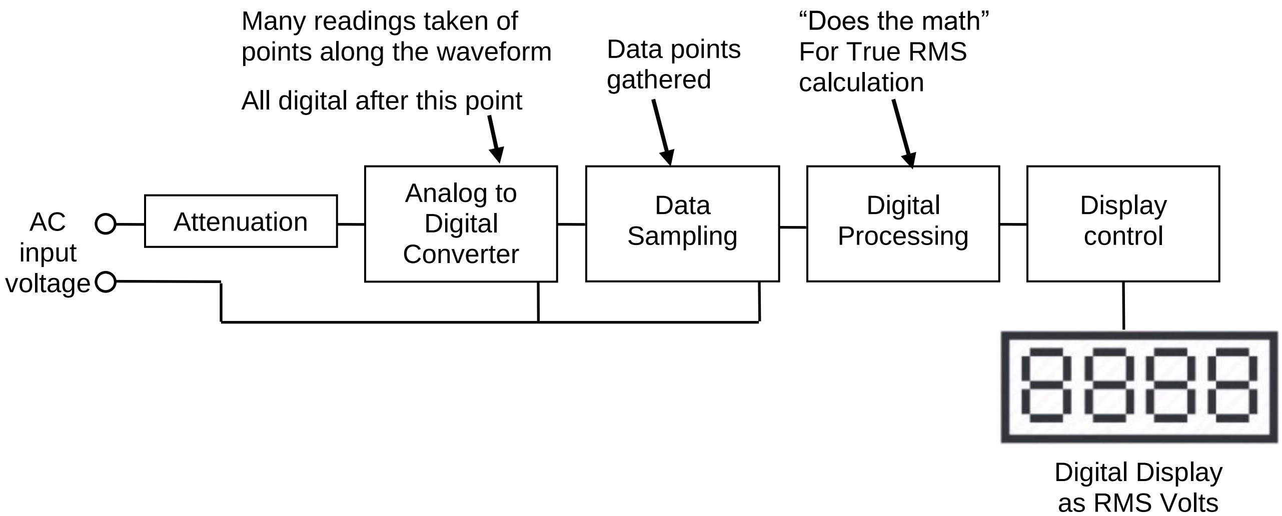


This is a block diagram of the Fluke 8060A-4003 True RMS converter. There is no digital processing. This is all circuitry involving transistors and such. It "does the math" shown.



This is schematic for the Analog Devices AD536A chip which a meter manufacturer might use as part of their "True RMS" meter design. All analog. They required some adjustment during manufacturing that was done by "laser trimming." Hard to get them identical. Costly to manufacture. In contrast, every copy of a software algorithm in a digital processing meter is identical.

True RMS Meter with Digital Calculation: Modern True RMS digital meters use digital signal processing (they contain a computer). Digital signal processing is cheaper and more consistent than analog circuitry. And it is not affected by things like heat. No matter how many you manufacture, at least that part of the meter will always perform exactly the same.



SUMMARY:

Is the meter True RMS?: Carefully check if the meter really is "True RMS." Regular "RMS" means it is only accurate for a sine wave and less accurate for other wave shapes.

Finding the AC voltage frequency response: Usually, the AC voltage frequency response is not shown in specifications on web page descriptions and such. ALWAYS check the manual if you don't know for sure.

Frequency counter capability: Don't get confused by a frequency MEASURING specification that may be shown. Some digital multimeters provide a frequency counter function. This is completely unrelated to the AC voltage frequency response and has nothing to do with it.

Dirty Little Secrets: If a meter is not True RMS, but has a high enough frequency response, you can know your DCC voltage is always reading about 11% high. So, you can know the actual reading is 90% of what is displayed, and you can just mentally adjust (or on paper) for that. If the meter's frequency response is not sufficient, it may still be reading high enough to provide usable readings, but you will have to figure out the error to know what scale factor to use for all your readings. You might even have a meter that is not True RMS making it read high, but with poor frequency response making it read low, such that those two error sources cancel out or nearly so.

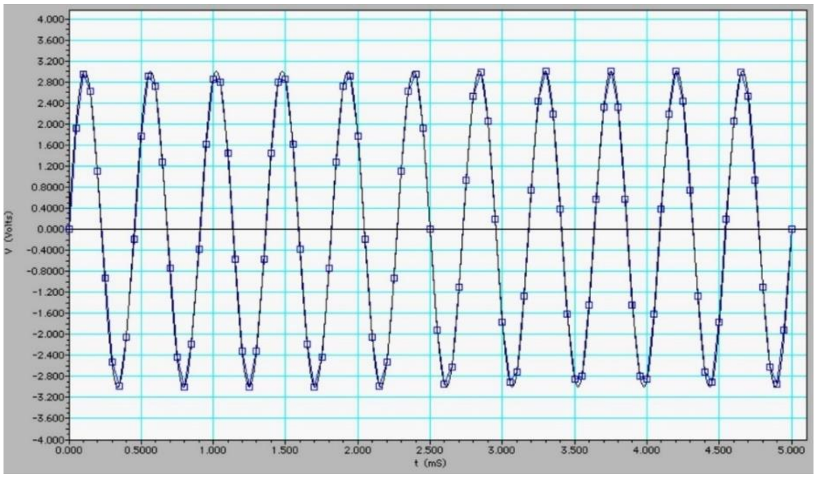
Why some meters read DCC voltage incorrectly: Many meters are not suitable for DCC voltage measurement because 1) They don't measure a square waveform shape accurately and/or 2) they don't have sufficient frequency response.

APPENDIX E: OSCILLOSCOPE ISSUES

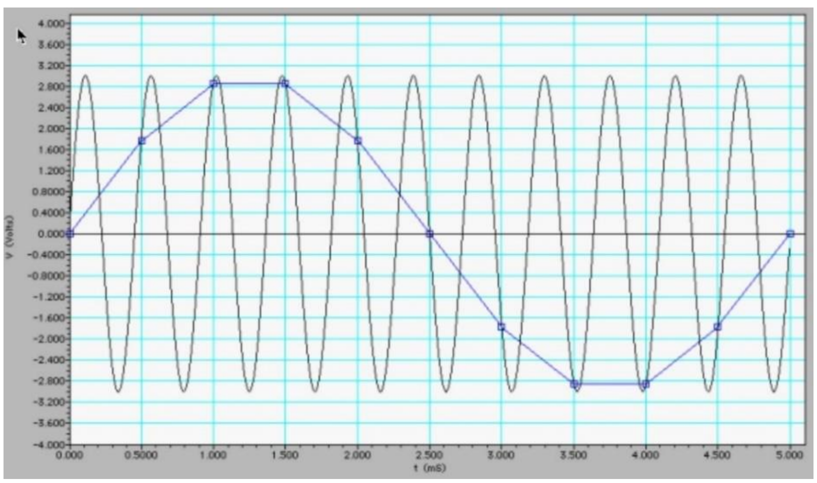
Aliasing in Digital Oscilloscopes

Aliasing is the display of false waveforms due to under sampling. In a digital oscilloscope, the actual waveform is sampled (instantaneous points read) at some rate. If the sampling rate is too low, the oscilloscope doesn't get enough information to figure out what the wave really looks like. The sampled data is processed, and then whatever the signal processor thinks it represents is created and displayed on the screen.

The usual way to present the aliasing problem is to first show what works, like this 2.2KHz waveform was sampled at the considerably higher frequency of 20 KHz. Each dot represents a sample. And there are enough of them to reasonably display the waveform.



This is the same 2.2 kHz waveform (the higher frequency for reference) sampled at 2 kHz. The blue single wave is what the signal processing has to assume and that is what is displayed. Not only are there not enough samples to figure out the waveform, but the samples will be mistaken for a waveform at a vastly lower frequency.

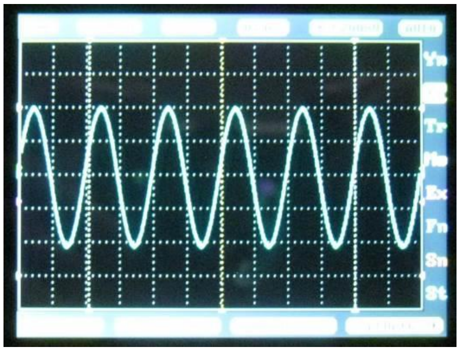


This is only a basic summary. There is the "Nyquist Sampling Theorem" stating your sampling frequency must be at least twice what you are trying to measure. But in real life that is very often not enough. Also, oscilloscopes can have complex algorithms and/or interleaved measurements to try to get better results. If you try to measure too high of a frequency, the oscilloscope presentation will start to look funny, or be at a very wrong frequency, or start to look mysteriously modulated.

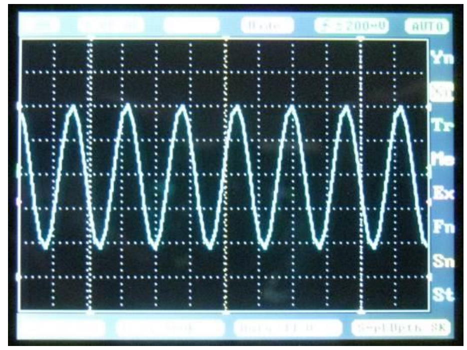
(continued on next page)

Aliasing Examples in an Oscilloscope

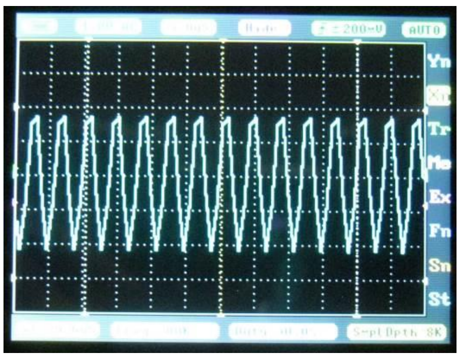
The following images are of a sine wave to a DSO211 Mini oscilloscope claimed to have a 200 kHz bandwidth. Once you are in a region of aliasing, even a change of 1 Hz can make a big change in how the scope fails.



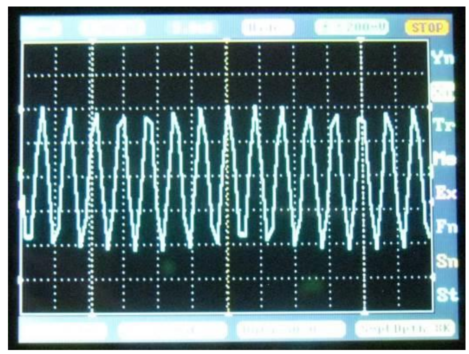
10 kHz 50 uS timebase.
Looks very good.



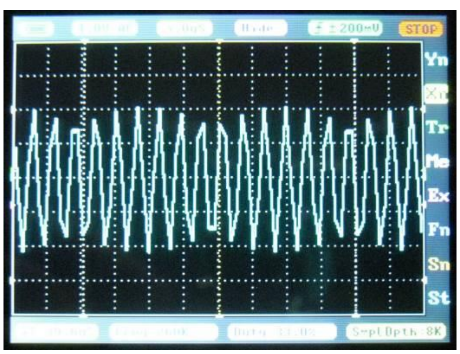
100 kHz 5 uS timebase.
Wave shape not looking as good.



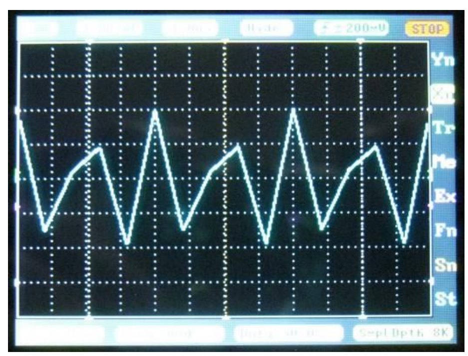
200 kHz 2 uS timebase.
Waveshape looking worse.



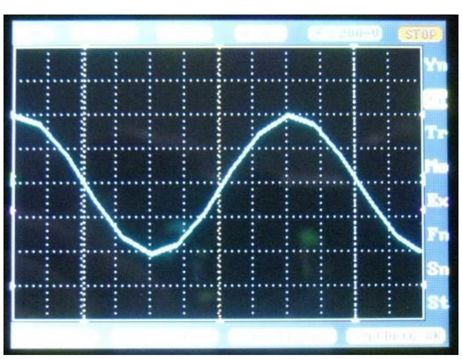
205 kHz 2 uS timebase.
Still worse and false modulation



260 kHz 2 uS timebase.
Much more false modulation.



400 kHz 1 uS timebase.
False low frequency and strange waveshape.



(At left) 900 kHz 1 uS timebase.
A classic example. The waveform is sine wave looking but shows at about 100 kHz instead of the 900 kHz it really is. Of course, this frequency is vastly beyond the manufacturer's specification.

(continued on next page)

Probe Compensation and 1X and 10X

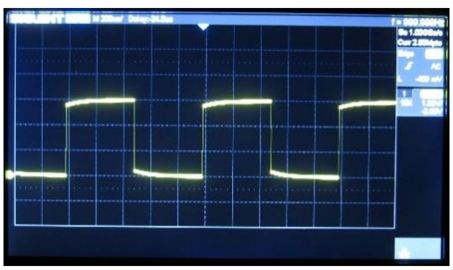
Many oscilloscope probes have a switch to select 1X or 10X. 1X means the voltage is connected directly to the oscilloscope input. 10X means it is attenuated by ten times and therefore puts far less load on the circuit under test. 10X also allows measuring a higher voltage (and there are also 100X and 1000X probes for measuring still higher voltages). Some probes do not have this feature are always 1X – direct connected.

The DCC voltage is too strong to be affected by a X1 probe, so it is not necessary to use the 10X. But if you do, it needs to be compensated if a compensation adjustment is available.

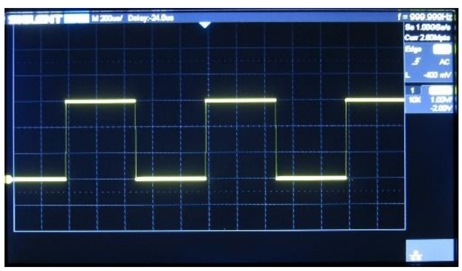
AC voltage and current are altered by capacitance. All wiring and circuit board traces have some capacitance. Probe compensation involves an adjustable capacitor to neutralize (compensate) for the undesirable fixed capacitances.

Compensation is usually done with a small adjustment screw on the probe while viewing a square wave. Many oscilloscopes have a square wave test output for this purpose. This should be done with a non-metallic tool which many electronics technicians might have, but most model railroaders don't. It is fine to use a small metal screwdriver, but it may have a small effect when in contact. You may have to do a little trial and error.

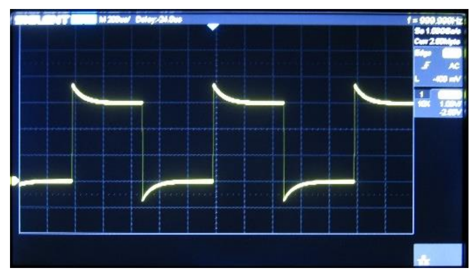
The following shows some actual adjustment results and is what you will see in many manuals as photos or drawings. This is on a Siglent bench style SDS1202E-X 200 MHz oscilloscope with a good quality probe with a compensation adjustment with the probe switch set to 10X.



Under compensated.

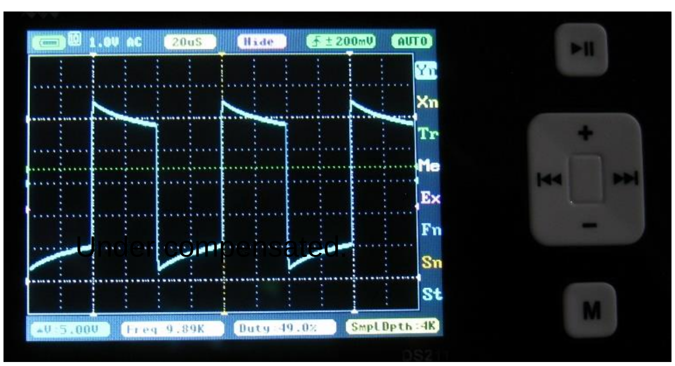


Correctly compensated.

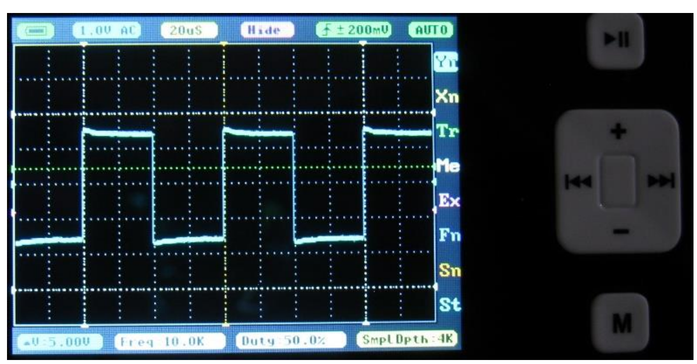


Over compensated.

The following is the little DSO211 oscilloscope with the low-cost probe that came with it which has a 10X/1X switch but does NOT have a compensation adjustment. Clearly, it would be better to use the probe set to 1X if possible.



10X probe with no means to adjust.
A lot of overshoot.



The same probe set to 1X.
A much more reasonable square wave.

APPENDIX F: WHY ARE FLUKE METERS SO EXPENSIVE

On various DCC blogs you may see comments like "I wish I had the Fluke but can't afford it" or "The Fluke is the best" or "The Fluke doesn't work" and such. There is no such thing as "the" Fluke. There are many.

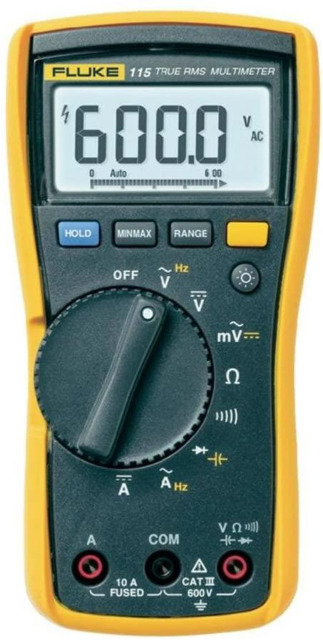
Fluke Corporation has an excellent reputation for their test equipment. Their multimeter product line includes a great many models so there really isn't just one "Fluke." Some typical ones a model railroader might consider are the 115, 87-V, and 77-4 (and not all can read DCC voltage accurately). There are differences in number of displayed digits, maximum voltage, and such. But even the low-end Fluke 115 is twice the cost of respectable alternatives for the average user.

Fluke's market is really professionals, not hobbyists. There are often differences in terms of accuracy, input protection, and ruggedness. But they also have a lifetime warranty, and they don't discontinue a model for a great many years. This matters to organizations (industrial, government, and military) that have procedures written around a particular meter. It also has the aura of "measurement confidence" which can be part of a belief system. Or it can be concern when a million-dollar contract requires proof of calibration with certificates. Let's face it. Most model railroaders don't have a schedule to send their multimeters to a facility for annual recalibration and recertification. But there is another world that must.

There is also peer pressure in industry where everybody else has some Fluke model, so you get one, too. And it can have a status symbol aspect. (Perhaps not unlike peer pressure and status in buying Snap-On tools.)

The slogan "No one ever got fired for buying IBM" was used as an example to buy something your boss accepted, even if more costly. You could also say, "No one ever got fired for buying Fluke." Fluke simply isn't really marketing to hobbyists. You can compare the models below online, as well as many other Fluke models and other brands with lower cost models.

OWON B41T+
$90



Fluke 115
$219

Fluke 77 IV
$368

Fluke 87-V
$467

So, Fluke does make high quality, consistently good, feature rich, high safety, products. They are probably the de facto standard. But for a hobbyist, you likely won't get more for your purposes than you get with something far less expensive.

(continued on next page)

If you want a Fluke model for all manner of measurements for model railroading OTHER than measuring the DCC frequency voltage, The Fluke 115 is probably the lowest cost choice. If you also want to measure DCC frequency voltage, you have to step up to an 87-V (sometimes called 87-5). You also need to be careful who you rely on for advice. And this includes Fluke themselves.

Here is some bad information I got from Fluke regarding what the 115 could do in answer to my query, “What is least expensive Fluke True RMS meter that can measure a 10 kHz square wave?” (My test results are on the next page.)

Charles,

It appears that your question took the long road to get to me. I apologize for that. There are a few options depending on your needs.

The Fluke 115/117 series DMM will make that measurement without any trouble, but in the 10 kHz range there is no accuracy specification as shown in this image from the manual.

			45 to 500 Hz	500 Hz to 1 kHz	
AC millivolts[1] True-rms	600.0 mV	0.1 mV	1.0 % + 3	2.0 % + 3	110, 114, 115, 117
AC Volts[1] True-rms	6.000 V	0.001 V	1.0 % + 3	2.0 % + 3	110, 114, 115, 117
	60.00 V	0.01 V			
	600.0 V	0.1 V			

The closest accuracy spec stops at 1 kHz and is ± 2% + 3 counts. I would not expect the accuracy to deviate substantially at 10 kHz but it is unspecified at that range.
Here is a copy of the Fluke 115/117 Users Manual for your review.

The FLUKE-115 TRUE RMS MULTIMETER is $218.99 MSRP.
The FLUKE-117 TRUE RMS MULTIMETER is $239.99 MSRP.

If you require an accuracy specification for your measurements, then I would suggest the Fluke 87V. In the 30V range that you mentioned the Fluke 87V has an accuracy of ± 2% + 20 counts. I have included the accuracy table from the manual for your convenience.

Function	Range	Resolution	Accuracy					
			45 – 65 Hz	30 – 200 Hz	200 – 440 Hz	440 Hz - 1 kHz	1 - 5 kHz	5 - 20 kHz[1]
$\tilde{V}$ [2,4]	600.0 mV	0.1 mV	± (0.7 % + 4)	± (1.0 % + 4)			± (2.0 % + 4)	± (2.0 % + 20)
	6.000 V	0.001 V	± (0.7 % + 2)					
	60.00 V	0.01 V						
	600.0 V	0.1 V					± (2.0 % + 4)[3]	unspecified
	1000 V	1 V					unspecified	unspecified
	Low pass filter		Same as 45-65 Hz	± (1.0 % + 4)	+1 % + 4 -6 % - 4[5]	unspecified	unspecified	unspecified

Here is a copy of the Fluke 87V Users Manual for your review.

The FLUKE-87-5 INDUSTRIAL TRUE RMS MULTIMETER is $466.99 MSRP.

I hope this information answers your question.

Best regards,

[Name deleted]

(continued on next page)

A quick test of the Fluke 115 showed that the information provided by the Fluke representative was incorrect. The Fluke 115 didn't come close to being accurate at 10 kHz.

Three Fluke meters were tested: an old 8060A, a new 87-V, and a new 115. The test signal source was a Siglent SDG1042X arbitrary waveform generator. The 8060A and 87-V were excellent, and their graphed lines are nearly on top of one another. The 115 drops off severely. And it has some other anomalies which might be due to some aliasing at frequencies too high for its sampling rate. Tabular and graphed data below.

10 Vp SINE WAVE

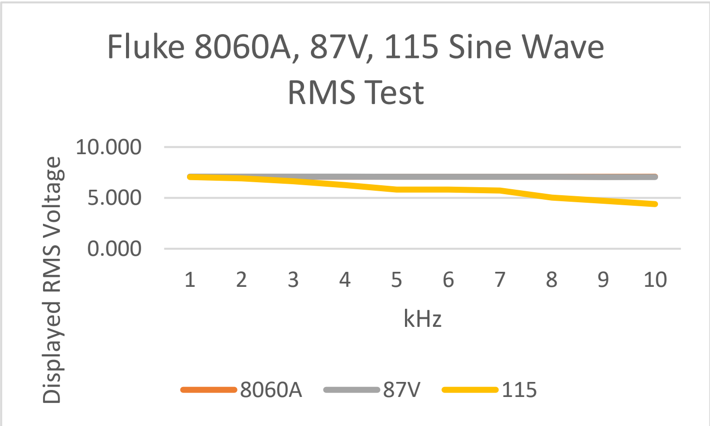
kHz	8060A	87V	115
1	7.078	7.09	7.05
2	7.080	7.09	6.91
3	7.081	7.09	6.63
4	7.081	7.09	6.25
5	7.082	7.08	5.81
6	7.083	7.08	5.814
7	7.083	7.07	5.707
8	7.084	7.07	5.040
9	7.085	7.06	4.699
10	7.086	7.05	4.388

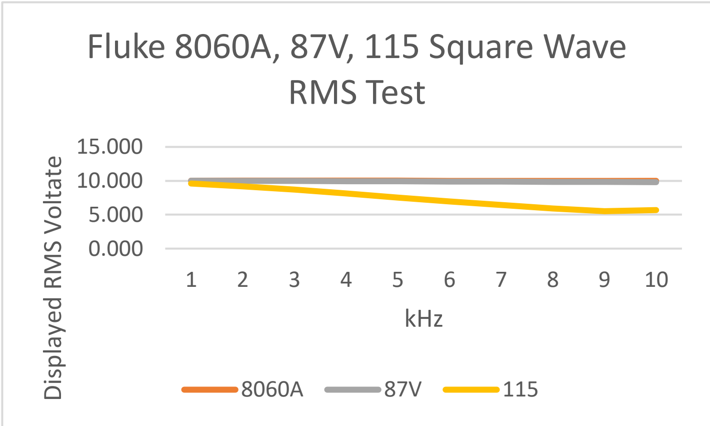
115 changed to 3 digits at 6 kHz

10 Vp SQUARE WAVE

kHz	8060A	87V	115
1	10.016	10.01	9.60
2	10.015	9.99	9.18
3	10.012	9.97	8.69
4	10.009	9.94	8.12
5	10.007	9.92	7.54
6	10.004	9.90	6.96
7	10.001	9.87	6.42
8	9.999	9.85	5.94
9	9.996	9.82	5.52
10	9.993	9.80	5.69

The 10 kHz 115 reading was extremely jumpy





APPENDIX G: SAVE MONEY WITH VINTAGE USED EQUIPMENT

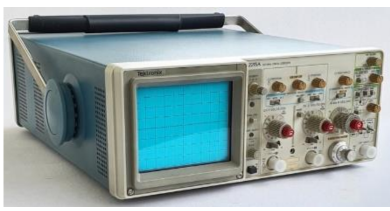
Buying used electronics equipment is typically something for the electronically savvy. (And if you are not, an electronics knowledgeable friend might assist.) But you can buy high quality equipment with plenty of life in it for incredibly less than original selling prices. There are a vast number of manufacturers and models. Just a few examples of "work horse" equipment that have stood the test of time are shown below.

Of course, you want one that works. And it may need calibration and how do you do that? And oscilloscopes of that vintage could be pretty heavy so can be costly to ship. But they can be bargains, especially if you can find one locally. Some, like the Tektronix 2246, even show voltage readings on the screen.

Tektronix 314 10 MHz Dual Trace Analog Storage Oscilloscope

Introduced 1975

Original MSRP $1195. $6193 in 2022 dollars.
Typical used prices range $100 to $200.



Tektronix 2215 60 MHz Dual Trace Analog Oscilloscope

Introduced in 1982.

Original MSRP $1400. $4,044 in 2022 dollars.
Typical used prices range $50 to $150.

High-End Tektronix Analog Scope Models (Industry standards in their day)

465, 465B, Introduced in 1972.
Original MSRP $1725. $11,506 in 2022 dollars.
Typical used prices range $100 to $300.

2246 Introduced in 1987.
Original MSRP $2400. $5,890 in 2022 dollars.
Typical used prices range $100 to $300.

Hitachi V-212 20 MHz Dual Trace Analog Oscilloscope.

Introduced in 1983.

Original MSRP $340. $952 in 2022 dollars.
Typical used prices range $50 to $120.

Fluke 8060A True RMS Multimeter.

Introduced in 1982.

Original MSRP $400. $1158 in 2022 dollars.
Typical used prices range from $40 to $100.

APPENDIX H: WHAT'S IN A SPECIFICATION

It is important to know something about specifications before you buy. Specifications let you judge if something is good enough for your measuring needs. But specifications are not always easy to understand and not always complete.

An elusive and confusing specification is the frequency response for AC voltage measurement and that, naturally, is one of the things you need to know to measure DCC voltage. The following are just a few specifications, but some of the most important.

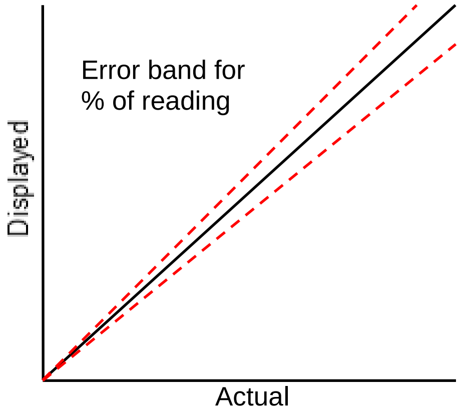
WHAT IS A "1/2" DIGIT IN A MULTIMETER? It is common to see digital multimeter displays described as "3 1/2 digits" or similar. This means the display can show three full digits and one more digit that can be a 0 or 1. By apparent agreement throughout the universe, that digit limited to 0 and 1 is called a "fractional digit" and in this case a "1/2 digit". So, the range is ± 1999. And if that fractional digit can more than just 0 and 1 but still not a full digit, it is a "3/4 digit". A "3/4 digit" would typically display 0, 1, 2, and 3, but sometimes more, such as 0, 1, 2, 3, 4, and 5. Examples:

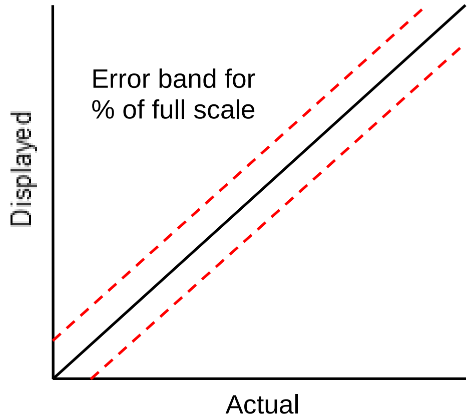
3 1/2 Digit	± 1999
4 1/2 Digit	± 19999
3 3/4 Digit	± 3999 if 0,1,2, and 3 used
4 3/4 Digit	± 59999 if 0, 1, 2, 3, 4, and 5 used (Brymen and maybe others say 4 5/6 digit)
4 Digit	± 9999 all digits can be 0 through 9, no "fractional digits"

ACCURACY is certainly one of the most important specifications. You might see "Accuracy: ± 1%". But ± 1% of what? Of reading? Of full scale (or "range")?

If "of reading," then the percentage applies to the value. If the meter is set to 20 VDC full scale and reading 1 VDC, the percentage applies to 1 VDC. The tolerance is ± 0.01 VDC. The closer you get to zero, the tighter the error band becomes.

If "of full scale" (or "range"), if the meter is set to 20 VDC full scale the tolerance is ± 0.2 VDC no matter where in the range you are trying to read. That same 1 VDC reading now has a tolerance 20 times higher than the "of reading" specification. The closer you get to zero, the error band remains the same. The charts below graphically show this important difference.





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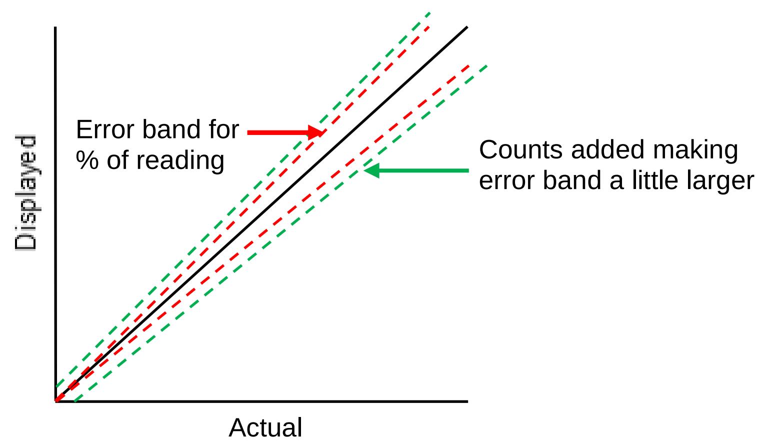
But in the case of "% of reading," it is unrealistic to expect perfection as you near zero. A bit more latitude is often added in terms of "counts of the display." A specification might say:

> 1% ± 2 counts or
> ± (1% + 10 counts) or
> ± (0.5% + 5dig)

These are all the same where you have your "percent of reading" (almost always) error band and on top of that, a number of digital display counts. Of course, the impact of the number of display counts depends on how many places are being shown below the decimal. If resolution is 0.01, then 5 counts is 0.05. If resolution is 0.001, the 5 counts is 0.005.

The chart below shows the error band for the "percent of reading" basic tolerance in red and the additional margin of "counts" in green. The accuracy still narrows when approaching zero, but there is a little bit more room for error at all points, especially noticeable near zero where most of the error band is in terms of "counts."



Below is part of the Fluke 87-V Multimeter User Manual Specifications for AC voltage measurement. What matters for the level and frequency of expected DCC voltage measurement is circled in red.

Table 10. Model 87 AC Voltage Function Specifications

Function	Range	Resolution	Accuracy					
			45 – 65 Hz	30 – 200 Hz	200 – 440 Hz	440 Hz - 1 kHz	1 - 5 kHz	5 - 20 kHz[1]
Ṽ [2,4]	600.0 mV	0.1 mV	± (0.7 % + 4)	± (1.0 % + 4)			± (2.0 % + 4)	± (2.0 % + 20)
	6.000 V	0.001 V	± (0.7 % + 2)					
	60.00 V	0.01 V						
	600.0 V	0.1 V					± (2.0 % + 4) [3]	unspecified
	1000 V	1 V					unspecified	unspecified
	Low pass filter		Same as 45-65 Hz	± (1.0 % + 4)	+1 % + 4 -6 % - 4[5]	unspecified	unspecified	unspecified

Example: Let's assume a 15 Vrms DCC voltage. The ± (2.0% + 20) means the reading might be off 2% of 15 Vrms which is 0.3 Vrms. And it might be off an additional 20 display "counts". Since the resolution for this range is 0.01, "20 counts" is 0.2 Vrms. The total error is the sum of those two tolerances which is 0.3 Vrms + 0.2 Vrms = 0.5 Vrms. So, the tolerance for a 15 Vrms reading is ± 0.5 Vrms. Now, that is going to be worst case (such as being at 20 kHz), and the meter will likely perform better for the DCC reading.

(continued on next page)

PRECISION is not accuracy although it sounds like it. It is really repeatability. Something can be very inaccurate, but if it produces the same reading over and over under unchanged conditions, it has high precision. If you weigh about 180 lbs. and get on a scale that says 150 lbs. but you step on it ten times and it always says 150 lbs., it has precision, but not accuracy. If you stepped on another scale many times and it said 175, 180, 186, 177, 181, etc., it has less precision, but is more accurate. "Precision" is sometimes infused into specifications to make something appear better than it is.

RESOLUTION is the smallest increment that can be displayed. Such as tenths, hundredths, thousandths, etc. More resolution does not necessarily mean more accuracy. However, typically equipment with higher resolution is more likely to also be designed to be more accurate. Higher resolution lets you see smaller changes more easily even if there isn't more accuracy.

FREQUENCY in multimeters can be confusing because all meters have a maximum AC frequency they can read accurately and only some also measure frequency directly. These are two completely different things. AC voltage can only be read accurately up to some frequency. Sometimes that frequency range isn't much such as "40 to 400 Hz". But if that same multimeter can measure frequency directly, it may have a specification for that like "5 MHz". The frequency counter specification has nothing to do with the upper frequency for AC voltage measurement. Most specifications shown on sales web pages and summaries do not mention the AC frequency range. So don't get confused if you see some AC voltage range and then just below it a frequency reading range. They aren't related.

SAMPLE RATE is a specification usually for digital storage oscilloscopes (although other measuring equipment might also work by taking samples). These oscilloscopes gather a number of readings into memory and then process that data and display it. The number of readings it can take in one second is the sampling rate. The rate is often in terms of millions of samples per second with the units MSa/s or a similar notation. Some oscilloscopes are even faster with sample rates of GSa/s (billions of samples per second).

The maximum frequency that can be accurately displayed is related to this frequency as well as how the software might try to figure out the waveform from limited samples. For example, the DSO211 has a sample rate of 1MSa/s and claims an analog bandwidth of 200 kHz. For a 1 kHz sine wave, there are 1,000 samples each complete waveform which is plenty enough to draw a nice sinusoidal waveform. But at 200 kHz, there are only 5 samples for each complete waveform. An algorithm will have a mathematical function(s) that will try to infer the waveform with such sparse data, it can't perform miracles. What is practical is somewhat subjective. But almost always less than claimed even for a sine way, and even less yet for a square wave.

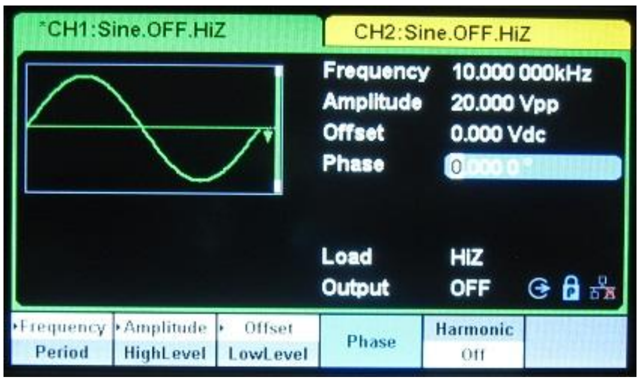
Another consideration is that some oscilloscopes with multiple channels spread the sampling across the number of channels you are using. For example, if you have a two-channel oscilloscope and are using two channels, each has one may have half the specified sample rate for the oscilloscope as a whole. This is just another thing to be aware of. If using only one channel, you may get an improvement by turning off the unused channel – or you may not.

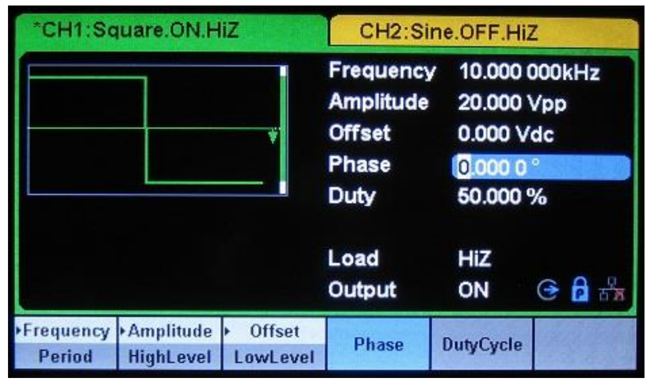
Some oscilloscopes use "interleaving" to help. On alternate gatherings of the sample, they measure with a very small phase shift. In this way, instead of taking the same set of readings over and over, they get more readings that help fill in the spaces. Like taking samples at times 1, 3, 5, 7, 9 etc. the first time and at times 2, 4, 6, 8, 10 etc. the next time.

Then there is something called the "Nyquist Theorem" that says you can reconstruct a sine wave so long as you sample at least twice the frequency. This is debated a lot and often works less well in practice than in theory. And that word "reconstruct" implies there must be fancy mathematical foot work to figure out the waveform from almost no data and some equipment doesn't do that as well as others. And it usually entails the huge assumption that the waveform will be a sine wave. And what if it isn't?

APPENDIX I: HOW TESTING WAS PERFORMED

Bench testing was done with a Siglent SDG2042X Arbitrary Waveform Generator at 10 kHz and at its maximum output voltage of 20 volts peak-to-peak for a sine wave and a square wave. Some testing used additional frequencies if determining the usable frequency response was needed. Generator screen shots:





A Siglent SDS1202X-E 200 MHz oscilloscope was used to display the waveforms shown in Appendix B: “What does the DCC waveform look like?”

Actual DCC voltage tests were performed at the Central Coast Model Railroad, part of the San Luis Obispo Railroad Museum. This is a Digitrax equipped layout.

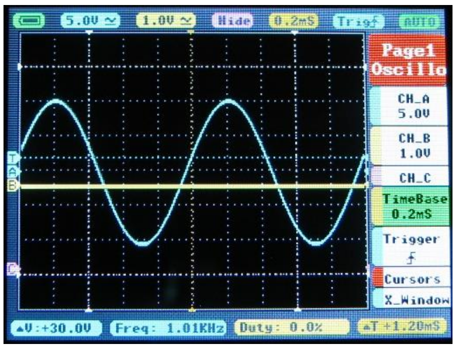
(continued on next page)

Bandwidth testing for oscilloscope functions was two-fold.

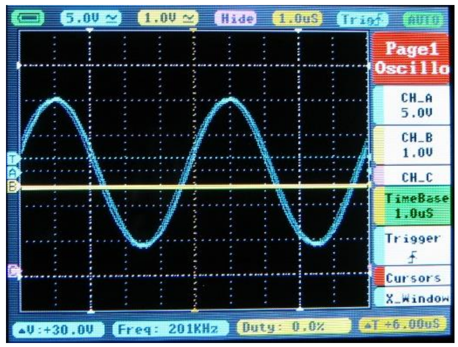
- A sign wave had to remain close to a correct amplitude AND present as a reasonable sine wave shape and all waves at the same height. (Varying heights or what would look like modulation at a slower sweep rate is an indication of a form of aliasing).
- A square wave had to remain close to correct amplitude AND have close to a vertical rising and falling edge. Perhaps no more than a five-degree tilt from a vertical line.

And yes, words like "close" are not really quantitative and are largely qualitative, so some of the conclusions are partially subjective.

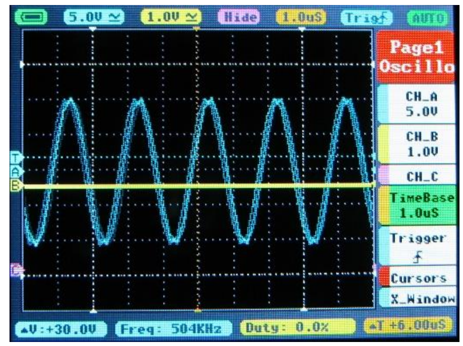
Example: The DSO212 claims 1 MHz bandwidth. 200 kHz (sine) and 100 kHz (square) seemed more realistic. The way DSO's "think" they tend to "do the math" better with sine waves than other wave shapes. So, you can often get a presentable sine wave at a higher frequency than for other wave shapes.



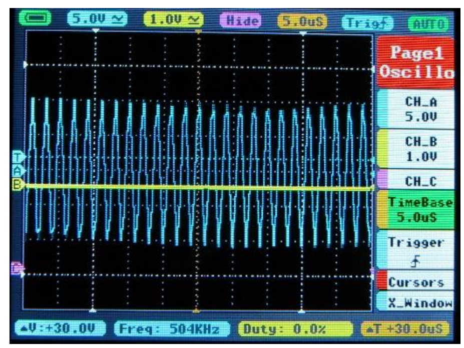
1 kHz 20 Vpp sine wave.
Looks good.



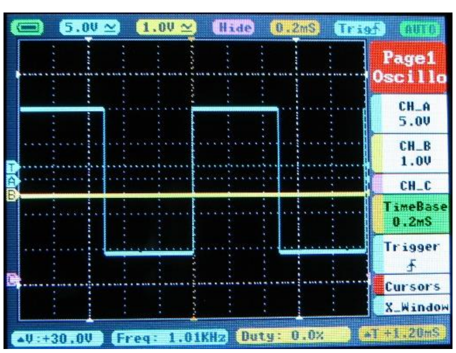
200 kHz 20 Vpp sine wave.
Looks OK, but a bit jittery.



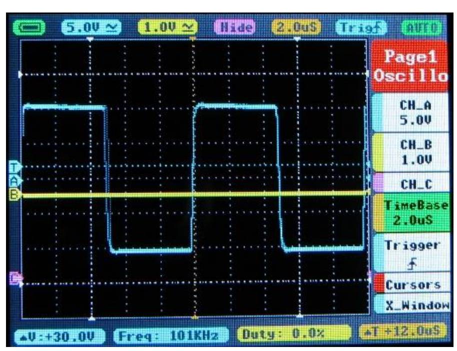
500 kHz 20 Vpp sine wave.
Distorted, undulating up and down.



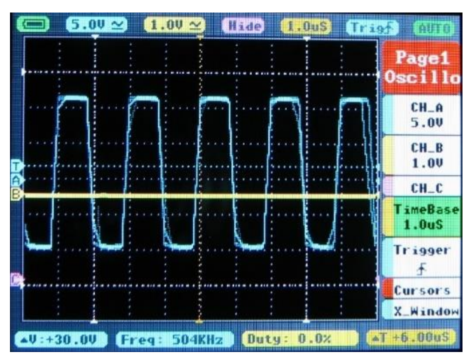
500 kHz 20 Vpp sine wave at slower sweep speed showing the waving artifact which is an aliasing problem.



1 kHz 20 Vpp square wave.
Looks good.



100 kHz 20 Vpp sine wave.
Looks fair, a bit trapezoid.



500 kHz 20 Vpp square wave.
Very trapezoid.