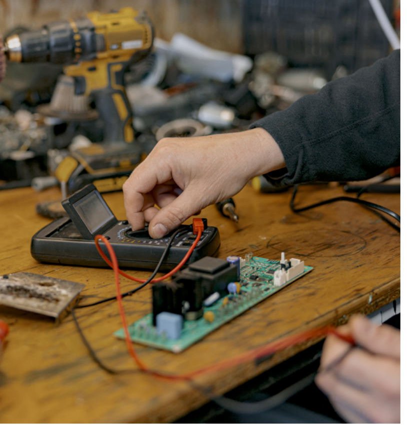
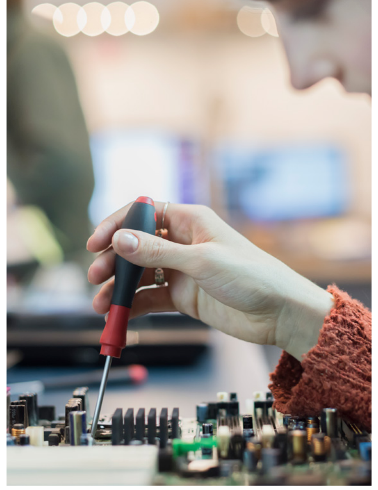
Tools, Test and Measurement | Volume 20

We get technical

DigiKey

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Editor's note

Welcome to the DigiKey eMagazine Volume 20 – Tools, Test and Measurement

This Volume will cover the essential tools, techniques, and technologies shaping today's electronics and maker landscapes. Whether you're a seasoned engineer, a passionate hobbyist, or somewhere in between, this edition has something for you.

We begin with a foundational look at spectrum analyzers, exploring what they are and the different types available, followed by a breakdown of high-voltage differential oscilloscope probes – both of which are critical tools for safe and accurate measurements. If you're assembling or troubleshooting circuits, don't miss our guide to crimping tool options that fit virtually any need.

For the makers and tinkerers, we're excited to present an introduction to G-code and ten essential commands every 3D printing enthusiast should know. You'll also find practical advice on choosing the right soldering iron when populating your PCBs, plus a hands-on feature on building 'A DIY Power Supply Unit for All Seasons'.

We will also explore PCB manufacturing techniques, with a spotlight on milling, and share some workspace wisdom with the benefits of using a rack to keep your bench organized and efficient. Lastly, we compare 8-bit vs. 12-bit oscilloscopes, showing how modern 12-bit scopes offer greater resolution and versatility for today's test and measurement demands.

As always, our goal is to empower you with practical knowledge, clear explanations, and tools you can use. Thanks for joining us – let's keep building, exploring, and pushing boundaries together.

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Tips for improved mechanical test and validation

Written by Electronic Specifier

NI CompactDAQ modular systems offer flexibility and scalability, allowing users to adapt to changing requirements. By expanding test coverage, the systems meet a wide range of application needs across different environments and distances.

This article is based on the Ethernet cDAQ-9183 (Figure 1, left) & cDAQ-9187 (Figure 2, left), and the USB-C cDAQ-9173 (Figure 1, right) & cDAQ-9177 (Figure 2, right) models of the CompactDAQ platform, showing the improvements these products provide as well as the features that make them superior enough to choose over similar devices.

Cost savings

CompactDAQ represented a cost-effective update to NI's popular USB cDAQ chassis, offering the lowest price in the current catalog for comparable products. Its modular design allowed users to add or swap modules to adjust the number of channels, sensor types, or resolution as needed. This reduced the need for future purchases and simplified modifications, all while using the same software stack. Users could easily scale their systems with CompactDAQ and the broader NI catalog.

Figure 1: The NI Ethernet cDAQ-9183 (left) and the NI USB-C cDAQ-9173 (right). Image source: NI

NI CompactDAQ systems can offer cost savings through a combination of factors, including streamlined, portable designs, the ability to digitize data closer to sensors, and the use of sensor-specific modules. This reduces cabling complexity and noise, making them a cost-effective alternative for benchtop measurements and distributed DAQ applications. NI's affordable and accessible list prices encourage customers to adopt DAQ systems.

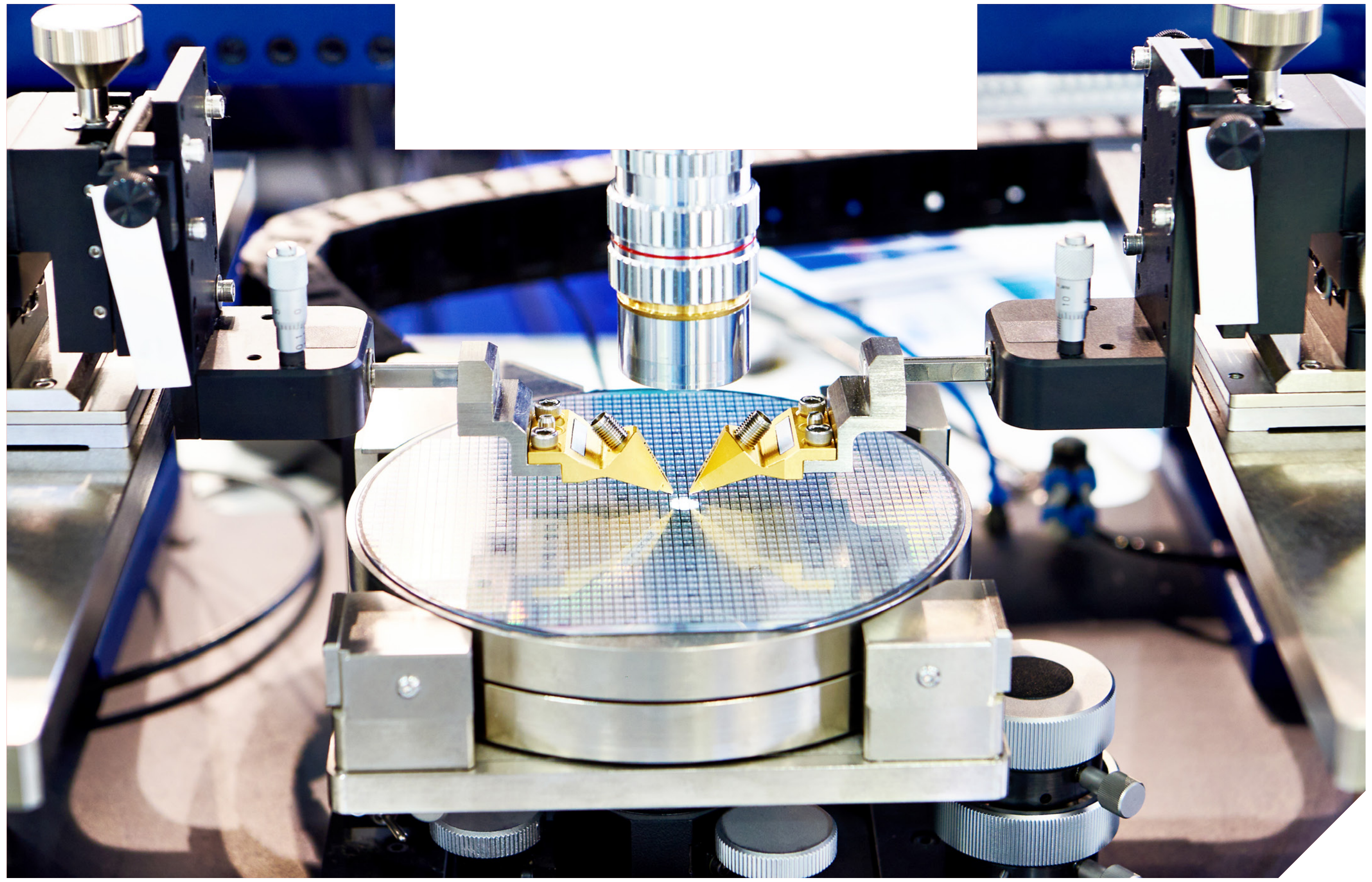
Better operating environmental specs

CompactDAQ is built for tough environments, with strong specifications for operating temperature, shock, and vibration. You can place it closer to the device under test (DUT) and run a single cable back to your PC – no need for a temperature-controlled lab with HVAC. For example, to meet the shock and vibration specifications of the cDAQ-9173, the system must be panel-mounted on a flat surface, with ferrules affixed to terminal line ends and an NI locking USB cable in use.

Designed to be both rugged and portable, CompactDAQ works just as well in the field as it does in the lab. Its compact form factor means you can pack it in a suitcase or backpack and take it to a customer site. With shock ratings up to 50g and an operating temperature range from -40 to 70°C, it's well-suited to harsh locations such as oil and gas fields or heavy industrial environments.

CompactDAQ also provides

Figure 2: The NI Ethernet cDAQ-9187 (left) and the NI USB-C cDAQ-9177 (right). Image source: NI



detailed specifications needed to calculate absolute accuracy, including offset, gain, noise, temperature drift, and calibration intervals.

QR-code

The CompactDAQ family includes QR-code links on product for quick access to relevant documentation to help streamline the setup process, transforming into a new experience that allows for improved usability.

Flexible platform

CompactDAQ offers the flexibility to adapt as your testing requirements evolve. Whether you need to add more channels, introduce different types of measurements, or use software in various programming languages, CompactDAQ provides the tools to scale and adjust your system.

By combining measurement and control in a single platform, it improves both test capability and overall efficiency.

For portable setups or systems that undergo frequent reconfiguration, CompactDAQ supports modules with quick connection options. These simplify setup and reduce the time spent on repetitive wiring tasks.

Each module includes dedicated circuitry tailored to specific measurements – ranging from analog and digital signals to specialized sensor inputs – allowing CompactDAQ to support a wide variety of applications.

By combining measurement and control in a single platform, it improves both test capability and overall efficiency.

A key feature of the system is its three independent analog input timing engines. This enables the creation of up to three separate analog input tasks, each with its own sample rate and configuration. As a result, you can efficiently combine slow-changing signals, such as temperature, with high-speed measurements like vibration or sound. By running these tasks in separate loops or threads within a program, you gain precise timing control and can optimize performance across a diverse set of sensors.

Software stack

NI provides a comprehensive software stack to support test and measurement applications, designed to maximize productivity and streamline development across a wide range of use cases.

Among the most notable we can mention:

- LabVIEW is a graphical programming environment with unique productivity accelerators for engineers developing test and measurement systems.
- LabVIEW+ accelerates and automates measurement data insights with modularity/scalability and ready-to-use test data visualization, processing, and reporting tools.
- NI has free DAQ/Logging software, making it possible to build a real-time display and log data to Excel or an open binary file. (TDMS) NI also has well-documented APIs for C/C++ and Python with over 50 examples for each language.

Future-proof

Ethernet cDAQ is built to support modern testing needs with Ethernet connectivity and modular flexibility. For users requiring distributed data acquisition, CompactDAQ supports network synchronization over a single Ethernet cable using time sensitive networking (TSN). TSN allows you to synchronize multiple CompactDAQ systems with precision, ensuring that you accurately correlate measurements from different locations.

Modular I/O for future expansion

The modular CompactDAQ I/O system is a rugged hardware platform offering flexibility and scalability to suit a wide range of application needs. It allows you to connect the sensors and electrical signals specific to your requirements, with the freedom to customize the system as needed. Modules can be selected based on current demands and easily added or swapped as testing needs change, making CompactDAQ a versatile choice for evolving test environments.

Connect to your PC over USB or Ethernet

CompactDAQ connects via USB or Ethernet, offering flexible options to fit different environments and applications. USB provides a simple, plug-and-play experience that is ideal for portable, desktop, or stand-alone setups. Ethernet connectivity supports distributed measurements by connecting CompactDAQ to local or enterprise networks, enabling multiple systems to run from a single PC with an extended reach up to 200 meters.

Conclusion

NI offers a broad portfolio of CompactDAQ modular systems designed to support both lab and field environments in managing complex testing tasks with flexibility and precision.

From integrating sensor-specific modules to using snap-in connectors and QR codes for streamlined setup, these solutions help optimize test operations with ease.

As measurement and control technologies continue to advance, NI remains well-placed to support evolving requirements, enabling more efficient, adaptable, and sustainable data acquisition platforms.

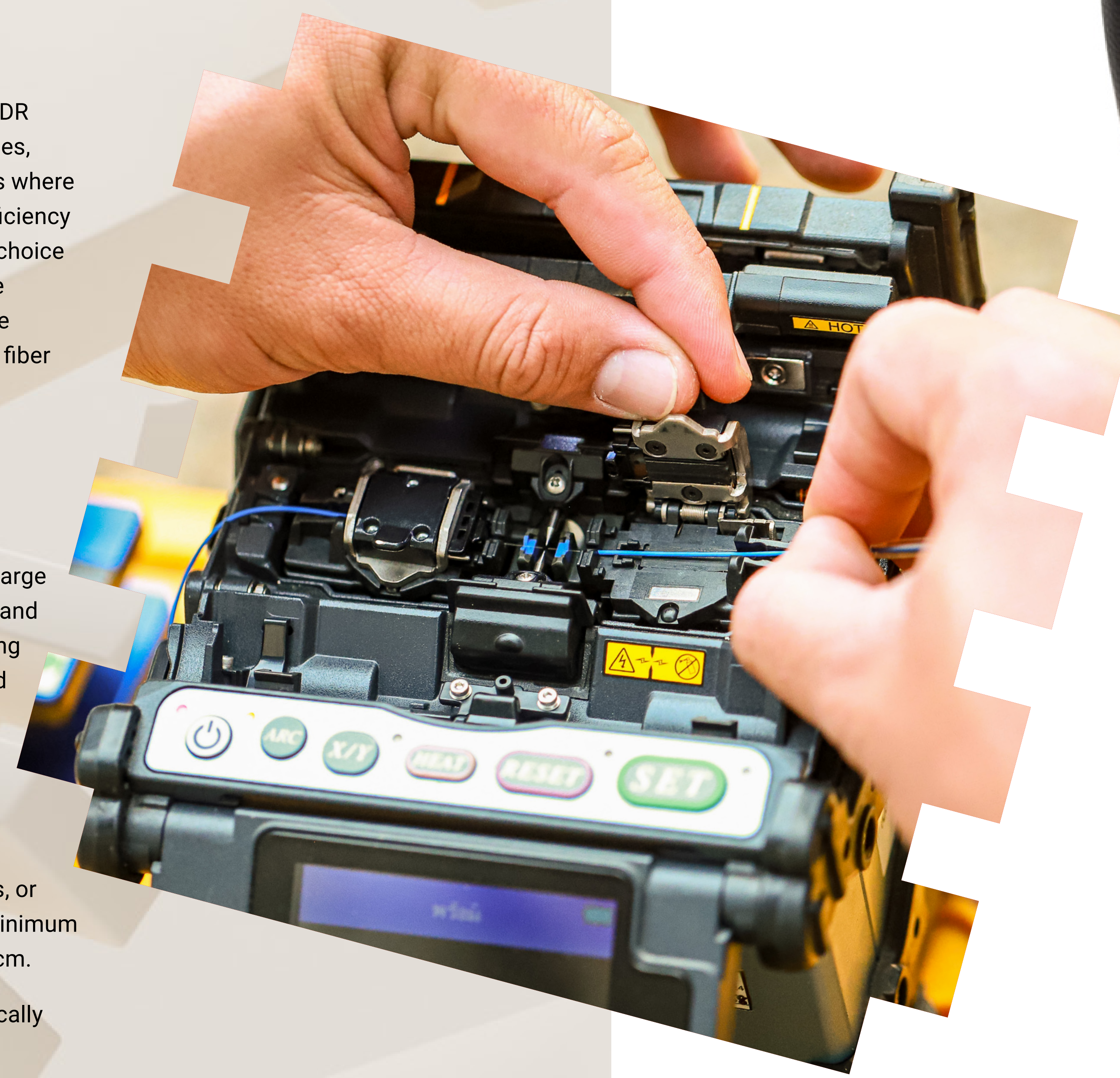
Testing with a professional multi-function OTDR-1500

Written by Electronic Specifier

This article focuses on the advantages of using a professional-grade optical time domain reflectometer (OTDR) over lower-cost alternatives. For critical or large-scale fiber installations, the initial investment is often offset by reduced downtime, fewer repeat site visits, and increased customer confidence.

[Jonard Tools](#)’ Professional Multi-Function [OTDR-1500](#) (Figure 1) is a handheld, all-in-one device designed for evaluating ‘Fiber to the X’ (FTTx) and access network construction and maintenance. It supports key tasks such as identifying fiber breakpoints, measuring cable length, and calculating relative optical power losses. The OTDR-1500 offers improved accuracy in dynamic range, event detection, and attenuation readings – helping engineers diagnose issues in fiber networks with greater confidence.

This professional-grade OTDR offers several key advantages, particularly in environments where precision, reliability, and efficiency are essential. It is a strong choice for those requiring accurate diagnostics and dependable performance in demanding fiber network applications.



Higher accuracy and resolution

The OTDR-1500 features a large dynamic range of 32/30dB and supports 256k data sampling points, making it well-suited for long-distance multi-branch communication network testing. It enables more accurate detection of closely spaced events such as splices, connectors, or breaks in the fiber, with a minimum sampling resolution of 2.5 cm.

Reflective event points typically occur at fixed connectors or fractured fiber ends and appear as peaks in the data. Non-reflective events include descending event points, ascending event points, and non-reflective fiber ends.

Figure 1: The Jonard Tools OTDR-1500 Image source: Jonard Tools

During data analysis, three types of threshold settings are used: loss analysis threshold, loss passing threshold (which includes joint loss and reflection loss thresholds), and fiber terminal threshold. For example, if the calculated connection loss at an event point exceeds the loss analysis threshold, the event is marked with an asterisk (*); otherwise, it is automatically ignored. Similarly, when the connection loss exceeds the fiber terminal threshold, the event point is identified as the fiber terminal.

Selecting the high-resolution test option increases the maximum number of sampling points to 256k, improving the instrument’s ability to resolve events occurring within a short distance.

Reliable fault detection

The OTDR-1500 can detect subtle faults that lower-cost units might miss, including microbends, macrobends, dirty or damaged connectors, and minor loss or reflectance issues such as poor splices or breaks.

When using the device, it is essential to keep both the

Figure 2: Event Viewer Interface Image source: Jonard Tools

instrument's optical output connector and the end face of the fiber under test clean. Contamination from substances such as ointment or other pollutants can cause measurement errors and, in severe cases, prevent the device from testing the optical fiber altogether.

Detailed and interpretable traces

This professional-grade tool provides clear, actionable data that can be easily analyzed and documented (Figure 2), including built-in analysis software or advanced PC software compatibility. Some of the events represented in a trace are:

- Distance: Measured along the horizontal axis, it shows the location of events within the fiber. Usually this is from the event point to the reference origin.
- Amplitude: Measured along the vertical axis, it shows the intensity of the reflected light, indicating the amount of signal loss at each point.
- Splices: These appear as peaks due to signal reflection. Higher peaks indicate poor quality splices.
- Connectors: These are similar to splices but generally include smaller peaks.
- Bends: These can cause gradual dips in the trace, with the severity depending upon the bend angle.
- Breaks: These show up as sudden drops in the trace, indicating complete signal loss.

> A distinctive feature of the OTDR-1500 is its ability to display results for two wavelengths simultaneously. By selecting the 'test conditions' button, users can typically choose to test at both 1310 nm and 1550 nm wavelengths.

Compliance with industry standards

Regulatory compliance is necessary for work that must meet IEC, TIA/EIA, or BICSI certification requirements, and is vital for enterprise networks, data centers, telecom backbones, and government contracts. For example, the safety level of the laser used in this device is: CLASS1 LASER PRODUCT: 21 CFR 1040.10 or CLASS 3A LASER PRODUCT: IEC 60825-1:Ed.2:2001

Advanced features

When set to Automatic test mode, the OTDR-1500 adjusts its settings automatically to test the connected fiber link. Once the test is complete, the device performs curve analysis and marks event points based on the configured loss analysis threshold. The event list then appears in the main operation window for easy review.

A distinctive feature of the OTDR-1500 is its ability to display results for two wavelengths simultaneously. By selecting the 'test conditions' button, users can typically choose to test at both 1310 nm and 1550 nm wavelengths. Having access to both wavelengths is useful, as certain faults are more easily detected at specific wavelengths depending on their nature.

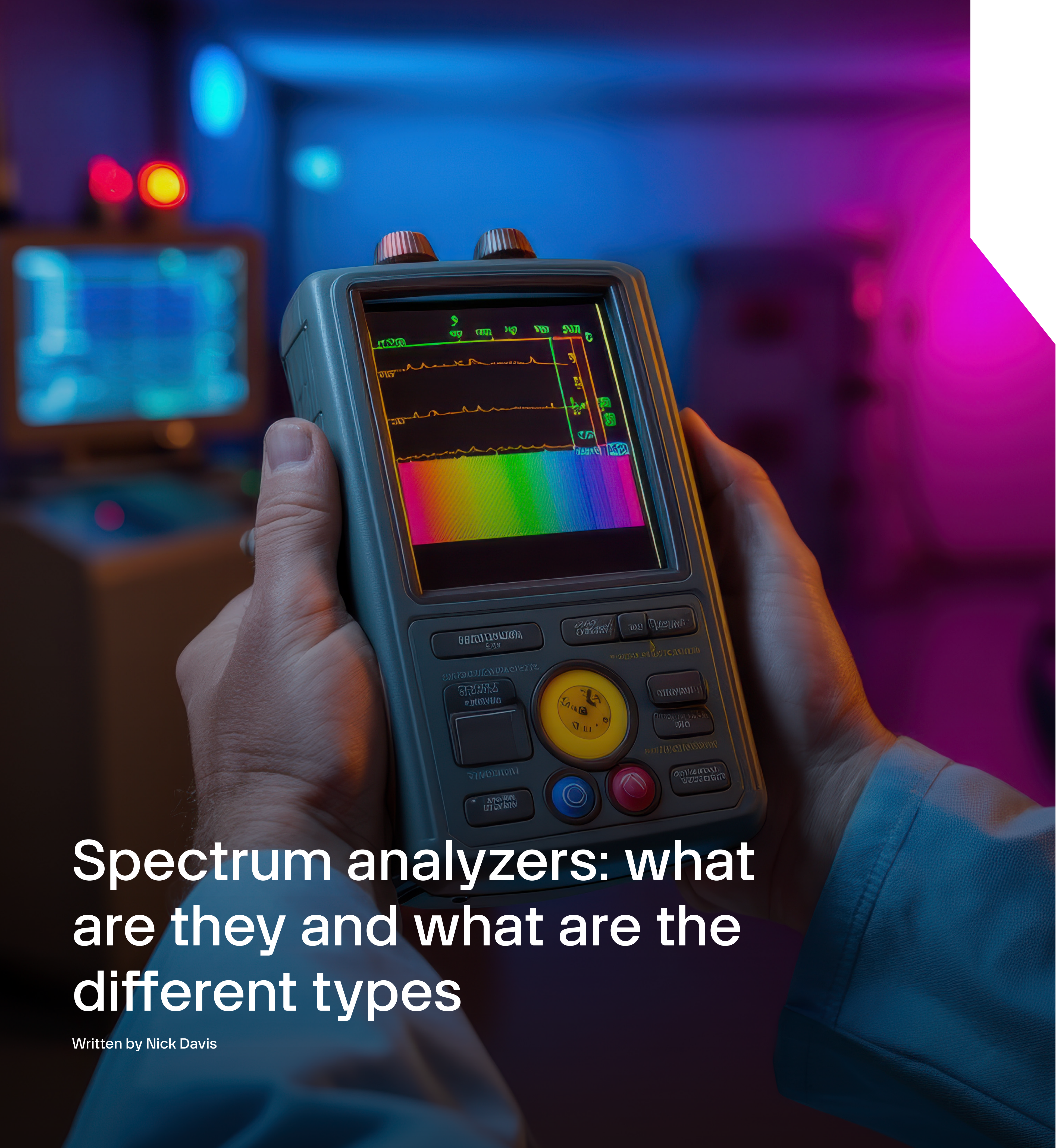
The device also generates a graphical representation to help identify faults within the fiber optic cable. The 'analyze' button on the screen provides access to this event map, which lists all detected events along the tested fiber. An integrated 'help' section guides users through interpreting the graphical data, reducing the chance of misinterpretation.

As a high-end device, the OTDR-1500 is more efficient, reducing time spent on troubleshooting and documentation. It features a rugged design and an intuitive UI, with an advanced anti-reflection LCD that ensures a clear and visible display interface suitable for field techs.

Conclusion

Professional tools such as the OTDR-1500 offer greater durability and reliability, supported by manufacturers with regular firmware updates, straightforward maintenance, and extended technical support. This makes them a sound long-term investment.

By delivering higher accuracy and resolution, detecting subtle faults, and producing clear, actionable data, these solutions provide an effective means to optimize fault diagnosis on large-scale fiber installations. As FTTx evaluation continues to develop, Jonard Tools remains well-placed to support access network builders and maintainers in achieving their objectives, enabling smarter, more efficient, and sustainable use of professional-grade OTDRs.



Spectrum analyzers: what are they and what are the different types

Written by Nick Davis

Are you an electrical engineer…? Have you ever used a spectrum analyzer?

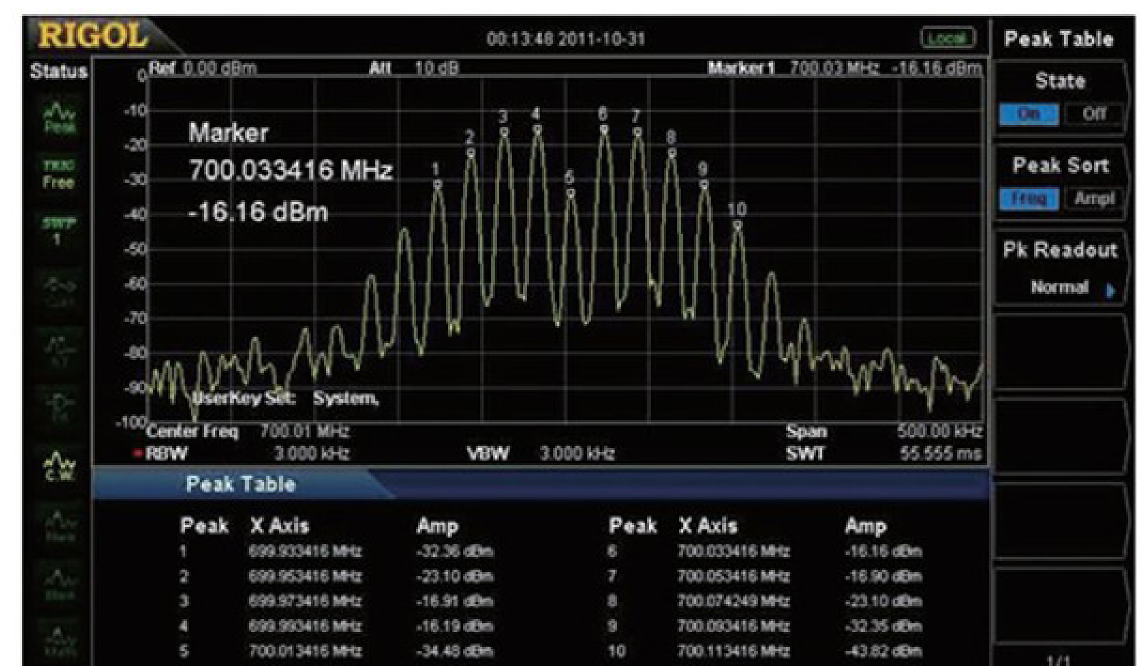
Most (and hopefully all!) electrical engineers – and perhaps many engineers from disciplines other than electrical – know what an oscilloscope is and have used one. I imagine the oscilloscope was introduced to the majority of electrical engineers during their freshman year of college. However, when dealing with spectrum analyzers, some practicing electrical engineers might not know what one is, let alone have ever used one.

What is a spectrum analyzer?

To many electrical engineers, a spectrum analyzer looks just like an oscilloscope except with more features and graphics. However, while both an oscilloscope and a spectrum analyzer display a signal's amplitude on the vertical axis, the difference between them is what's shown on the horizontal axis; an oscilloscope displays time, whereas the spectrum analyzer shows frequency. Figure 1 shows multiple frequency measurements being displayed on Rigol's DSA815-TG Spectrum Analyzer.

According to Keysight Technologies, a spectrum analyzer "measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. Its primary use is to measure the power of the spectrum of known and unknown signals." [2] In other words, a spectrum

Figure 1: Spectrum analyzers display frequency measurements on the horizontal axis.
Image source: Rigol Technologies



analyzer allows users to "analyze a spectrum," where a spectrum is defined as a collection of sine waves combined to produce a time-domain signal.

As an example, let's observe a signal on an oscilloscope (Figure 2).

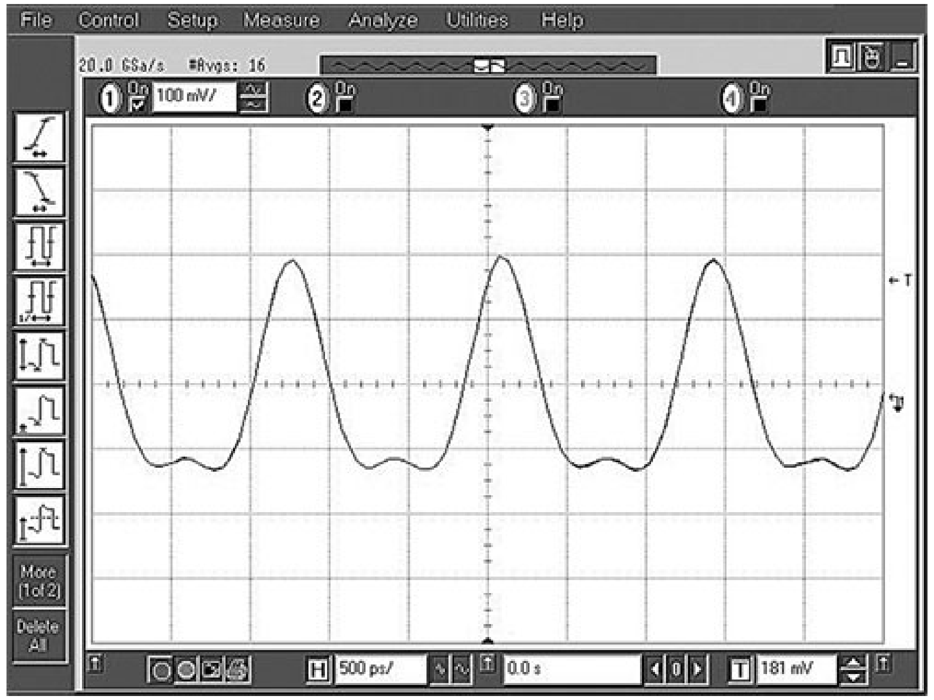


Figure 2: A signal displayed on an oscilloscope Image source: Agilent Technologies [3]

While this signal is obviously not a pure sinusoidal waveform, a spectrum analyzer determines each of the individual sinusoidal waveforms that make up this signal. And after the spectrum analyzer has identified these waveforms, it plots the amplitude versus frequency of each individual waveform. As you can see in Figure 3, the signal from Figure 2 is made up of only two sinusoidal waveforms.

Types of spectrum analyzers: technology types and form factors

There are two main categories of spectrum analyzers: swept-tuned analyzers and real-time analyzers, also referred to as real-time spectrum analyzers, or RTSA. Both types, which have been used for many years, display amplitude on the vertical axis and frequency on the horizontal axis, but how they go about "analyzing a spectrum" is what distinguishes them.

Given that a swept-tuned spectrum analyzer is "nothing more than a frequency-selective voltmeter with a frequency range that's tuned (swept) automatically,"[4] it's not at all surprising to realize that these traditional types of analyzers "descended from radio receivers."[4] And because swept-tuned spectrum analyzers "cannot evaluate all frequencies in a given span simultaneously,"[4] they are primarily used for measuring steady-state or repetitive signals. These analyzers have successfully served the compliance engineering community (think pre-compliance testing and EMC/EMI testing) for several decades.

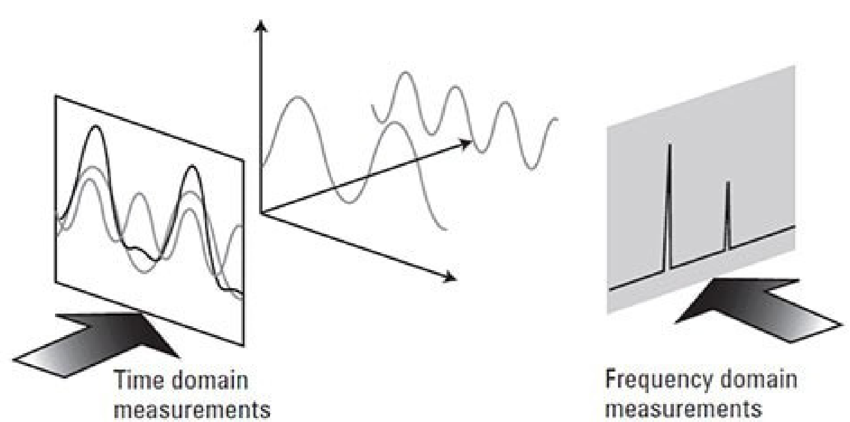


Figure 3: Relationship between a time domain signal (of which is displayed on an oscilloscope) and frequency domain signals (of which are displayed on spectrum analyzers) Image source: Agilent Technologies [3]

Benchtop models typically outperform their handheld counterparts but can carry a higher price tag.

Unlike swept-tuned spectrum analyzers, real-time spectrum analyzers can evaluate all frequencies simultaneously. A real-time spectrum analyzer works by first acquiring data in the time domain and then converting that data into the frequency domain by use of the fast Fourier transform (FFT).

Spectrum analyzers come in a variety of form factors, including benchtop (Figure 4), handheld (Figure 5), and portable.

Benchtop models typically outperform their handheld counterparts but can carry a higher price tag. Handheld spectrum analyzers are both less expensive and smaller, but they offer only a subset capability relative to benchtop analyzers. Portable analyzers are simply those (including some benchtop versions) that can be taken into the field thanks to their battery packs.

Conclusion

While all (we hope!) electrical engineers know what an oscilloscope is and how to use one, it can be surmised that only some electrical engineers have ever used a spectrum analyzer. Although oscilloscopes and some spectrum analyzers (the benchtop versions) may look similar in both form factor and display, they are quite different; a spectrum analyzer presents its acquired data in an amplitude-versus-frequency fashion, whereas an oscilloscope displays its information in an amplitude-versus-time method.

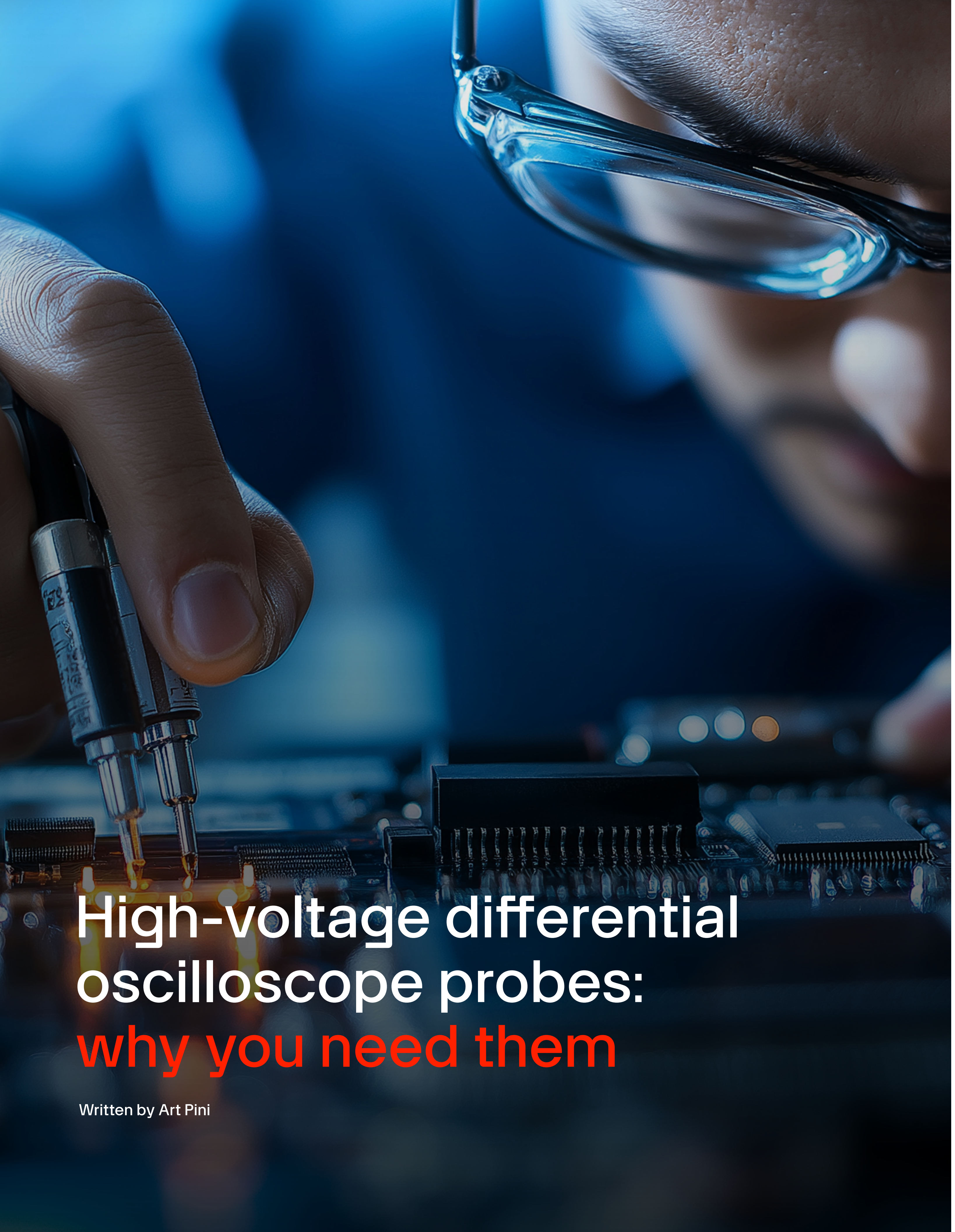
Figure 4: Teledyne LeCroy's T3SA3200 Benchtop Spectrum Analyzer offers a frequency range from 9kHz to 3.2GHz. Image source: Teledyne LeCroy [5]

Figure 5: Seeed Technology's RF Explorer Model 2.4G is a 2.35 to 2.55GHz Handheld Spectrum Analyzer. Image source: Seeed Technology

However, just like oscilloscopes, various spectrum analyzer types are available depending on one's needs and budget.

References

1. Rigol Technologies, "DSA800 Spectrum Analyzer Datasheet" (page 3)
2. Keysight Technologies, "What is a Spectrum Analyzer?"
3. Agilent Technologies, "Agilent Spectrum Analysis Basics" (pages 4-5)
4. Keysight Technologies, "Different Types of Analyzers"
5. Teledyne LeCroy, "T3SA3100/T3SA3200 Data Sheet" (page 2)



High-voltage differential oscilloscope probes: why you need them

Written by Art Pini

When it comes to taking measurements, modern power conversion devices using switching techniques require special handling, including the need for differential probes. This is because, unlike their analog predecessors, they don't employ transformers to reduce the line voltage. Instead, they use the rectified line voltage as the DC bus source (Figure 1). This topology has interesting implications with respect to grounding and differential signals.

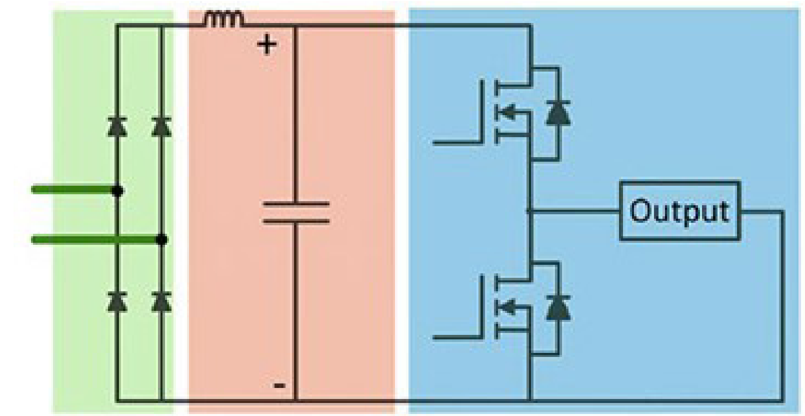


Figure 1: Shown is a functional block diagram of a switched-mode power converter for full-wave rectification of the line voltage to generate a DC bus voltage. Image source: Teledyne LeCroy

In the configuration of Figure 1, the circuit full-wave rectifies the AC line. For a 120rms AC line, the peak-to-peak voltage is 340 VAC. The full-wave-rectified voltage across the capacitor is 170 volts DC. A 240 volt line would double those numbers. This is used as the DC source for the switched-mode voltage regulator.

The power switches are configured in a half-bridge topology, with upper and lower switches alternately connected to the output. The voltage regulator (not shown) generates pulse width modulated (PWM) signals which regulate the output voltage by driving the gate-to-source voltage of the MOSFETs.

Why you need differential probes

Looking at Figure 1, there are some things to note. First, no point in the circuit is referenced to ground. The input line has a hot and a neutral wire. The neutral is ground referenced at its source and may be several volts off ground before reaching the powered device. The voltages in the power converter are essentially floating. Attempting to make a voltage measurement with an oscilloscope using a common passive probe requires connecting the oscilloscope ground somewhere. Connecting a ground lead to any point in this circuit could cause problems.

The second thing to note is that the upper MOSFET voltages are riding on the lower MOSFET's drain voltage. This is switching between zero volts and the DC bus voltage.

This presents another problem for a ground-referenced oscilloscope measurement.

The solution to this measurement problem is to use a differential probe.

Given the voltages encountered – up to 680 volts – it will have to be a high-voltage differential probe (Figure 2).

A differential probe measures the difference between the inputs. High-voltage differential probes include attenuators and overload protection on each input. Typical attenuation values are in the range

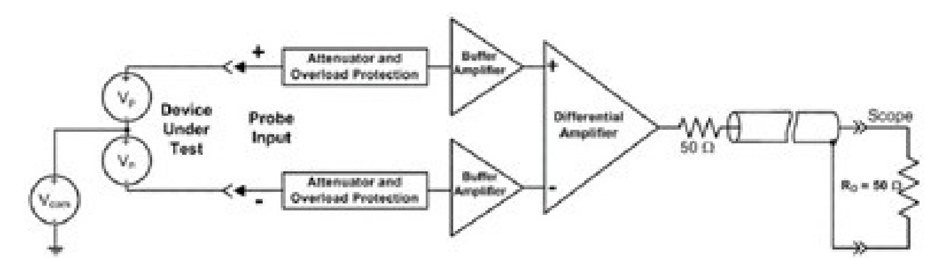


Figure 2: Shown is the functional block diagram of a high-voltage differential probe which does not require a ground connection as it measures the voltage difference between the + and – probe inputs. Image source: Art Pini

High-voltage differential probes are useful in situations where there is no ground reference and where the signal to be measured is riding on top of another, high-voltage signal.

of 50:1 to 2000:1. This gives high-voltage differential probes an input voltage range from 1500 to 7000 volts.

The device being measured is modeled as a differential source consisting of two differential sources, a positive component (V_P) and a negative component (V_N), as well as a common-mode component (V_{COM}). The common-mode component is shared with both the + and – inputs. The + input sees $V_P + V_{COM}$ while the – input sees $V_{COM} - V_N$. The probe, ideally, measures the difference between these input voltages or $V_P + V_N$, eliminating the V_{COM} term. Real-life differential probes attenuate the common-mode voltage but do not eliminate it completely. The differential probe's common-mode rejection ratio (CMMR), the ratio of the attenuated common mode signal to its unattenuated amplitude expressed in decibels (dB), indicates the effectiveness of the differential probe. This figure of merit is frequency-dependent, generally falling with increasing frequency.

How to use a differential probe

Let's look at using a high-voltage differential probe to measure the upper gate to source voltage in a 120 volt input, switched-mode power converter, similar to the one shown in Figure 1. The DC bus voltage will be about 170 volts. The gate-to-source of the upper MOSFET will ride on the switching signal of the lower MOSFET, a PWM signal switching between zero and 170 volts. The gate-to-source voltage will be on the order of 4 to 12 volts.

For this measurement, I recommend a Teledyne LeCroy HVD3106A-NOACC high-voltage differential probe. This 120MHz bandwidth probe has a voltage rating of 1000 volts RMS. Its differential voltage rating is 1500 volts (DC plus peak AC), well matched to even a power converter operating off of 240 volts AC. It has an offset range of 1500 volts, making it easy to vertically expand the measured waveform to see details. The probe has a CMRR of 85dB up to 60 Hertz (Hz) and 65dB at 1 megahertz (MHz). This means that the 170 volt common-mode signals will be attenuated by better than 65dB. The attenuated common-mode signal would have an amplitude of about 95 millivolts (mV). Since the gate-to-source voltage is on the order of 4 to 12 volts, the common-mode interference will have very little effect on the measurement.

Figure 3: Some of the high-voltage differential probe configurations for the HVD3000A series, which are offered with or without accessories and oscilloscope cable lengths up to 6m. Image source: Teledyne LeCroy

For higher voltages such as those associated with 1500 volt DC solar photovoltaic (PV) inverter measurements, I'd recommend the HVD3206A. It has a maximum differential voltage rating of 2000 volts (DC plus peak AC) and has the same bandwidth and CMRR as the HVD3106A-NOACC probe.

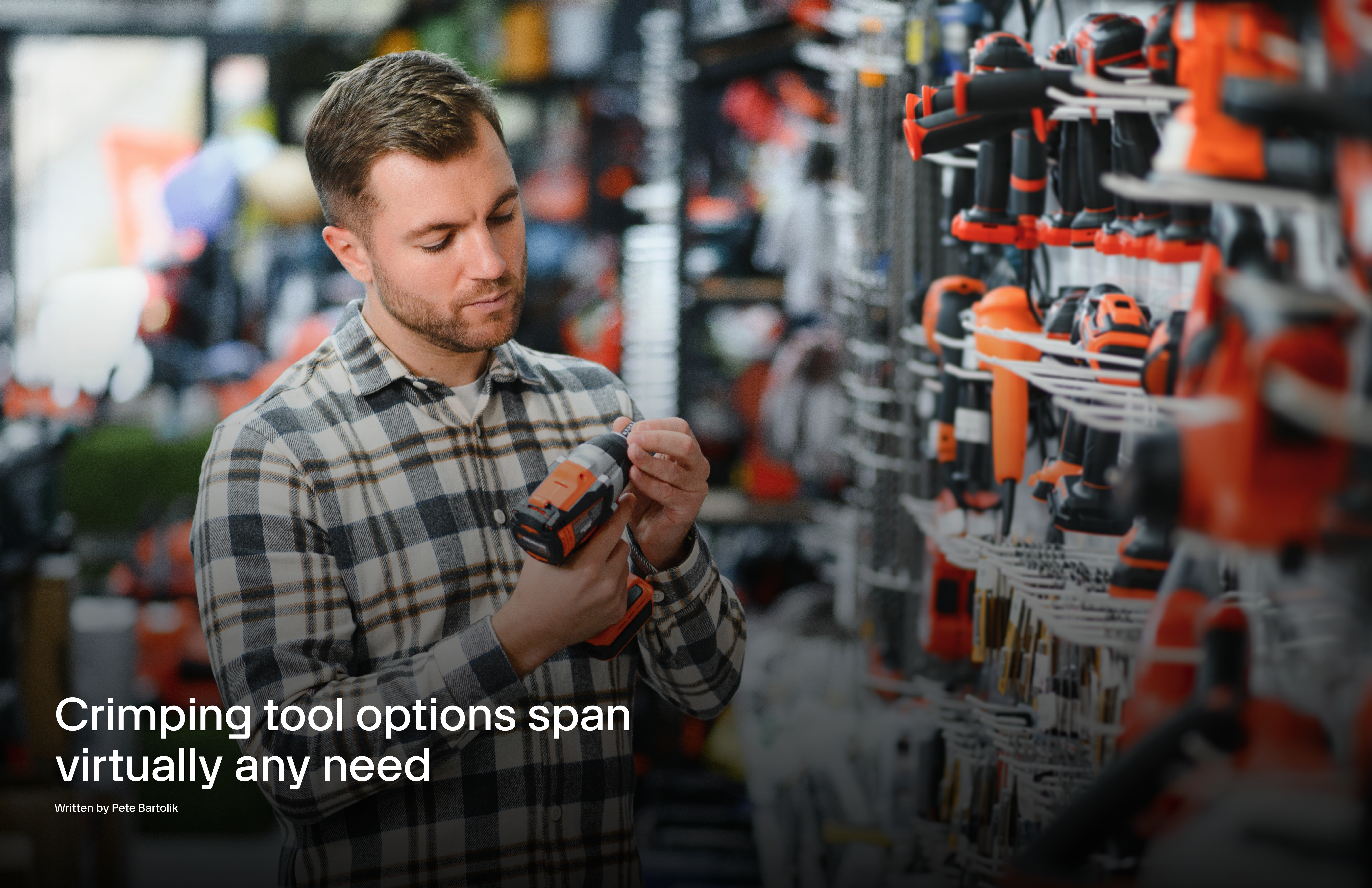
Finally, for large three-phase machines and their controllers, the HVD3605A with its maximum voltage input of 7000 volts (DC plus peak AC), is the high-voltage differential probe I'd recommend. The high voltage range is the result of the 200:1 or 2000:1 attenuator available in this probe. It has a CMRR of 85dB at 60Hz, 70dB at 10 kilohertz (kHz), and 64dB at 1MHz, and an offset range of 6000 volts.

The HVD3000A series probes all have gain accuracies of 1% or better, are available with and without accessories, and with oscilloscope cable lead lengths of 2.25 and 6 meters (m) (Figure 3).

Accessory kits vary with the model and include voltage-suitable clips or micro-grabbers.

Conclusion

High-voltage differential probes are useful in situations where there is no ground reference and where the signal to be measured is riding on top of another, high-voltage signal. For these situations, Teledyne LeCroy provides the HVD3000A series. All of these probes are well-matched to switched-mode power converter measurements requiring ground isolation. They are fully integrated into the Teledyne LeCroy oscilloscope operating system and are automatically sensed and scaled for accurate measurements.



Crimping tool options span virtually any need

Written by Pete Bartolik

Someday, perhaps, manually adroit robots will be able to overcome any and every electrical connection challenge for even the most ad hoc application or hit-or-miss prototyping effort. Until then – and probably long after that point – we'll still often rely on humans wielding manual or powered crimping tools to ensure high-quality connections that defy automation.

Automation works best where scale and uniformity can be applied to mass production, justifying the high costs of development, deployment, training, and maintenance. It does not work so well in situations that require flexibility and adaptability, such as prototyping and limited production runs, which can't promise ROI from investment in automated crimping systems. Field repair and maintenance is another area that is likely to resist automation far into the future.

Crimping is invaluable in the solderless joining and termination of conductors. Its roots are said to date back to ancient jewelry making and metalworking. In the modern era, it has had a momentous impact with its adoption across the ever-expanding range of electrical and electronic applications.

Soldering continues to be utilized in electrical engineering, of course, particularly in smaller-scale production runs. But crimping generally is faster and provides reliable, vibration-resistant connections. That's why it's been popular across a broad range of automotive, aerospace, consumer electronics, and power applications

Selection criteria

As always, the needs of the application are the key determinants in selecting the appropriate crimping tool. But other key factors at play include budget, anticipated ROI, adaptability, and operator productivity.

Today, many types of crimping tools are available, most intended for specific applications. They are also available in versions that can be manually operated, powered by battery or AC, utilize hydraulic or pneumatic energy sources, and come in a variety of form factors, from portable to bench-mounted. Costs range from tens of dollars for manual devices to thousands for pneumatic-powered or automated solutions.

The lower cost of many manual crimping tools is an obvious benefit when vendors are unable to justify the price of more advanced options. But powered tools are likely to boost productivity in high-volume productions and improve the quality and consistency of crimps. In either scenario, ease of operation and ergonomics are important to ensure operators achieve the desired crimping results.

Crimpers to meet any needs

It's impossible to cover all crimping options here, but the following examples illustrate the range of tools available to meet operators' needs.

Klein Tools offers a popular, versatile ratcheting tool, the 3005CR (Figure 1). Designed for crimping insulated terminals to stranded copper wire, it has three side-entry cavities accommodating the most common wire gauges. The vendor says the rachet ensures a uniform crimp "every time."

Figure 1: The 3005CR ratcheting crimp tool. Image source: Klein Tools, Inc.

In the modern era, it has had a momentous impact with its adoption across the ever-expanding range of electrical and electronic applications.

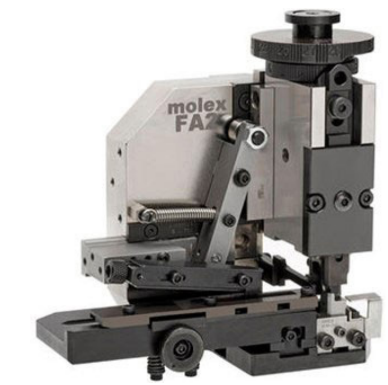
Figure 2: Klein Tools' VDV226-110 tool for stripping and crimping twisted pair wiring. Image source: Klein Tools, Inc.

Klein Tools also offers Pass-Thru modular crimpers, including the VDV226-110 (Figure 2), for cutting and stripping twisted pair cable and crimping it to its line of RJ45 CAT5E and CAT6 Pass-Thru connectors.

For coaxial cables, the ATHT-K3081 (Figure 3) crimp tool kit from Adam Tech includes a rachet crimper with six interchangeable dies, along with a cable cutter and stripper. The toolset comes in a portable storage case and is suitable for cutting and crimping various coaxial cable sizes.

Figure 3: Adam Tech's ATHT-K3081 handy toolkit for coaxial cable cutting, stripping, and crimping coaxial cable. Image source: Adam Tech

Figure 4: Molex provides the FA2 mechanical feed crimping applicator for workbench use. Image source: Molex



Molex, the manufacturer of connectors and cable assemblies, offers hundreds of crimping tools, ranging from the WM18730-ND basic hand crimper, to high-end mechanical feed applicators such as the FA2 series 900-2157860100-ND (Figure 4).

Another vendor with a wide range of crimping tools is Panduit, a global supplier of networking and electrical infrastructure products. Its CT-1701 is a crimp tool with a controlled cycle designed to ensure connections are fully completed

Figure 5: Panduit's hydraulic, battery-operated CT-2931/STBT can deliver 12 tons of force for crimping operations. Image source: Panduit

Figure 6: The 1208199-ND stripping and crimping solution from Phoenix Contact can process up to 1,000 operations per hour. Image source: Phoenix Contact

and uniform. At the high end of its product portfolio, the BlackfinÔ CT-2931/STBT (Figure 5) is a battery-powered hydraulic tool that can deliver a force of 12 tons and features a rotating flip-top crimp head.

Another high-end option is the Phoenix Contact CF 1000-series 1208199-ND (Figure 6). The AC powered, pneumatic operation machine automates stripping and crimping, processing up to 1,000 operations per hour.

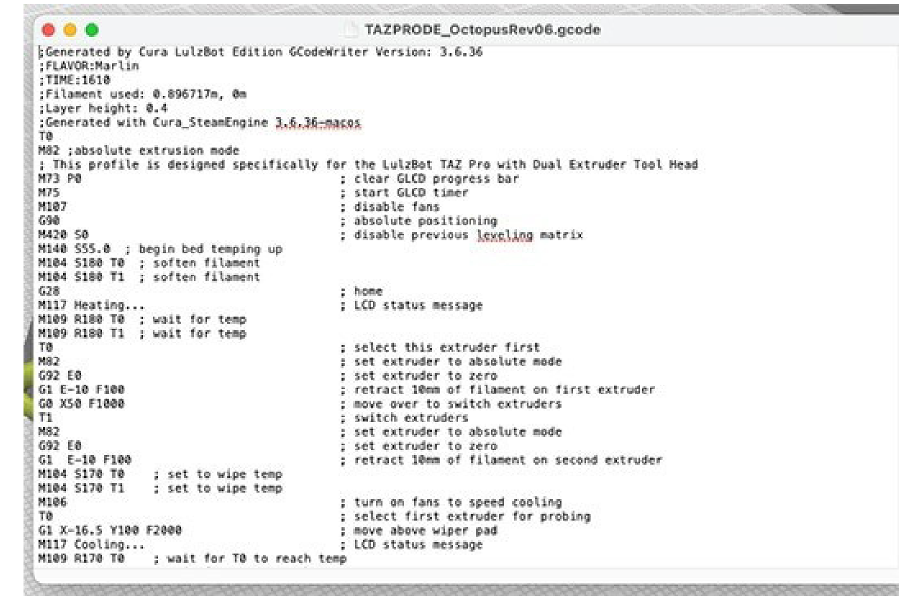
Conclusion

To sum it up, there is a crimping tool available to suit virtually any specific need. Whether that need is simple or complex, numerous vendors provide tools for a wide variety of crimping applications. This ensures product developers have almost unlimited flexibility in finding the right balance of cost, utility, ergonomics, and productivity to achieve the desired production results.

Introduction to GCode and ten essential commands for 3D printing

Written by Maker.io Staff

Image Source:
pixabay.com/photos/printer-3d-print-3d-printing-white-2416269/



TAZPRODE_OctopusRev06.gcode

```
;Generated by Cura LulzBot Edition GCodeWriter Version: 3.6.36
;FLAVOR:Marlin
;TIME:1610
;Filament used: 0.896717m, 0m
;Layer height: 0.4
;Generated with Cura_SteamEngine 3.6.36-macos
T0
M82 ;absolute extrusion mode
; This profile is designed specifically for the LulzBot TAZ Pro with Dual Extruder Tool Head
M73 P0                                  ; clear GLCD progress bar
M75                                     ; start GLCD timer
M107                                    ; disable fans
G90                                     ; absolute positioning
M420 S0                                 ; disable previous leveling matrix
M140 S55.0  ; begin bed temping up
M104 S180 T0  ; soften filament
M104 S180 T1  ; soften filament
G28                                     ; home
M117 Heating...                         ; LCD status message
M109 R180 T0  ; wait for temp
M109 R180 T1  ; wait for temp
T0                                      ; select this extruder first
M82                                     ; set extruder to absolute mode
G92 E0                                  ; set extruder to zero
G1 E-10 F100                            ; retract 10mm of filament on first extruder
G0 X50 F1000                            ; move over to switch extruders
T1                                      ; switch extruders
M82                                     ; set extruder to absolute mode
G92 E0                                  ; set extruder to zero
G1  E-10 F100                           ; retract 10mm of filament on second extruder
M104 S170 T0    ; set to wipe temp
M104 S170 T1    ; set to wipe temp
M106                                    ; turn on fans to speed cooling
T0                                      ; select first extruder for probing
G1 X-16.5 Y100 F2000                    ; move above wiper pad
M117 Cooling...                         ; LCD status message
M109 R170 T0    ; wait for T0 to reach temp
```

This image shows an example GCode program created using Cura.

GCode is one of the oldest programming languages, yet it still plays a crucial role in numerous industrial and desktop manufacturing machines around the world. We'll cover GCode and delve into ten essential commands you should know to step up your 3D printing game.

What is GCode, and why do 3D printers use it?

GCode, also known as Gerber or Geometric Code, is a standardized set of commands introduced in the 1950s to control CNC equipment such as drilling, milling, and cutting machines. GCode is very versatile, and aside from its use in instructing industrial CNC devices, it's also suitable for controlling other machines such as 3D printers, 2D plotters, or even regular inkjet printers you might find in a home office.

This versatility is possible because GCode contains only a set of lines where each line represents a single command, typically composed of an alphanumeric code and parameters. These instructions tell the CNC machine what to perform and are sent to a controller board responsible for interpreting the commands and performing the desired actions.

As the example shows, each line must contain exactly one command. However, there may be an additional comment explaining how a line of code functions. Such comments start with a semi-colon character, and the interpreting controller ignores everything following a semi-colon.

G-code remains widely used today because of its simplicity, broad compatibility, and extensive support from various manufacturers. The standardized set of commands also ensures that controllers can depend on a consistent framework. At the same time, slicer software – specifically for 3D printing – can confidently generate and send code files to 3D printers, knowing they will be highly compatible.

Essential movement-related GCode commands for makers

The first command you should know is G28. This particular command instructs the 3D printer to home its axes, returning the extruder and print bed to their reference positions. Doing so is necessary because the motors can't remember where they are between prints or when powered off, and issuing a G28 command ensures a consistent starting point for subsequent operations. You can use the command on its own to home all axes or together with the axis to home (e.g., G28 X0 to home only the X-axis).

Using G1, you can instruct the printer to move along one or multiple axes in a linear motion. Parameters control the axis and distance. For example, G1 X100 Y100 instructs the printer to move its X and Y axes 100 units. In addition to axes, G1 can also control the printer's extruder and feed rate. When the printer is in absolute positioning mode, G1 moves the axes to the specified position, which also applies to the extruder.

Many CNC machines, such as engravers, 3D printers, mills, and laser cutters, support standard and sometimes modified GCode commands. Image Source: pixabay.com/photos/engraving-on-metal-milling-details-4047890/

Issuing G1 commands to the extruder in absolute positioning mode may not be desirable, as it complicates calculations. Often, it's easier to have the extruder push out 1mm of the filament rather than telling it to advance the filament to a certain length, as would be the case in absolute mode. Therefore, you can instruct the 3D printer to switch to relative extrusion mode using M83 and revert to absolute filament positioning using M82.

G92 allows you to set the current position of the 3D printer's axes, and it's commonly used to define custom origin points or adjust the coordinates during the print process. G92 is, for example, also helpful in resetting the extruder to enforce the belief that it's at the origin in absolute positioning mode.

When discussing movements, you need to remember that any moving machine will eventually go out of alignment, regardless of how perfectly it was calibrated at one point. The M92 command allows you to set the steps per unit for any 3D printer axis, which helps calibrate the movement control by adjusting the number of steps required for the motors to move a specific distance. You can adjust this number by extruding a specified length of the filament and then measuring the extruded distance using calipers, for example. Then, change the number until the extruded length matches the expected value.

GCode, introduced in the 1950s, is a universal programming language used to control CNC equipment and other machines such as 3D printers.

Heating-related GCode commands for 3D printing

M302 is an instruction that lets you disable or enable extrusion when the printer's nozzle is cold. Typically, the 3D printer's controller doesn't allow cold extrusion to prevent damaging the extruder mechanism. However, for testing and calibration purposes, you may want to circumvent this safety mechanism by using the M302 command.

GCode programs for 3D printing typically contain either M104 or M109 in the first few lines, as these commands set the temperature of the printer's nozzle. M104 sets the temperature but instructs the printer to immediately continue with the next instruction, while M109 makes the printer wait until its nozzle reaches the target temperature.

Controlling a printer's fan using GCode commands

Lastly, some printers have fans that help them cool parts during critical points in the print process, such as when creating bridges. Blowing on the freshly placed material while bridging a gap may help create a better surface finish and prevent drooping. M106 allows you to control a printer's fan speed, and M107 lets you turn off the fan.

Summary

GCode, introduced in the 1950s, is a universal programming language used to control CNC equipment and other machines such as 3D printers. It consists of lines with alphanumeric codes and parameters the device's controller board interprets.

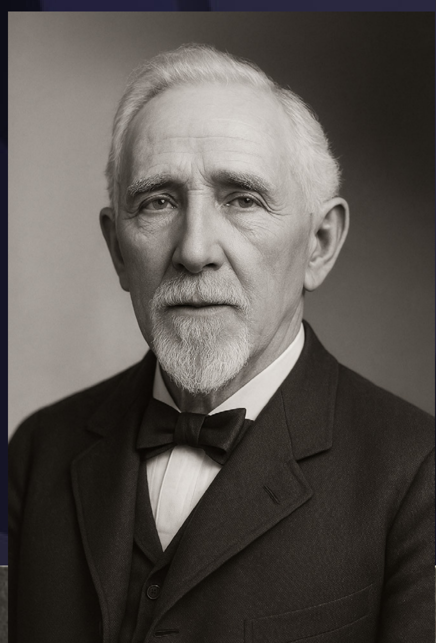
The commands discussed include G28 for homing axes, G1 for linear movement control, M83 for relative extrusion mode, G92 for setting positions, M92 for calibrating steps per unit, M302 for enabling cold extrusion, and M104, M109, M106, and M107 for temperature and fan control.

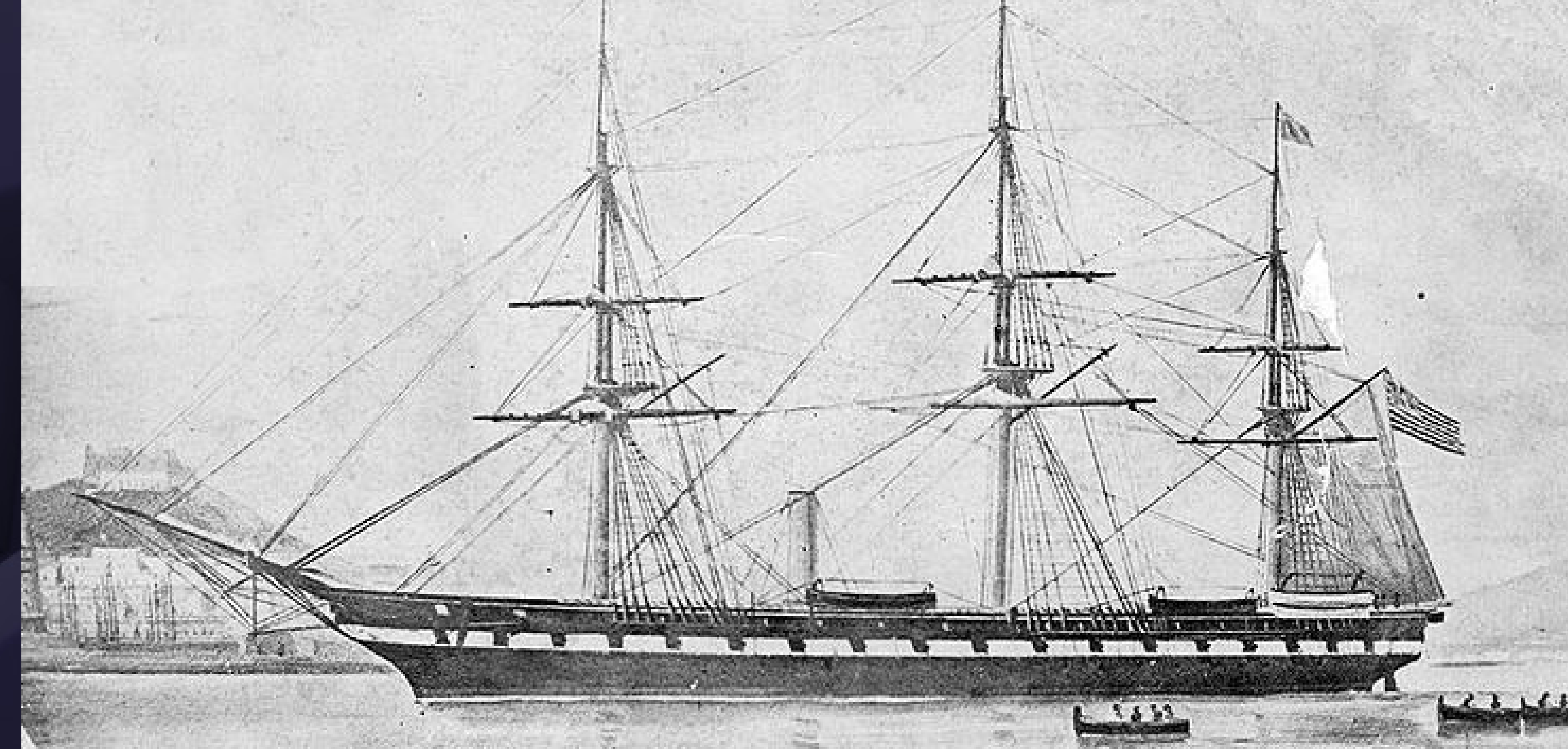
Still have questions about GCode? Visit the 3D Printing area of our TechForum to find more info and ask our experts!

Steel and steam: the most important tool of the 19th Century

Written by David Ray,
Cyber City Circuits

Dan Stillson





"The Roanoke was a frigate used for diplomatic missions before the Civil War."

Industrial ingenuity

In the second half of the nineteenth century, America was headlong into a technological revolution powered by steel, steam, and a new spirit of industrial ingenuity. Among the many mechanical breakthroughs of the era, few tools would prove as vital – and as enduring – as the Stillson wrench. Born from the challenges of maintaining steamships under fire and forged in the workshops of Boston, the Stillson wrench transformed pipe fitting forever. This story follows the remarkable journey of Daniel Stillson, a Civil War sailor turned inventor, and the creation of a tool so influential that it earned its place alongside the greatest innovations of all time.

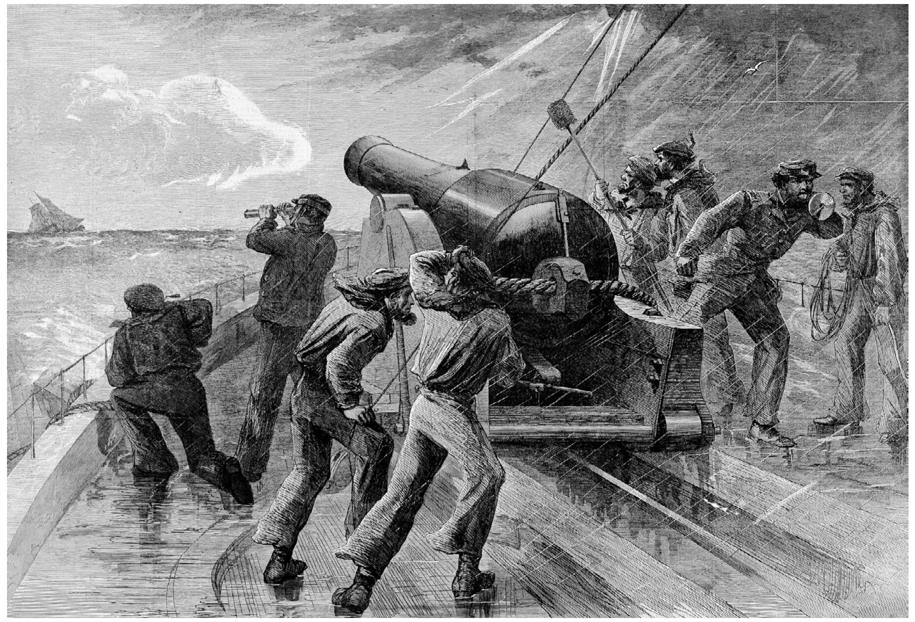
Daniel Stillson – civil war sailor

Daniel Stillson was born in Durham, New Hampshire, in 1826. He started his career as a machinist/mechanic at the Charlestown Navy Yard (Now the Boston Navy Yard). He became very skilled in working on steam engines. The late 1850s to the late 1870s was the golden age for steam-based technology. Steam dominated the industry until the 1890s when Frank J Sprague started mass-producing his electric traction motors.

In 1861, at the age of 35, Stillson enlisted in the Union Navy against the Confederates. History shows that he manned several different ships during his enlistment. He started on the steamship R.B. Forbes, but soon after, the ship was ran aground and wrecked after a devastating windstorm on February 25, 1862. Everyone survived and was transferred to other ships.

"The Battle of Hampton Roads, fought in March 1862, marked the first clash between ironclad warships."

Stillson was reassigned to the Roanoke, which was sitting on the sideline, in viewing distance of the 'Battle of Hampton Roads' and the Battle of the Monitor and the Merrimack. Soon after that, he was moved to another ship, the Somerset, patrolling the area surrounding Cuba, where he participated in the blockade and capture of Cedar Key, Florida. By August of his first year of service, he had become very ill. Records don't show what the illness that affected Stillson, but it may have been typhoid fever or dysentery. With this, he resigned from the US Navy to convalesce.



"The Battle of Hampton Roads, fought in March 1862, marked the first clash between ironclad warships."

Blockade runners

There was much action in the regions surrounding the Gulf, Louisiana, Florida, and Mobile, Alabama, which drew in the Union Navy. They regularly engaged in battles with blockade runners. Blockade runners were designed to move very quickly and stealthily. The British traded with the Confederates, supplying weapons, ammunition, clothing, cannons, etc., in exchange for resources like tobacco and cotton. Cutting off this trade route was key to the Union's strategy. Going into the Civil War, the Navy was split and ill-prepared on either side. Every effort was made to purchase as many steamships as they could.

The USS Santiago de Cuba was initially constructed in Cuba to establish trade routes to New York. It was officially launched on April 2, 1861, and the Civil War officially started ten days later, eliminating any hope for proper and safe trade routes to New England. Soon after, it was purchased by the Union Navy and put into service, assigned to blockading duty.

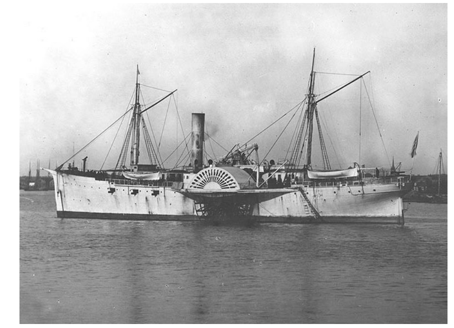
Boarding and commandeering a British vessel

After several months of recuperation, Daniel Stillson rejoined the Navy and was assigned to the USS Santiago de Cuba under the command of Commander Robert H Wyman. Here he met Colonel Levi Green, who was the First Assistant Engineer on the ship, and Stillson worked directly under him.

U. S. S. QUEEN.

Acquisition.—Captured, June 21, 1863, by the *Santiago de Cuba*. Purchased, September 29, 1863, from Boston prize court by Navy Department.
Cost.—$65,000.
Description.—
Class: Screw steamer; iron.
Rate: 4th.
Tonnage.—630.
Dimension.—Length, 168′ 8″; beam, 28′ 4″; depth, 13′.
Draft.—July 13, 1863, forward, 3′ 8″; aft, 9′ 9″.
Engines.—One; inverted, vertical, direct-acting. Diameter of cylinder, 40″; stroke, 42″.
Boilers.—One; water bottom, horizontal, tubular.
Battery.—August 13, 1863, 3 32-pdrs. 51 cwt., 1 12-pdr. rifle; December 5, 1863, 1 20-pdr. Parrott rifle, 4 32-pdrs. 51 cwt., 2 12-pdr, rifles.
Disposition.—Sold, tender after auction, October 16, 1865, at New York, by Admiral C. H. Bell, to Smith & Dunning, for $51,300.
Remarks.—She was the blockade runner *Victory*; name changed, August 1, 1863, from *Victory* to *Queen*. Commissioned, April 15, 1865; went out of commission, June 21, 1865, at New York Navy Yard.

"Pictures of the USS Queen are unavailable, but here is a description of the ship."



"The Santiago de Cuba was a converted trade ship. The ship was very fast and was best suited for blockade duty."

In June 1863, they captured a British blockade runner named 'Victory' after a long chase. The ship broke through the blockade surrounding the port of Wilmington with cargo that included cotton, tobacco, and turpentine, attempting to reach a port in the Gulf, likely Mobile Bay, Alabama. Colonel Green and Stillson boarded the ship and took control of engineering. The vessel was taken to Boston and made fit for Union service. Renamed the USS Queen, it became one of the fastest ships in the Union. Outfitted to serve as a supply ship, it navigated the Gulf while being based in New Orleans, Louisiana.

Stillson spent the remainder of his Navy career with Levi Green on the USS Queen.

Suggested thought exercise

Imagine the life of a fireman and engineer aboard a wooden steamship in the open ocean, constantly under the threat of cannon fire. Each shift brought the risk that a single well-aimed cannonball could rupture the coal bunkers or ignite the boiler fires, turning the vessel into an uncontrollable inferno. Under relentless stress, crews worked deep within the ship's belly – hot, cramped, often in smoky candlelight or utter darkness. Split-second decisions and constant vigilance were not optional; they were survival skills. Picture enduring these conditions not for hours but for weeks at a time, with little hope of rescue if disaster struck. He had just witnessed the Battle of the Monitor and Merrimack a year earlier and now he is boarding British privateer ships.

A lesser man would let anxiety and fear govern his abilities, but not Daniel Stillson.

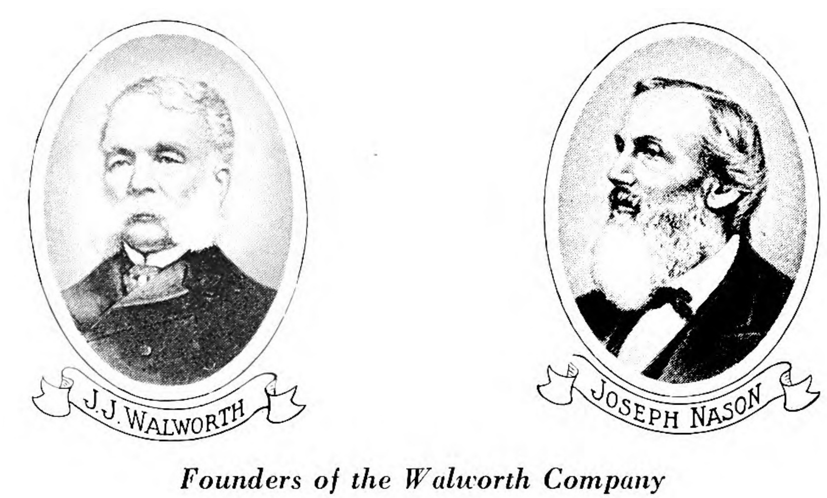
Now, back to the story.

Retro Electro fun fact: in 1853, Walworth Manufacturing installed the White House's first steam heating system during President Pierce's administration.

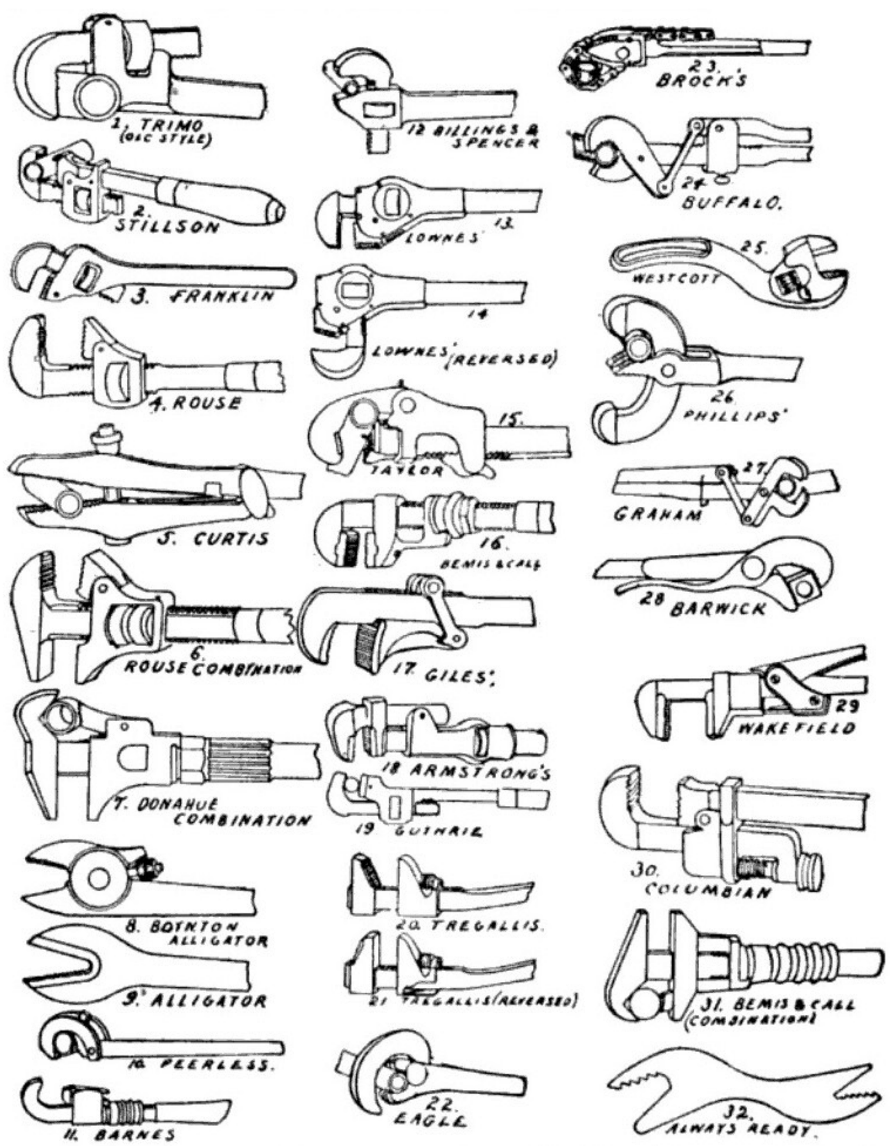
Walworth Manufacturing Company

Walworth Manufacturing Company was founded in Boston, Massachusetts, in 1842 by James Jones Walworth and Joseph Nason.

At that time, steam heating systems represented cutting-edge technology. Joseph Nason traveled to Great Britain to review this new technology and brought some of it back with him. Applying what he learned abroad, J.J. Walworth and Nason established Walworth Manufacturing Co. specifically to sell steam systems. The company initially focused on manufacturing iron pipes for household heating.



"J.J. Walworth and Joseph Nason founded Walworth Manufacturing."



"Wrenches came in all shapes and sizes, many trying to solve the same problem that the Stillson Wrench solved."

However, their expertise quickly expanded to include the installation of boilers, hot water, and steam heating systems in buildings, ships, and textile mills, making them the largest manufacturer of steam systems in the New World.

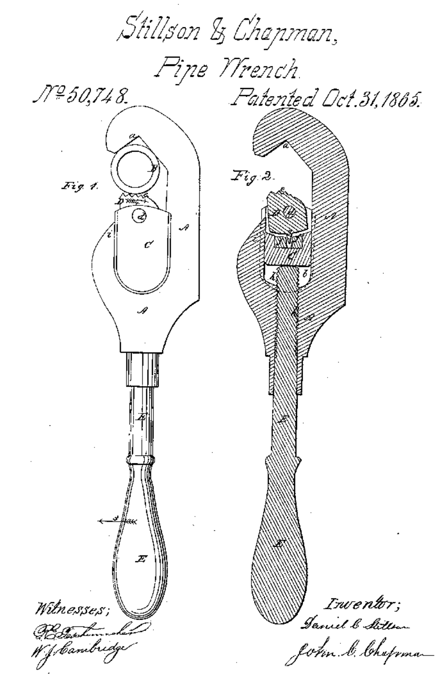
The Walworth Manufacturing Company collaborated with the US Navy in Boston during the mid-19th Century, particularly through its work on steam systems and fittings. Being based in Boston was ideal for the Navy since the Charleston Navy Yard was where much of the pre-war Navy was constructed. Since Stillson already had an established career at the Charleston Navy Yard before the war, it is reasonable to assume that he and members of the team at Walworth Manufacturing Co. were familiar and friendly with each other. There is a chance that he had already worked for Walworth before the war. The records of this time are sparse, but it sounds like it was a strong, connected ship-building community at the time.

Challenges with early pipe wrenches

This era marked the golden age of steam systems. While the practical electric motor was just around the corner, steam was the peak technology driving the Industrial Revolution during this time. Before the invention of the Stillson wrench in 1869, working with pipes was an arduous and frustrating task. The tools available were not designed for gripping round, smooth surfaces under heavy torque. Instead, craftsmen had to make do with general-purpose wrenches like monkey wrenches or adjustable spanners – tools suited for flat-sided fasteners, not cylindrical pipes.

Monkey wrenches, first patented in the 1840s by Loring Coes, were adjustable and sturdy, but their smooth jaws had little ability to grip the slick, round surfaces of steam pipes or gas fittings. Mechanics and plumbers often had to apply enormous hand strength to maintain pressure between the wrench jaws and the pipe while turning. If the user's grip slipped even slightly, the wrench would lose purchase, spinning freely or worse, rounding off and damaging the pipe.

"The 1865 patent for an early Stillson Wrench attempt."



The difficulty was compounded in industrial settings such as steamships, factories, and railroad yards. Pipes were often rusted, oily, or hot. Working conditions were cramped, with minimal lighting and limited access to fittings. Maintaining two-handed pressure on a traditional wrench was nearly impossible in these environments. A pipe that slipped out of a wrench's jaws could result in delays, injuries, or catastrophic leaks in steam systems – a genuine hazard in the high-pressure world of 19th-century industry. The sudden release of super-heated steam often resulted in lethal burn injuries to workers and bystanders.

Writer's note: information about Levi Green is hard to find, and some inaccuracies may exist. Many sources state that Levi Green left the Navy ahead of Stillson and assisted Stillson in getting a job with him at Walworth Manufacturing Company, but the Navy's own records indicate that Green did not leave the Navy until 1869. One thing is sure: They worked together, with Green as the Chief Engineer, at Walworth Manufacturing Co. in 1869.

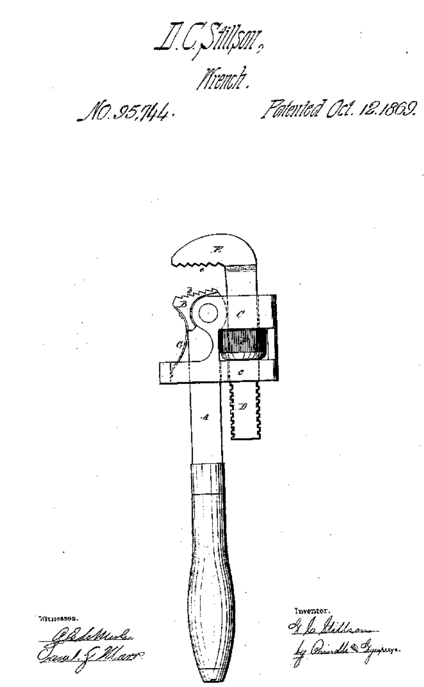
Post-war career

Following the war, Stillson resigned from the Navy and joined the team at Walworth Manufacturing. Soon after he filed a patent for a new pipe wrench in 1865. This particular wrench was made obsolete soon after, but it was the first to be adjustable with a self-tightening bite action, making it easy to use on rounded steam pipes. The patent was filed so soon after the war, it is easy to imagine that he was crafting and perfecting this tool, while servicing the steam engine and boiler on the USS Queen.

The legend of the Stillson wrench

The lack of a reliable, one-handed pipe tool also slowed America's expansion of steam heating systems, plumbing infrastructure, and industrial piping. Every installation, maintenance job, or repair involving pipes took longer and cost more labor before the wrench's release. The need for a better solution was obvious to anyone working with steam or water systems. Yet no commercially available wrench fully solved the problem until Stillson created a pipe wrench with serrated jaws, an adjustable threaded nut, and a self-tightening pivoting head that bit into the pipe harder the more torque was applied.

As a career expert steam pipe worker, he had a level of experience with his hand tools that most men will never have. Consider the smoke-filled boiler rooms in the wooden steamships in the middle of the night, with nothing but your hands and your tools. These



"The 1970 Patent for the Stillson Wrench"

Writer's note: the legend has been told in two different ways. In the 1920s, the Walworth Manufacturing Company launched an advertising campaign that claimed Stillson twisted a 1 ¼" thick pipe into pieces within minutes. This is the story that leading historians tell. However, in 1920, Howard Coonley, then president of Walworth Manufacturing Co, shared the story of the Stillson Wrench by stating that it took 'some days' to twist a piece of ¾" pipe. The strength difference between ¾" pipe and 1 ¼" pipe is significant. While it does sound like an impressive feat of the strength to twist any pipe, ¾" pipe appears more realistic. That being said, the writer is certain that Daniel Stillson was a very large and strong man who could bend a pipe with his bare hands, for all the writer knows.

experiences shaped his abilities and helped create the world's first truly one-handed adjustable wrench.

Over a period in 1869, Stillson crafted a fully wooden concept piece for a new wrench. Green and Walworth, both intrigued by this latest improvement on the wrench, authorized the machine shop to fabricate several functional pieces. After the wrench was completed, Walworth handed it off to Stillson along with a length of pipe and instructed him to twist it into two or break the wrench trying. Eventually, the pipe snapped, and Stillson brought it to Walworth's offices, where they quickly authorized the necessary funds for Stillson to file his own patent for this new tool.

It has been said that patent 95,744, 'Improvement in Wrench', was the most valuable patent of the nineteenth century.

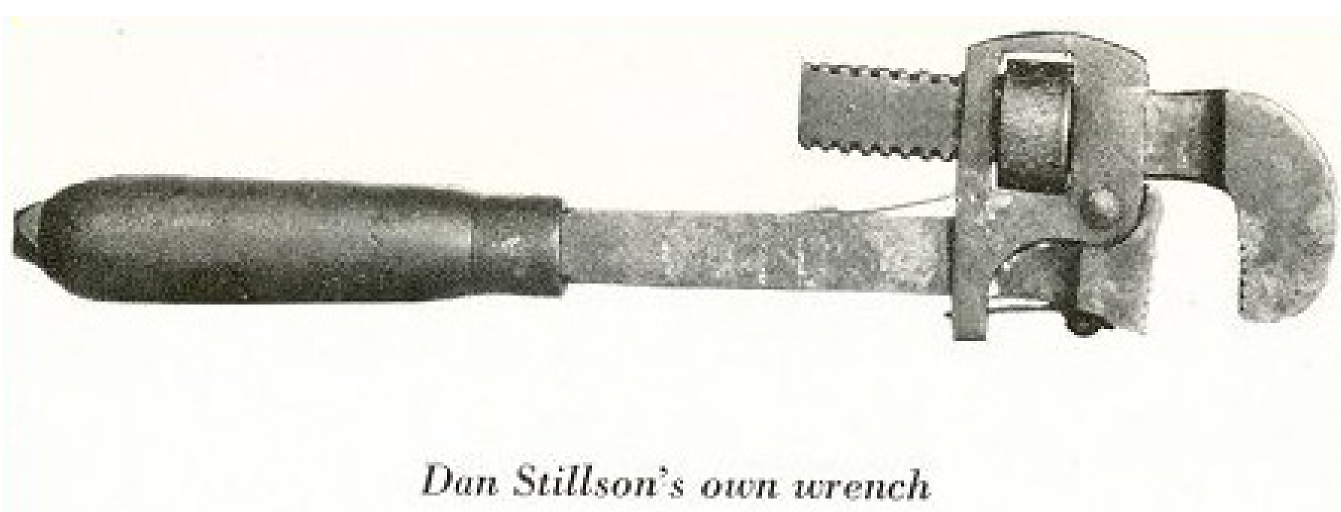
The patent was submitted in 1869 and was approved in 1870, but the tool does not appear in the 1870 Walworth Catalog.

The Stillson wrench

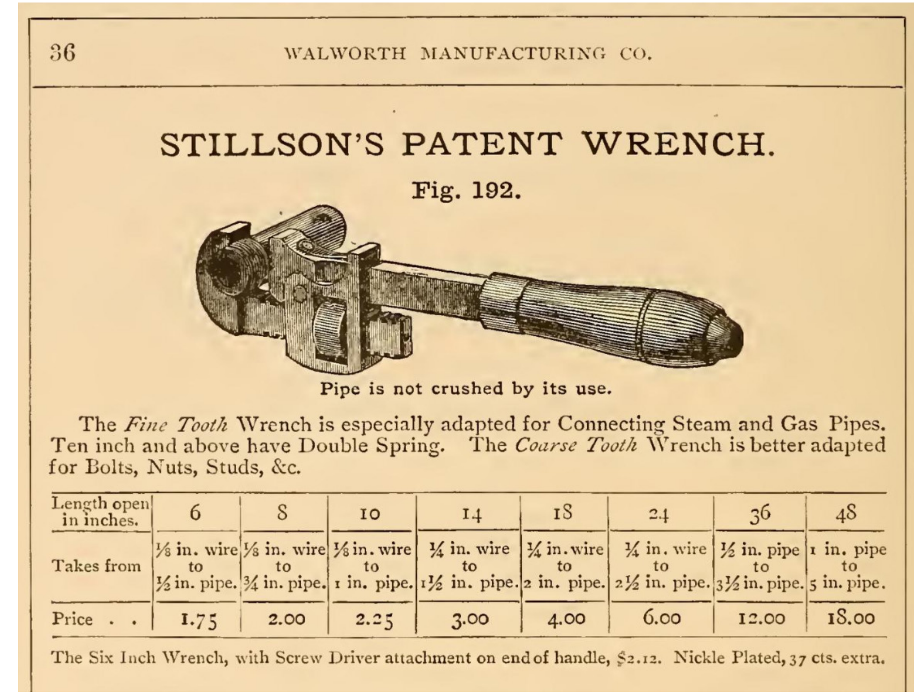
The first Stillson wrenches, built after Daniel Stillson's 1870 patent, were heavy, rugged tools that instantly stood apart from anything that had come before. Designed specifically for gripping and turning pipes, these wrenches combined raw mechanical leverage with a clever self-tightening action that made them revolutionary. According to the company's history, the wrench was added to its catalog in 1872.

"The Fine Tooth Wrench is especially adapted for Connecting Steam and Gas Pipes. Ten inch and above have Double Springs. The Course Tooth Wrench is better adapted for Bolts, Nuts, Studs, etc." – Walworth Catalog, 1878

At first glance, a Stillson wrench looks deceptively simple. A long, solid forged iron handle anchored the tool. At the head, a sturdy pivot frame held two jaws – one fixed,



Dan Stillson's own wrench



36 WALWORTH MANUFACTURING CO.

STILLSON'S PATENT WRENCH.

Fig. 192.

Pipe is not crushed by its use.

The *Fine Tooth* Wrench is especially adapted for Connecting Steam and Gas Pipes. Ten inch and above have Double Spring. The *Coarse Tooth* Wrench is better adapted for Bolts, Nuts, Studs, &c.

Length open in inches.	6	8	10	14	18	24	36	48
Takes from	⅛ in. wire to ½ in. pipe.	⅛ in. wire to ¾ in. pipe.	⅛ in. wire to 1 in. pipe.	¼ in. wire to 1½ in. pipe.	¼ in. wire to 2 in. pipe.	¼ in. wire to 2½ in. pipe.	½ in. pipe to 3½ in. pipe.	1 in. pipe to 5 in. pipe.
Price . .	1.75	2.00	2.25	3.00	4.00	6.00	12.00	18.00

The Six Inch Wrench, with Screw Driver attachment on end of handle, $2.12. Nickle Plated, 37 cts. extra.

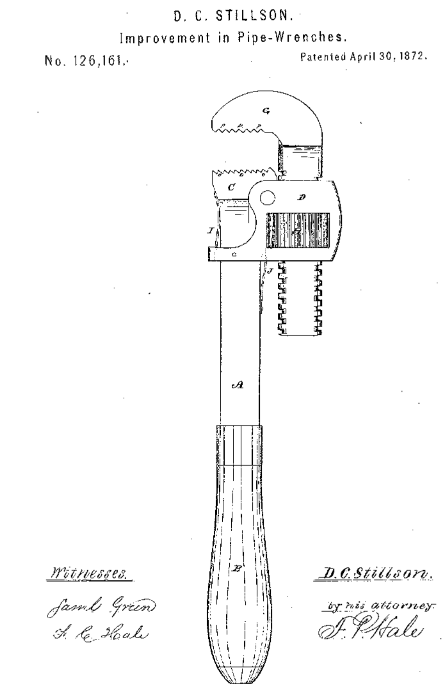
"Listing for the Stillson Wrench in a 1878 Walworth Catalog."

the other adjustable by a large knurled nut. Unlike earlier wrenches with smooth faces, both jaws were equipped with sharp, aggressive, serrated teeth. These teeth bit into the smooth surface of iron pipes, creating a mechanical lock that got tighter the harder you turned.

The early Stillson wrench feels like a pure industrial muscle in your hand. It was heavy, built to survive the brutal realities of 19th-century steam fitting and plumbing work. The forged iron handle was slightly curved, allowing users to generate more torque without slipping. Turning the adjustment nut gives a gritty, mechanical satisfaction, adjusting the jaws to the needed size. The pivoting head would flex slightly as force was applied, clamping the pipe with an unstoppable grip, enabling workers to focus on turning the pipe instead of wrestling with the tool. It was fast, efficient, and powerful. A good Stillson wrench could strip a fitting free in seconds when older tools would fail, slip, or damage the pipe, potentially injuring workers in the process.

The Boston fire of 1872

In 1872, there was a great fire in downtown Boston. Seven hundred and seventy-six buildings were damaged, and the Walworth building had to be dynamited and demolished. Before the demolition, they could recover much of the finished Stillson wrenches for the scheduled release. The need for better steam heating systems during the rebuild following the fire spurred growth in the business. Despite the catastrophic fire, the



"In 1872 Stillson patented some improvements, including a larger jaw and a tighter spring."

company exceeded a million dollars in revenue that year. Very quickly, the wrench became popular in the industry.

Retro Electro fun fact: Frank J Sprague attended the 1876 World's Fair, and influenced his entire career. Learn more in the Retro Electro article "Frank J Sprague and the Richmond Union Passenger Railway." (Link: emedia.digikey.com/view/251481832/17)

Additional improvements on the wrench

Over the next several decades, only a few improvements were made.

Eventually, a spring was added on the inside of the forge handle to return the pivoting head to a resting position. A look through all catalogs shows how companies have tried many different approaches to enhance the tool, but none were lasting. Today, you can still buy a wrench at your local hardware store that is virtually identical to the one sold by Walworth in the late 1800s.

"Daniel Stillson built his wrench well – so well, in fact, that though we have had experts working on it constantly, we have been able to make no improvements of importance." – Howard Coonley, President Walworth Manufacturing Co. 1920

Writer's note: the writer contacted the Central Public Library in Somerville, and nobody there could find any such plaque.

An unexpected connection at Walworth's wires

In this unrelated story, in 1876, while Colonel Green and Stillson managed the engineering department at the Boston Walworth central offices, Alexander Graham Bell first demonstrated the new telephone at the First World's Fair in Philadelphia. Between March and October, Thomas Watson and Alexander Graham Bell collaborated to design a practical voice device. When it was time to show investors that it worked over a distance, J. J. Walworth, owner of Walworth Manufacturing, installed the very first telephones between his office in Boston and his home two miles away. This arrangement was ideal because he already had telegraph lines connecting his home and the factory.

Neither Green nor Stillson is mentioned in the history of the first telephone call, yet they were both overseeing the company's engineering department at that time. It is not a stretch to believe that Daniel Stillson may have been involved in making the very first phone call.

Dan Stillson's late life

Soon after Walworth released the Stillson Wrench, Dan Stillson built a house in Somerville, Massachusetts, and moved his family there. This home is still standing today. It is said that, in his lifetime, he received up to $100,000 in royalties for his patent. He continued his life of innovation by patenting several other tools, fire extinguishers, plumbing faucets, water heaters, etc., earning nearly two dozen patents in his lifetime.

In retirement, he worked as a local politician and performed charity work. A plaque to him is on display in the Somerville Public Library, which was dedicated in 1884. Daniel Stillson passed away in August 1899 at the age of 73.

The life of the Stillson Wrench

The patent expired in 1886, and then the wrench was widely copied.

"Moore Drop Forge often placed advertisements for their Stillson Wrench in the same magazines and newspapers where Walworth was advertising their Genuine Stillson."

Competition exploded. This tool was such a great revenue stream entire factories were dedicated solely to its production, and when the patent expired, dozens of companies started knocking it off, flooding the market. For many years, the thought was that you didn't need to trademark something that was patented, so nobody trademarked the Stillson name until it was too late.

In the early 1900s, after J.J. Walworth's passing, the business was run by his son, A.C. Walworth. In 1905, he filed the trademark for the name 'Stillson' and even started a new company named Walworth Stillson specifically to sell this wrench. In the 1920s, Walworth made a strong commitment to the Stillson brand with large magazine advertising campaigns. The problem was that, in many magazine issues, you would find competitors selling the same wrench, which they also named Stillson. This rivalry made Walworth go in even harder trying to protect their brand with the 'Genuine Stillson Diamond' trademark and in 1925 they sued their largest competitor, Moore Drop Forge over trademark infringement over the 'Stillson' brand. In a landmark case that set a precedent that has effects even today, it was determined that in 1925 the term 'Stillson Wrench' had become a "generic descriptive term" for a type of pipe wrench. Walworth could not exclusively control the name anymore.

Advertising went from talking about the legend of the wrench to talking more about the superior quality with taglines like 'Buy the real thing', 'Walworth Quality', and 'Service you can trust', emphasizing the Walworth brand over Stillson.

The Stillson Wrench is still used today, made by dozens of manufacturers globally. You can buy one in the tools or plumbing section of any hardware store across the country, while today, they are simply referred to as a 'pipe wrench.' However, the reader can easily purchase one from the 1800s today for less than $20 online, which will be as good quality, if not better, than the $120 wrenches you can buy today.

Suggested reading

1. Tells How Stillson Wrench Was Invented (American Artisan and Hardware Record 1920-11-13: Vol 80 Iss 20) archive.org/details/sim_american-artisan-the-warm-heating-and-sheet-metal_1920-11-13_80_20/page/18/mode/2up?q=Daniel+Stillson
2. Pipe Wrenches – Tooling Around the Matheson History Museum mathesontools.weebly.com/blog/pipe-wrenches
3. The Stillson Pipe Wrench – Tool Lore www.youtube.com/watch?v=tQsKvmDExxc
4. Biography of Daniel C. Stillson – Kevin Bochynski www.bochynski.com/stillson/html/biography.html
5. USS Queen – Wikipedia en.wikipedia.org/wiki/USS_Queen
6. Catalogue and Price List 1870 - James J. Walworth & Co. archive.org/details/jamesjwalworthandcocatalogue1870/page/n7/mode/2up?q=stillson
7. Illustrated Catalogue of Wrought and Cast Iron Pipe 1878 – Walworth Manufacturing Company archive.org/detailsillustratedcatal00walw/page/36/mode/2up
8. A History of One Hundred Years of Valve Manufacturing – Walworth Manufacturing Company babel.hathitrust.org/cgi/pt?id=uiug.30112071165192&seq=1
9. Organization and Methods of the Walworth Manufacturing Company – James O. McKinsey archive.org/details/jstor-1822717/page/n1/mode/2up

1826

Daniel Stillson is born in Durham, New Hampshire.

1840s-1850s

Stillson works as a machinist and mechanic at the Charlestown Navy Yard (now Boston Navy Yard).

1861

Stillson enlists in the Union Navy at age 35.

Initially assigned to the steamship R.B. Forbes

Spring 1862

Stillson participates in blockading operations around Cuba and the capture of Cedar Key, Florida.

August 1862

Falls severely ill (possibly Typhoid Fever) and resigns from the Navy to recover.

Late 1862 / Early 1863

Recovers and reenlists in the Union Navy.

Assigned to USS Santiago de Cuba and meets Colonel Levi Greene.

June 1863

Stillson and Greene assist in capturing the British blockade runner "Victory," renamed the USS Queen.

Stillson serves on USS Queen under Greene for the remainder of his service.

1865

Civil War ends and Stillson resigns from the Navy.

Joins Walworth Manufacturing Company.

Files an early wrench patent (not the famous one).

1869

Designs and prototypes the iconic pipe wrench.

Greene and Walworth approve metal prototypes.

Stillson tests the wrench by twisting a pipe until it breaks.

September 13, 1870

U.S. Patent No. 95,744 issued for "Improvement in Wrench."

1872

Walworth building was destroyed in the Great Boston Fire.

Wrench formally appears in Walworth's catalog.

1876

Alexander Graham Bell's first telephone tests at Walworth.

Stillson and Greene oversee engineering at Walworth during this time.

Late 1800s

Stillson continues to patent various mechanical devices.

Engages in local politics and charity work.

1886

Stillson's patent expires.

Other companies begin producing "Stillson" style wrenches.

August 1899

Daniel Stillson dies at age 73.

1905

Walworth files trademark application for "Stillson" name.

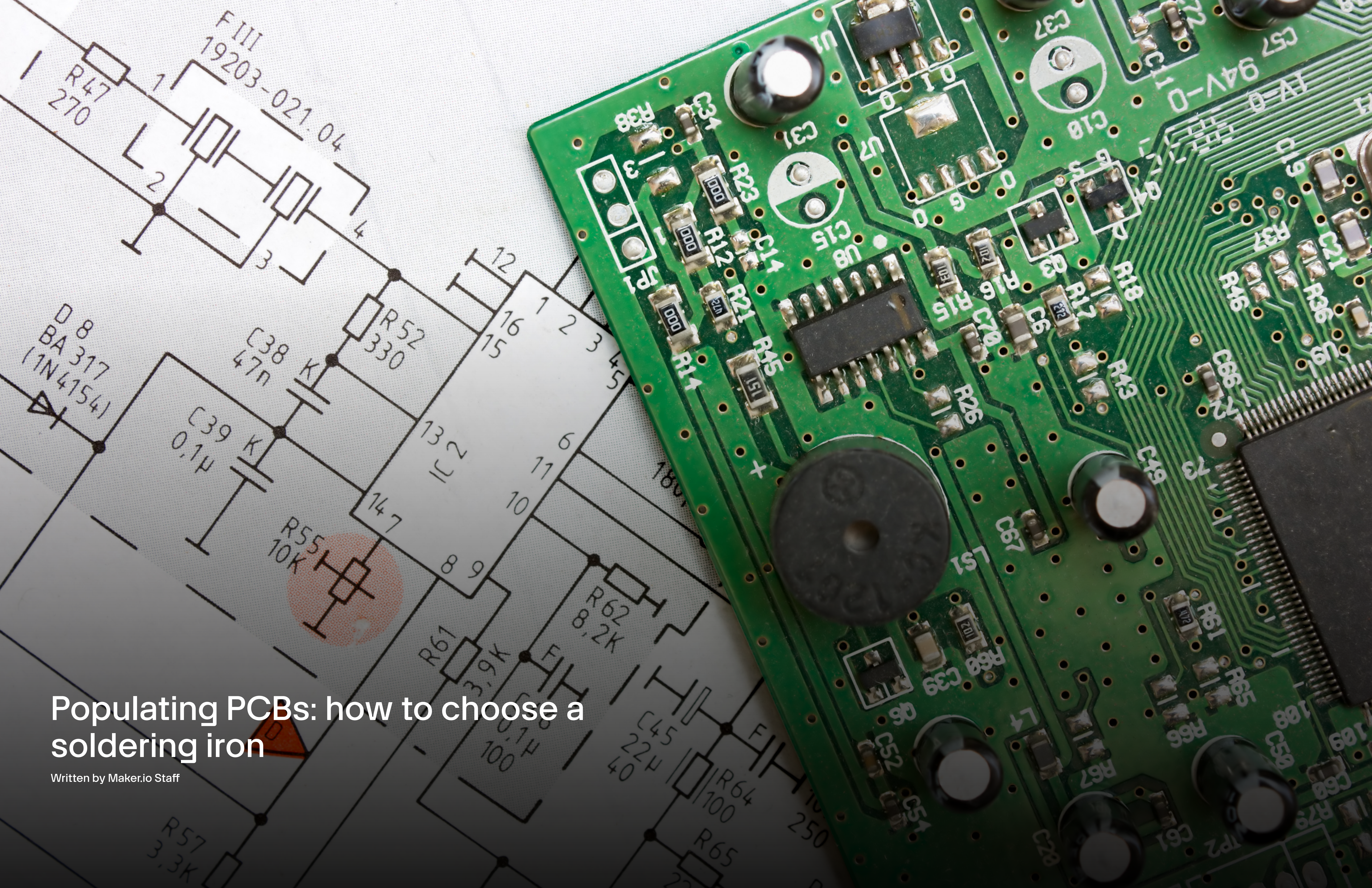
1920s

Walworth launches "Genuine Stillson" advertising campaign.

1925

Landmark court ruling: "Stillson" becomes a generic term.

Walworth loses exclusive rights to the name.



Populating PCBs: how to choose a soldering iron

Written by Maker.io Staff

There's no such thing as a universally perfect tool for soldering. What works well for one person might be unsuitable for others, and the suggestions in this article refer to my personal preference and experience.

When you're just starting to work on DIY electronics projects, you might wonder how to choose the correct tools to assemble custom PCBs. We covered some of these basics in our last blog in this series, and for this article, we'll talk about a particularly important detail: what soldering iron to use?

The large variety of different types, makes, and models of soldering irons can be overwhelming for beginners. But is it necessary to buy a high-powered and expensive soldering iron if you're a beginner? This article gives you an introduction to soldering irons and how to choose one that works well for you.

Different types of soldering irons

There's no such thing as a universally perfect tool for soldering. What works well for one person might be unsuitable for others, and the suggestions in this article refer to my personal preference and experience. It might take a while before you find a solution that works well for you. There are generally four types of soldering tools that are relevant for hobbyists and makers.

The simple classic soldering iron comes shaped like a pen with a cable attached to it. The tip heats up while the body remains cool enough to hold. These devices are typically cheap, reliable, and easy to use. However, they rarely offer any temperature control. They heat to a predetermined temperature and then self-regulate. Many such devices allow you to swap out the heated tip for different applications. This is often a preferred tool for soldering since it is very versatile and easy to carry around.

Suggested products:

- SOLDERING IRON 15W 120V

Soldering guns are another type of tool for soldering. However, I can't recommend using them for electronics if you're a beginner, as these tools usually heat quickly and aggressively, and you can easily destroy smaller components if you heat them for too long. Usually, these tools are used for cutting different materials and in woodworking. However, you can use them to solder electronics, and they certainly have their

A Weller-brand soldering gun. Source: SOLDERING GUN 200W 300W 120V

applications. As mentioned, they heat quickly and are typically also very powerful. These properties make soldering guns a fantastic choice for soldering large joints and heatsinks, for example.

Soldering stations are a more advanced version of simple soldering irons, as they offer a few additional features. Most notably, you can specify a target temperature, which enables you to work with many types of electronic components. If you have a workbench that allows you to set up a soldering station, I recommend you buy one, especially if you plan to solder more often. You should, however, invest in a decent one, as the more expensive devices are of better quality. Keep in mind that you aren't supposed to carry soldering stations around a lot, so the soldering iron might come with a shorter cable, which might make it more difficult to maneuver around a tight workbench.

Recommended products:

- SOLDER STATION 75W
- SOLDER STATION 58W 1 CH 110-130V

Hot air systems and rework stations are mainly intended for professional use and to repair PCBs. I can't recommend that you use these systems as a beginner, not only because they're typically more costly than a good quality soldering iron or soldering station. Besides that, these systems can be rather complicated to work with if you're a beginner. Hot air stations, however, are great for working with SMD parts.

What to know about power ratings

As we've seen so far, various soldering tools have different uses, strengths, and weaknesses. So, before you look into buying one, evaluate your situation and how you plan to use your new tool.

Next, you'll have to consider the tool's power rating. I use a 25W soldering iron, which is suitable for a wide range of soldering jobs. However, it might be a bit too powerful for beginners, and I'd recommend that you buy a 15 to 20W model at first and see how that works for you.

Regardless of the wattage, you'll want to buy a soldering iron that can reach temperatures between 300 and 400°C (570 to 750°F). The temperature setting is where soldering stations are ahead of the cheaper competition, as you can easily vary the temperature for different applications and jobs.

Accessories

This section mainly applies to the simple soldering irons and guns. Some of them come with accessories included in the package. However, some more cost-effective options might require you to get some additional extras that make it easier to work with the device. I recommend investing in a proper metal stand that also offers a space for a small cleaning sponge. You can also get a more sophisticated cleaning accessory that uses brass wool to clean the soldering iron tip.

Recommended products:

- SOLDER STATION 58W 1 CH 110-130V
- SOLDERING IRON STAND

A typical soldering station that offers more features than a simple soldering pen. Source: SOLDER STATION 75W

Make sure to invest in a good quality stand when you opt for a soldering pen. Good soldering iron holders are sturdy and offer a space for a cleaning sponge or brass wool. Source: SOLDER STATION 58W 1 CH 110-130V

Summary

Choosing a soldering iron is a very personal thing. There's no one-size-fits-all solution that'll work in every application and for every user. You'll most likely have to try a few different ones before you find one that works well for you. This article has covered some good rules of thumb: ensure that the tool has an exchangeable tip and doesn't go too high on the power rating. Usually, 15 to 25W is sufficient for beginners and hobbyists when working with electronic components. You should also invest in a good quality stand and cleaning supplies if your soldering tool doesn't include them in the package.

A DIY power supply unit for all seasons

Written by Clive “Max” Maxfield

I have a friend (stop laughing; it’s true!). We will call him Joe (because that’s his name). To be honest, I no longer recall how we met, although I do know it was via the Internet. Joe and I were email chatting about this earlier today as I pen these words. Joe says he has emails dating from April 2006, but these already reflect an ongoing discussion, so we’ve decided to set the date we were introduced as April 1, 2005. That means, in just three years, we will have known each other for two decades (break out the party hats). Apart from anything else, this made me realize that I’ve met a large proportion of the people I now count amongst my closest friends via the internet, which certainly gives one food for thought.

Have you seen the TV series The Equalizer starring Queen Latifah as Robyn McCall? One of her friends is Harry Keshegian (played by Adam Goldberg). Harry is a master hacker who lives underground in an unused subway station, which – since I was brought up on Batman and Robin – I always think of as being his ‘Batcave’. Well, Joe is the English equivalent of Harry, rarely emerging into the light of day, living in an idyllic country hamlet just outside Cambridge, where he telecommutes to his full-time (day) job as a senior software and hardware engineer with the London Ambulance Service. In the evenings (often through the nights), Joe creates the most amazing thingamajigs and thingamabobs you’ve never seen.

The reason I’m waffling on about this here is that in the same way Robyn calls on Harry when she has a problem, I call on Joe. A couple of weeks ago, for example, an interesting project landed on my desk. It involved the use of old-school 8-bit PIC microcontrollers, like the PIC16F18346-I/P from Microchip Technology.

I may regale you with tales of my adventures with PICs in a future blog. For the moment, however, we have other fish to fry. My problem is that, in addition to programming these little rascals, I also need to subject them to a suite of tests. In turn, this requires me to create a custom board with a 20-pin DIL zero insertion force (ZIF) socket, such as the 222-3343-00-0602J from 3M, surrounded by a bunch of other things like DIP switches, 1P12T rotary switches, probe terminals for my oscilloscope, and… the list goes on (if you are really unlucky, this board may be featured in a future blog).

Amongst his many other talents, Joe is a PIC guru (he may even hold a black belt in PIC technology), so we set up a Zoom call for me to ask his advice. We spent a happy hour or so bouncing ideas back and forth and then broke for the day. You can only imagine my surprise and delight the following morning to discover that Joe had decided to create the PC board design ‘just because’.

And in this corner…

While Joe was walking me through the pc board schematic and layout (once again, all thanks to the wonders of Zoom), he made a throwaway comment along the lines of, “And this area in this corner is my standard power circuit.” When I asked for more details, Joe explained that he had decided it would be a good idea to test the PICs at both 5 and 3.3 volts, so he threw in a tried-and-true circuit he uses for many of his designs.

Joe told me that he never uses USB to power his creations because “You cannot be sure of a solid 5 volts.” He also explained that, ever since one lied to him, he doesn’t trust power supplies that say they have +Ve on the inner connector and 0 V (ground) on the outer connector. To be honest, this reminded me of a pair of rather tasty computer speakers I acquired that went up in a puff of smoke due to a somewhat similar occurrence. All of this led Joe to create his own circuit that accepts 7 to 25 volts as input, where this can be AC or DC (the DC can be either polarity). In turn, this supply provides rock-solid 5 and 3.3 volt DC values to power his gadgets and gizmos.

This struck me as a jolly good idea. So good that I asked Joe if he could spin this off as a separate board that could be used by other enthusiasts (like yours truly) for their own hobby projects. You’ve probably already guessed that the very next morning I found this design sitting in my email Inbox, along with Joe’s permission to make it available to anyone interested.

Feel the power

The circuit diagram for Joe’s power supply unit (PSU) is shown in Figure 1. At first glance, you may think that this is nothing revolutionary. The deeper you dive, however, the more you realize that a lot of thought has gone into this. Such as the fact the pc board is single-sided, thereby allowing enthusiasts to make their own at home if they so desire (Joe has also kindly supplied the design files for those who would rather have their boards fabricated professionally).

To discuss the components, we also need to consider the layout as shown in Figure 2. Let’s start with power connector SK1, which can be any pc board barrel-type connector with the correct footprint. Based on my existing wall wart supplies, I would typically use a 2.1 millimeter (mm) version, such as the 54-00166 from Tensility International Corp. As an alternative, you can simply solder the wires from the power source to pads ‘a’ and ‘b’ on the PC board.

In the case of the output connector, SK2, a five-pin version from Molex is ideal as it allows for the board to be easily disconnected from the rest of the project. However, you can use any five-pin connector with a standard 0.1” (2.54mm) pitch, or you can solder header pins, or even solder wires directly to the PC board.

When it comes to BR1, any bridge rectifier with a working voltage of at least 50 volts and a current rating of a minimum of 1 ampere (A) (always slightly more than the combined maximum load of the board) can be used.

With respect to our particular implementation of this design, we require both a 5 volt output, which is generated by IC1, and a 3.3 volt output, which is generated by IC2. The component we used for IC1 was a 7805 that was lying around in Joe’s treasure chest of spare parts (the part we employed was similar to the MC7805ACTG from onsemi). In the case of IC2, the original design, which is reflected on the silkscreen, is specified as using an LD1117V33 LDO (low dropout) regulator, such as the LD1117V33 from STMicroelectronics. This is shown on the right side of Figure 3, which shows the finished PSU.

Capacitor C1 is a 470 microfarad

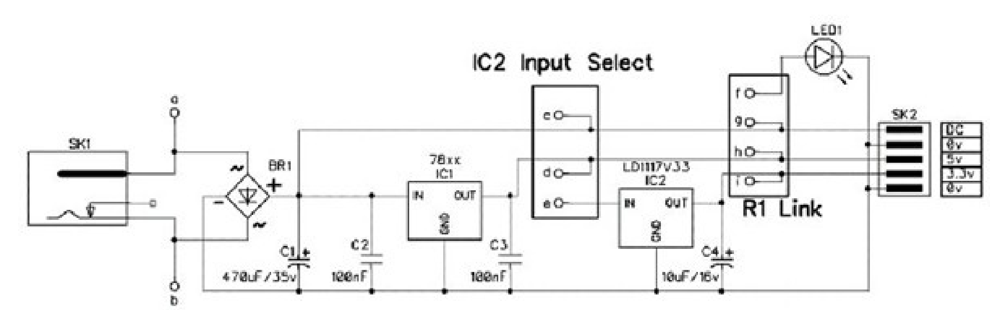


Figure 1: The circuit diagram for the PSU looks straightforward at first glance, but a lot of thought has gone into it, such as the fact the pc board design file is single-sided, allowing enthusiasts to make their own at home.
Image source: Joe Farr

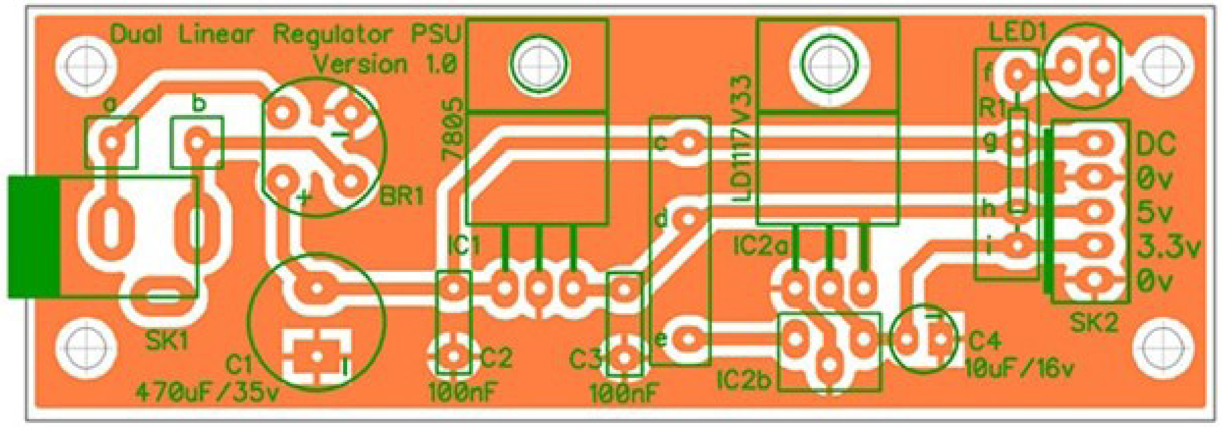


Figure 2 : Using the component values, types, and placements indicated on the silkscreen (e.g., the regulator IC2 is shown connected to pads/vias IC2a), the PSU accepts 7 to 25 volts AC or DC as input, returning rock-solid 5 and 3.3 volt outputs. However, by swapping some of the components (e.g., connecting a different type of regulator to the pads/vias IC2b), a variety of other voltage combinations can be achieved. Image source: Joe Farr

(μF) electrolytic device that must have a voltage rating higher than the maximum expected board input voltage (we used a 35 volt part). In the case of capacitors C2 and C3, pretty much any 100 nanofarad (nF) capacitor with a working voltage greater than 35 volts can be used. With respect to capacitor C4, if IC2 is an LD1117V33 regulator, then a 10 μF/16 volt capacitor is ideal. However, if a 78xx regulator is used for IC2 (see also the discussions on the regulators below), this capacitor should be changed for another 100nF capacitor that is identical to C2 and C3.

LED1 is any 5 or 3mm light-emitting diode (LED) with a forward voltage of around 2 volts. The value of the current limiting resistor, R1, which should be rated at 0.25 watts, depends on what output voltage will be used to drive the LED (see the discussions below).

Pertinent points to ponder

A regulator works by taking the input voltage and lowering it to match its specified output voltage. In the case of the regulators used here, the difference between the input and output voltage is dissipated as heat, which means the regulator can get extremely hot. To minimize the heat that needs to be dissipated, try to set the input voltage so that it's around 3 volts higher than the output of whatever regulators are connected to it. Also, when running the board from DC, account for the bridge rectifier dropping the input voltage by around 1 volt.

Some regulators – the LD1117V33 being a prime example – have the metal mounting tab connected to the device's output pin. By comparison, 78xx regulators have the mounting tab connected to the center (ground) pin.

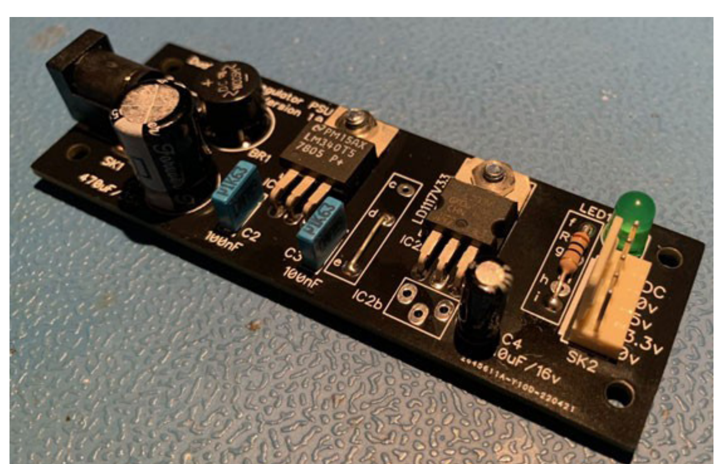


Figure 3: The finished PSU. The jumper between 'd' and 'e' (center) means that the input to IC2 is driven by the output of IC1 (see notes below). Connecting the current limiting resistor (R1) between 'f' and 'i' means that LED1 is powered by the output from IC2, thereby indicating that all elements of the power chain (BR1, IC1, and IC2) are functioning. Image source: Joe Farr

As we previously discussed, the design presented here is intended to provide 5t and 3.3 volt outputs, but it can be easily modified to accommodate other voltage combos, such as 12 and 5 volts, as required. In this case, the regulator used for IC1 can be any 78xx style regulator (do NOT attempt to use a 79xx series regulator anywhere on this board as the pinout is different).

There are two options for IC2. As we already discussed, the original design utilizes an LD1117V33 3.3 volt regulator. These regulators should use the IC2a pads as they have a different pinout compared with the more common 78xx series devices. If you wish to use a 78xx for the second regulator, then the pads labeled IC2b should be used.

Regulator IC1 is always fed directly from the output of the bridge rectifier and capacitor C1. By comparison, depending on your requirements, there are two possibilities for driving regulator IC2. If you wish, it can be fed directly from the bridge rectifier (fit jumper 'c' to 'e'). Alternatively, it can be fed from the output of IC1 (fit jumper 'd' to 'e'). This latter option is useful if the voltage output of IC1 is higher than the minimum input voltage required for IC2, as is the case with my implementation. This will reduce heat, but it assumes that regulator IC1 has sufficient capacity to provide power to your circuit as well as regulator IC2.

If LED1's current limiting resistor, R1, is connected between 'f' and 'g', the LED will be powered by the output of the bridge rectifier, BR1. If R1 is connected between 'f' and 'h', it will be powered by the output of IC1. And if R1 is connected between 'f' and 'i', it will be powered by the output of IC2. Depending on the input voltage applied to the LED, the R1 resistor value needs to be adjusted to give a reasonable brightness. Aiming for around 10 milliamperes (mA), which gives a nice brightness without stressing the LED, some suggested resistor values for different voltages are: 3.3 volts = 150 Ω, 5 volts = 330 Ω, 12 volts = 1 KΩ, 15 volts = 1.2 KΩ.

Conclusion

So, there you have it. This may not be a space-age Jetson-sque PSU with lots of bells and whistles, but it's a nice little DIY workhorse board that can be used to satisfy the requirements of a lot of home projects. I'm planning on keeping a stash of these available, along with a collection of regulators, ready to leap into action for future projects. What say you? As always, I welcome your comments, questions, and suggestions.

Deep dive into PCB manufacturing techniques: milling

Written by Jake Hertz

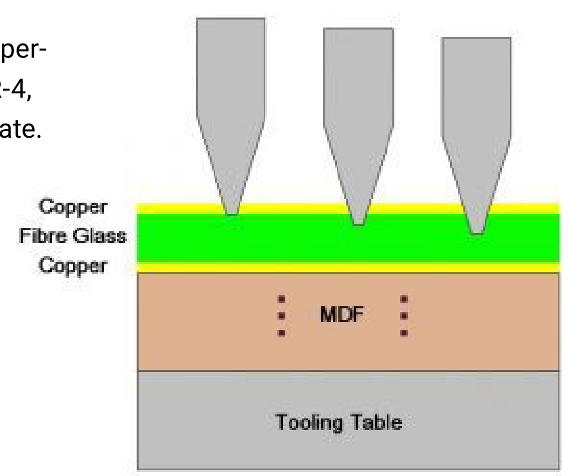
Printed circuit boards (PCBs) are the backbone of modern electronics, serving as the foundation for nearly all electronic devices. Among the various methods used to produce PCBs, milling is a popular technique, particularly for prototyping and small-scale production. This blog explores the intricacies of PCB milling, the milling process, its advantages, challenges, and applications.

Understanding PCB milling

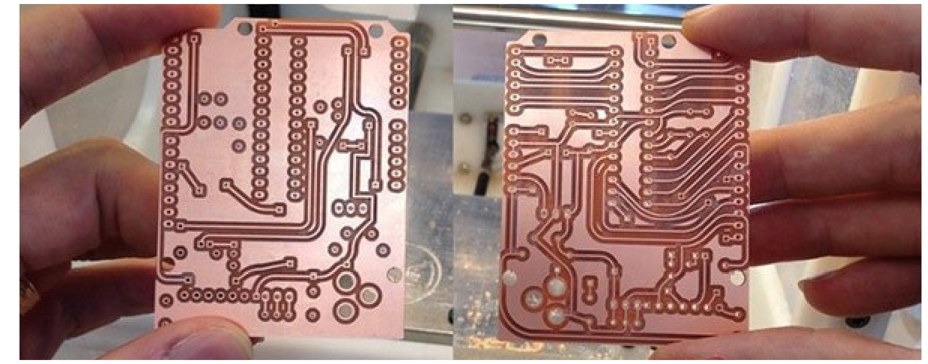
PCB milling involves mechanically removing material from a copper-clad board to create electrical isolation and form circuit patterns. Unlike traditional etching methods, which use chemical solutions to dissolve unwanted copper, milling uses precision-controlled milling bits to physically carve out the desired traces. The process is typically carried out using a Computer Numerical Control (CNC) milling machine, which is programmed to follow a specific design layout to guarantee accuracy and repeatability.

The conventional PCB milling process is as follows:

1. Design preparation: the process begins with designing the PCB layout using CAD (Computer-Aided Design) software. This digital design is then converted into G-code, a language understood by CNC machines, which dictates the tool paths for the milling bit
2. Material selection: a copper-clad laminate, usually FR-4, is selected as the substrate. The thickness of the copper layer is chosen based on the required current-carrying capacity and design specifications
3. Milling: the CNC machine, equipped with a high-speed spindle and a micro-milling bit, begins the milling process. The bit follows the tool paths specified in the G-code, removing copper, and creating the circuit traces. The machine's precision allows for intricate designs and fine-pitch components
4. Drilling and cutting: after milling, the machine drills holes for vias and component leads. The PCB is then cut to the desired shape, completing the manufacturing process



The milling process involves mechanically removing material from a copper-clad board.



A double-sided milled PCB.

Advantages of PCB milling

When considering PCB fabrication techniques, you might wonder why milling is preferred over more conventional methods like etching. Some of the major advantages of milling are:

- Prototyping efficiency: milling is particularly advantageous for rapid prototyping. It allows for quick iterations of PCB designs without the need for chemical processing, making it ideal for small production runs or development work
- No chemical waste: unlike etching, milling does not involve hazardous chemicals, making it a more environmentally friendly option. This also simplifies the setup, as there is no need for waste disposal systems
- Precision and control: the CNC milling process offers high precision, with the ability to create fine traces and intricate patterns. This precision is important for high-density designs and modern electronics requiring tight tolerances

Challenges in PCB milling

Despite the many benefits of milling, it is not without its challenges. These include:

- Tool wear and maintenance: the micro-milling bits used in the process are subject to wear, particularly when milling hard materials or thick copper layers. Regular maintenance and bit replacement are essential to maintain quality and accuracy
- Surface finish: milling can leave burrs or uneven surfaces, which may require additional processing, such as sanding or polishing, to achieve a smooth finish. This consideration applies to high-frequency PCBs where surface roughness can affect signal integrity
- Limited layer count: while milling is excellent for single or double-sided PCBs, it is less suitable for multi-layer boards due to the complexity of aligning and milling multiple layers

Applications for PCB milling

Given the advantages and disadvantages of milling, the technique is widely used in scenarios where prototyping is the main objective.

Engineers often rely on PCB milling to quickly produce and test new designs, iterating as necessary before committing to large-scale manufacturing. Swiftly producing a working PCB can significantly shorten the development cycle and help bring products to market faster.

Additionally, small businesses or hobbyists who need to produce custom PCBs might find milling an accessible and cost-effective solution. Milling provides a practical alternative for projects that don't justify the setup costs of large-scale production methods.

Conclusion

While PCB milling may not be the best choice for high-volume production, it excels in scenarios requiring rapid prototyping, precision, and environmental friendliness. Understanding when and why to use milling can help you make informed decisions in your PCB manufacturing process and help you select the most appropriate technique for your specific needs.

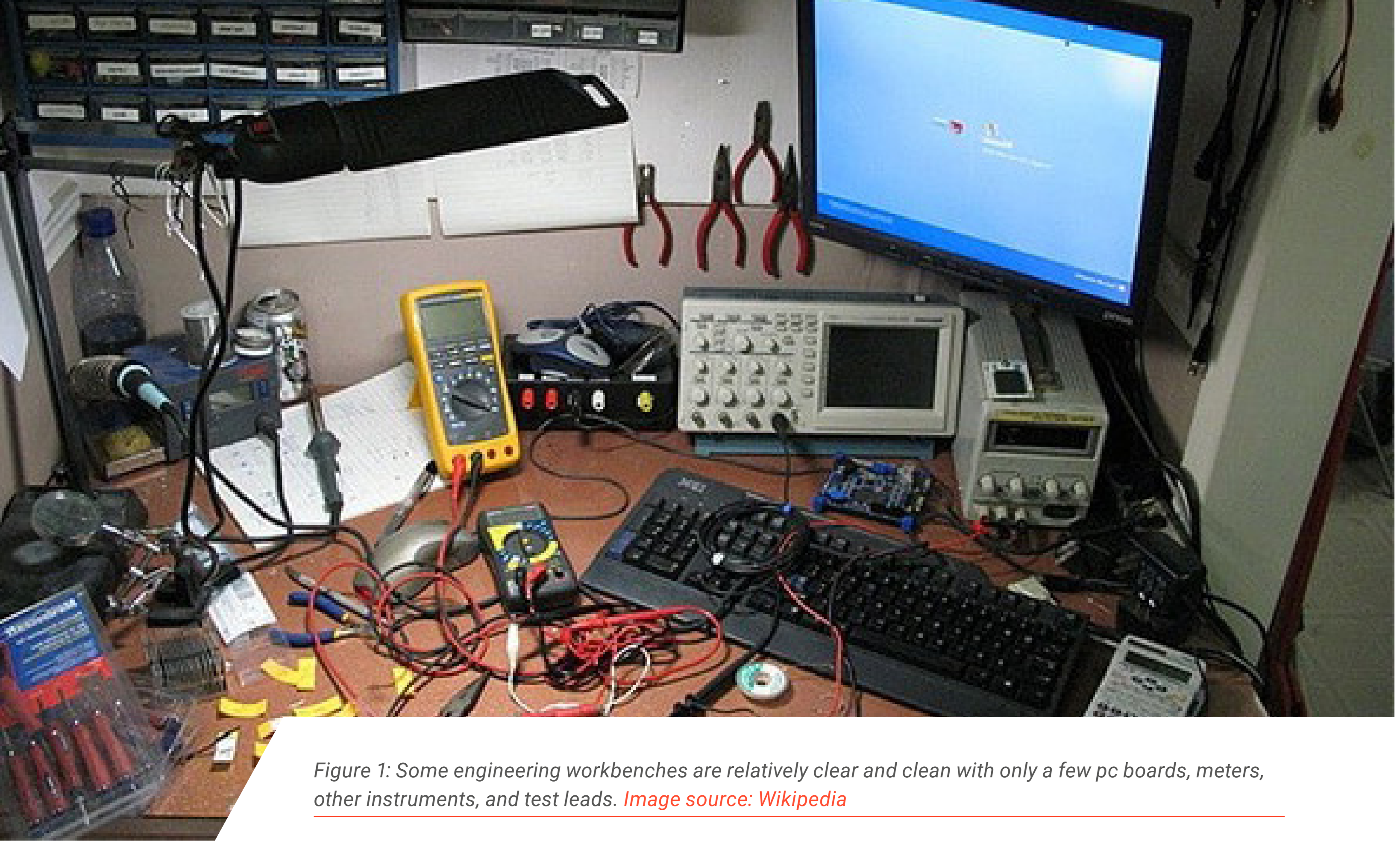


Figure 1: Some engineering workbenches are relatively clear and clean with only a few pc boards, meters, other instruments, and test leads. Image source: Wikipedia

The benefits of using a rack to keep your workbench tidy

Written by Bill Schweber

One common stereotypical image in the mind of the non-engineering public is that the work area of the typical design engineer is chaotic. Circuit boards and boxes are scattered semi-randomly around the bench along with a rat's nest of cables connecting everything. Though many prototype test benches are reasonably neat and organized, there is an element of truth to this cliché – especially as the development cycle progresses.

So why should benches be such a mess? As with almost all engineering questions, there is no 'one-size-fits-all' answer. I say this as a former hands-on engineer who has also visited dozens of EEs at their benches while they were working on advanced projects. Sooner or later, the prototype bench often ends up a mess, even though the design team starts out with the best of clutter-free intentions (Figure 1).

This happens as more instruments and test leads are needed; temporary and improvised fixtures are used to simulate inputs and operating conditions; larger battery packs are added for longer-running tests; and documentation – datasheets, user manuals, hand-written notes and reminders, and 'DO NOT TOUCH' admonitions – pile up.

Is clutter detrimental to product development?

Does this clutter lead to inefficient product development, debug, and assessment? The answers range from 'it sure is' to 'it's not a problem for me', and there are examples to back up all of these contentions.

Look at the super-cluttered yet highly productive bench of the late, brilliant analog electronics engineer Jim Williams of Linear Technology Corp., now part of Analog Devices (Figure 2). After his untimely passing in 2011, his legendary workbench was displayed – exactly as he left it – in a special 2012 exhibit at the Computer History Museum in Mountain View, CA1.

He consistently developed innovative circuits and systems at what looked like a hoarder's stash of random components and instrumentation. The justification for this, at which Jim only winked slyly when I visited him a few months before he passed away, was that the mess was the way he liked to work, and it also discouraged 'temporary' borrowing of test equipment by his co-workers.

Still, Jim's bench may be the exception: for most engineers and projects, a neat work area – though not necessarily obsessively ultra-neat – is increasingly a necessity rather than a preference. With the ever-higher frequencies of even modest circuits such as 2 megahertz (MHz) DC/DC switching converters and multi-gigahertz RF circuits, having wires and connectors in suspension in mid-air is begging for trouble at all phases of the prototype and breadboard stage.

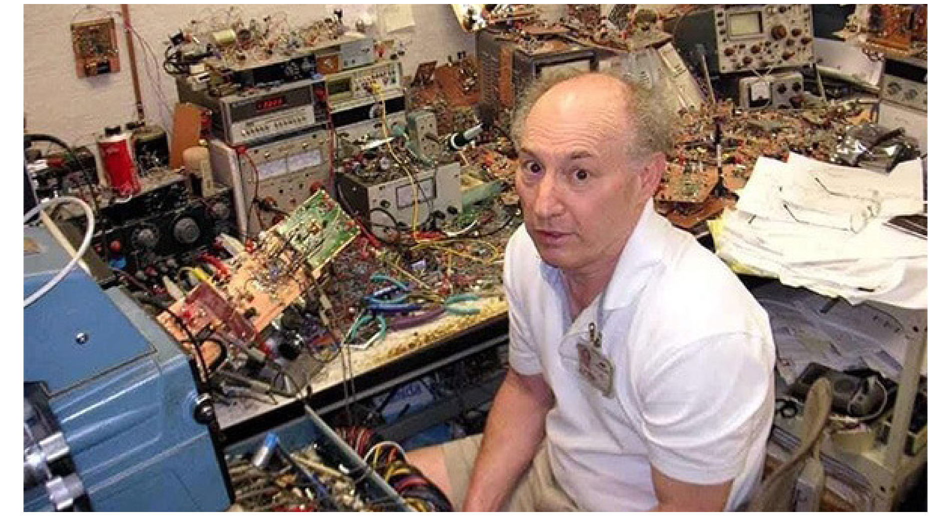


Figure 2: The legendary analog circuit design genius Jim Williams looking up from his famous, hyper-cluttered workbench at Linear Technology Corp. Image source: Mercury News

There's an easy solution

It's nice when there is a straightforward, hassle-free, low-tech solution to a problem. In the case of benchtop clutter, there is one: the 19 inch rack.

There's nothing new about the use of racks in engineering, of course. They are often used for large automated test equipment (ATE) set-ups, for example. Nearly all instruments such as oscilloscopes, waveform generators, and spectrum analyzers are directly rack mountable, or can be racked with a modest add-on kit.

Nonetheless, I have rarely seen these instruments in a rack at the engineer's bench. There could be any one of several reasons for this absence: perhaps it's due to the incremental nature of the clutter growth; or having one might send a subliminal but premature message to management that 'we're almost finished'; or having a nearby rack requires stringing numerous cables between the rack and the prototype under evaluation, which is often inconvenient.

But racks come in a variety of types and configurations that can overcome these concerns. There's the heavy-duty, double-frame 86 inch (in.) high rack such as the Hammond Manufacturing C2F197823LG1 full-height rack (Figure 3).

Figure 3: This double-frame, full-height 19 in. rack can take a large amount of test equipment off the designer's bench. Image source: Hammond Manufacturing

There are also single-frame units for lighter total load weight such as the Bud Industries RR-1264-BT which is nearly as high as the C2F197823LG1 at 70 in., and which offers somewhat easier access to the front and back of its contents (Figure 4).

These full-height floor racks may be too much for the bench-top development scenario, but there's an attractive alternative: a shorter, 11" high rack such as the Hammond Manufacturing RCHV1900817BK1, which can be placed on the corner of the benchtop rather than next to it (Figure 5).

Racks are not just for mounting of vendor-supplier instrumentation units, either. Many years ago, I was involved in the design of a controller for a large electromechanical test frame which had some frame-mounted switches that tripped when the piston's excursion exceeded a set value. For initial testing we needed to emulate the limit switch closure but did not want to energize an actual frame.

Figure 4: A single-frame full-height rack can also clear the test bench while offering easy access to front and back sides of the mounted units. Image source: Bud Industries

Figure 5: Even a modest 11-inch-high rack placed directly on the corner of the workbench will help clear the clutter and encourage discipline. Image source: Hammond Manufacturing

The solution was simple. One of our team's engineers had a military surplus radio toggle-switch array about 7" wide and 2 ½ in. high (Figure 6). We used these switches (which had the smoothest toggling action I have ever encountered) to allow the software engineer to easily initiate a limit-switch event while sitting at the keyboard, and the set-up worked well.

However, as the project proceeded, there were more instruments, leads, power supplies, and fixtures on the bench. Soon that set of toggle switches was hard to find and getting tangled in everything. The solution was straightforward: we placed a tabletop 19" rack on the corner of the bench and had the in-house model shop make a narrow rack panel with a cutout for the toggle switch array, thus giving it a fixed home. We even took further advantage of the new rack by mounting a few other small instruments in it and added some full-width shelves so we had a place for small boards which could not be easily rack mounted. The result was greater efficiency, fewer foolish mistakes, and fewer items disappearing when we weren't looking!

There's an aspect of longevity in the rack story. The 19" rack as we know it was developed about 100 years ago, according to the well-written Wikipedia article '19 inch rack'. While Wikipedia postings are not necessarily definitive or always completely accurate, they are often a useful starting point: this one references a 1922 article, 'Telephone Equipment for Long Cable Circuits' from the venerable Bell System Technology Journal which has been scanned and is available at the Internet Archive, so you can see the rational and specifics of rack development from the primary source.

Figure 6: This array of military surplus toggle switches was used to simulate the action of limit switches on a load frame during an ongoing product development process. Image source: Bill Schweber

Note that in the first half of the 20th century, the market position and technical expertise of the Bell Telephone System with respect to design, manufacturing, research, and installation was so dominant that they could set de facto industry standards, and often did.

If your initial acquisition of instrumentation and equipment did not include a rack-mount kit, it is still worth consideration as your project moves ahead. Even a basic small form factor power supply unit (PSU) can migrate from the benchtop to a nearby rack. For example, the XP Power PLS600 series of benchtop PSUs can be easily put into a rack using the vendor-supplied PLS600 Rack-Mount Kit which supports mounting of two of these PSUs side-by-side (Figure 7).

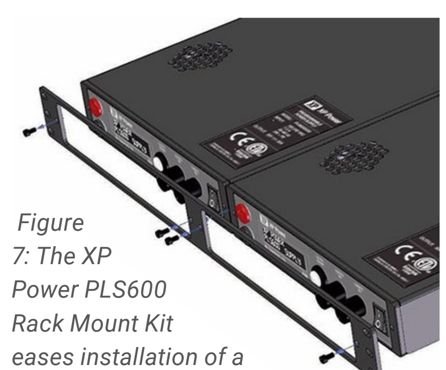


Figure 7: The XP Power PLS600 Rack Mount Kit eases installation of a single PLS600 unit or a side-by-side pair in a standard chassis equipment rack. Image source: XP Power

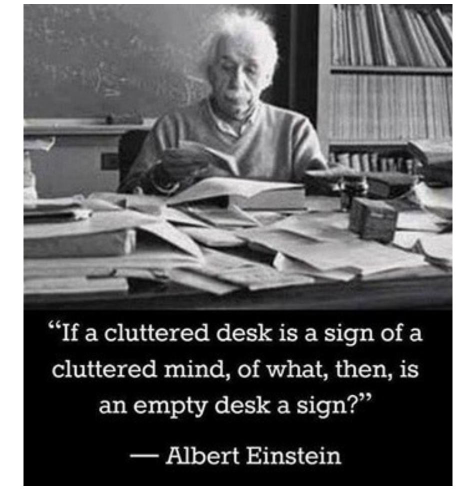


Figure 8: This quote attributed to Albert Einstein does not necessarily also apply to product design, development, and debug. Image source: Quora

Don't let Einstein's wit compromise your productivity

You may have seen the 'clever' saying attributed to Albert Einstein on a poster similar to the one shown in Figure 8.

Maybe that's the situation for advanced physics, but for hands-on engineers at the bench, it's not. This is made very clear in the excellent book 'Debugging: The 9 Indispensable Rules of Finding Even the Most Elusive Software and Hardware Problems' (Figure 9). In this indispensable work, author David J. Agans details the many benefits of having an organized work area with clear documentation, so you know what you have to work with and what you have done.

It only takes one bad experience of wasting hours, days, or weeks trying to find and fix a bug within an inefficient and misleading benchtop arrangement or finding out that the problem was in the test set-up and not the prototype. To make it clear: an organized workbench is your partner, and a low-tech rack can help make that happen.

Reference

1. Mercury News, 'Jim Williams' workbench captures his life and Silicon Valley' www.mercurynews.com/2011/11/17/cassidy-jim-williams-workbench-captures-his-life-and-silicon-valley

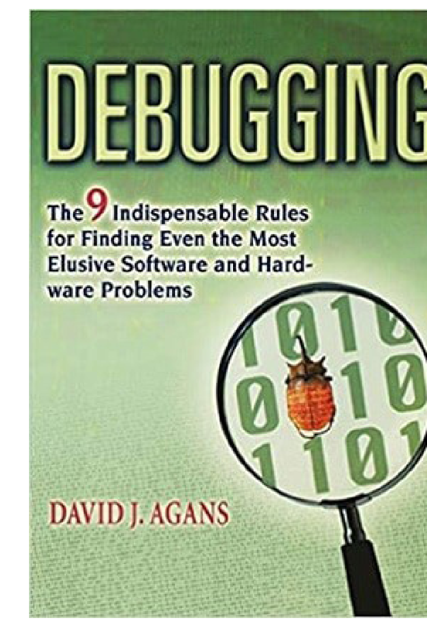
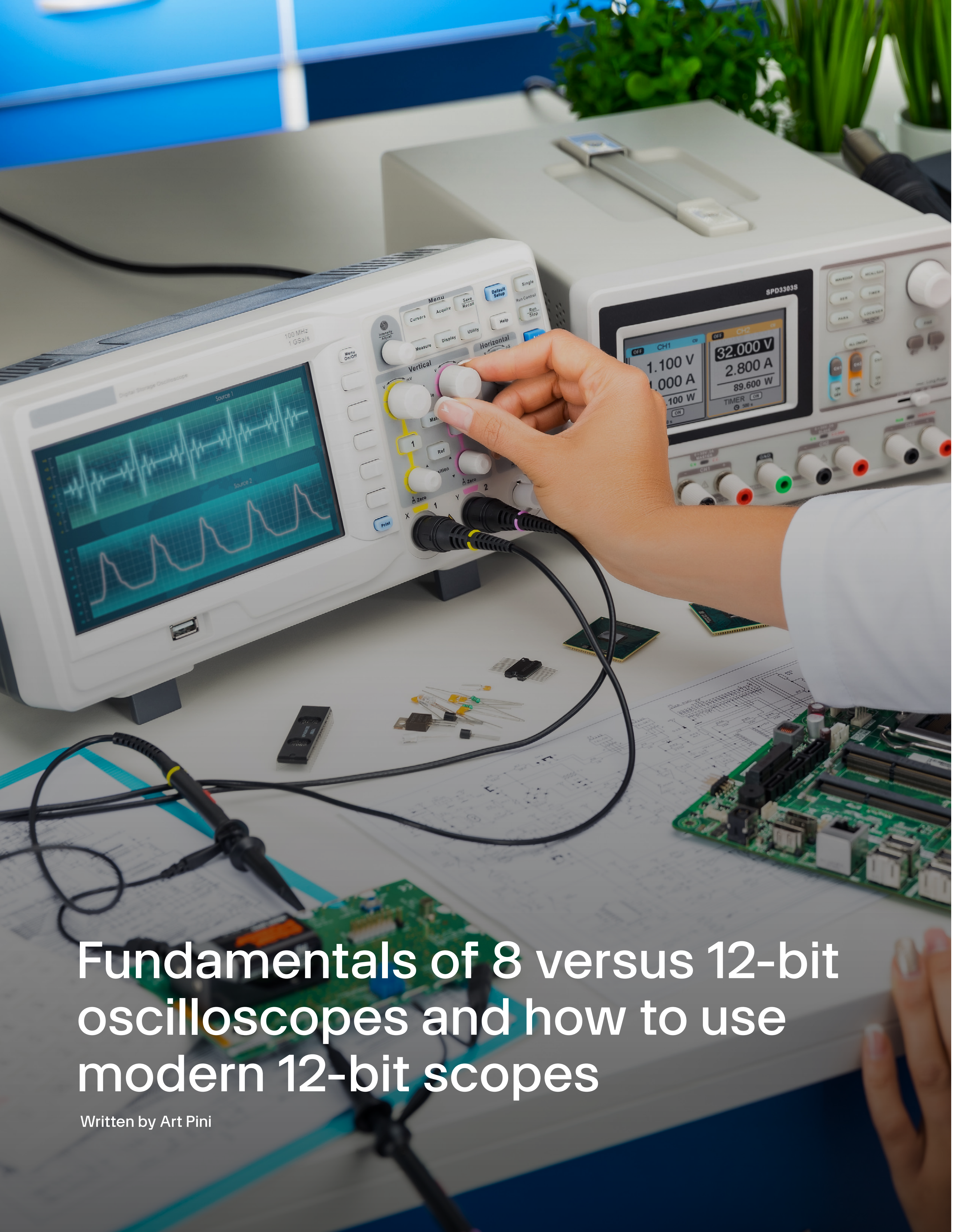


Figure 9: Debugging is among the most difficult engineering skills to master, and this book is a very insightful resource into strategies and tactics for hardware and software debugging. Image source: Amazon



Fundamentals of 8 versus 12-bit oscilloscopes and how to use modern 12-bit scopes

Written by Art Pini

This article will discuss the difficulty of high dynamic range measurements, the role of high-definition oscilloscopes, and how they can be used effectively for high dynamic range measurements.

There are many applications where designers and test and measurement engineers need to make wide dynamic range measurements to look at very small signals in the presence of large signal amplitudes. Power integrity assurance, echo location and ranging systems like radar and sonar, medical imaging systems such as nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI), as well as non-destructive testing using ultrasound, are among these types of applications.

Oscilloscopes are of course the go-to tool for making these measurements in the system development and prototyping stages, but these are primarily limited by the vertical resolution of the scope's front-end. For example, an 8-bit oscilloscope has a dynamic range of 256:1, so on a 1 volt range, the theoretical minimum signal is 3.9 millivolts (mV). When trying to view millivolt level ripple signals on a 3.3 volt bus, higher sensitivity and offset range are needed. Also, when using high attenuation probes to prevent circuit loading, signal levels will be attenuated at the scope input and so will be hard to measure unless the instrument has a high resolution.

The problem is that higher sensitivity in the presence of a larger signal or offset requires higher resolution scopes, and these typically are costly, especially for a quality scope with low noise inputs. Higher resolution without a lower noise floor is useless.

What designers and developers need is a reasonably priced 12-bit scope with a low front-end noise floor. One solution to this need for high resolution with front-end low noise at low cost is Teledyne LeCroy's WaveSurfer 4000HD series of high definition oscilloscopes. This article will discuss the difficulty of high dynamic range measurements, the role of high-definition oscilloscopes, and how they can be used effectively for high dynamic range measurements.

Oscilloscope vertical resolution

Oscilloscope vertical resolution refers to the ratio of the highest input signal the oscilloscope can handle to the smallest signal amplitude it can detect. Resolution is generally quantified by the number of bits in the analog-to-digital converter (ADC). The resolution is equal to 2 raised to the power of the number of bits. As such, an 8-bit converter has a resolution of 28 or 256:1. A 12-bit converter has a resolution of 4096:1, which is 16 times greater than an 8-bit converter.

For years, digital oscilloscopes offered 8-bit resolution in higher bandwidth oscilloscopes. This is because of an engineering tradeoff in ADCs that makes resolution, measured by the number of bits, inversely proportional to the ADC's maximum sampling rate. About eight years ago, Teledyne LeCroy pioneered 12-bit oscilloscopes termed high definition or 'HD' oscilloscopes. They have recently added the WaveSurfer 4000HD series to the HD product line. The series includes four oscilloscopes with bandwidths of 200, 350, 500, and 1000 megahertz (MHz). They all sample at 5 Gigasamples per second (GS/s) which is very respectable for a 12-bit oscilloscope. Internal mixed-signal digital inputs, DVM, function generator and frequency counter are available to round out this multi-instrument offering. The family offers all of this along with 12-bit resolution at a reasonable price point.

Of course, increasing the resolution of an oscilloscope requires more than simply changing the ADC. It also requires improving the signal-to-noise ratio (SNR) of the oscilloscope's front-end so that the sensitive ADC is not filled with noise. A 12-bit scope with an 8-bit front-end is still an 8-bit scope. The WaveSurfer 4000HD oscilloscope family, however, has successfully implemented the HD concept. Its 12-bit vertical resolution, coupled with a low noise front-end, delivers 12-bit performance that, in the real world, actually is 16 times more sensitive on any given amplitude range than an 8-bit scope.

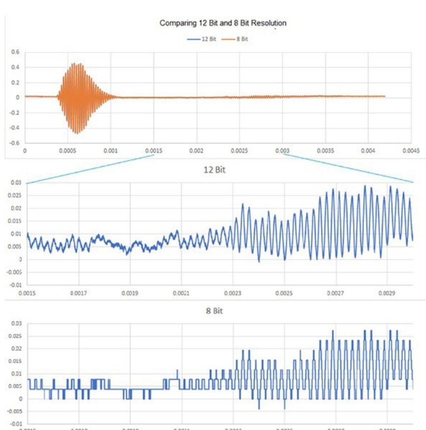


Figure 1: The same ultrasonic signal rendered with both 12-bit and 8-bit vertical resolution. The upper trace comprises both versions of the full signal overlaid on each other. The lower traces show a zoomed portion of the waveform. There is little difference looking at the high amplitude signal components, but the lower level signals show a clear advantage for the 12-bit rendering. Image source: DigiKey

Figure 2: A Teledyne LeCroy WaveSurfer 4104HD oscilloscope used in the acquisition of a 40 kilohertz (kHz) ultrasonic range finder signal. At top it shows five pulses for each measurement spaced about 16.8 milliseconds (ms) apart. Image source: DigiKey

12 vs 8-bit measurements

HD oscilloscopes are intended for measurement applications that have waveforms exhibiting high dynamic range. These are measurements that simultaneously include a high amplitude signal component along with low signal levels. Consider an application such as an ultrasound range finder. It transmits a high amplitude pulse, then waits for a low amplitude echo from the target. The high amplitude signal determines the voltage range of the scope's vertical amplifier that is required. The resolution and system noise determine the smallest echo signal that can be measured (Figure 1).

The upper grid shows the acquired signals in both 12-bit and 8-bit resolution overlaid. There is little observable difference between the overlaid waveforms. The center grid shows the 12-bit waveform expanded both horizontally and vertically. The bottom grid is the same portion of the 8-bit waveform. The loss in detail for the low-level signals in the 8-bit version is quite apparent. Note also that the signal peaks in the 12-bit rendering show obvious differences which are lost in the 8-bit version.

High dynamic range measurement applications

High dynamic range measurements include all echo location and ranging applications like radar, sonar, and LiDAR. Many medical imaging technologies like NMR and MRI are based on similar techniques: bouncing a high-level transmitted pulse off the body and acquiring and analyzing echoes or stimulated emissions due to the transmitted signal. Similarly, ultrasonic-based technology like non-destructive testing (NDT) uses reflected ultrasonic pulses to discover cracks and faults in solid materials.

Power integrity measurements, where small, millivolt, signals like noise and ripple are measured on bus voltages of between 1 and 48 volts, or greater, also need high dynamic range scopes.

Consider measuring signals from even a simple ultrasonic range finder or electronic tape measure (Figure 2). The ultrasonic range finder emits five pulses for each measurement spaced about 16.8ms apart in time. Rather than capture the deadtime between these pulses, the Teledyne LeCroy WaveSurfer 4104HD 12-bit oscilloscope uses a sequence mode acquisition which breaks the scope's memory into a user-selected number of segments, five in this example.

Each segment acquires one transmitted pulse and time stamps the trigger point. The upper trace is the acquired waveform with each segment marked. A zoom trace (bottom grid) shows a selected segment, in this case the first one. The table at the bottom of the screen shows the time stamps marking the time of each trigger, the time since segment 1, and the time between segments. The transmitted pulse has a peak to peak amplitude of 362 mV, while the reflected echo has a peak to peak amplitude of only 21.8mV. It is this difference in amplitude that makes this a high dynamic range measurement. The figure uses an echo amplitude that can be seen on the screen, but 12-bit resolution captures this signal at amplitudes lower than the pixel rendering of the scope, as seen in Figure 1.

Figure 3: A power integrity measurement on a 5 volt bus for a daughter card shows the ripple voltage and the FFT of the ripple. Image source: DigiKey

Power integrity measurements also require scopes with high dynamic range. Ripple voltage measurements require being able to measure millivolt signals riding on power buses. In the Figure 3 example, the upper trace measures ripple on a 5 volt bus. The ripple voltage is 45 mVpeak-to-peak riding on a bus voltage of 4.98 volts as directly read using the WaveSurfer 4104HD's measurement parameters P2 and P1, respectively. The lower trace is the fast Fourier transform (FFT) of the ripple voltage showing a harmonic rich spectrum with a fundamental component of 982Hz.

In addition to high resolution, this application requires an oscilloscope with a good offset range. In this example, the scope has a ±8 volt offset range on the 10mV scale. The offset range scales with the vertical range of the oscilloscope. If greater offset range is required, Teledyne LeCroy has the RP4060 rail probe with a 60 volt offset range. Rail probes are specifically designed for probing of low impedance power rails. They feature large built-in offset, high input impedance, and low attenuation and noise. This particular probe has a bandwidth of 4 gigahertz (GHz), an attenuation of 1.2, and an input impedance of 50 kilohms (kΩ).

Figure 4: Characterizing an SMPC's losses involves measuring the voltage and current of the power switch devices and then calculating power loss in each phase of the power switching cycle. Image source: DigiKey

HD oscilloscopes can also handle higher voltage measurements like those encountered in switched mode power converters (SMPCs). SMPCs include power supplies, inverters, and industrial controllers. They control power by adjusting the duty cycle or frequency of a switched waveform. The main measurements involve the voltage across and the current through the power switching device(s), usually a field effect transistor (FET). To help developers with SMPC measurements, Teledyne LeCroy provides application-specific software and voltage and current probes. A typical measurement is shown in Figure 4.

The current, the pink trace, is measured with a Teledyne LeCroy model CP030B current probe. This clamp-on probe has a maximum current input of 30 amperes (A)and a bandwidth of 50MHz. The voltage waveform, shown as a beige trace, is measured using a Teledyne LeCroy HVP1306 high voltage differential probe. This probe is rated for a maximum CATIII voltage of 1000 volts at a bandwidth of 120MHz. Both probes are recognized by the WaveSurfer scope, which automatically scales the measured waveforms to account for the probe's gains and units of measure.

Figure 5: The Teledyne LeCroy WaveSurfer 4000HD oscilloscopes are compatible with the company's extensive line of probes, including the power measurement related probes shown here. Image source: Teledyne LeCroy

The power measurement software automates the most common SMPC measurements. Figure 4 shows the calculation of device power dissipation as the yellow trace. This is calculated from the current and voltage waveforms for the whole switching cycle. Measurement parameters isolate and display turn-on, conduction, turnoff, and off-state losses based on the acquired waveforms, with each zone clearly delimited by a color overlay. It also shows the total loss from all zones as well as the switching frequency. Other available measurements, in addition to device measurements shown in the Figure, help characterize control loop dynamics, line power, and performance characteristics such as efficiency.

The 12-bit resolution is also useful in power measurements when calculating the drain source resistance (Rds) of the power FET. This requires measuring a voltage on the order of one or two volts on a waveform with a peak-to-peak swing on the order of 400 volts. The WaveSurfer 4000HD series is compatible with all Teledyne LeCroy probes compatible with the scope's bandwidth range (Figure 5).

Wide range of applications set higher standard for 'workhorse' scope

The WaveSurfer 4000HD series is not limited to only high dynamic range applications. It is an excellent scope in its own right and may set a higher standard for 'workhorse' scopes. It is a good choice for low-speed serial data troubleshooting, offering analysis packages and probes to support serial buses like SPI, I2C, UART-based links, as well as automotive buses like LIN, CAN, and FLEXRAY.

Serial bus analysis requires the ability to acquire and decode the bus protocol and to read the data content (Figure 6). The color-coded overlay shows each packet. The red overlay indicates the address data while the blue overlays mark the data packets. The address and data content appear within the overlay. Decode information is available in binary, hex, or ASCII format. The table at the bottom of the display summarizes acquired transactions showing time relative to the trigger point, address length, address, direction (read or write), the number of packets, and the data content. Triggering can be based on activity, address, data content, or a combination of address and data.

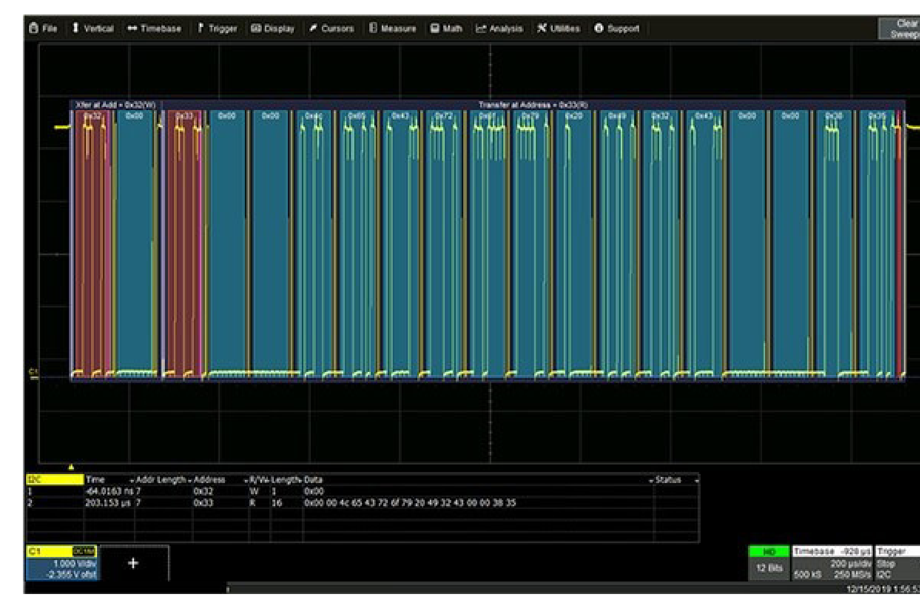
The Teledyne LeCroy ZD1000 active differential probe is a good choice for measuring serial data. This 10:1 probe has an input impedance of 1 Megaohm, has a bandwidth of 1 GHz, and can handle differential voltages of up to 16 volts and common mode voltages of up to 20 volts. It is especially well matched to differential buses such as CAN.

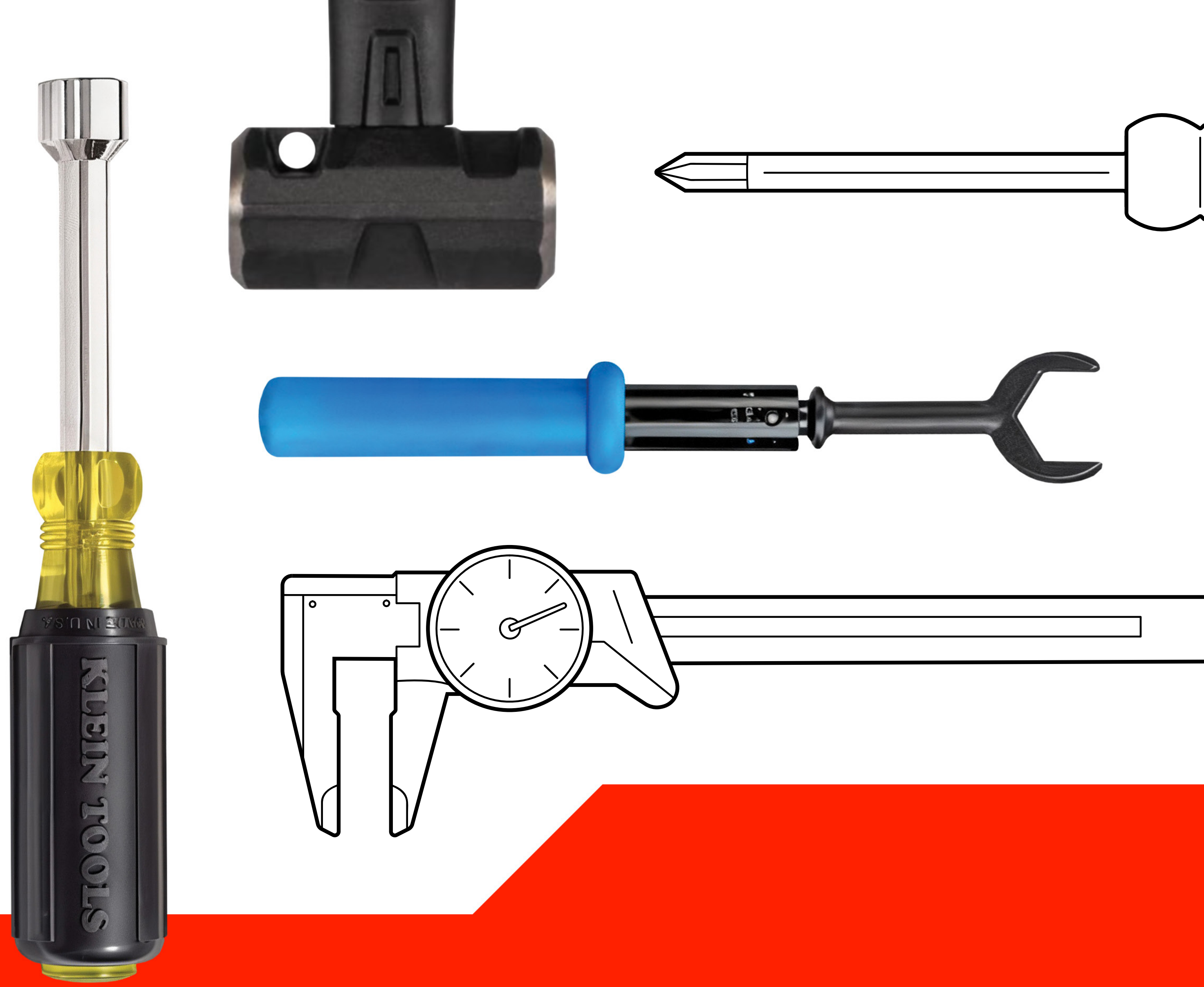
Conclusion

While 8-bit oscilloscopes will always have a place, there are many applications that could use the HD and wide dynamic range of a true 12-bit oscilloscope, but their relatively high cost has kept them out of reach of many designers and test engineers. The Teledyne LeCroy WaveSurfer 4000HD series oscilloscopes go a long way toward addressing that problem with a much lower cost entry point.

It provides HD measurements based on 12-bit vertical resolution, a 5 GS/s maximum sampling rate, and a low noise floor. It is also compatible with Teledyne LeCroy probes and analysis software packages. As such, the scopes open the door to cost effective high-dynamic-range measurements and move its availability from the research lab to the engineer's bench or factory floor.

Figure 6: Low-speed serial trigger and decode of the I2C bus includes the ability to read the data content of the bus. Shown is the acquisition and decoding of an I^{2}C bus signal for both a read and a write operation. Image source: DigiKey

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