Paranormal Instrumentation
The Oscilloscope

As more and more groups out there are broadening their technology capacity, I am fielding more and more personal E-mail questions about the practical use of oscilloscopes. Before I go into considerations for selecting a team device, let's take a brief look at just exactly what an oscilloscope is.

An oscilloscope (sometimes abbreviated CRO, for cathode-ray oscilloscope, or commonly just scope or O-scope) is a type of electronic test equipment that allows signal voltages to be viewed, usually as a two-dimensional graph of one or more electrical potential differences (vertical axis) plotted as a function of time or of some other voltage (horizontal axis). This is particularly useful in analyzing *frequencies present.*

Components

Exterior Appearance

Typically, an oscilloscope is an enclosure of some type with a display screen, numerous input connectors, with controls on the front panel. To aid measurement, a grid called the graticule is drawn on the face of the display. Each square in the graticule is known as a division.

Inputs

A signal from a detection or sensing device is fed into one of the input connectors, which is usually a coaxial connector such as a BNC or N type. If the signal source has its own coaxial connector, then a simple coaxial cable is used; otherwise, a specialized cable called a 'scope probe', supplied with the oscilloscope, is used. General-purpose oscilloscopes have a standardized input impedance of 1 megohm in parallel with a capacitance of around 20 picofarads. This facilitates the use of standard oscilloscope probes. Scopes for use with very high frequencies may have 50-ohm impedance inputs, which must be either connected directly to a 50-ohm signal source or used with Z0 or active probes. It is used for measuring voltage and frequency.

The trace
Simplistically, the oscilloscope repeatedly draws a horizontal line called the trace across the middle of the screen from left to right. One of the controls, the time-base control, sets the speed at which the line is drawn, and is calibrated in seconds per division. If the input voltage departs from the zero reference point, the trace is deflected either upwards or downwards. Another control, the vertical control, sets the scale of the vertical deflection, and is calibrated in volts per

division. The resulting trace is a graph of voltage against time, with the more distant past on the left and the more recent past on the right, hence frequency can be accurately measured, and a waveform can be observed.

If the input signal is periodic, then a near stable trace can be obtained by setting the time-base parameters to match the frequency of the input signal. For example, if the input signal is a 50 Hz sine wave, then its period is 20 ms (milliseconds), so the time-base is adjusted to insure that the time between successive horizontal sweeps is 20 ms. This mode is called continual sweep. Unfortunately, an oscilloscope's time-base is not perfectly accurate, and the frequency of most input signals are not perfectly stable, so the trace will drift across the screen making measurements difficult.

Trigger

To provide a more stable trace, modern oscilloscopes have a function called the saddle. When using saddling, the scope will pause each time the sweep reaches the extreme right side of the screen. The scope then waits for a specified event before drawing the next trace. The trigger event is usually the input waveform reaching a user-specified parameter voltage in the specified direction (going positive or going negative).

The effect is to resynchronize the time-base to the input signal, preventing horizontal drift of the trace. The triggering allows the display of periodic signals such as sine waves and square waves. Trigger circuits additionally allow the display of non-periodic signals such as single pulses or pulses that don't recur at a fixed rate.

Common trigger types

- External trigger, a pulse from an internal source connected to a dedicated input on the scope.
- Edge trigger, an edge-detector that generates a pulse when the input signal crosses a specified threshold voltage in a specified direction.
- Video trigger, a circuit that extracts synchronizing pulses from video formats such as PAL and NTSC and triggers the time-base on every line, a specified line, every field, or every frame. This circuit is typically found in a waveform monitor device.
- Delayed trigger, which waits a specified time after an edge trigger before starting the sweep. No trigger circuit acts instantaneously, so there is always a certain delay, but a trigger delay circuit extends this delay to a known and adjustable interval. In this way, the operator can examine a particular pulse in a long train of pulses.

X-Y mode

All modern bench oscilloscopes and some handheld models have several inputs for voltages that allow them to be used to plot one varying voltage in reference to another. This is especially useful for graphing I-V curves (current versus voltage characteristics) for components such as diodes, as well as Lissajous patterns. Lissajous figures are an example of how an oscilloscope can be used to track phase differences between multiple input signals. This is very frequently used in broadcast engineering to plot the left and right stereophonic channels, to ensure that the stereo generator is calibrated properly. It is also quite useful in analyzing background noise at a paranormal investigation

Other features

Some oscilloscopes have cursors, which are lines that can be moved about the screen to measure the time interval between two points, or the difference between two voltages. This is a handy, but not essential accessory.

Oscilloscopes can have two or more input channels, allowing them to display more than one input signal on the screen. Usually the oscilloscope has a separate set of vertical controls for each channel, but they share the triggering system and time-base.

Sometimes the event that the analyzer wants to observes may only happen occasionally, particularly in our field where we are dealing with random events. To observe these events, some oscilloscopes, known as "storage scopes", preserve the most recent sweep on the screen. This was originally achieved by using a special CRT, a "storage tube", which would retain the image of even a very brief event for a long time. With todays ever increasing LCD and Plasma Technologies, however, CRT displays are becoming a thing of the past.

A few select digital oscilloscopes can sweep at speeds as slow as once per hour, emulating a strip chart recorder. That is, the signal scrolls across the screen from right to left. Most oscilloscopes with this facility switch from a sweep to a strip-chart mode at about one sweep per ten seconds. This is because otherwise, the scope looks broken: it's collecting data, but the dot cannot be seen. This is also a handy, but not essential function of the oscilloscope in our particular application.

Oscilloscopes were originally analog devices. In more recent times digital signal sampling is more often used for all but the simplest models.

Many larger oscilloscopes have different plug-in modules for different purposes, such as high-sensitivity amplifiers of relatively narrow bandwidth, differential amplifiers, amplifiers with 4 or more channels, sampling plug-ins for repetitive signals of very high frequency, and assorted special-purpose plug-ins.

Examples of use

One of the most frequent uses of scopes is troubleshooting malfunctioning electronic equipment. One of the advantages of a scope is that it can graphically show signals: where a voltmeter may show a totally unexpected voltage, a scope may reveal that the circuit is oscillating. In other cases the precise shape of a pulse is important.

In a piece of electronic equipment, for example, the connections between stages (such as electronic mixers, electronic oscillators, amplifiers, etc) may be 'probed' for the expected signal, using the scope as a simple signal tracer. If the expected signal is absent or incorrect, some preceding stage of the electronics is not operating correctly. Since most failures occur because of a single faulty component, each measurement can prove that half of the stages of a complex piece of equipment either work, or probably did not cause the fault.

Once the faulty stage is found, further probing can usually tell a skilled technician exactly which component has failed. Once the component is replaced, the unit can be restored to service, or at least the next fault can be isolated. This is what the equipment was originally designed to do.

Another use is to check newly designed circuitry. Very often a newly designed circuit will misbehave because of design errors, bad voltage levels, electrical noise etc. Digital electronics usually operate from a clock, so a dual-trace scope which shows both the clock signal and a test signal dependent upon the clock is useful. "Storage scopes" are helpful for "capturing" rare electronic events that cause defective operation.

Another use is for software engineers who must program electronics. Often a scope is the only way to see if the software is running the electronics properly.

For our purposes, we can look at and analyze complex EMF waveforms, background noise in audio and RF spectrums, or any frequency generating source.

Software

A large proportion of modern day oscilloscopes provide one or more external interfaces to allow remote instrument control by external software. These interfaces (or buses) include GPIB, Ethernet, serial port, and USB. A USB interface is extremely important if you want to save and document your data on a PC or Laptop computer.

How the oscilloscope works

Cathode-ray oscilloscope (CRO)

The earliest and simplest type of oscilloscope consisted of a cathode ray tube, a vertical amplifier, a time-base, a horizontal amplifier and a power supply. These are now called 'analog' scopes to distinguish them from the 'digital' scopes that became common in the 1990s through today.

Prior to the introduction of the CRO in its current form, the cathode ray tube had already been in use as a measuring device. The cathode ray tube is an evacuated glass envelope, similar to that in a black-and-white television set, with its flat face covered in a phosphorescent material (the phosphor). The screen is typically less than 5 inches in diameter, much smaller than the one in a typical television set.

In the neck of the tube is an electron gun, which is a heated metal plate with a wire mesh (the grid) in front of it. A small grid potential is used to block electrons from being accelerated when the electron beam needs to be turned off, as during sweep retrace or when no trigger events occur. A potential difference of at least several hundred volts and more commonly, several thousand volts is applied to make the heated plate (the cathode) negatively charged relative to the deflection plates. For higher bandwidth oscilloscopes where the trace may move more rapidly across the phosphor target, a positive post-deflection acceleration voltage of over 10,000 volts is commonly used, increasing the energy (speed) of the electrons that strike the phosphor, as well as dramatically increasing the cost of the device. The kinetic energy of the electrons is converted by the phosphor into visible light at the point of impact. When switched on, a CRT normally displays a single bright dot in the center of the screen, but the dot can be moved about electrostatically or magnetically. The CRT in an oscilloscope uses electrostatic deflection.

The path between the electron gun and the screen contain two opposed pairs of metal plates called the deflection plates. The vertical amplifier generates a potential difference across one pair of plates, giving rise to a vertical electric field through which the electron beam passes. When the plate potentials are the same, the beam is not deflected.

When the top plate is positive with respect to the bottom plate, the beam is deflected upwards; when the field is reversed, the beam is deflected downwards. The horizontal amplifier does a similar job with the other pair of deflection plates, causing the beam to move left or right. This deflection system is called electrostatic deflection, and is quite different from the electromagnetic deflection system used in television tubes. In comparison to magnetic deflection, electrostatic deflection can more readily follow random changes (decreased response time) in potential, but it is also limited to small deflection angles.

The time-base is an electronic circuit that generates a ramp voltage. This is a voltage that changes continuously and linearly with time. When it reaches a predefined value the ramp is reset, with the voltage reestablishing its initial value. When a trigger event is recognized the reset is released, allowing the ramp to increase again. The time-base voltage usually drives the horizontal amplifier. Its effect is to sweep the electron beam at constant speed from left to right across the screen and quickly return the beam to the left in time to begin the next sweep. The time-base can be adjusted to match the sweep time to the period of the signal.

At the same time the vertical amplifier is driven by an external voltage (the vertical input) that is taken from the circuit or experiment, or event that is being measured. The amplifier has high input impedance, typically as we mentioned before around one megohm, which limits the power that it draws to only a tiny amount of current from the signal source. The amplifier drives the vertical deflection plates with a voltage that is proportional to the vertical input. Since the electrons have already been accelerated by hundreds or thousands of volts, this amplifier also has to deliver almost the same amount of potential in volts as well as providing a very broad response bandwidth. The gain of the vertical amplifier can be adjusted to suit the amplitude of the input voltage. A positive input voltage bends the electron beam upwards, and a negative voltage bends it downwards, so that the vertical deflection of the dot shows the value of the input. The response of this system is much faster than that of mechanical measuring devices such as the analog multimeter (not a digital readout version, the mechanical meter version), where the inertia of the meter needle or indicator slows down its response to the input.

When all these components work together, the result is a bright trace on the screen that represents a graph of voltage against time. Voltage is on the vertical axis, and time on the horizontal.

Observing high speed signals, especially non-repetitive signals, with a conventional CRO is difficult, if not impossible due to the non-stable or changing triggering threshold which makes it harder to "freeze" the waveform on the screen. This often requires the room to be darkened or a special viewing hood to be placed over the face of the display tube. To aid in viewing such signals, special oscilloscopes have borrowed from night vision technology, employing a microchannel plate in the tube face to amplify faint light signals.

Although a CRO allows the operator or observer to view a signal, in its basic form it has no means of recording that signal on paper for the purpose of documentation. Therefore, special oscilloscope cameras were developed to photograph the screen directly. Early cameras used roll or plate film, while in the 1970s Polaroid® instant cameras became popular. This is now a thing of the past. Many oscilloscopes have a computer interface

The vertical amplifier and time-base controls are calibrated to show the vertical distance on the screen that corresponds to a given voltage difference, and the horizontal distance that corresponds to a given time interval.

The power supply is also an important component of the scope. It provides low voltages to power the cathode heater in the tube, and the vertical and horizontal amplifiers. High voltages are needed to drive the electrostatic deflection plates. These voltages must be very stable, highly regulated sources. Any variations will cause errors in the position and brightness of the trace. A variance of less that .1 volts will dramatically affect the accuracy of the scope as well.

The more recently manufactured analog oscilloscopes incorporated digital processing to the standard design. The same basic architecture - cathode ray tube, vertical and horizontal amplifiers - was retained, but the electron beam was controlled by digital circuitry that could display graphics and text mixed with the analog waveforms. The extra features that this system provides include:

- On-screen display of amplifier and time-base settings
- Voltage cursors - adjustable horizontal lines with voltage display
- Time cursors - adjustable vertical lines with time display
- On-screen menus for trigger settings and other functions.

The Dual Beam oscilloscope
A dual beam oscilloscope was a type of oscilloscope once used to compare one signal with another. There were two beams produced in a special type of CRT. Unlike an ordinary "dual-trace" oscilloscope (which time-shared a single electron beam, thus losing about 50% of each signal), a dual beam oscilloscope simultaneously produced two separate electron beams, capturing the entirety of both signals.

Two pairs of vertical plates deflected the beams. Vertical plates for channel A had no effect on channel B beam. Similarly for channel B, separate vertical plates existed which deflected the beam B only.

On some scopes the time base, horizontal plates and horizontal amplifier were common to both beams; on more elaborate scopes like the Tektronix 556 there were two independent time bases and two sets of horizontal plates and horizontal amplifiers. Thus one could look at a very fast signal on one beam and a slow signal on another beam. This is also why Tektronix scopes were among the most expensive scopes on the market. However, as any other product, you get what you pay for.

The vast majority of multichannel scopes do not really have multiple electron beams. Instead, they display only one dot at a time, but switch the dot between one channel and the other either on alternate sweeps (ALT mode) or many times per sweep (CHOP mode). Very few real dual beam oscilloscopes were built.

With the advent of digital signal capture, true dual beam oscilloscopes became obsolete, as it was then possible to display two truly simultaneous signals from memory using either the ALT or CHOP display technique, or even possibly a raster display mode.

Analog storage oscilloscope

A relative recent feature available on some analog scopes is the addition of 'storage' or ‘memory’. This function allows the trace pattern that normally decays in a fraction of a second to remain on the screen for several minutes or longer. An electrical circuit can then be deliberately activated to store and erase the trace on the screen.

The storage is accomplished using the principle of secondary emission. When the ordinary writing electron beam passes a point on the phosphor surface, not only does it momentarily cause the phosphor to illuminate, but the kinetic energy of the electron beam knocks other electrons loose from the phosphor surface. This can leave a net positive charge. Storage oscilloscopes then provide one or more secondary electron guns (called the "flood guns") that provide a steady flood of low-energy electrons traveling towards the phosphor screen. The electrons from the flood guns are more strongly drawn to the areas of the phosphor screen where the writing gun has left a net positive charge; in this way, the electrons from the flood guns re-illuminate the phosphor in these positively-charged areas of the phosphor screen. It did not employ actual “memory as we know it today.

If the energy of the flood gun electrons is properly balanced, each impinging flood gun electron knocks out one secondary electron from the phosphor screen, thus preserving the net positive charge in the illuminated areas of the phosphor screen. In this way, the image originally written by the writing gun can be maintained for a long time. After a period of time though, small imbalances in the secondary emission ratio will cause the entire screen to "fade positive" (light up) or cause the originally-written trace to "fade negative" (extinguish). It is these imbalances that limit the ultimate storage time possible.

Some oscilloscopes used a strictly binary (on/off) form of storage known as "bistable storage". Others permitted a constant series of short, incomplete erasure cycles which created the impression of a phosphor with "variable persistence". Certain oscilloscopes also allowed the partial or complete shutdown of the flood guns, allowing the preservation (albeit invisibly) of the latent stored image for later viewing. (Fading positive or fading negative only occurs when the flood guns are "on"; with the flood guns off, only leakage of the charges on the phosphor screen degrades the stored image.)

Digital storage oscilloscope

The digital storage oscilloscope, or DSO for short, is currently the preferred type for most industrial applications, although simple analog CROs are still used by hobbyists (and can be purchased relatively cheap on E-Bay). For our purposes, these older analog scopes will perform nicely in the areas we examine. But a Digress. Back to the Digital Storage Scope. This type of oscilloscope utilizes technology that supersedes the unreliable storage method used in analog storage scopes with digital memory, which can store data as long as required without degradation. It also allows complex processing of the signal by high-speed digital signal processing (DSP) circuits.

The vertical input, instead of driving the vertical amplifier, is digitized by an analog to digital converter to create data that is then stored in the memory of a microprocessor, or in dedicated memory chips. The data is processed and then sent to the display, which in early DSOs was a still the old reliable cathode ray tube, but currently an LCD flat panel is employed. DSOs with color LCD displays are now common. The data can be sent over a LAN or a WAN for processing or archiving. The screen image can be directly recorded on paper by means of an attached printer or plotter, without the need for an oscilloscope camera. The scope's own signal analysis software can extract many useful time-domain features (such as rise time, pulse width, amplitude, etc), frequency spectra, histograms and statistics, persistence maps, and a large number of parameters meaningful to engineers in specialized fields such as telecommunications, disk drive analysis power electronics, and yes, even paranormal analysis.

Digital oscilloscopes are limited principally by the performance of the analog input circuitry and the sampling frequency. In general, the sampling frequency should be at least the Nyquist rate, double the frequency of the highest-frequency component of the observed signal, otherwise a condition called “aliasing” may occur.

Digital storage also makes possible another unique type of oscilloscope, the equivalent-time sample scope. Instead of taking consecutive samples after the trigger event, only one sample is taken. However, the oscilloscope is able to vary its time-base to precisely time its sample, allowing it to build up the picture of the signal over the subsequent repetitions of the signal. This requires that either a clock or repeating pattern be provided by the scopes circuitry. This type of scope is frequently used for very high speed communication because it allows for a very high "sample rate" and low amplitude noise compared to traditional real-time scopes.

Advantages over the analog oscilloscope:

1. Brighter and bigger display with color to distinguish multiple traces
2. Equivalent time sampling and Average across consecutive samples or scans lead to higher resolution down to µV
3. Peak detection

4. Pre-trigger
5. Easy pan and zoom across multiple stored traces allows beginners to work without a trigger
6. Requires a higher refreshment rate of the display (some scopes have up to a 1 second delay)
7. The knobs have to be large and turn smoothly
8. Allows slow traces like the temperature variation across a day can be recorded
9. The memory of the oscilloscope can be arranged not only as a one-dimensional list but also as a two-dimensional array to simulate a phosphorus screen. The digital technique allows a quantitative analysis (E.g. Eye diagram)
10. Allows for automation, though most models lock the access to their software

A disadvantage of digital oscilloscopes is the limited refresh rate of the screen. On an analog oscilloscope, the user can get an intuitive sense of the trigger rate simply by looking at the steadiness of the CRT trace. For a digital oscilloscope, the screen looks exactly the same for any signal rate which exceeds the screen's refresh rate. Additionally, it is sometimes hard to spot "glitches" or other rare phenomena on the black-and-white screens of standard digital oscilloscopes; the slight persistence of CRT phosphors on analog scopes makes glitches visible even if many subsequent triggers overwrite them. However, *both of these difficulties have been overcome recently by "digital phosphor oscilloscopes", which store data at a very high refresh rate and display it with variable intensity, to simulate the trace persistence of a CRT scope.*

Mixed signal oscilloscope
A mixed signal oscilloscope (or MSO) has two kinds of inputs, a small number (typically two or four) of analog channels, and a larger number (typically sixteen) of digital channels. These measurements are acquired with a single time base, they are viewed on a single display, and any combination of these signals can be used to trigger the oscilloscope.

An MSO combines all the measurement capabilities and the use protocols of a Digital Storage Oscilloscope (DSO) with the addition of some of the measurement capabilities of a logic analyzer. MSOs typically lack the advanced digital measurement capabilities and the large number of digital acquisition channels of full-fledged logic analyzers, but they are also much easier to use. Typical mixed-signal measurement uses include the characterization and debugging of hybrid analog/digital circuits like: embedded systems, Analog-to-digital converters (ADCs), Digital-to-analog converters (DACs), and control systems. While if you happen to get one of these for free, they are generally cost prohibitive to most paranormal organizations.

Hand held oscilloscope
Originally just as expensive as a full size scope, these models have dropped significantly in price over the last few years. Manufacturers such as Velleman offer a 20 megahertz version for under a $150.00

PC-based oscilloscope (PCO)

Although most people think of an oscilloscope as a self-contained instrument in a box, a new type of "oscilloscope" is emerging that consists of a specialized signal acquisition board (which can be an external USB or Parallel port device, or an internal add-on PCI or ISA card). The hardware itself usually consists of an electrical interface providing insulation and automatic gain controls, several hi-speed analog-to-digital converters and some buffer memory, or even on-board DSPs. Depending on the exact hardware configuration, the hardware could be best described as a digitizer, a data logger or as a part of a specialized automatic control system. The most common form of this in use today in paranormal groups are “freeware versions” available from Download.com. These are not true oscilloscopes, rather software that “emulates” oscilloscope functionality. They are also limited to the frequency response of the embedded PC sound card, which is never better than 20 Kilohertz. This is fine for frequencies in the audio spectrum, but useless above that region.

The PC provides the display, control interface, disc storage, networking and often the electrical power for the acquisition hardware. The viability of PC-based oscilloscopes depends on the current widespread use and low cost of standardized PCs. Since prices can range from as little as $100 to as much as $3000 depending on their capabilities, such instruments are particularly suitable for the educational market, where PCs are commonplace but equipment budgets are often low. The acquisition hardware, in certain cases, may only consist of a standard sound card or even a game port, if only audio and low frequency signals are involved. Higher frequency uses require specialized interfaces capable of detecting and passing the higher frequencies, such as those in the radio frequency and light spectrums.

The advantages of PC-based oscilloscope

1. Lower cost compared to a stand-alone oscilloscope, assuming the user already owns a PC, although professional-grade PCO hardware (with bandwidth in the MHz rather than in the kHz range) tends to be more expensive than a typical PCI or embedded sound card, and some laboratory standard units can even cost more than a new PC.
2. Easy exporting of data to standard PC software such as spreadsheets and word processors.
3. Ability to control the instrument by running a custom program on the PC.
4. Use of the PC's networking and disc storage functions, which cost extra when added to a self-contained oscilloscope.

5. PC's typically have larger and higher resolution color displays which can be easier to read. Color can be utilized to differentiate waveforms. It can also show increased information including more of the waveform or extras like automatic waveform measurements and simultaneous alternative views.
6. Easier portability when used with a laptop PC.

The disadvantages

1. Need for the owner to install oscilloscope software on the PC.
2. Time taken for the PC to boot, compared with the almost instant start-up of a self-contained oscilloscope (although, as some modern oscilloscopes are actually PCs or similar machines in disguise, this distinction is narrowing).
3. Reduced portability when used with a desktop PC.
4. Inconvenience of using part of the PC's screen for the oscilloscope display.
5. If a sound card is used instead of dedicated signal acquisition hardware, frequency response is usually limited in the audio range, the number of inputs is limited by the number of recording channels (usually no more than the two usual stereo channels) and the inputs can handle only line-level voltages without the risk of damage.
6. If the game port is used as the acquisition hardware, the sampling frequency is very low, typically below 1 kHz, and the input voltages can only vary between TTL. In addition, the game port cannot easily be programmed for a specific sampling rate, nor can it be easily assigned a precise quantization step. These limitations only make it suitable for low precision visualization of low frequency signals.

The differences are becoming increasingly blurred, however, as mainstream oscilloscope vendors such as Tektronix convert their product line over to large-screen, PC-based oscilloscopes as well, albeit PCs equipped with very fast (multi-GHz) input digitizers and highly-customized human interfaces.