Advanced Oscilloscope Handbook

For Technicians and Engineers

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ADVANCED OSCILLOSCOPE HANDBOOK

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PREFACE

The oscilloscope—the most general-purpose and most basic tool of the designer—has also evolved into one of the most important troubleshooting instruments. Sophistication is the order of the day, and traditional analog displays are now supplemented by data-domain displays of digital data by oscilloscopes with built-in digital memory and digital delay facilities. In turn, a need has arisen for an advanced oscilloscope handbook, suitable both for self-instruction and for classroom use. This state-of-the-art handbook provides a wide range of practical application information within both the real-time (frequency) domain, and the data domain. The reader is introduced to the chief types of oscilloscopes, with a general overview of applications. Principles of waveform analysis are detailed for both the steady state and for the transient state.

Audio troubleshooting procedure is explained, including basic stereo servicing procedures. Both black-and-white and color television troubleshooting procedures are discussed and illustrated, with emphasis on localization of malfunctions by waveform analysis. Industrial-electronic test procedures are covered, with particular attention to "building-block" circuit response, so that the troubleshooter can interpret test results in systems to best advantage. Semiconductor-device tests and measurements are detailed with primary attention to curve-tracer data. Both in-circuit and out-of-circuit test procedures are considered. Ignition and power-supply tests are covered, including key troubleshooting waveforms for regulated and high-voltage supplies. The final chapter presents a practical introduction to the data domain and familiarizes the reader with both the input/output analog relations of basic digital devices and their corresponding truth tables.

Mathematical treatment has been minimized in this handbook, to facilitate learning by students whose mathematical background may be limited. Where need arises during discussions of tests and measurements, charts and tables are provided for quantitative reference. It is assumed that the reader has completed courses in electricity, electronics, radio communication, and television theory, or that he has attained a practical working background in these areas. A student who is taking a concurrent course in black-and-white or color television will be able to assimilate the associated chapters in this book by "looking up" various technical terms and topics with which he may be unfamiliar.

Acknowledgement is made to those who have preceded the author by their development of other books on oscilloscope technology. This book can be properly described as a team effort, and it is appropriate that the work be dedicated as a teaching tool to the instructors and students of our junior colleges and technical schools.

DEREK CAMERON

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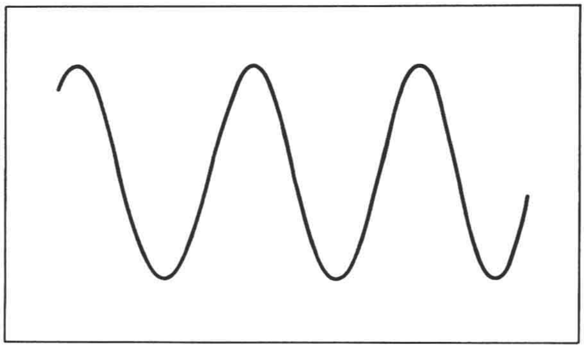
1

OSCILLOSCOPE TYPES AND APPLICATIONS

1-1 Basic Oscilloscope Functions

An *oscilloscope* is defined as an instrument that displays the instantaneous values of one or more rapidly varying electrical quantities as a function of time or of another electrical quantity. In the strict sense of the term, it does not provide a permanent record of these events. An *oscillograph* is an instrument that does produce a permanent record of such events. This distinction tends to become blurred in practice, inasmuch as a Polaroid camera may be mounted in front of an oscilloscope screen, thereby converting the instrument into an oscillograph. Again, an oscilloscope may be provided with semipermanent storage facilities, thereby occupying a "gray area" between traditional oscilloscopes and oscillographs. Even the conventional definition of an oscilloscope as a time- or frequency-domain instrument has become blurred with the advent of oscilloscopic instruments that operate in the data domain. Figure 1-1 shows typical time-frequency-domain and data-domain displays.

Basic oscilloscope application categories are shown in Fig. 1-2. Waveform analysis is a very extensive area that includes operations such as rise-time measurement; duration or period measurements; pulse-width



(a)

0000	0000	0000	000	000	000	000
0000	0001	0000	000	000	010	000
0000	0010	0000	000	000	100	000
0000	0011	0000	000	000	110	000
0000	0100	0000	000	001	000	000
0000	0101	0000	000	001	010	000
0000	0110	0000	000	001	100	000
0000	0111	0000	000	001	110	000
0000	1000	0000	000	010	000	000
0000	1001	0000	000	010	010	000
0000	0000	0000	000	000	000	000
0000	0001	0000	000	000	010	000
0000	0010	0000	000	000	100	000
0000	0011	0000	000	000	110	000
0000	0100	0000	000	001	000	000
0000	0101	0000	000	001	010	000

(b)

FIG. 1-1. *Typical oscilloscopic instrument displays. (a) Time or frequency domain display. (b) Data domain display.* (Courtesy, *Hewlett Packard Co.*)

measurements; duty-cycle and repetition-rate measurements; amplitude, frequency, and phase measurements; jitter and distortion measurements; modulation monitoring; spectrum analysis; damping-time measurements; and so on. In turn, various specialized types of oscilloscopes are utilized in particular areas of waveform analysis. As an illustration, an oscilloscope with free-running sweeps is adequate for audio signal-tracing or visual-alignment procedures. On the other hand, pulse rise-time measurements require the availability of triggered-sweep operation with calibrated time

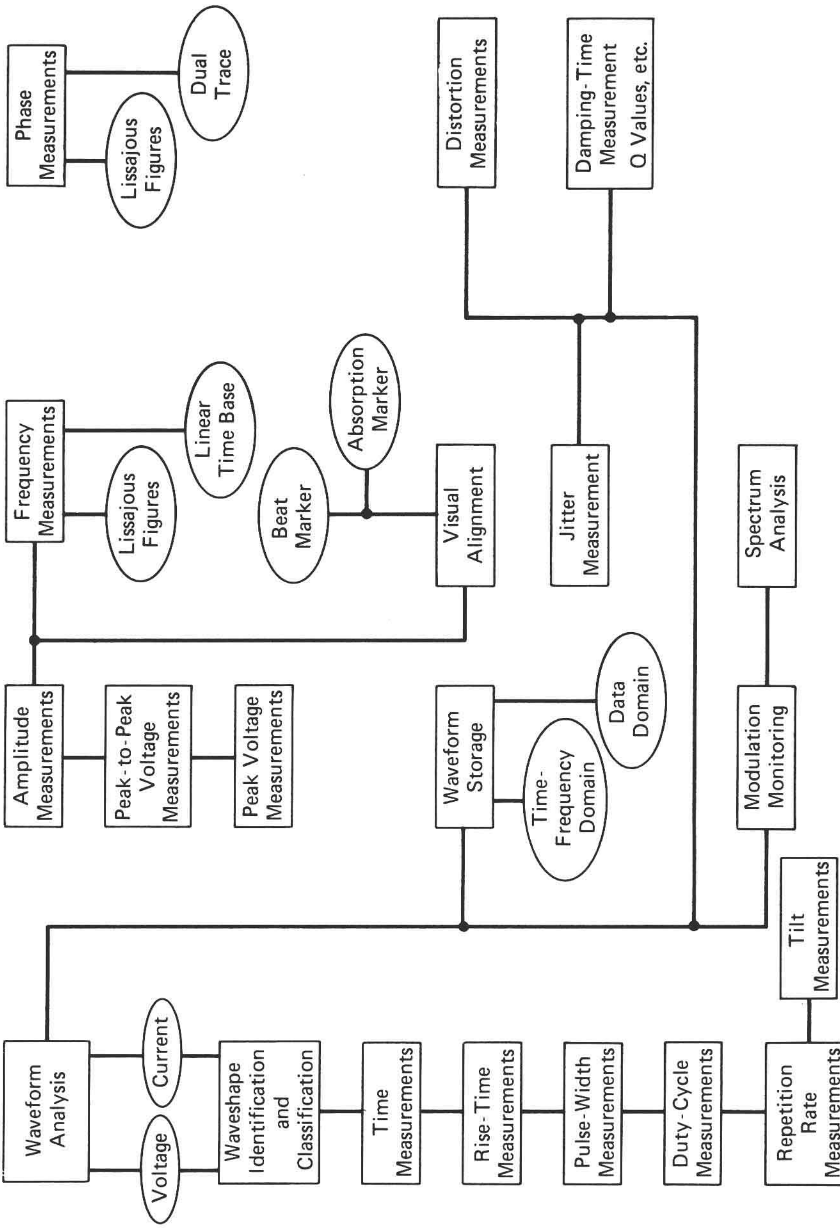

Waveform Analysis
Voltage
Current
Waveshape Identification and Classification
Time Measurements
Rise-Time Measurements
Pulse-Width Measurements
Duty-Cycle Measurements
Repetition Rate Measurements
Tilt Measurements
Amplitude Measurements
Peak-to-Peak Voltage Measurements
Peak Voltage Measurements
Waveform Storage
Time-Frequency Domain
Data Domain
Modulation Monitoring
Spectrum Analysis
Frequency Measurements
Lissajous Figures
Linear Time Base
Beat Marker
Absorption Marker
Visual Alignment
Jitter Measurement
Phase Measurements
Lissajous Figures
Dual Trace
Distortion Measurements
Damping-Time Measurement Q Values, etc.

FIG. 1-2.

bases, plus a delay-line section in the vertical amplifier. Again, data-domain displays require a multitrace oscilloscope with storage facilities.

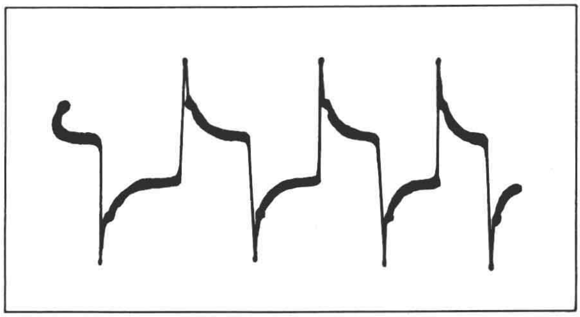
An oscilloscope that has vertical-amplifier frequency response to 20 kHz, with a simple potentiometer-type vertical attenuator, is satisfactory for audio signal-tracing procedures. Note that a sine-wave display as pictured in Fig. 1-1(a) progresses in the steady-state domain. On the other hand, a square wave, for example, progresses in the transient domain. Transient response imposes comparatively rigid demands on both vertical-amplifier and vertical-attenuator characteristics. As an illustration, Fig. 1-3 exemplifies serious square-wave distortions that occur when a simple potentiometer-type vertical attenuator is employed. To avoid this characteristic distortion, oscilloscopes designed for transient test work are provided with frequency-compensated step attenuators. A comparatively simple oscilloscope with a three-step frequency-compensated vertical attenuator is depicted in Fig. 1-4.

If an oscilloscope is to be used to check amplitude linearity of audio amplifiers, both its vertical and horizontal amplifiers must have high-fidelity characteristics. In other words, the oscilloscope amplifiers must have better linearity than the audio amplifier under test. Otherwise, deficiencies in oscilloscope response would be falsely charged to the amplifier under test. Oscilloscopes that are used to make frequency-response tests of audio or video amplifiers must have greater vertical-amplifier bandwidth than the amplifier under test. In addition, the oscilloscope needs to have highly uniform response over this frequency band. Oscilloscopes that are used to check the square-wave response of audio or video amplifiers must have better transient response than the amplifier under test. An oscilloscope is easily checked for adequacy in these respects, as depicted in Fig. 1-5.

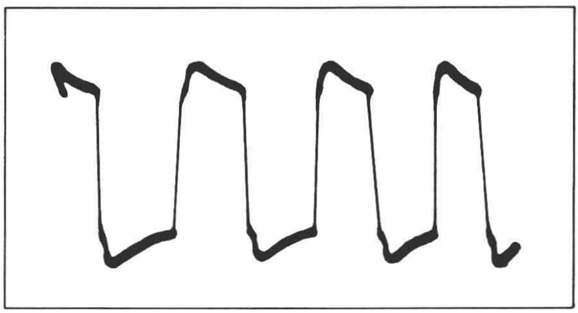
Note in passing that the audio oscillator indicated in Fig. 1-5(a) need not have a pure sine-waveform output. This relaxation of the generator characteristic is possible in view of the type of display that is employed. On the other hand, the video sweep generator indicated in Fig. 1-5(c) must be rated for a highly uniform ("flat") output over the swept band. Otherwise, generator waveform deficiencies would be falsely attributed to the oscilloscope under test. Similarly, the square-wave generator indicated in Fig. 1-5(e) must have a faster rise time and better waveform characteristics than the oscilloscope under test. In this regard, it is instructive to note that the bandwidth of a vertical amplifier (or any amplifier) is related to its rise time by the approximate formula

$$T = \frac{1}{3f_c}$$

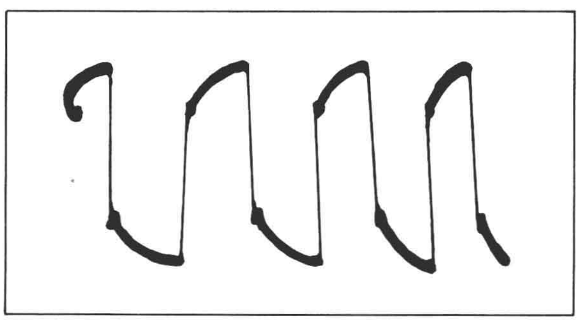
where T = rise time of the amplifier
f_c = − 3 decibel cutoff frequency of the amplifier



(a)



(b)



(c)

FIG. 1-3. *Square-wave distortions produced by simple potentiometer attenuator. (a) Low setting. (b) Midpoint setting. (c) High setting.* (Courtesy, U.S. GPO.)

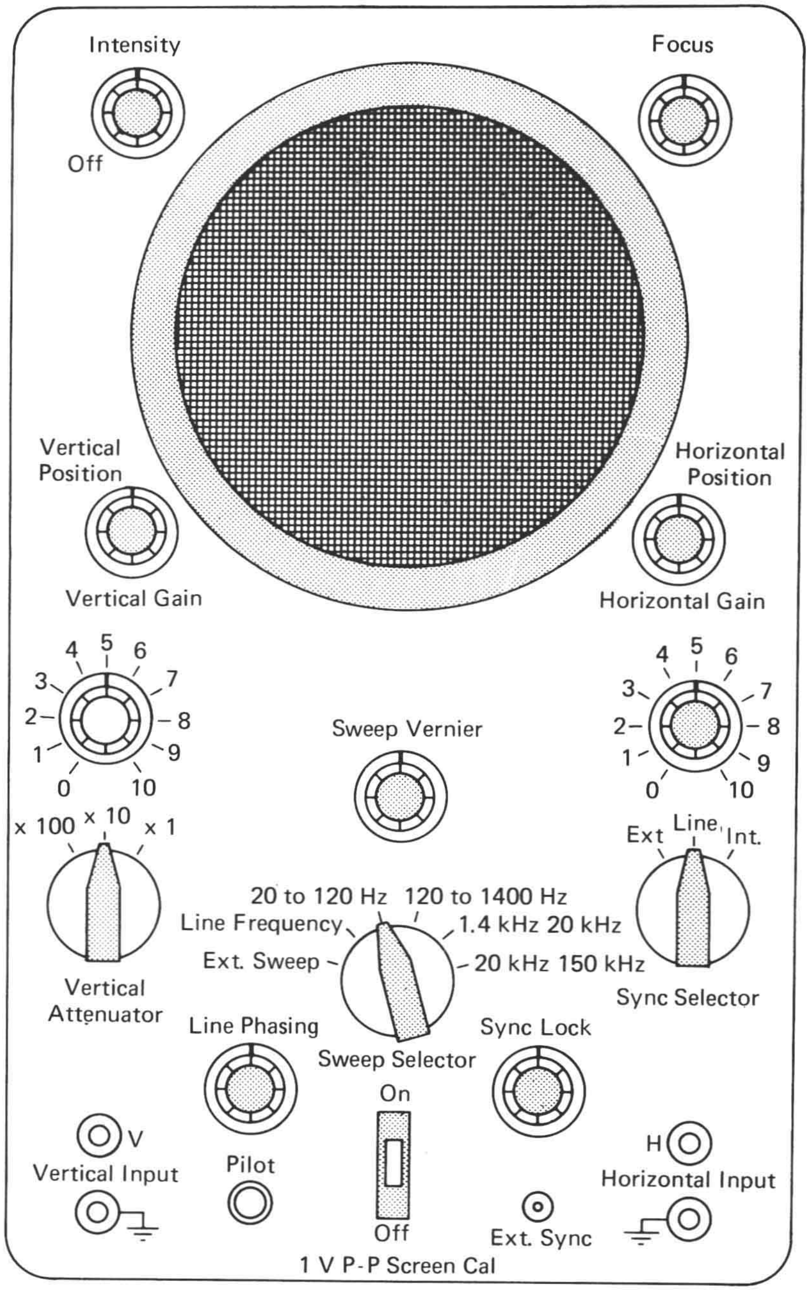


FIG. 1-4. Control arrangement for a simple service-type oscilloscope.

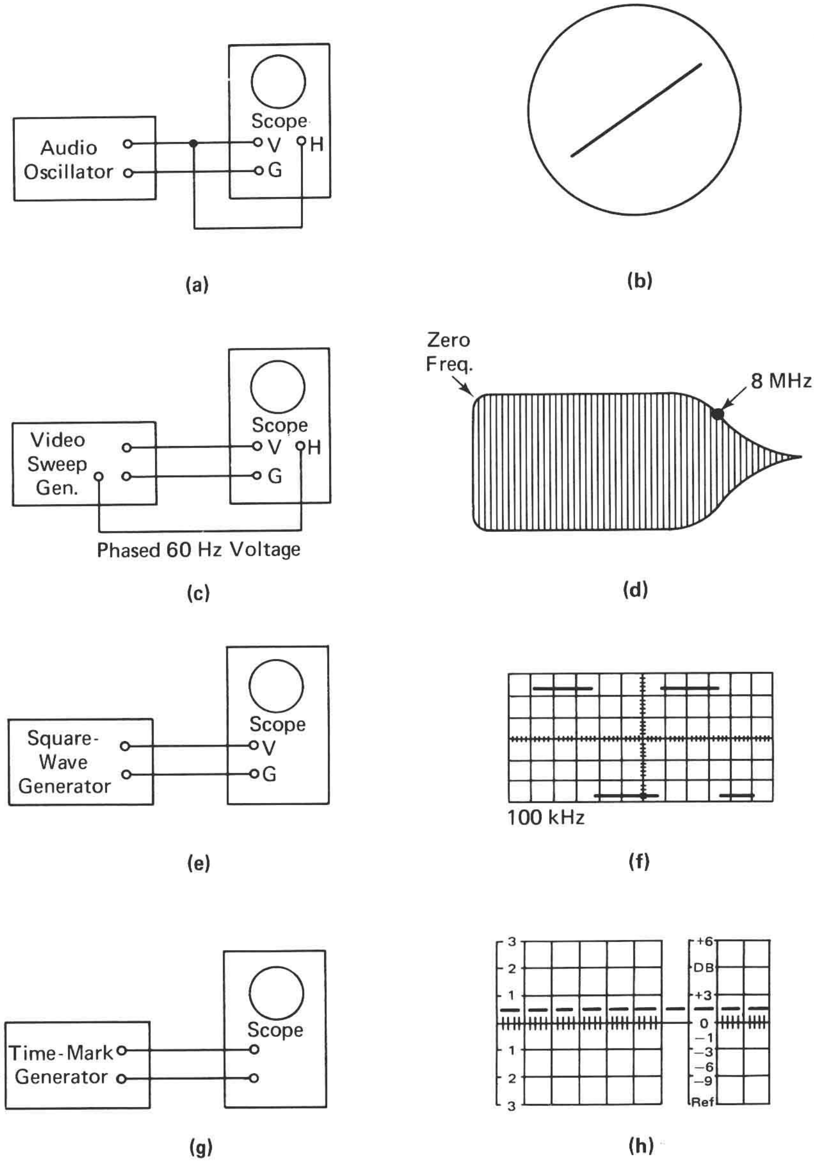


FIG. 1-5. *Scope performance tests. (a) Amplitude linearity test setup. (b) Trace is precisely straight if scope amplifiers are linear. (c) Frequency response test setup. (d) Normal pattern has uniform amplitude. (e) Transient-response test setup. (f) Normal 100-kHz square-wave response. (g) Deflection linearity test setup. (h) Horizontal intervals are the same if deflection is linear.*

1-2 Oscilloscope Functions and Waveform Aspects

Since an oscilloscope such as exemplified in Fig. 1-4 has a vertical-gain control, a horizontal-gain control, and a sweep-rate control, the aspect of a displayed waveform may depend considerably upon these control settings. In some cases, the waveform may remain recognizable as the control settings are varied. In other cases, the waveform may appear to change into another type—except to the experienced operator. Basic sine-wave amplitude and frequency displays are shown in Fig. 1-6. As the vertical-gain control is varied, and as the signal frequency is varied, the waveform aspect changes to some extent. Nevertheless, the sine waveform remains identifiable even to the inexperienced operator.

Next, consider the square-wave displays exemplified in Fig. 1-7. When the vertical-gain control and the horizontal sweep-rate control are adjusted to display vertical and horizontal excursions of equal lengths, it is evident at a glance that a square wave is being displayed. However, when the vertical-gain control setting is advanced, and the horizontal sweep-rate control setting is reduced, the displayed waveform has a substantially different aspect. A beginning operator is likely to misinterpret the displayed waveform, and to perceive it as a pulse waveform. On the other hand, an experienced operator will immediately observe that the top and bottom excursions of the waveform are equal, and will recognize that a square wave is being displayed.

Next, it is instructive to consider the pulse displays shown in Fig. 1-8. First, a pulse width of 0.02 millisecond (ms) and a repetition rate of 0.12 ms is displayed at a rate of 0.02 ms/centimeter (cm). The fact that this is a pulse waveform is clearly evident. As the sweep speed is increased to 10 microseconds (μs)/cm, the pulse waveshape becomes less apparent. At 5 μs/cm it becomes questionable whether a pulse waveform or a square waveform is being displayed. Then, at a 0.2-μs/cm sweep speed, the type of waveform becomes highly questionable, although various details of the leading edge become clearly visible. Finally, at a sweep speed of 0.04 μs/cm, virtually the only aspect of significance in the display is the leading edge of the waveform. This leading edge is sufficiently expanded that the rise time of the waveform can be measured with reasonable accuracy; in this example, the rise time is approximately 0.02 μs.

Waveform aspects can also be greatly changed by control misadjustment. A block diagram for a simple oscilloscope is shown in Fig. 1-9. This is an example of a free-running time base. If the sweep-frequency control is set so that the repetition rate of the time base is the same as the frequency of the incoming signal, one cycle of the signal will be displayed