SERVICE SCOPE

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A NEW PHYSIOLOGICAL MONITOR

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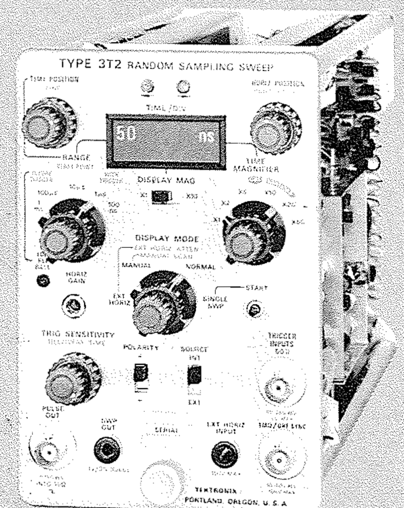

A NEW MEASUREMENT CONCEPT—RANDOM SAMPLING

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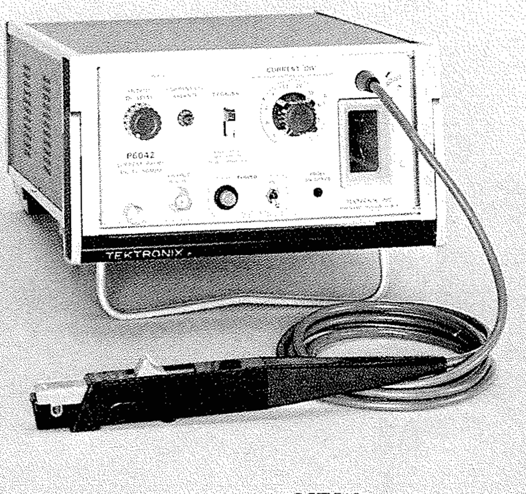

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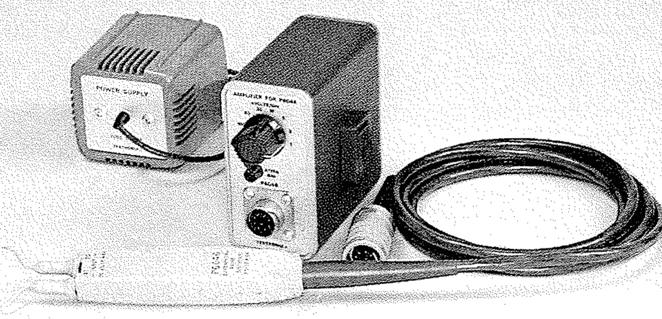

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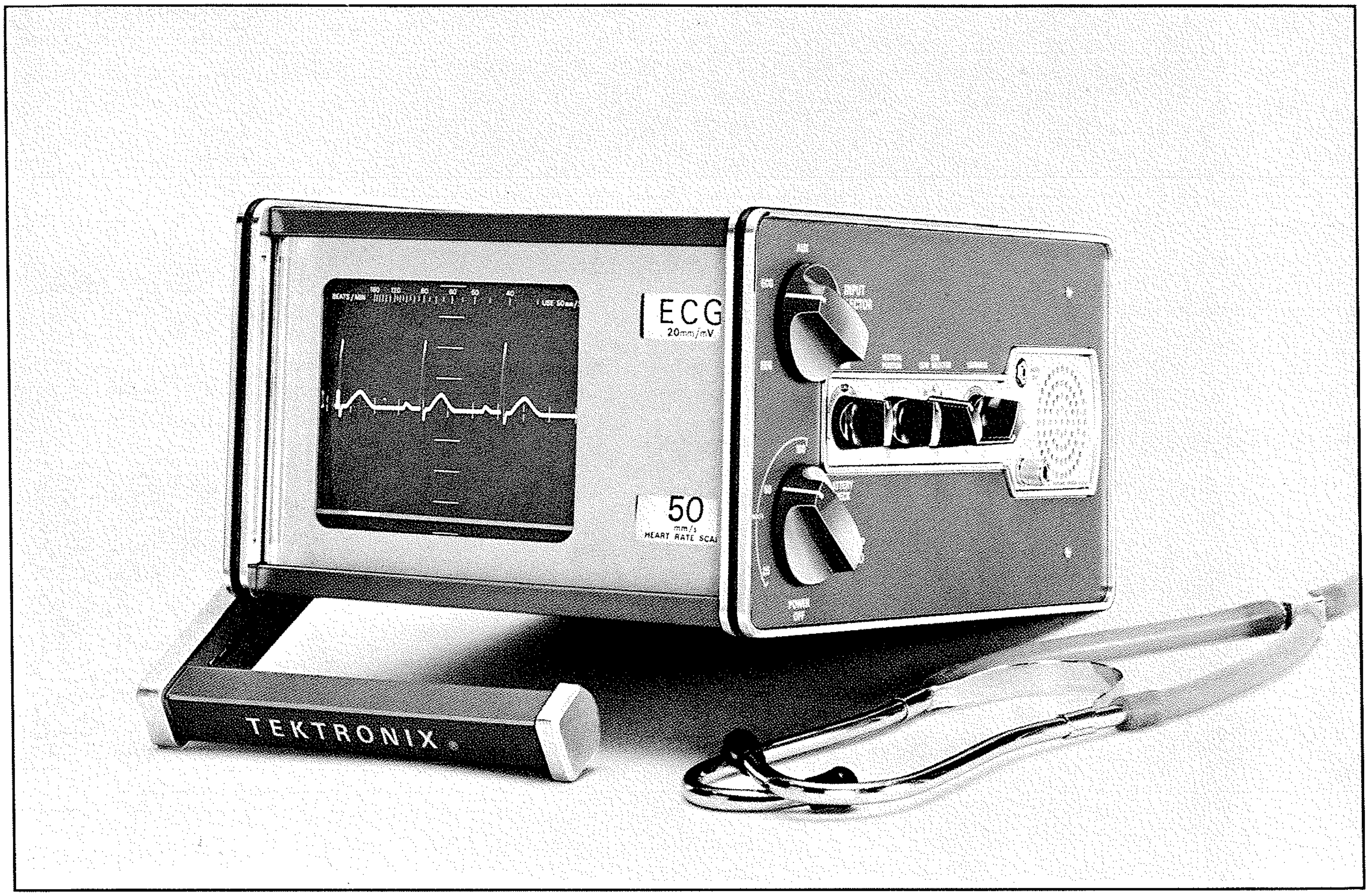
A SIMPLIFIED OSCILLOSCOPE FOR THE OPERATING ROOM

by Don L. Clark



INTRODUCTION

Tektronix recently introduced the Type 410 Physiological Monitor, a special purpose oscilloscope for use in clinical medicine. The instrument is *small* and powered by a rechargeable battery pack. Despite its compactness, it features a large 8 x 10 centimeter display area made possible by a wide-angle, magnetically-deflected cathode-ray tube (CRT). More importantly, the monitor is tailored to the unique requirements of the medical clinician.

For example, the controls are greatly simplified from those found on many oscilloscopes and are labeled in terms meaningful to medical personnel (Fig 1). The size and optional mounting fixtures permit the instrument to be used in the crowded perimeter of the surgical operating table.

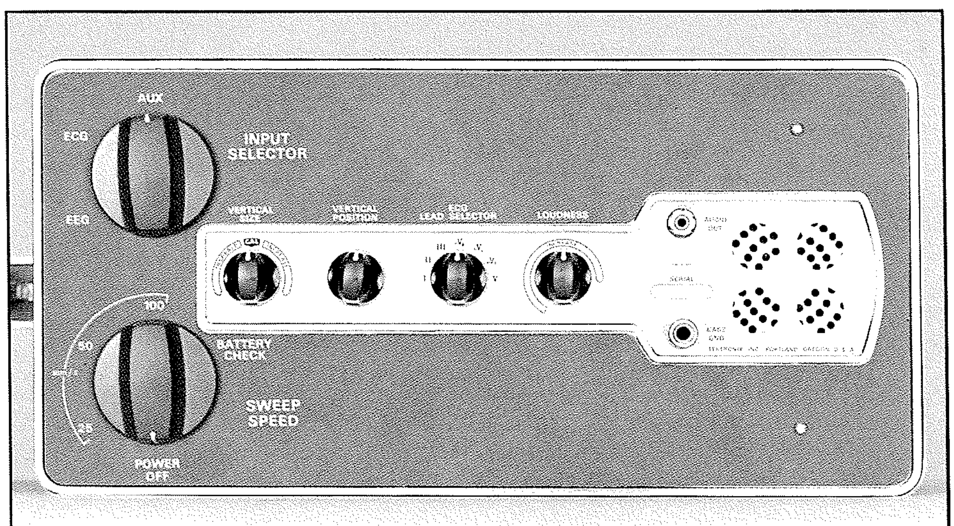


Fig 1. Type 410 Operating Controls

You can monitor any of three important physiological signals with the Type 410:

ECG—(or EKG, the Electrocardiogram) An electrical signal produced by the heart which can be detected on the surface of the body.

Pulse—Pulsations of blood sensed in the finger or elsewhere with the appropriate transducer.

EEG—(Electroencephalogram) An electrical signal produced by the brain.

The 410 was designed to be used wherever surveillance of patient condition is vital. In the operating room, a physiological monitor provides information regarding reactions to anesthesia and surgical procedures. In the recovery room and the intensive care unit, which by their very existence indicate the importance of constant surveillance, the physiological monitor provides a continuous display of valuable data.

SIGNALS FROM THE HUMAN BODY

The human body provides many indexes of relative well-being. Excessive body temperature has long been known to accompany ailments ranging from the minor to the serious. In a similar sense, and with varying degrees of reliability, eye dilation, pulse rate, respiration rate and others provide worthwhile information regarding the viability of the human body. When considered in the time domain, certain of these physiological indicators become more critically important and can yield substantially more information than others.

For example, one or two degrees of excessive body temperature persisting for several days would be of comparatively less cause for alarm than a heart stoppage for ten seconds. Moreover, the thermal mass of the body is such that hourly sampling might provide all the information required. But the nature of the heart is such that significant information may be observed from events lasting only a few hundredths of a second.

Thus, the physiological signals can be classified according to (1) the magnitude of deviation from the norm, (2) the relative importance to the human body, (3) the rapidity with which the change can occur, and (4) the time duration of the shortest significant event within the data. Signals involving comparatively short duration cyclical events and potentially rapid change can yield considerable information when displayed in graphical form on a monitor such as the Type 410.

THE ELECTROCARDIOGRAM (ECG)

Among the key physiological indicators is the ECG; a graphical recording of the heart electrical activity. This signal is associated with the muscular contraction which produces the pumping action. Effective pumping requires coordination of the individual heart muscles, with related cyclical patterns in the electrical signal.

While the electrical signal occurs within the heart muscle tissue, it can be detected on the surface of the body. The sensing electrodes can be placed at many different sites and each pair or combination of electrodes provides a different perspective of the complex three-dimensional signal generator, the heart.

Figure 2 shows an idealized waveform representing the electrocardiogram from one of the more popular monitoring configurations which consist of a differential measurement between electrodes on the right arm and left leg with a third electrode on the right leg serving as a common-mode reference to the monitoring system.

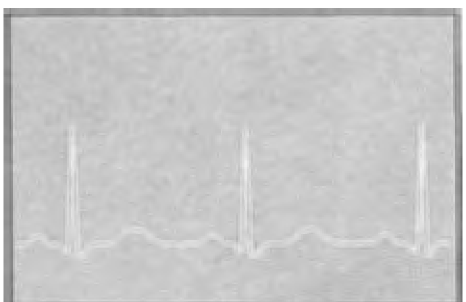


Fig 2. ECG Waveform

The information obtainable from the ECG is far too broad and technically complex to detail here, but several general uses can be mentioned: (1) Heart rate can readily be determined as can improper rhythm. (2) Heart attacks may involve dead tissue and coagulated blood in portions of the heart which can produce an abnormal ECG. (3) During certain stages of pregnancy, the fetal ECG can be detected. The presence of more than one fetus has sometimes been determined by this method. Orientation of the fetus in the womb may be determined by noting the fetal ECG polarity. (4) Victims of electrical shock may die due to heart fibrillation, a condition in which little or no blood is pumped by the heart. Fibrillation is a total loss of coordination between the various heart muscles which causes the heart to quiver rapidly rather than rhythmically contracting and expanding. Defibrillation can often be accomplished by applying a powerful electrical shock (up to 400 watt seconds in a ten-millisecond pulse) which temporarily locks the heart muscles. Within a few seconds after the intentional shock, the heart will often restart with the proper coordination. The electrical activity of the heart before and after defibrillation is readily monitored with the Type 410. Input circuitry of the instrument is protected against destruction by the defibrillator pulse so that there is no need to disconnect the monitoring electrodes during defibrillation.

THE PULSE

A normal ECG is no proof that blood is properly circulating throughout the body. Monitoring of the pulse by touch on the wrist, neck or elsewhere can show that blood is circulating, at least in that portion of the body and, in some cases, the judgement can be made that the pulse is "weak" or "strong".

The Pulse Sensor can more than replace the conventional touch method. The sensor is easily attached to the patient and will provide continuous, hands-off monitoring.

As the blood pressure rises and falls with each heart beat, the amount of blood present in any particular portion of the flesh varies slightly with the expansion and contraction of the blood vessels. This slight change can be detected from the correspondingly slight change in the translucency of the flesh. A small, low-power incandescent lamp directs light into the flesh and an adjacent photoresistor senses the light variation.

The finger tip, toe, and forehead are particularly good locations for the sensor. Contact pressure between the sensor and flesh is an important factor; excessive pressure will block blood flow and too little pressure will result in an excessive sensitivity to movement, thereby introducing interference. The Pulse Sensor is shown in Figure 3 with a removable finger adapter.

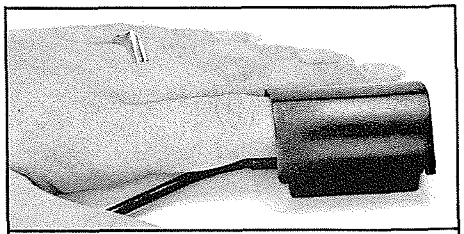


Fig 3. Pulse Sensor

This spring-loaded adapter not only holds the sensor against the finger with the proper pressure, but also excludes potentially interfering modulated light from fluorescent lamps or other sources. The adapter can be quickly attached and is self-holding on the finger.

For quick determination of heart rate, a direct reading Heart Rate Scale is provided across the top of the Type 410 graticule as shown in Figure 4. This scale is possible through the use of automatically triggered sweeps for both ECG and pulse displays,

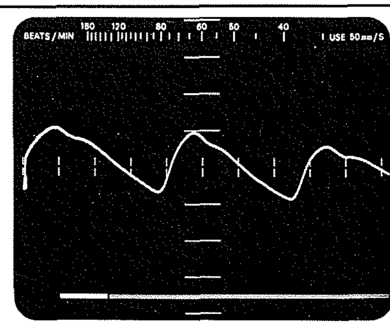


Fig 4. Pulse Sensor Waveform

and by the accurate sweep speeds of the Type 410. Three sweep speeds are provided: 25, 50, and 100 millimeters per second. The Heart Rate Scale is calibrated for use with the 50 mm/s speed.

The portion of the signal which has the greatest amplitude triggers the sweep and therefore appears at the lefthand edge of the graticule as shown in Figure 4. The corresponding portion of the next cycle appears to the right of the first at a distance determined by the time interval between the events and the horizontal sweep speed of the Type 410. From the known sweep speed and the measured distance, a simple calculation gives the pulse rate. The Heart Rate Scale is derived from this calculation and can be used with either a pulse or ECG display. (Display shows 75 beats/min.)

While the event which produces sweep triggering remains stationary at the lefthand edge of the graticule with successive sweeps, the second event changes position with any variation in heart rate. If the heart rate is uniform, the display need be watched for only two or three seconds to obtain an accurate rate indication. The scale can also be used with slightly less accuracy with the other two sweep speeds; dividing by two on 25 mm/s and multiplying by two on 100 mm/s.

THE ELECTROENCEPHALOGRAM (EEG)

In some surgical procedures, the heart is intentionally stopped and blood circulation is maintained by an external mechanical pump making it more difficult to determine the relative well being of the patient. In such cases the Type 410 can be used to monitor the EEG, the electrical activity of the brain. This complex signal, seemingly random to the layman (Figure 5), can yield valuable information through analysis of amplitude and frequency content.

The EEG is detected upon the surface of the head with electrodes similar to those used for ECG.

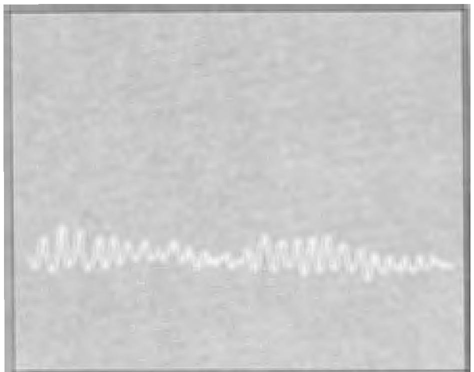


Fig 5. EEG Waveform

MONITORING CONVENIENCE

Note that all three types of signals previously discussed as applicable to the Type 410 are not only among the *most* important indicators of patient well being, but that all are available at the surface of the body.

For maximum monitoring capability and cross correlation between signals, seven electrodes and the pulse sensor may be connected to the patient as shown in Figure 6. Using only the INPUT SELECTOR switch, the user can select the EEG, ECG, or pulse waveform. With a second switch, the ECG LEAD SELECTOR, any of seven standard combinations of ECG electrodes may be chosen.

THE CLINICIAN AND HIS ENVIRONMENT

The Type 410 is of particular value to the anesthesiologist, a medical doctor specializing in anesthesiology. His activities in the operating room go far beyond the administration of anesthetics; he is responsible for monitoring patient well-being, assists the patient's breathing, monitors blood loss and replacement, monitors blood pressure, administers drugs, and in general watches for any unfavorable reaction due to the anesthetic or the surgical procedure.

Instrumentation which can provide some of the needed data can be of considerable value. To provide the anesthesiologist with continuous information, the Type 410 produces an audible "beep" coincident with the most significant event in each cycle of the ECG or pulse waveform. Most doctors and nurses, through experience, will be able to estimate heart rate quite accurately by listening to the "beep" and will most certainly be able to detect poor rhythm. Should a more qualitative determination of heart rate be desired, a quick look at the Heart Rate Scale will suffice. With the LOUDNESS control, the sound can be made audible to the entire surgical team or only to the anesthesiologist.

Several features of the Type 410 combine to insure that a display is available under nearly all circumstances. These features include the elimination of input coupling capacitors so as not to retard recovery from overdrive by high amplitude defibrillator pulses or electrocautery arcs. AC coupling for drift elimination is provided between amplifier stages and includes an overdrive scan limiter for quick recovery.

Automatic sweep triggering circuits, which require no operator controls, seek out the event of dominant amplitude in the ECG or pulse signal, regardless of polarity. If the amplitude of the dominant event should suddenly decrease, the sweep and audio "beep" temporarily stop while the trigger circuits search for lower amplitudes. However useful information continues to be available. The CRT spot will appear at the lefthand edge of the graticule and any available heart signal will cause the spot to bounce vertically. If, within two to four seconds, the triggering circuits have not found a lower amplitude signal, the audio "beep" restarts, sounding at a rapid rate to serve as an alarm.

The operating room presents several unique restrictions to the use of instrumentation. The area immediately surrounding the operating table is often crowded with people and equipment. Certain of these people must move around during the operation and their pathway must not be obstructed by equipment, patient monitoring cables or power cords. *Battery operation* of the Type 410 avoids power cords across the floor.

A suitable location for the Type 410 is available on the anesthesiologist's gas machine. This machine is usually located near the patient's head and is a wheeled cart containing gas cylinders, distribution manifolds, valves, flow gauges, etc. There is often a set of drawers in a cabinet which provides a small table top. Hoses from the gas machine connect to the face mask through which the patient breathes. By mounting the Type 410 on this machine, the patient cable parallels the hoses to the patient and therefore is not an added obstruction to traffic. The instrument is then at a convenient viewing distance for the anesthesiologist and the controls are within easy reach.

An optional mounting fixture is available for mounting the Type 410 to the side of the gas machine so that the much-needed table space is not occupied. The mount can be attached to a flat surface on the side of the drawer cabinet or to one of the vertical pipes used as structural support in some machines. The Type 410 is supported five feet above the floor by the mounting fixture in order to comply with safety regulations, and is a convenient level which permits most members of the surgical team to see the display when desired.

When a surgical operation is completed, the patient must often remain under close observation for several hours. The first stage of observation usually takes place in the recovery room adjacent to the operating room. It is sometimes undesirable to interrupt the electronic monitoring of the patient while moving from surgery to recovery room. The battery-operated Type 410 simply lifts off the mounting fixture and is easily carried along with the patient for continuous monitoring.

MEASUREMENT BARRIERS

The real test of any physiological monitor is the fidelity with which it displays the bioelectric signal. The human body is considerably less than an ideal signal source. The signals of interest are small, about one millivolt. Unless the body is grounded, it usually bears an interfering 60-Hertz signal of several volts which is electrostatically induced by power line sources such as nearby lighting fixtures and appliances. This signal will

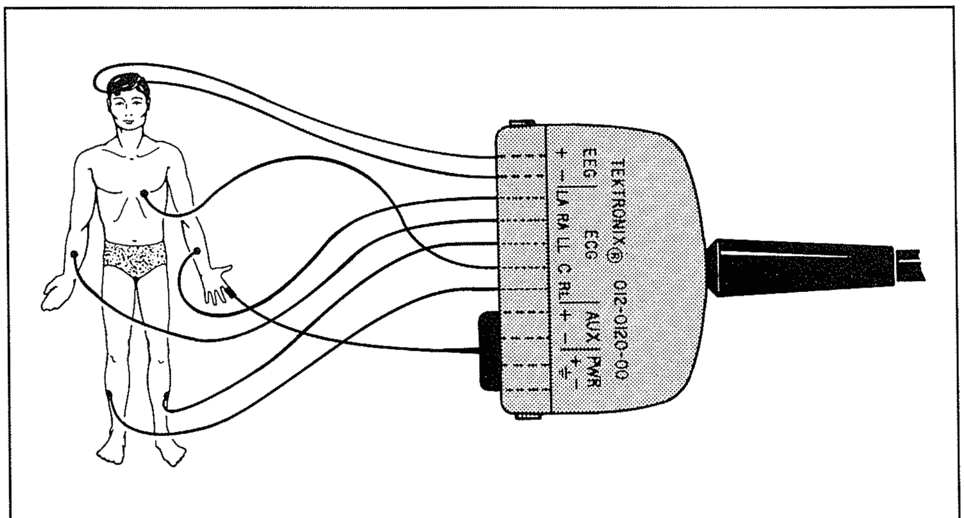


Fig 6. Electrode and Sensor Connections for Cross Correlation of Signals

be common to all active signal leads to the monitoring device and is termed common-mode signal.

The outer layer of skin is of comparatively high resistance and is therefore an undesirable element in the signal path. Moreover, when a metallic electrode is placed upon the body, the body fluids constitute an electrolyte and one-half of a battery is formed. Dissimilarities among the several electrodes on the body can cause a DC voltage to exist between them. But since they form a poor battery, the terminal voltage can vary with patient movement, perspiration, etc. This voltage variation cannot be separated from the desired bio-electric signal and therefore must be eliminated at its source.

Certain desirable characteristics of a physiological monitor can now be described. High skin resistance must be reduced and any voltage difference between electrodes must be small and stable. The monitor should be unaffected by the common-mode interference signal.

The ability of a monitoring system to reject a common-mode signal is often limited by an inability to transport the common-mode signal to the monitor by the two different paths without having the signal arrive at the monitor in dissimilar forms. If this happens, at least part of the signal is no longer in common mode, but has become a differential signal which cannot be rejected by the monitor. This problem can occur due to the skin resistance at each electrode forming an attenuator with the shunt input impedance to circuit ground within the monitor.

It is common practice to use a saline paste under each electrode to impregnate the skin, thus reducing the resistance between the highly conductive body fluids and the electrode. This can reduce skin resistance from a high of perhaps one megohm to as little as a few hundred ohms with careful preparation. However, a more practical degree of skin preparation will result in resistances ranging from one to five kilohms. Since it is highly unlikely that the resistances at the various electrode sites will match, it is probable that dissimilar attenuators will be formed with the monitor input circuitry. A few simple calculations will show that shunt impedances to circuit ground within the monitor of several hundred megohms are required to reduce this effect to an acceptable level.

The Type 410 provides excellent common-mode interference rejection capabilities by actively driving the shunt impedances in the input circuitry. This technique is called "guarding" and effectively multiplies the input impedances to several thousand times their actual values. The common-mode signal therefore arrives at the monitor in a form which permits virtually complete rejection.

The silver/silver-chloride electrodes supplied with the Type 410 eliminate virtually all of the electrochemical problems associated with ordinary electrodes. These small electrodes can be comfortably worn by the patient for many hours at a time. Electrode adapter cables are also provided with the

Type 410 which permit the use of many other standard electrode types.

POWER REQUIREMENTS

The Type 410 obtains power from a removable battery pack in the rear of the instrument. The pack contains ten rechargeable size "C" Nickel-Cadmium cells and a complete line-operated charger. Recharging is started by simply inserting the power cord into the rear of the battery pack. The battery provides eight to twelve hours of instrument operation for each recharge.

When the Type 410 is used in an Intensive Care Unit, continuous operation for days or weeks may be required. This presents no problem. With the power cord attached, the instrument can operate indefinitely because the charging current slightly exceeds the current required by the monitor.

PACKAGING CONCEPTS

The top, bottom, and sides of the Type 410 are rugged aluminum-alloy castings which provide an easily cleaned, dust-tight cabinet. The monitor weight is only 12½ pounds including the battery pack. Eighteen handle positions are provided for carrying or for tilting the instrument to the best viewing angle. The handle hub is specially shaped to fit into a cup-shaped bracket on the mounting fixture (Fig. 7).

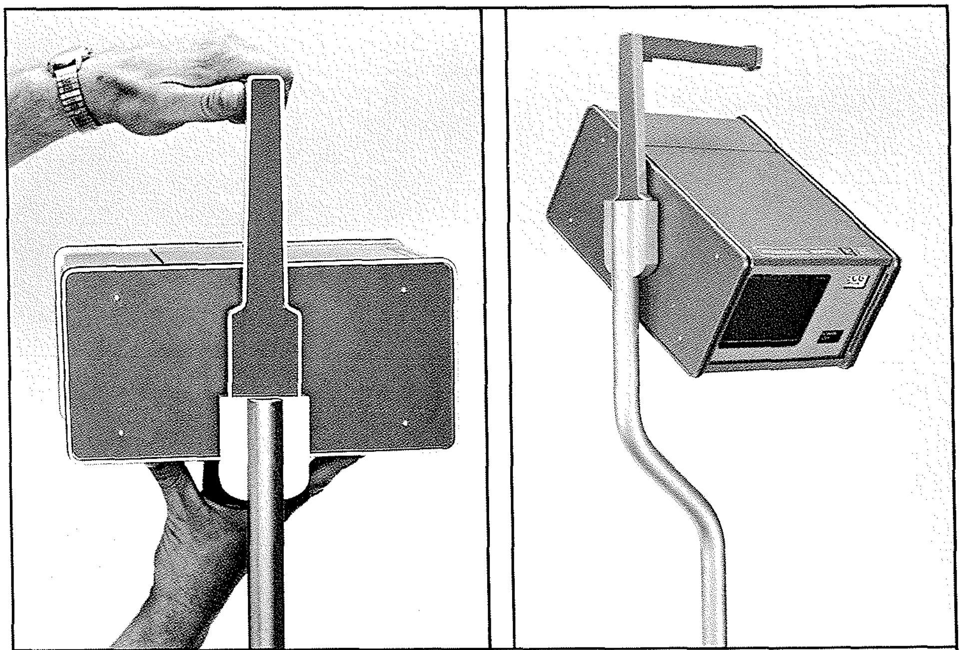


Fig 7. Attaching the Type 410 to the Mounting Stand

SUMMARY

The Type 410 Physiological Monitor was designed for patient surveillance. Only a few of the many necessary considerations have been discussed here; the physiological signals, the intended user, the environment, the fidelity of signal display, etc. The area of possible application is broad.

Output signals available from the rear of the monitor can drive a recorder to provide a permanent record as is usually required in diagnostic applications. This portable, simple-to-operate instrument will also find application in medical research with both people and animals, as well as in Veterinary Medicine.

TYPE 410 PHYSIOLOGICAL MONITOR CHARACTERISTIC SUMMARY

VERTICAL

Bandwidth

ECG and AUX	≤0.1 Hz to 250 Hz ±15%
EEG	≤0.1 Hz to 100 Hz ±15%

Calibrated Deflection Sensitivity

Display mode	Deflection Sensitivity	Accuracy ≤20 mV DC offset	Accuracy At 100 mV DC offset
EEG	10 mm/50 μV	±5%	0 to −10%
ECG	20 mm/mV	±5%	0 to −10%
AUX	2 mm/mV	±5%	0 to −10%

Vertical Size Range ≤ X1/3 to ≥ X3

Differential Input Resistance

EEG and ECG	2 MΩ ± 15%
AUX	20 MΩ ± 15%

Differential Dynamic Range

At least 100 mV of either polarity

Common Mode Rejection Ratio

With ≤5-kΩ Source Impedance unbalance (at 60 Hz) and using properly applied electrodes.

EEG	≥ 150,000:1
ECG	≥ 150,000:1
AUX	≥ 150,000:1

Common-Mode Dynamic Range

+3 V to −3 V

Drift

≤0.5 cm/h (after 10 s warm-up)

Nondestructive Input Voltage Limits

Instrument need not be disconnected from patient during DC defibrillation or cautery

Differential Overload Recovery Time

≤4 seconds (all cases)

TRIGGER

Trigger Requirements

0.5 cm ECG display (≥ 40 beats/min)
0.5 cm blood pulse display (≥40 pulsations/minute)

Delay Before Sweep Free-runs

2 to 4 s after last trigger

HORIZONTAL & AUDIO

Sweep Speed

25, 50, 100 mm/s ±5%

Battery Check Scale

Green—Normal Operation
Yellow—Recharge needed
Operation not harmful to instrument
Red—Do not operate

Heart Rate Scale Accuracy

±5% of reading (50 mm/s range, 35 to 110 beats/min)

Audio

Audio "Beep" at heart rate with alarm activated upon loss of signal

POWER SOURCE

Line Voltage

90 V to 136 VAC
180 V to 272 VAC

Line Frequency

48 Hz to 440 Hz

Battery Operating Range

11.9 V to 15.0 V

AC Input Power

≤7 W at 115 V, 60 Hz

Battery Pack

Ten Size "C" NiCd cells; 1.8 Ah

Charging Time

14 to 16 hours

Discharge Time

8 to 12 hours operation with maximum accessory load at +20° to +25° C

OTHER

Turn-on time

≤4 sec

Warm-up time

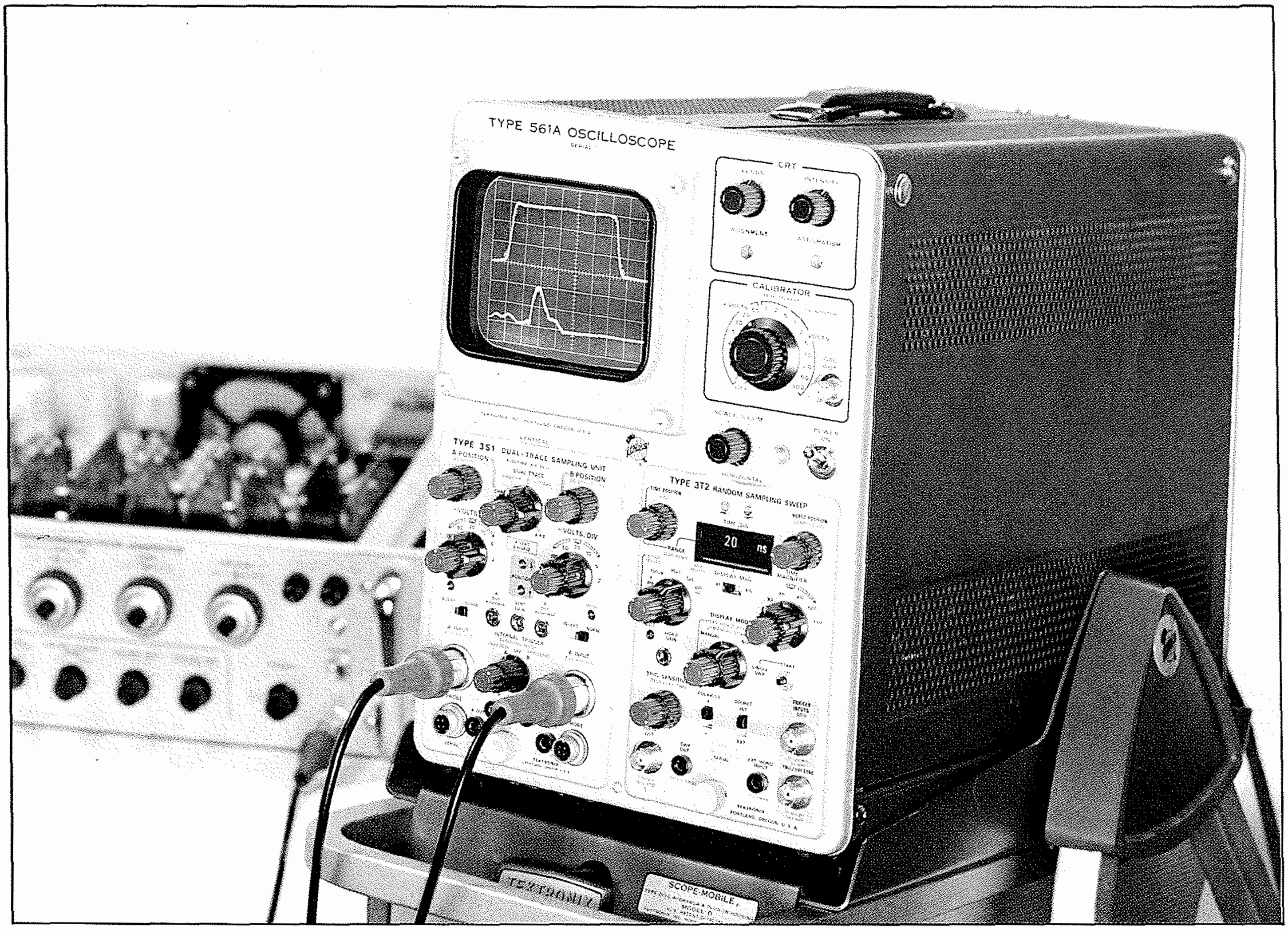
≤10 sec

CRT

5″ with P-7 phosphor

RANDOM SAMPLING—
A NEW WAY OF FAST PULSE DISPLAY

by Al Zimmerman



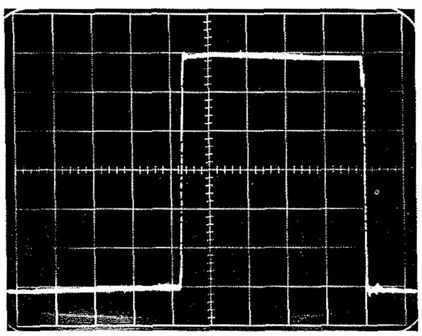


Fig 1A. 3T2 Unit in "BEFORE TRIGGER" mode: the leading edge can be observed.

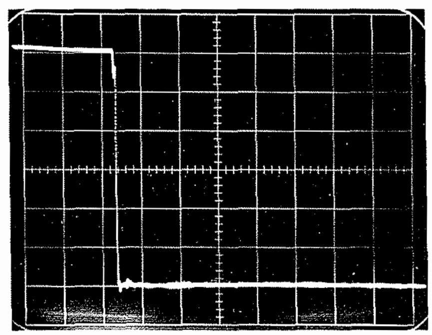


Fig 1B. 3T2 Unit in "WITH TRIGGER" mode (conventional sampling): the leading edge cannot be observed without a delay line or pretrigger.

INTRODUCTION

The Type 3T2 Random Sampling Sweep Unit provides a unique state of the art advancement in measurement capability. It permits observation of the leading edge or other portions of the signal even when used with vertical units that have *no delay lines and without a pretrigger.*

The advantages of eliminating delay line or pretrigger application are evident:

1. The inherent distortions and risetime limitations of signal delay lines are eliminated.

2. It is no longer necessary to work into the 50-Ω characteristic impedance of a delay line, so that direct sampling probes may be used for convenient high-impedance in-circuit signal pickup.

3. Trigger may occur prior to, coincident with, or after the displayed signal without sacrificing lead time in the display.

4. Signals with no convenient source of a stable pretrigger can be observed without display jitter.

HOW RANDOM SAMPLING WORKS

In the following explanation of the principles of the Random Sampling process, (how it is used in Tektronix Type 3T2 Plug-in Unit) an understanding of conventional sampling is advantageous.

The Random Sampling process is composed of two basic operations:

1. Originating the sample pulses randomly distributed in a time window around the part of the signal to be displayed.

2. Constructing a pulse display by deriving two analog signals, representing X and Y coordinates, from a series of those samples.

ORIGINATING THE SAMPLE PULSES

To find the right time for originating the samples a "Trigger Rate Meter" is used, which measures the trigger repetition rate. This rate meter gets its input from the trigger recognizer and holdoff circuit. On the basis of several sequential trigger rate measurements, the rate meter starts a negative going signal (slewing ramp) which generates samples within the time window. The start time of this slewing ramp is *before* the next trigger signal (ΔT) and is a forecast resulting from the previous trigger-rate measurements. So it can be seen that the start time of the slewing ramp is not in a fixed time relation to the next trigger signal, but more the "best guess" of the rate meter.

The display thus becomes a random sampling display because of the inability of the rate meter to make a perfect "guess" of when to take a sample.

The rate meter provides maximum display dot density by gathering the samples around just that section of the waveform that is used for the CRT display (see Fig. 2). This time window can be a very small portion of the total signal period. The samples which fall outside the time window do not have any contribution to the display construction and are kept as few as possible.

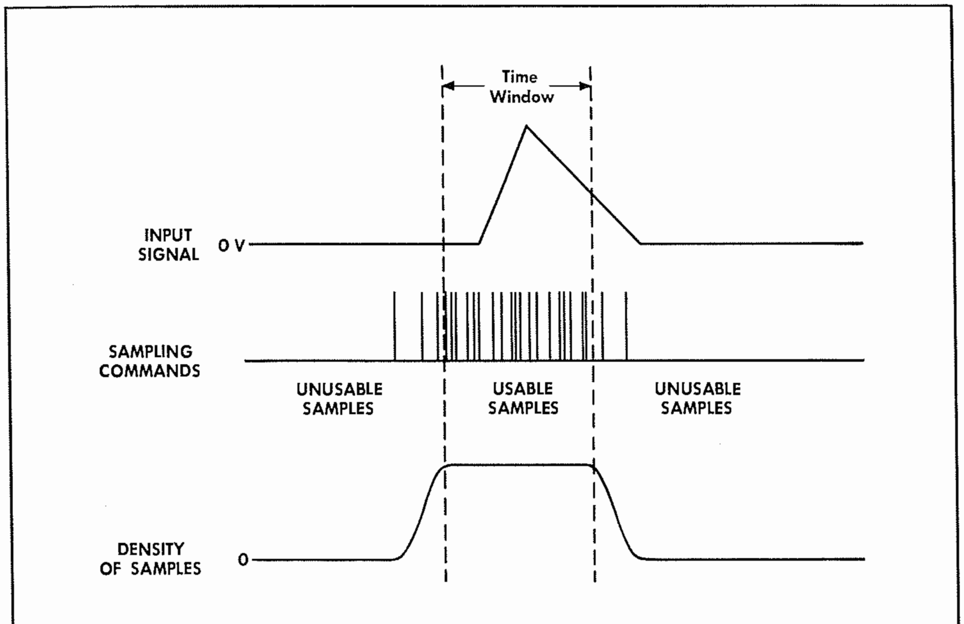


Fig 2. Distribution of samples over a time window, which covers the section of the signal to be displayed.

Error Correction

If too many samples fall outside the time window, on either one side or the other, a correction of the rate meter "guess" has to be made. The principle of that correction is based on a comparison (dot position comparator) of the horizontal signal with the staircase signal. An error signal is generated when the horizontal signal does not track along with the staircase on a basis of an average of many samples. The error signal adjusts the rate meter to make a better "guess" or forecast for the next start of the slewing ramp. Fig 3 shows the correction loop.

CONSTRUCTING A PULSE DISPLAY

In order to be displayed, a sample must have a particular time relationship to the sampled pulse. The rate meter has tried to place each sample within the time window. If a sample does occur in this time window, a dot is displayed on the CRT.

The "Y" or vertical coordinate of a sample is obtained by the same sample-and-hold process used in a conventional sampling oscilloscope. The "X", or horizontal, coordinate of the sample is obtained differently, however, and this process is illustrated in Figure 4.

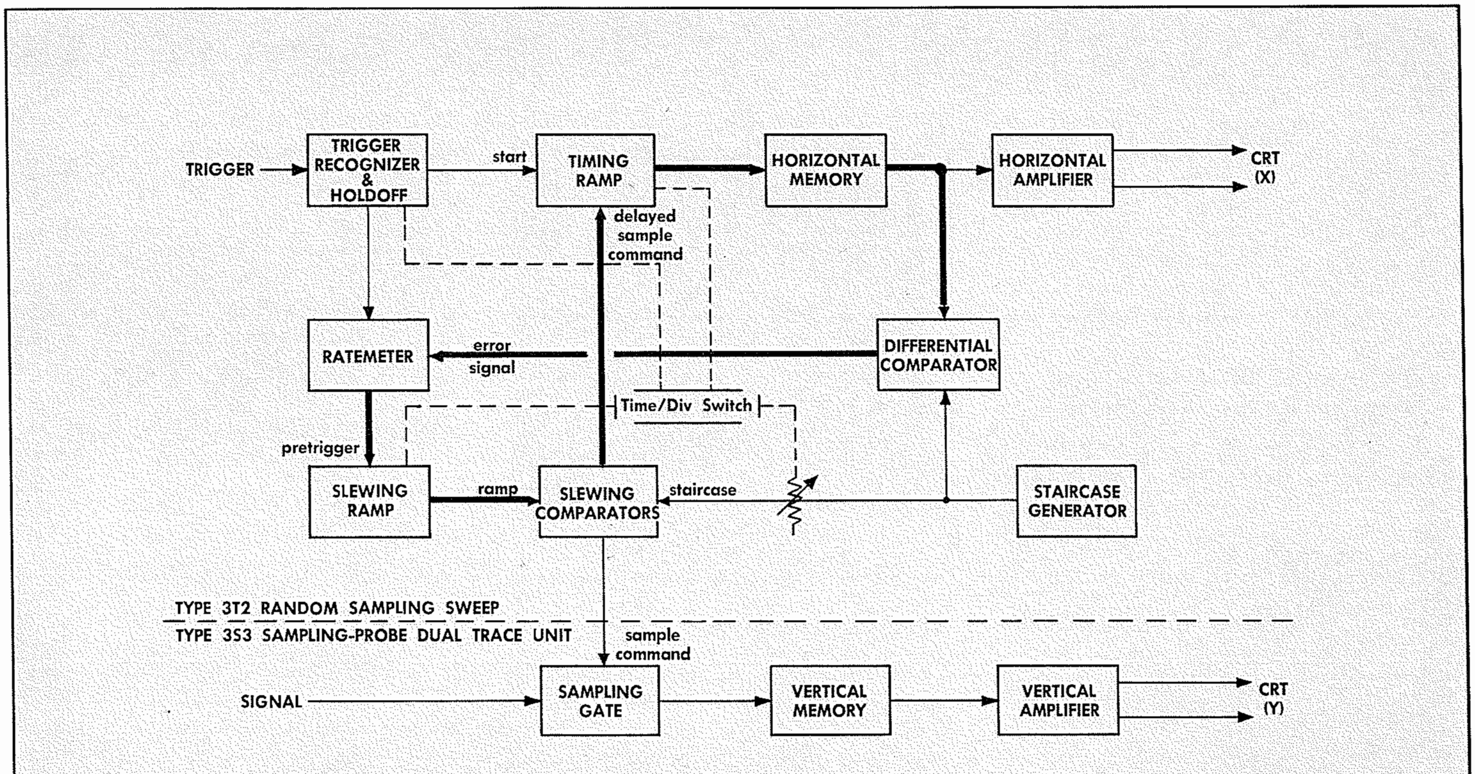


Fig 3. Block diagram of the Random Sampling process used in Tektronix Type 3T2. The dark line shows the correction process for the slewing ramp start.

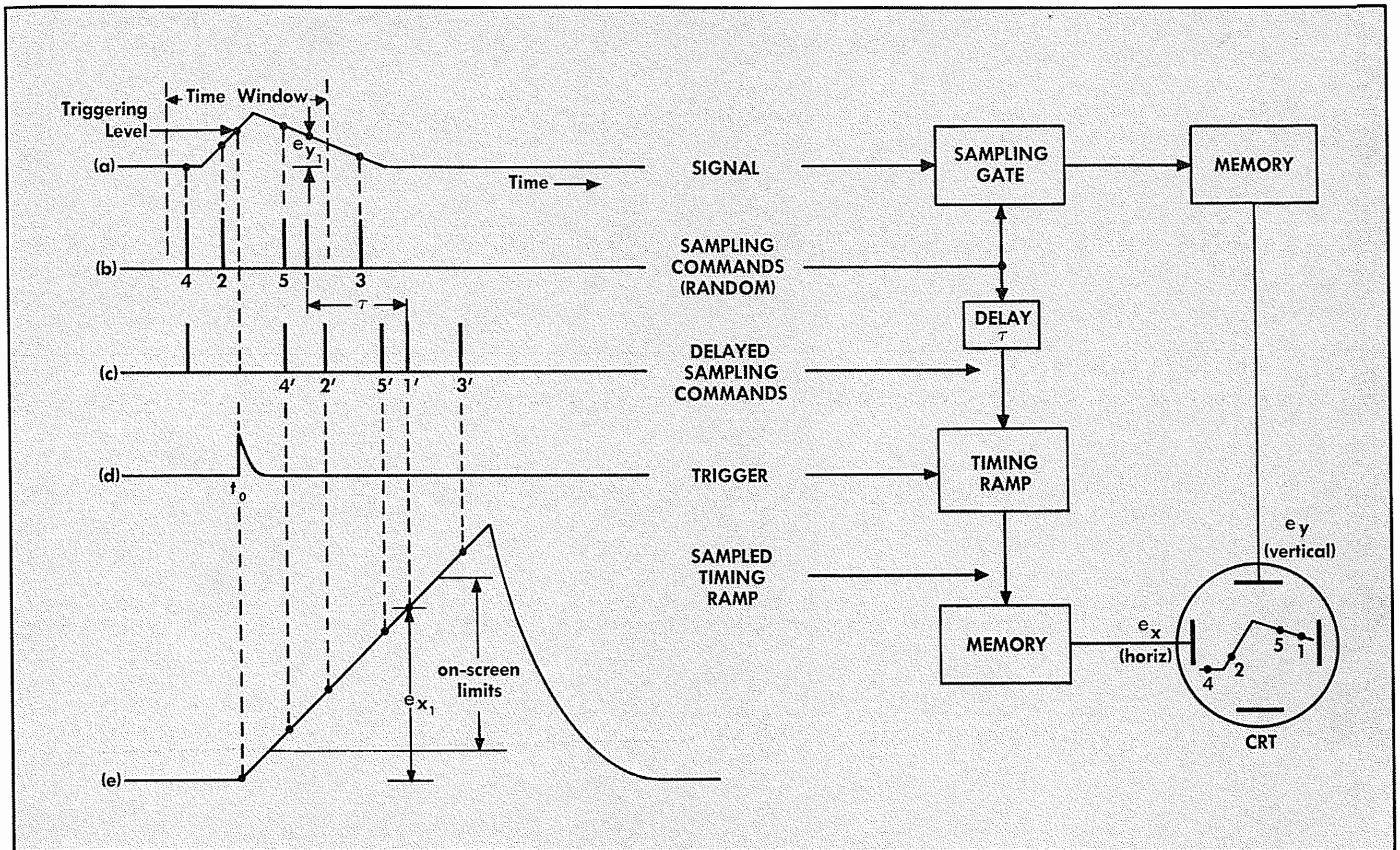


Fig 4. Derivation of "x" and "y" deflection signals.

As shown, five randomly placed samples are taken of the signal. It must be kept in mind that these five samples are taken on SUCCESSIVE repetitions of the signal. They are random samples in the "best guess" time window.

The y-component, e_y, of the first sample is held and subsequently used to position the CRT spot vertically. The sampling command which took the first sample is then delayed by a *fixed interval* τ, as indicated in Figure 4c. This delayed sampling command 1′ is used to sample a timing ramp which was started by trigger recognition along the input signal at t_0. The resulting sample e_x is held and subsequently used to position the CRT spot horizontally.

By this same process subsequent samples supply both vertical and horizontal information to deflect the CRT beam from dot to dot thus constructing a display of the signal from those samples which fall within the time window.

Some reflection will show that as the fixed interval τ is increased, more lead time will appear in the display. It should be clear that such an increase in τ for more lead time will also require a time shift of the sampling distribution to the left in Figure 4b (i.e. earlier in time) in order that the required information be collected for the display.

Figure 3 shows a complete operational block diagram of the random sampling oscilloscope including those portions which control the distribution of samples across the time window.

CHARACTERISTICS

SWEEP TIME/DIV

100 μs/div to 200 ps/div, 1-2-5 sequence, extending to 20 ps/div with X10 DISPLAY MAGNIFIER. Basic accuracy without X10 magnifier, ±3%; with magnifier, ±5%. TIME/DIV is a resultant of the combined settings of TIME POSITION RANGE, TIME MAGNIFIER, and DISPLAY MAG. The sweep rate is displayed (digitally) in the TIME/DIV "window" for all combinations of these controls.

TIME POSITION RANGE

100 ns, 1 μs, 10 μs, 100 μs, and 1 ms. TIME POSITION and FINE variable controls position start of the display through a time scale equal to TIME POSITION RANGE setting.

SAMPLES/DIV

Continuously variable adjustment of samples displayed per horizontal division from approx 5 samples/div to an immeasurable number of samples/div.

An internal switch, CALIBRATED SAMPLES/DIV, disables the front-panel SAMPLES/DIV control and converts to 100 samples/div, calibrated, for use in Digital Oscilloscopes.

START POINT

Two-position switch (concentric with TIME POSITION RANGE switch) selects either random sampling (BEFORE TRIGGER) or conventional, sequentially-stepped sampling (WITH TRIGGER).

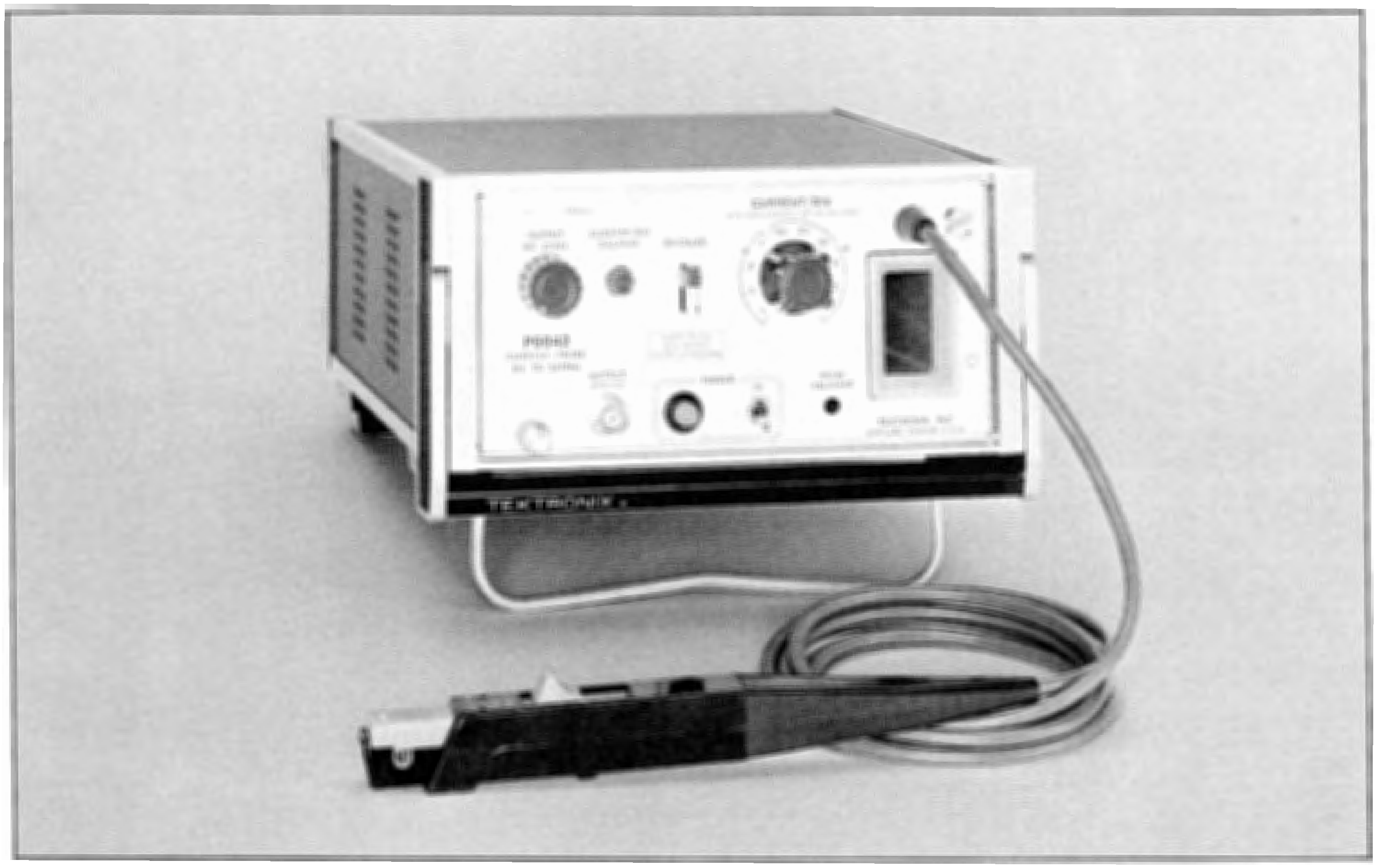
In BEFORE TRIGGER mode, the displayed "time window" may be positioned in time up to one-half times the TIME POSITION RANGE setting ahead of the trigger. This provides a base line up to 5 divisions long before the leading edge of the pulse to be viewed.

TRIGGER JITTER

Depends on signal shape, repetition rate, triggering mode. May be as low as 30 ps under optimum conditions.

P6042 DC-to-50 MHz CURRENT PROBE

by Cal Hongel



INTRODUCTION

Current probes have become increasingly useful and popular with the expanding use of semiconductor devices which are current sensing devices (current amplifiers). A new current probe has just been developed at Tektronix that provides unique measurement capabilities.

Utilizing the Hall-effect plus AC current probe technology (P6019/P6020), the P6042 DC-to-50 MHz current probe can be used simultaneously for both high-frequency and direct-current measurements. AC signals with DC components can be displayed on an oscilloscope with true waveform presentation. The probe is particularly useful for evaluating the performance of semi-conductor circuits where a wide range of parameters exist. Fast switching transients, low-frequency response, and DC level can all be displayed simultaneously (Figure 1). The P6042 can also be used to measure the sums or differences of currents in separate wires. When the probe is clipped around two wires carrying current in the same direction, the sum is displayed; around two wires carrying current in the opposite direction, the difference is displayed. For increased sensitivity the wire can be looped through the probe several times increasing the sensitivity by the number of loops.

The probe is easy to use. The conductor is simply placed into the slot of the probe and the spring loaded slide closed . . . no need to break the circuit under test. Measurements can be made only when the probe is in the locked position (push slide forward to lock). A warning light on the front panel indicates when the slide is in the unlocked position. A compartment is provided in the front panel for convenient storage of the probe when the system is not in use and an inter-lock is provided in this compartment for degaussing the probe. The probe can be degaussed only when in the compartment to prevent possible damage to the circuit under test.

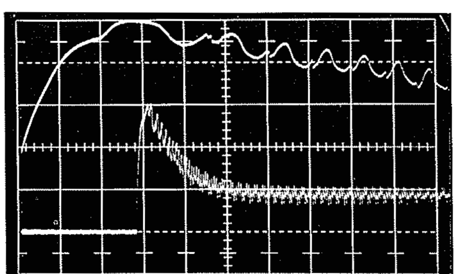


Fig 1. Double exposure photograph using the P6042 and a Type 547/1A5 Oscilloscope to display the current characteristics of a small DC motor. Lower display shows the zero current level, starting current, and running current. Current/div setting is 0.2 A/div with a sweep rate of 50 ms/cm. In the upper display, the sweep rate is increased to 5 ms/cm to show the current change as the commutator bars pass the brushes.

DESIGN CONCEPTS

The P6042 Current Probe includes a sliding-core type probe and associated amplifier as shown in Figure 2. The probe contains a stationary core around which is wound a 50-turn secondary, a moveable core which slides over the end of the stationary core and the current-carrying conductor, and a Hall voltage device. The amplifier houses the power supplies, low-frequency amplifiers, attenuators and the output amplifier.

High Frequency

High-frequency measurements are made in the same manner as in an AC current probe. The AC current probe is basically a transformer. The current-carrying conductor forms a one-turn primary winding for the transformer; the windings in the probe around the core form the 50-turn secondary winding. The relationship between the current, voltage and turns is shown below:

$$N_p I_p = N_s I_s$$

For a one-turn primary,

$$I_p = N_s I_s$$

Then for a 50-turn secondary,

$$I_s = \frac{I_p}{50}$$

The secondary voltage is

$$E_s = I_s R_s$$

R_s is 50 Ω, so $E_s = \frac{I_p}{50} (50\,\Omega)$

or $E_s = I_p\ (\Omega)$

For AC signals the voltage output of the current probe into the secondary load (R_s) is 1 mV per mA of input current.

DC and Low Frequency

The heart of the DC measurement capability is a highly-sensitive Hall device developed by the Tektronix Integrated Circuit Department. The Hall device is located in a cross section of the ferrite core contained in the probe head. At the point where the AC response of the core becomes ineffective due to the low-frequency L/R time constant of the core, the back EMF of the secondary no longer cancels the flux generated in the core by the primary current. The flux remaining in the core (primarily flux due to DC and low-frequency current) passes through the Hall device generating a small voltage directly related to the applied field. Figure 3 shows the current, voltage, and flux relationship of a Hall device.

The Hall device voltage (about 50 μV per mA of applied current) is amplified by the operational amplifier (A-1) and applied to the 50-turn secondary, to cancel the remaining flux in the core. Most of the flux in the core is cancelled either by the back EMF of the secondary or by feedback from the operational amplifier. As a result, the non-linearity of the core does not affect accuracy, nor does it directly limit maximum current handling ability. At DC and low frequencies, the operational amplifier supplies an output across the secondary load (R_s) of 1 mV per mA of primary current.

The maximum input current is related to the current handling ability of the operational amplifier. To handle ± 10 A in the primary, the amplifier (A-1) must supply $10\,A \times \frac{1}{50}$ to the 50-turn secondary to cancel the flux at DC and to supply ± 200 mA across R_s.

Attenuator and Output Amplifier

The current induced in the secondary by the primary (at high frequency) and the current applied to the secondary at low frequency by amplifier (A-1), produces a voltage across the secondary load that is directly related to the input current. The adding of the low-frequency signal to the high-frequency signal is done in such a way as to force one to take over where the other leaves off (see Figure 4). This is commonly known as a forced complement system.

The sensitivity at this point is 1 mV output for a 1 mA of primary current (input current). The 50-Ω secondary load is in the form of a 50-Ω attenuator that provides attenuation of up to 1000X (1 A/div) in 10 steps with a 1-2-5 sequence. The signal from the 50-Ω attenuator is applied to a 50X DC-to-50 MHz output amplifier. The output amplifier supplies an output of 50 mV per mA of primary current or 1 mA/div with the oscilloscope deflection set at 50 mV/div.

The P6042 output amplifier has an output impedance of 50 Ω. A 50-Ω termination is supplied with the P6042 probe for use with oscilloscopes having 1-MΩ inputs.

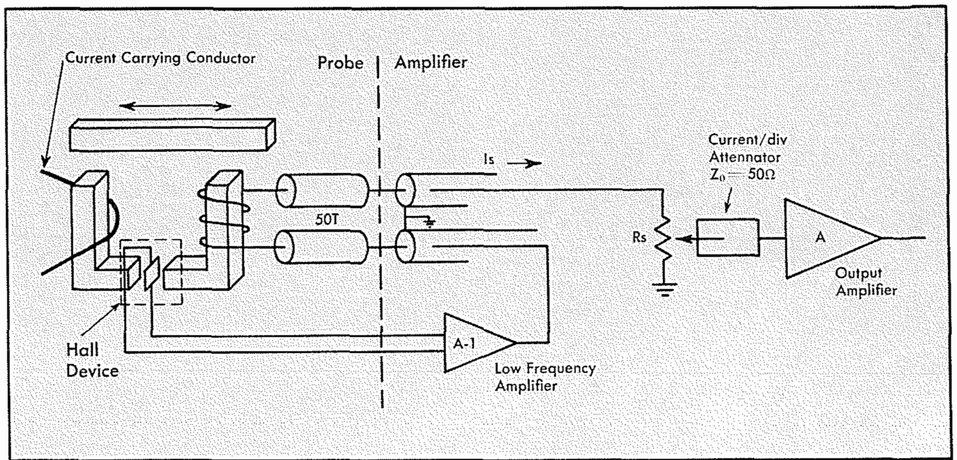


Fig 2. Block Diagram of P6042 Probe.

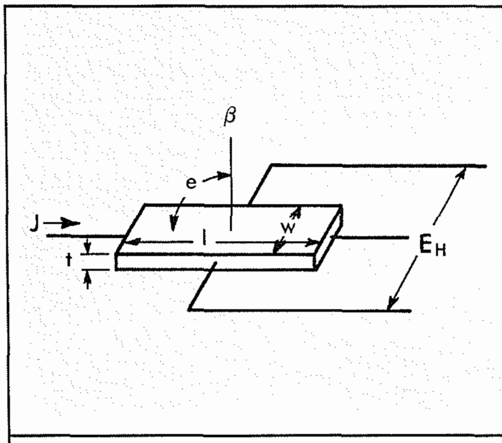


Fig 3. Hall device.

The Hall device is a thin rectangular sheet of semiconductor material sandwiched in the stationary portion of the transformer core. The Hall effect is a voltage generated across opposite edges of a current carrying conductor placed in the magnetic field.

The basis for the effect is the Lorentz force which is the deflection of charged particles moving in a magnetic field. The force is both perpendicular to the direction of the particle (current) flow and the direction of the magnetic field. Equation follows:

$E_{Hall} = wR_H\,J\,\beta \sin\phi$

E_{Hall} = voltage from Hall device

w = width of Hall element

R_H = Hall coefficient

J = current density

β = field strength

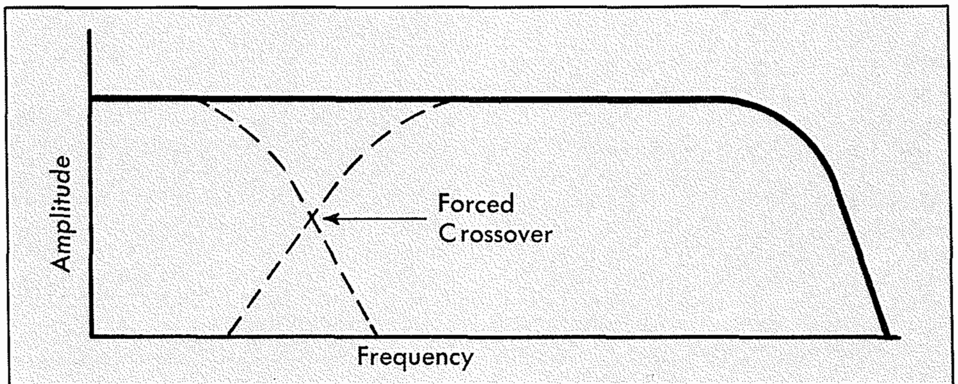


Fig 4. Forced crossover.

CIRCUIT LOADING

All probes load the circuit under test in one form or another. Voltage probes have input capacitance and DC resistance. Current probes load in a different manner. They have an insertion impedance due to the secondary load being reflected into the primary and very low-capacitive loading.

Reflected Load

The secondary inductance and load resistance is reflected through the turns ratio squared and appears as a series load in the primary (current-carrying conductor). Calculations of the typical reflected loading of P6042 current probe is shown below:

$$R_p = \frac{R_s}{T^2} = \frac{50\,\Omega}{(50)^2} = 0.02\,\Omega$$

$$L_p = \frac{L_s}{T^2} = \frac{0.5\,\text{mH}}{(50)^2} = 0.2\,\mu\text{H}$$

Shield Inductance

Another factor affecting circuit loading is the reflection of the current probe shield into the current carrying conductor. The shield appears as a shorted turn around the conductor. Leakage inductance also appears in series with the primary.

Stray Capacitance

The only other factor involved with circuit loading is the stray capacitance between the probe and the conductor. This capacitance depends on the size of the current carrying conductor and its position in the hole. It is typically 1 pF and can be measured using a Type 130 LC Meter. As with voltage probes, stray capacitance can limit the risetime of the measurement ($T_{rise} = 2.2\ R_{source}\ C_{strays}$). By inserting the current probe on the ground or B+ side of the load resistor the stray capacitance loading can be reduced.

The total insertion impedance can best be represented by the graph in figure 5.

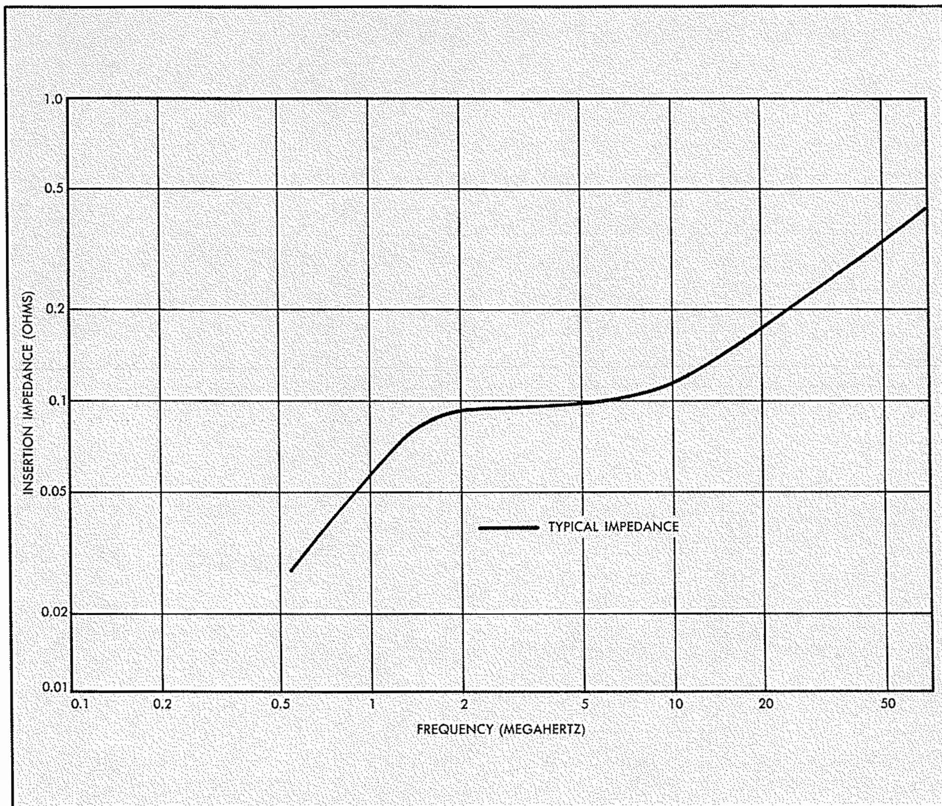


Fig 5. Insertion impedance.

PROBE DEGAUSSING

Whenever a magnetic field is applied to the transformer core in the probe with the system turned off, or if a current beyond the maximum specified level is applied, the core may become magnetized. A portion of this magnetic flux is likely to remain in the current probe core causing measurement errors. To remove this flux the probe is placed in the storage compartment and the degaussing switch is depressed. The degaussing switch connects the 50-turn secondary winding to an oscillator as shown in Figure 6. The oscillator produces a 10-kHz exponentially decreasing sinewave which initially saturates the core. The decaying current eliminates stored flux due to core hysteresis.

An interlock switch for the degaussing oscillator is provided in the probe storage compartment. The switch eliminates any possibility of introducing transformed current from the oscillator into the test circuit. The compartment, accessible from the front panel, provides convenient storage for the probe when not in use.

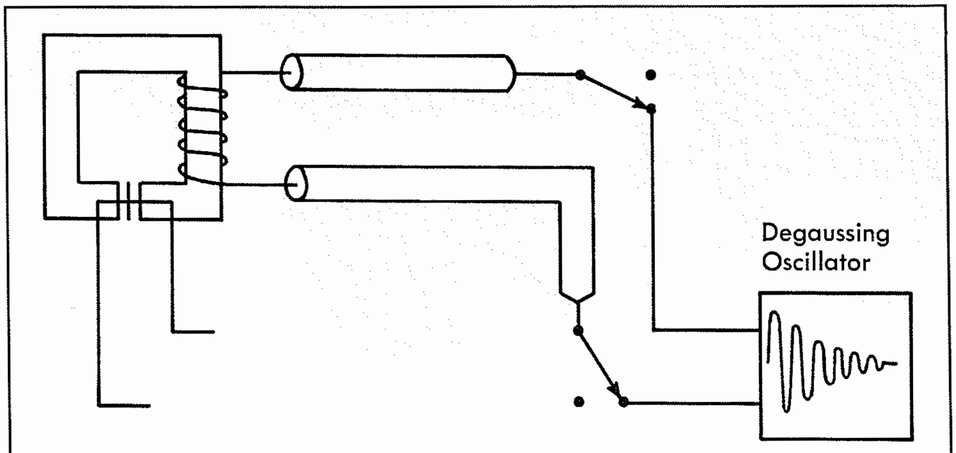


Fig 6. Probe degaussing.

CHARACTERISTICS

Probe and Amplifier

SENSITIVITY is 1 mA/div to 1 A/div in 10 calibrated steps, 1-2-5 sequence, accurate within 3% (with an oscilloscope deflection factor of 50 mV/div).

BANDWIDTH is DC to 50 MHz at 3-dB down.

RISETIME is 7 ns or less.

DYNAMIC RANGE is + and − 10 divisions of display.

NOISE (periodic and random deviation) is 0.5 mA or less plus 0.2 or less major divisions of display. Random trace shift is 1.5 mA or less.

THERMAL DRIFT is 2 mA/°C or less, plus 0.2 or less major division of display per °C.

MAXIMUM INPUT CURRENT is 10 A (DC plus Peak AC).*

*Peak-to-peak current derating is necessary for CW frequencies higher than 2 MHz. At 50 MHz, the maximum allowable current is 2 A.

MAXIMUM INPUT VOLTAGE is 600 V (DC plus Peak AC).

OUTPUT IMPEDANCE is 50 Ω through a BNC-type connector. A 50-Ω termination is supplied with the probe for use with 1-megohm systems.

AMPLIFIER POWER REQUIREMENT is approximately 10 W, 50 Hz to 400 Hz. Quick-change line-voltage selector permits operation from 90 V to 136 V or 180 V to 272 V.

DIMENSIONS AND WEIGHT of the amplifier are 4½ in. (11.4 cm) high by 7½ in. (19.2 cm) wide by 9¾ in. (24.8 cm) deep; 6½ lbs. (3.1 kg).

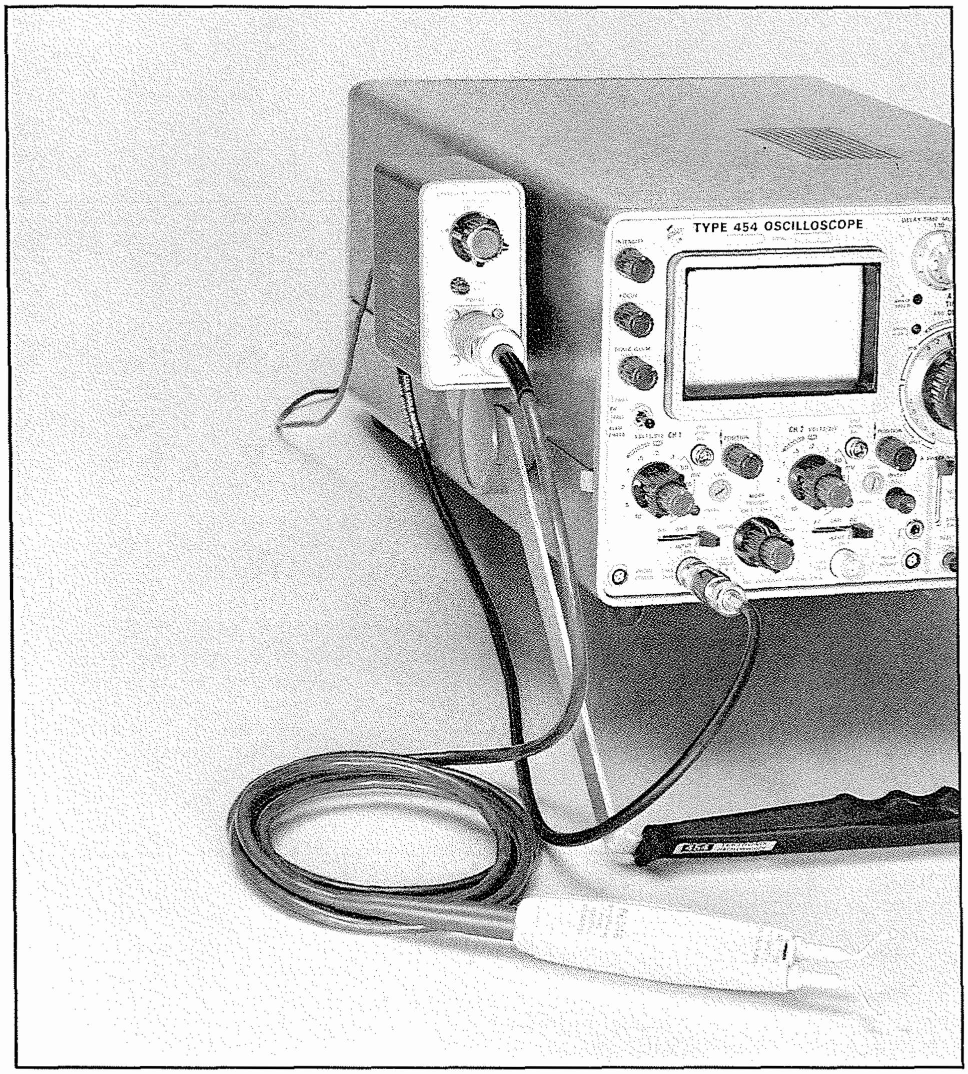
PROBE CABLE is 6 feet long, permanently connected between the probe head and amplifier.

P6042 DC CURRENT PROBE PACKAGE (010-0207-00)

Includes: 50-Ω BNC cable (012-0057-01); 50-Ω BNC termination (011-0049-00); 3-inch ground lead (175-0263-00); 5-inch ground lead (175-0124-00); two alligator clips (344-0046-00); 3-wire to 2-wire adapter (103-0013-00); instruction manual (070-0629-00).

P6046 DC-to-100 MHz DIFFERENTIAL PROBE AND AMPLIFIER

by Glenn Bateman



INTRODUCTION

The P6046 Differential Probe and P6046 Amplifier Unit provides new measurement capabilities when used with all Tektronix oscilloscopes. With this new probe system, the differential - signal processing takes place in the probe itself, resulting in high common-mode signal rejection at higher frequencies. Differential probe-tip signal processing minimizes the measurement errors caused by differences in probes, cable lengths, and input attenuators. In addition, the wide-band capability of the P6046 Probe and Amplifier provides DC-to-100 MHz single-ended measurement performance.

The P6046 probe circuitry utilizes 13 semiconductors including dual FET's for the balanced input. A switch on the probe selects AC or DC input coupling. Accessories include a plug-on 10X attenuator for increasing the differential input voltage range, and a ground tip for applications requiring single-ended input. Unique swivel tips provide variable spacing to accommodate the varying distance between test points.

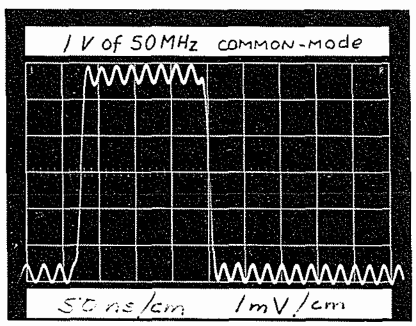


Fig 1. High-frequency differential measurement.

The P6046 Amplifier mounts conveniently on the side of the oscilloscope and features a calibrated 1 mV/div to 200 mV/div (2 V/div with 10X attenuator) deflection factor (oscilloscope deflection factor set at 10 mV/div). Output impedance of the amplifier is 50 Ω. A 50-Ω cable and termination is supplied with the amplifier for use with 1-MΩ systems.

DIFFERENTIAL AMPLIFIERS

The primary use of differential amplifiers is to measure the signal difference between two points that need not be referenced to ground.

An oscilloscope differential amplifier is a device that amplifies and displays the voltage difference that exists at every instant between signals applied to its two inputs. For example, two pulses that differ in both amplitude and coincidence that are applied to a differential amplifier will cause the oscilloscope display to be a complex waveform that represents the instantaneous difference between the two pulses. On the other hand, two signals that are identical in every respect will cause no output on the CRT screen (limitations to this statement will be described under Common-Mode Rejection).

The amount of difference signal due to common-mode signal that one can expect from a particular differential amplifier is specified by the common-mode rejection ratio (CMRR). This ratio and associated terms are defined as follows:

Common-Mode Signal—The instantaneous algebraic average of two signals applied to a balanced circuit, all signals referred to a common reference.

Common-Mode Rejection—The ability of a differential amplifier to reject common-mode signals.

Common-Mode Rejection Ratio (CMRR)—The ratio of the deflection factor for a common-mode signal to the deflection factor for a differential signal.

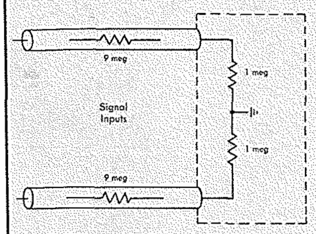
Differential Signal—The instantaneous, algebraic difference between two signals.

Measurements made with a differential amplifier should contain an allowance for the output voltage that is due to a common-mode signal. For example, if an amplifier with a CMRR of 1,000:1 is used to measure the difference between two similar five-volt signals, the output seen on the oscilloscope screen is the result of two voltages: (1) the actual difference between the input signals, and (2) the difference voltage that results from the common-mode signal. Because of this combination, the actual difference voltage cannot be exactly measured. Therefore, the voltage measured on the CRT screen should include a tolerance that is equal to the computed, or measured output voltage due to the common-mode signal.

In the above example, CMRR of 1,000:1 with a common-mode signal of 5 V, if a difference signal of 0.015 V is measured on the CRT, it should be recorded as 0.015 V ±0.005 V.

MEASUREMENT PROBLEMS

The major difficulty in making differential measurements is in connecting the signal source to the measuring device. Measurement errors can be caused by differences in probes, cable lengths, and input attenuators.



Probe	Tolerance	CMRR (Apparent)
A	+1%	50:1
B	−1%	50:1
C	+2%	25:1
D	−2%	25:1
E	+3%	16:1
F	−3%	16:1

Fig 2. Simplified input circuit and table that shows the change in CMRR (apparent) due to X10 probes that have a 1, 2, and 3% difference in their attenuation value.

Probes

Attenuator probes extend the usable voltage range of a differential amplifier by reducing the input signals to a level that is below the maximum common-mode linear dynamic range. In doing this, however, the probes may cause a reduction in the apparent CMRR due to component value differences within the probes. For example, Figure 2 illustrates the change in CMRR (apparent) due to X10 probes that have a 1, 2, and 3% difference in their attenuation value. Bear in mind that the reduction in apparent CMRR can also be caused by different values of the signal source resistance.

Cable Length

Probes and cables of different lengths may introduce enough signal delay between them to cause a difference voltage at the input to the amplifier. At 50 MHz, an 0.1-inch difference in cable length will reduce the CMRR from 1,000:1 to 250:1. Also an inductance difference due to a ⅛-inch difference of lead length at 50 MHz can reduce the CMRR from 1,000:1 to 400:1. Processing the differential signal in the probe reduces these problems.

Input Attenuators

To minimize measurement errors due to input attenuators, the P6046 Probe and Amplifier provides attenuation by reducing the differential gain and common-mode gain within the amplifier. High-frequency common-mode rejection is difficult to obtain when using input attenuators. This is due to the stray capacitance that is distributed along the resistor length resulting in an infinite number of RC time constants that cannot be compensated for over a wide frequency range.

The dual 10X attenuator head included with the P6046 is calibrated with the P6046 to provide maximum CMRR. The attenuator head is keyed with the probe so that the + and — inputs are always matched. The attenuator head should be used only when necessary as it will reduce the CMRR at 50 MHz from 1,000:1 to ≈50:1.

Source Impedance

As the signal source impedance increases, the common-mode measurement problems increase. If the source impedance of the two signals to be measured is different, the CMRR will change due to the different ratios between the source impedance and the input impedance. At high frequencies an increase of source impedance will magnify the problems of CMRR measurements due to a mismatch of stray capacity.

DESIGN CONCEPT

The design objective was to develop a system that would overcome most of the differential measurement problems of high frequency differential amplifiers. The solution was to process the differential signal at the signal source, thereby eliminating most of the problems caused by probes, cable length and input attenuators. It was also necessary to obtain good common-mode rejection for high-frequencies of reasonable voltage levels. These capabilities had to be built into a reasonably small and convenient-to-use probe.

P6046 Probe

In order to obtain high common-mode rejection ratios at higher frequency, the design is a departure from conventional input systems using emitter followers, bootstrapped for all frequencies into the differential comparator. This approach is limited at high frequencies by the bootstrap system.

The input comparator of the P6046 rejects the common-mode signals directly without using an emitter-follower input stage. The thermal time constants of the dual FET's limits the low-frequency CMRR. To eliminate these problems, the input comparator is bootstrapped only for low frequencies (DC-to-100 kHz).

The input-comparator FET's operate with a gain of 0.4. This low gain permits a larger differential dynamic range and a wider bandwidth. An amplifier in the probe restores the probe gain to unity. The probe has one differential attenuator circuit that is controlled from the amplifier and reduces the differential gain and common-mode gain to 1/10.

P6046 Amplifier

Gain changing and converting from a differential-signal to single-ended operation is accomplished in the P6046 Amplifier. Gain changing in the P6046 Amplifier eliminates the differential measurement problems associated with input attenuators.

The P6046 Amplifier has a gain of 10 and features a calibrated 1 mV/div to 200 mV/div deflection factor (with oscilloscope deflection factor set at 10 mV/div).

The output impedance of the amplifier is 50 Ω. A 50-Ω termination is supplied with the P6046 Amplifier for use with oscilloscopes having 1-MΩ input impedances.

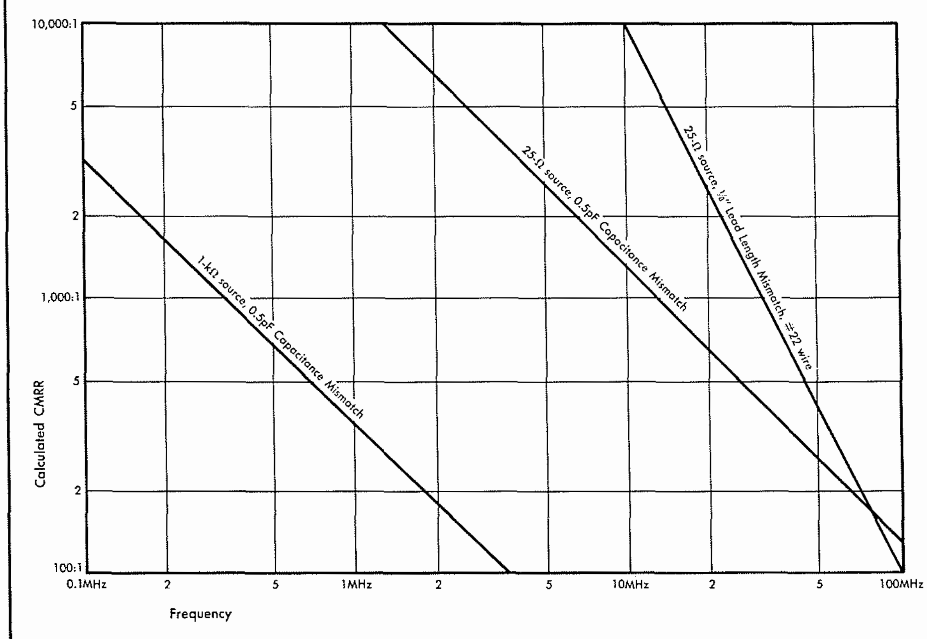


Fig 3. CMRR vs frequency with capacitance mismatch and different source impedances.

MECHANICAL DESIGN

Mechanically, the P6046 probe is made as rugged as possible without sacrificing performance or usability. Thirteen semiconductors, including dual FET's for the balanced input, are housed in the P6046 probe.

The body of the probe is made of high-impact plastic, plating grade. The inside of the body is plated with a low-resistance material that provides an excellent ground plane and electrostatic shield from outside radiation.

Several probe tips have been designed for the P6046 probe. The probe-tip input connectors are mounted on ½-inch centers and are designed to mate with coaxial connectors permanently mounted on circuit boards. The permanent connectors provide excellent ground and signal connection and should be used whenever possible.

When it is not convenient to use the permanent coaxial connectors, a number of special tips are included. For making measurements from test points that are not spaced ½-inch apart, swivel tips are included that provide variable spacing from 3/16 inch to 1½ inches. See Figure 4.

Also included is a ground tip that shorts one of the input tips to the coaxial ground for single-ended measurements, hooked tips for hanging the probe into circuits, and sleeve-type adapters for insulating the tip's coaxial ground. The dual 10X attenuator head included with the P6046 probe has the same tip configuration as the probe.

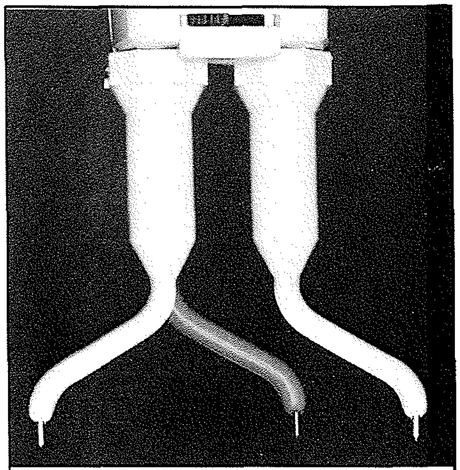


Fig. 4. P6046 Swivel tips.

CHARACTERISTICS

Probe and Amplifier

DEFLECTION FACTOR is 1 mV/div to 200 mV/div in 8 calibrated steps, 1-2-5 sequence, accurate within 3% (with an oscilloscope deflection factor of 10 mV/div).

BANDWIDTH is DC-to-100 MHz at 3-dB down.

RISETIME is 3.5 ns or less.

COMMON - MODE REJECTION RATIOS with deflection factors of 1 mV/div to 20 mV/div are 10,000:1 at DC, 1,000:1 at 50 MHz, and typically 100:1 at 100 MHz.

COMMON - MODE LINEAR DYNAMIC RANGE is ±5 V (DC + peak AC), ± 50 V with 10X attenuator.

INPUT RC is 1 MΩ paralleled by approximately 10 pF.

INPUT COUPLING is AC or DC, selected by a switch on the probe. Low-frequency response AC-coupled is 3-dB down at 20 Hz, at 2 Hz with 10X attenuator.

NOISE (periodic and random deviation) referred to the input is 280 µV or less.

MAXIMUM INPUT VOLTAGE is ±25 V (DC + peak AC), ±250 V with 10X attenuator.

OUTPUT IMPEDANCE is 50 Ω through a BNC-type connector. A 50-Ω termination is supplied with the probe for use with 1-megohm systems.

LINEAR OUTPUT is ± 10 div with the oscilloscope set at 10 mV/div.

PROBE CABLE is 6-feet long, terminated with a special nine-pin connector.

P6046 DIFFERENTIAL PROBE AND AMPLIFIER (010-0106-00)

Includes P6046 Probe (010-0214-00); Amplifier for P6046; 50-Ω BNC cable (012-0076-01); 50-Ω BNC termination (011-0049-00); dual 10X attenuator head (010-0361-00); four swivel-tip assemblies (010-0362-00); special ground tips (010-0363-00); 5-inch ground lead (175-0124-00); 12-inch ground lead (175-0125-00); two alligator clips (344-0046-00); two hook tips (206-0114-00); two test jacks (131-0258-00); two insulating tubes (166-0404-00); two ground clips (214-0283-00); carrying case (016-0111-00); two instruction manuals (070-0756-00).

THE TYPE 1A5 DIFFERENTIAL PLUG-IN with the Type 530, 540, 550, 580-Series Oscilloscopes can use the P6046 Differential Probe without the P6046 Amplifier. The P6046 probe extends the Type 1A5 differential measurement capabilities to 50 MHz, CMRR is 1,000:1 at 50 MHz.

P6046 PROBE PACKAGE (010-0213-00)

SERVICE SCOPE

USEFUL INFORMATION FOR

USERS OF TEKTRONIX INSTRUMENTS

Tektronix, Inc.
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