TEKTRONIX

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A NEW PHYSIOLOGICAL MONITOR

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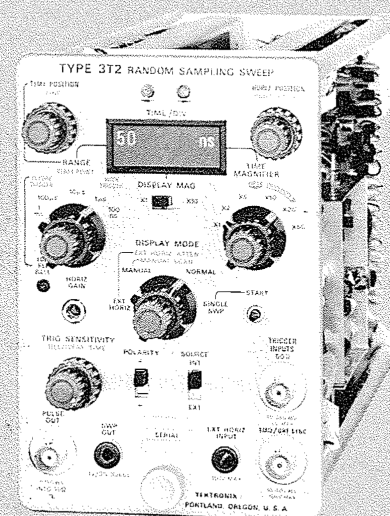

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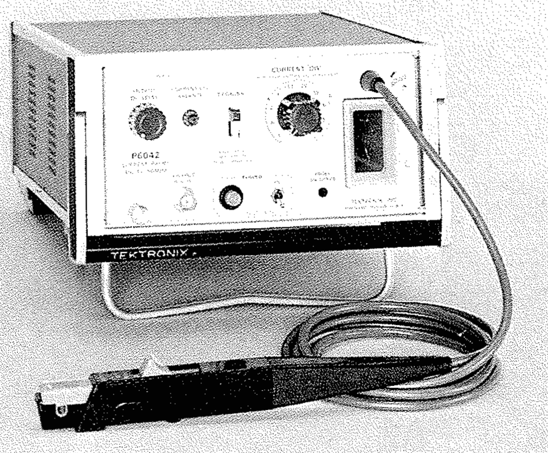

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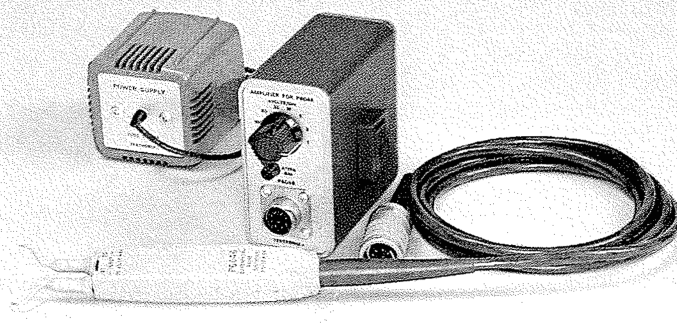

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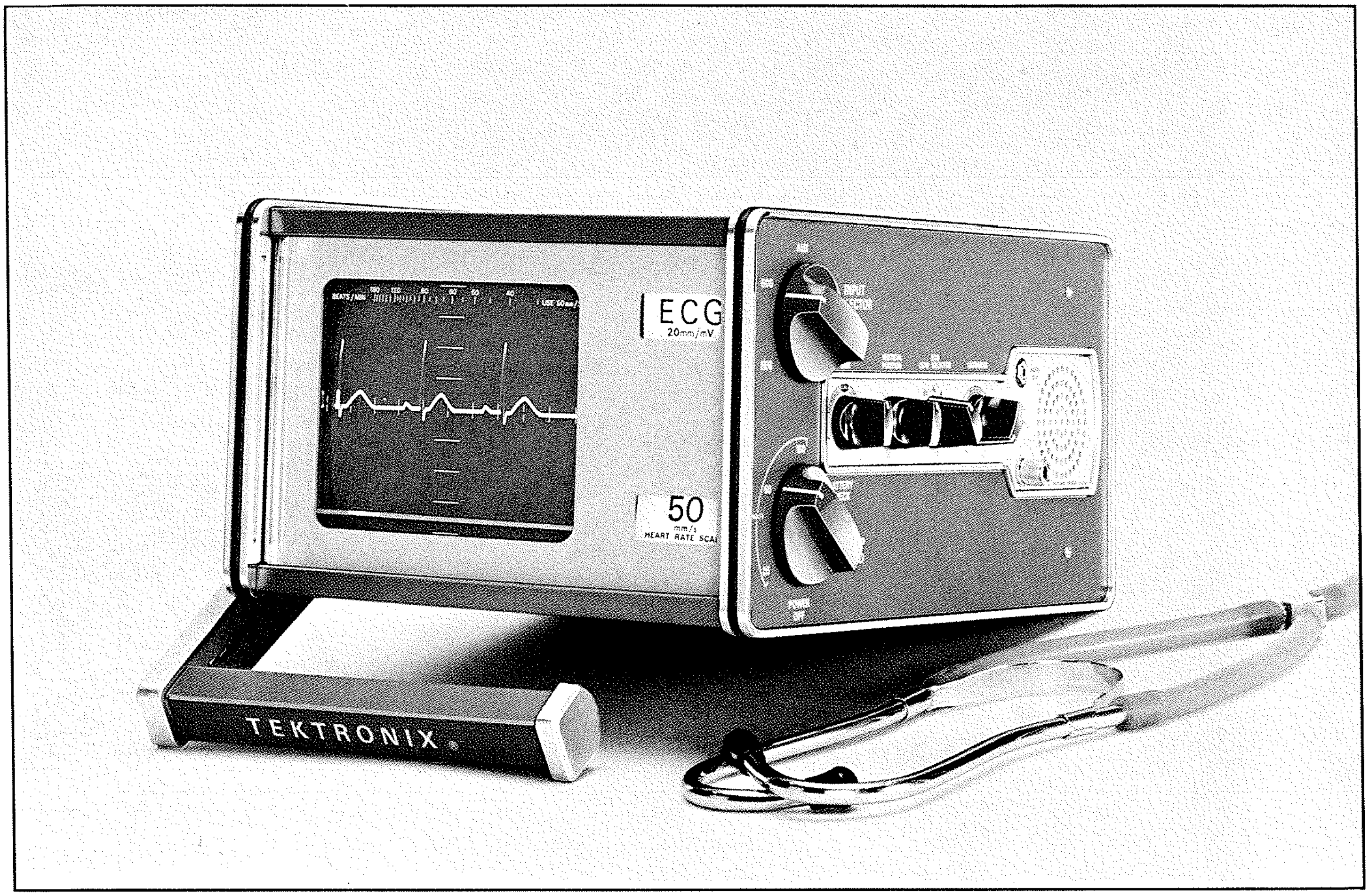
A SIMPLIFIED OSCILLOSCOPE FOR THE OPERATING ROOM

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.

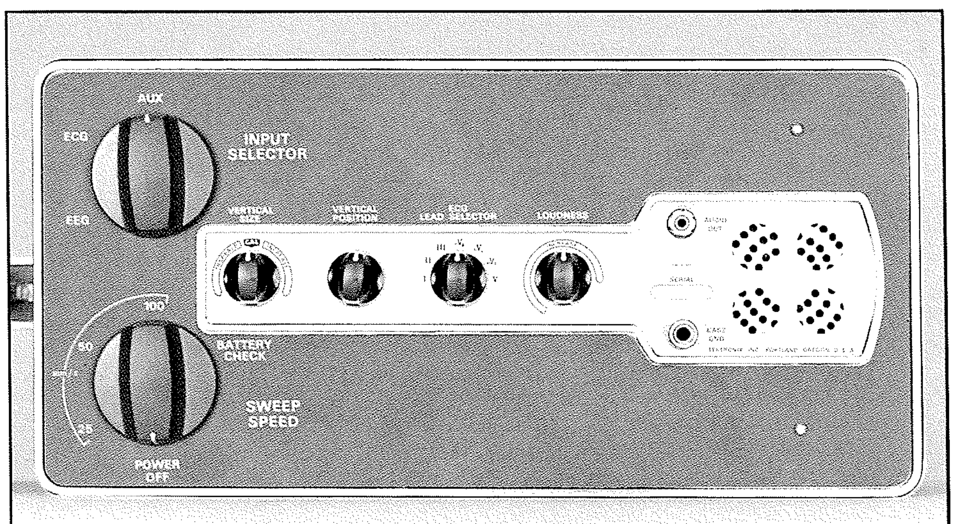


Fig 1. Type 410 Operating Controls

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.

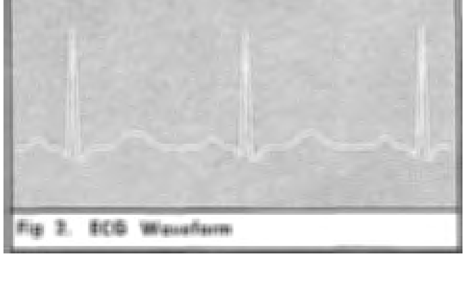


Fig 2. ECG Waveform

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.

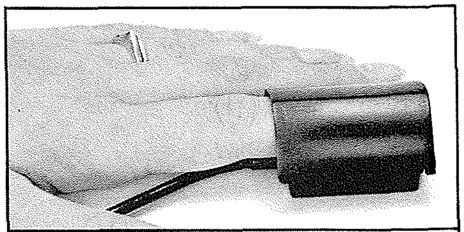


Fig 3. Pulse Sensor

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,

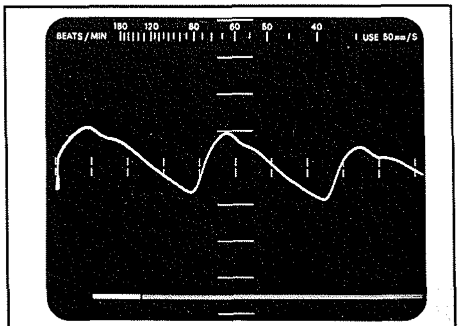


Fig 4. Pulse Sensor Waveform

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.

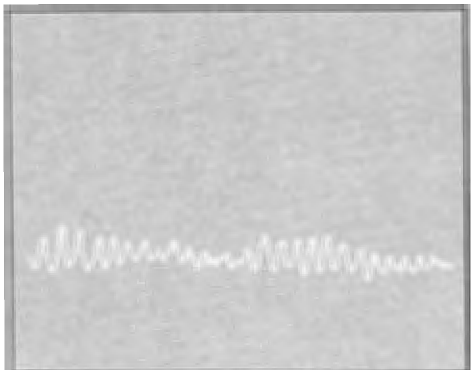


Fig 5. EEG Waveform

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

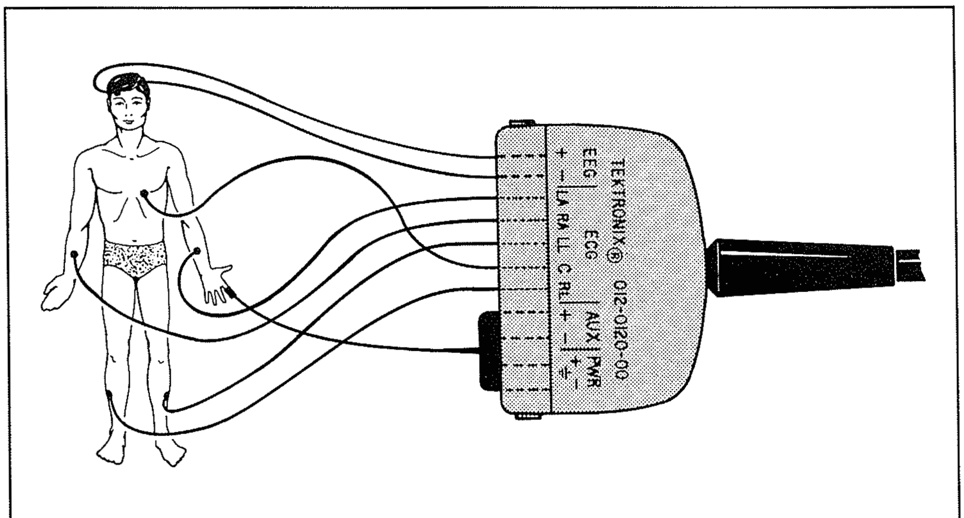


Fig 6. Electrode and Sensor Connections for Cross Correlation of Signals

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).

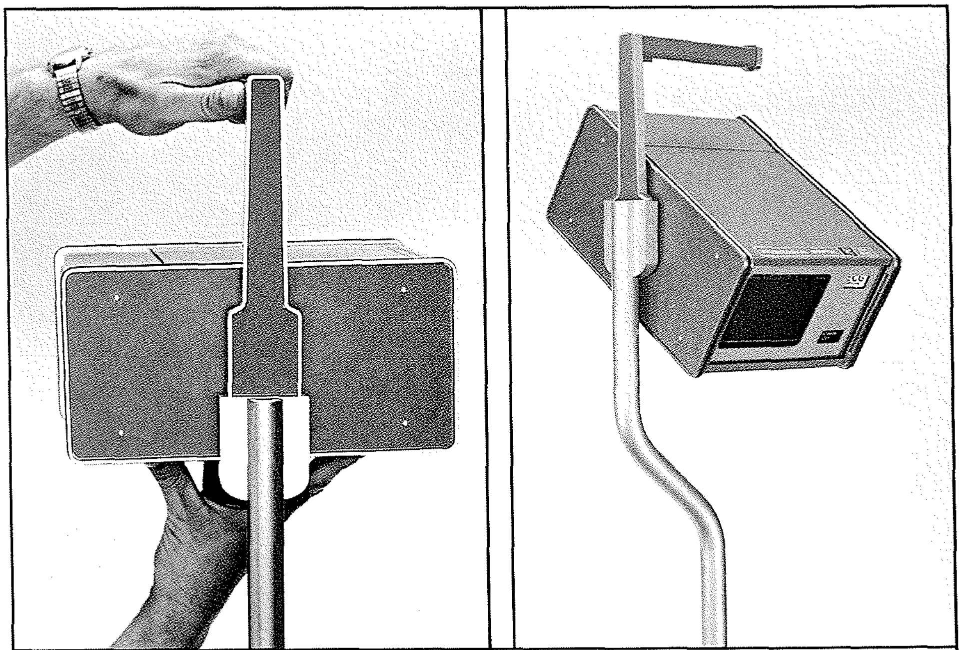


Fig 7. Attaching the Type 410 to the Mounting Stand

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