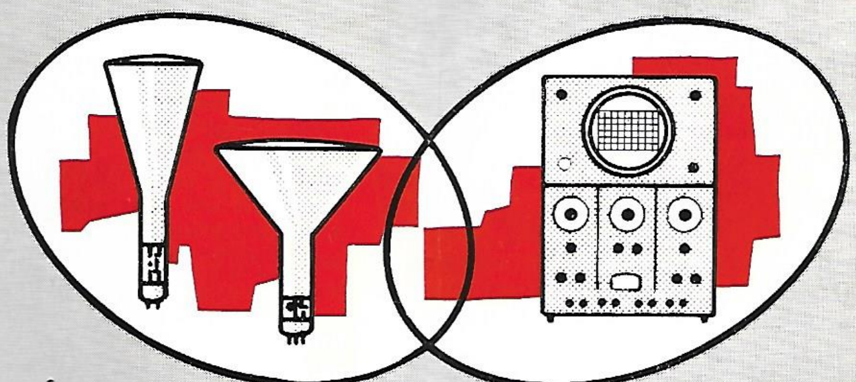
ISSUE 8

DUMONT Instrument Journal



DUMONT

INSTRUMENT DIVISION

DU MONT Instrument Journal

A PUBLICATION DEVOTED TO ELECTRONIC INSTRUMENTATION, ELECTRONIC TUBES AND THEIR RELATED FIELDS — PROVIDING THE LATEST INFORMATION ON DEVELOPMENTS, APPLICATIONS AND TECHNIQUES. PERMISSION FOR REPRINTING ANY MATERIAL CONTAINED THEREIN MAY BE OBTAINED BY WRITING TO THE EDITOR AT THE ADDRESS BELOW.

PUBLISHED QUARTERLY AND COPYRIGHT 1960 BY
ALLEN B. DU MONT LABORATORIES, INC.
750 BLOOMFIELD AVENUE
CLIFTON, NEW JERSEY

Editor: L. A. Hoyt

On The Cover

An artist's conception of the interlocking, or "wedding", of electronic instruments and electronic tubes — depicting the new format of the Du Mont Instrument Journal beginning with this issue. With two such closely related product lines, it is difficult to talk about one without the other. So, as our masthead says, we will henceforth publish authoritative articles on cathode-ray tubes and multiplier phototubes — or on any tubes of interest to the field, as well as articles on electronic instruments. We're certain that our audience will find greater appreciation for these subjects — since they will be presented in greater interlocking depth.

Binders Available

Vinyl plastic binders with capacity for at least a 6 years supply of *Du Mont Instrument Journals* are now available. See page 15.

Table of Contents

Feature

Printed Wiring and Techniques of Repairs 3

Problems encountered and resulting solutions in the development of printed wiring — by one of the pioneers in such work. Procedures for repairing printed wiring is also given as an aid to service firms.

Application

Simulation Testing For Reliability 11

How a dual-beam oscilloscope used in conjunction with a controlled motion machine tests for mechanical reliability prior to actual use.

Research

About Cathode-Ray Tube Screens, Part I 13

A detailed discussion of cathode-ray tube screens. The article will assist users in understanding the theory, applications, and in the selection of phosphors. Important information for the designer.

Development

Four New Cathode-Ray Tube Developments 10

Miscellaneous

Next Issue 9

Local Sales of Du Mont CRT's 12

Binders for Du Mont Instrument Journal 15

PRINTED WIRING AND TECHNIQUES OF REPAIRS

A frank discussion of the historical development of printed wiring at Du Mont — one of the pioneers of such circuitry. Trials and tribulations are openly stated, along with the detailed developments culminating in a successful method. A step by step procedure for repairing printed wiring — the result of extensive research — is also given.

Original Method

One of the first basic systems employed in printed wiring is commonly called "Pin Type Printed Wiring". This system was widely used in Du Mont Instruments throughout the years 1952 to the latter part of 1956, and certain equipments toward the end of their normal production life continued to use the same method, with variations in processing, as late as 1957. In essence, through connections between the front and back of the printed wiring panels were made by brass bead chain pins similar to the part illustrated in Figure 1. These pins and the surfaces of the printed wiring conductors were solder coated.

In the process of assembly, the pins were staked into the board as shown in Figure 1 in a manner very similar to that employed in eyeletting. Components were loaded on to the board on the side opposite to the pin extension with leads inserted into the pins and generally protruding slightly beyond the end of the pin. With loading complete, the boards were fluxed and dipped into a solder pot operating at a relatively high temperature (550°F) with control of immersion set so that the ends of the pins entered the solder pot to within 1/8" of the bottom board surface. The board itself was never in contact with the melted solder. The purpose of this method of solder dipping was to avoid possible damage to the phenolic board or to the printed wiring bond by the high temperatures involved. An additional intent was to keep the components themselves from high temperature exposure.

Problems Encountered

Since the only fresh solder brought to the interfaces of the pin and printed wiring conductors was that brought to the top side by capillary action through the center of the pin (an uncertain method at best), the condition of the solder coated surfaces of both pin and board was of exceptional importance. Absolute cleanliness was essential, and it was necessary that solder composition be controlled accurately and as close to the eutectic as possible in order to maintain the lowest practical melting point. This requirement was imposed because all heat brought to these junctions had to be carried through the pin which, being of brass, was a relatively poor conductor.

As a matter of interest, the problem of heat conduction is one of the basic weaknesses of this system. Too little heat results in lack of fusion in the solder connections; too much is likely to damage the lower surface of the board and the tolerance range between these two extremes is far too narrow. As a result, manufacturing control is extremely difficult.

In addition to the difficulty in producing good joints was added the

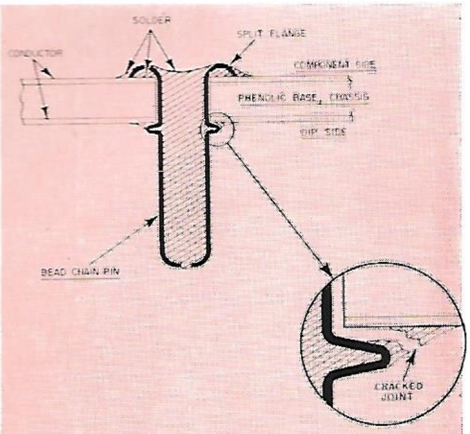


Figure 1. Cracked solder joint, bead chain pin.

subsequent difficulty in determining whether or not these joints were satisfactory. Inspection by visual means could only be carried out, with any degree of certainty, by microscopic examination. Examination of joints by mechanical sectioning gave over-optomistic results because of the tendency of the solder in the connections to draw across voids during the cutting process — giving an appearance of solder where none existed. This was not known until later.

Many variations were tried to improve this technique; tight staking, loose staking, modifiications of time and temperature cycles being only a few. The net result of all these attempts was still highly unsatisfactory. As a result, new processes were investigated.

New Process Investigations

The first major step in this direction was made in 1956. It eliminated the use of the bead chain pin in favor of a simple rolled flanged brass eyelet. Along with the use of the eyelet, a change in dipping procedure was instituted — lowering the solder pot temperature to 450°F and changing the soldering method to complete immersion of the lower surface of the board into the solder bath. New base materials and adhesives developed during the period 1952 to 1956 practically eliminated the bond strength and blistering problems of the early days of printed wiring. With this change in process, it was no longer necessary to depend on conduction of heat through the wall of the eyelet in order to obtain solder joints on the upper surface of the boards. Fresh solder was brought through the center of the eyelet by capillary action to the top of the board where it fused with the solder coating already present on both eyelet and printed wiring conductors.

The appearance of joints produced by this process was far superior to that produced by the pin process described above. Larger fillets of solder were built up and the surface of the solder was generally bright and clean. In order to facilitate flow of solder on the upper surface, the roll of the eyelet was split in eight places — producing a segmented appearance, and allowing the solder to flow readily over the rim of the eyelet and down to the conductor surface. Time and temperature dipping cycles were carefully controlled and the apparent reliability of this system was excellent. Temperature cycling tests which were run before this system was put into production seemed to show a high rate of reliability. Cross sections of connections looked excellent, but, it was not until the system had been in production for quite a while that reports began to come back indicating a significant amount of field trouble.

New Problems

Boards returned and examined showed evidence of microscopic cracks in the solder fillets between the eyelet and the board. These were similar to cracks previously noted on the pin type boards. This necessitated development of new techniques in examination — since it was apparent that our previous methods led to false conclusions. These techniques demonstrated clearly that the solder fillet around the rolled head of the eyelet did not extend beneath the head and that there was a void in this area leaving only a relatively thin walled fillet, as shown in Figure 2. Careful examination of the surfaces under the eyelet head showed evidence of entrapped oxides which prevented solder flow and fusion in this area. The thickness of solder fillet was not strong enough to withstand the stresses produced by differential expansion of eyelet and board—resulting from differing thermal coefficients of expansion between the brass of the eyelet and the solder, and the phenolic base material of the board.

We were able to demonstrate, by extended thermal cycling of boards produced by this method, that a multiplicity of defective joints could appear in as few as 25 temperature cycles between 0 and 85°C. This performance could be improved by extreme care in the production cycle, including, once again, very careful control of surface conditions on the board, eyelet and component leads. It could be considerably worsened by lack of control and deterioration of these surfaces, but it could not be made fully reliable with any practical production method.

Normal hand soldering or resoldering produces exactly the same type of joint. The better the solder flow appears, the weaker the joint will be. This explained the number of repeat repairs required on instruments found defective and "fixed" in the field.

Further Investigations Into A New Process

Since the faults in the connections were predominately in the solder joints at the rolled head of the eyelet on the dipped side of the board, investigations were conducted with a view to improving the quality of the joint at this surface. The final outcome was the use of the funnel eyelet in Figure 3. With the funnel on the dipped side of the board, it was possible to build an exceptionally large fillet of solder as shown in the illustration. The void existing under the head of the rolled flange eyelet could no longer occur since surfaces were completely open to good fluxing action. Solder completely filled the space at the junction of the conductor pad and the eyelet flange to produce the heavy fillet section shown. This solid ring of solder between the eyelet and conductor was more than adequate to resist the stresses of expansion and contraction. Normal production controls had always given good connections on the other side of the board where the split eyelet roll allows solder to flow under and around the roll. (Trouble at this point could always be traced to low time cycles or inadequate pot temperature during dipping, or to improper solder composition. These items are *not* difficult to control.)

Samples produced with funnel eyelets were subjected to a long program of cycling both in hot and cold solutions and in temperature controlled chambers. Immersion cycling was conducted to the point where the base material of the board had been so mistreated that its rigidity was completely destroyed, and cracks began to develop in the printed wiring conductors as a result of board flexing. After tests extending out to over 400 immersion cycles without failures

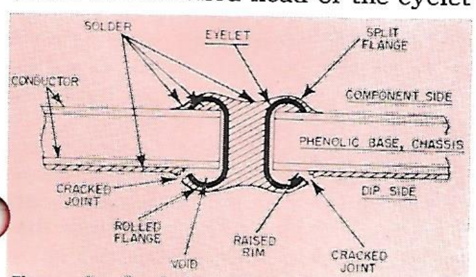


Figure 2. Cracked solder joint, rolled flange eyelet.

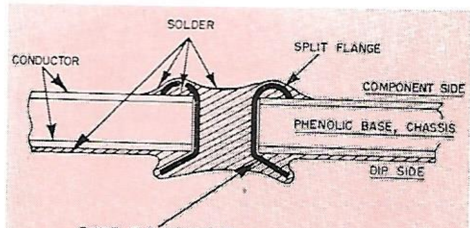


Figure 3. Funnel flanged eyelet.

in the printed wiring joints, it was evident that a major order of improvement had been obtained.

PW Repairs Investigated

With this background of information we returned to the problem of finding a satisfactory method of performing field repairs on equipments already out. The solder bond between the rolled head of the eyelet and the board was investigated to see whether there was any way of obtaining satisfactory flow under the eyelet head. When this proved impractical, we investigated the possibility of building up the size of the fillet in order to obtain strength by increasing the thickness of the solder deposited. It was found that careful control of soldering temperatures and techniques could achieve this result and it is this method which will be described in the next section. This system of repair has proven reliable, when properly executed, by cycling tests similar to those described above conducted on repaired boards which were known to be defective before repairing.

Resoldering Technique

General

Cracked solder joints between the circuit conductors and eyelets usually do not occur in isolated cases on a P.W. chassis. If the condition exists at all it can be expected to develop progressively, so that all eyelets on such a chassis must be resoldered.

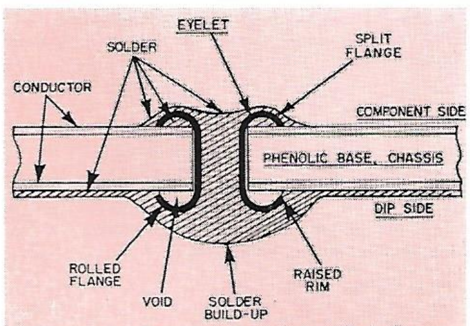


Figure 4. Resoldered eyelet, rolled flange.

Solder cracks are easily visible under 10X magnification as a jagged dark line on the solder fillet surrounding the eyelet head (See Figure 2.). The cracks may extend partially or completely around the joint, and are mainly confined to the dip side.

Resoldered eyelets may be easily recognized by their similarity to Figure 4, as opposed to the characteristics of Figure 2. Solder build-up on the eyelet should be a round dome shape which completely covers the outline of the eyelet and flows completely over the eyelet pad area. The newly added solder should not be sitting on the eyelet like a hat, but completely fused with the original solder and flowed down on to the pad all around the eyelet. The rim of the rolled flange must no longer be discernable at any point as in Figure 4.

The solder build-up as shown will provide enough mass of metal to resist the expansion and contraction stresses set up during the warm-up and cooling periods between the eyelets and eyelet pads. Where component lead-ends, wires or pins project through the eyelet, the ideal smooth, round surface of the added solder will not be obtained.

Resoldering is restricted to those P.W. chassis having the rolled flange eyelet construction which have not already been factory resoldered (See Figure 4.) and have cracked solder joints (See Figure 2.) as seen by visual inspection, or have open or intermittent connections as found by electrical test. Resoldering is also required on factory resoldered chassis where joints have been missed, causing open or intermittent connections.

Resoldering is done on the dip side of Chassis at all those joints between eyelets and P.W. conductors, and between eyelets and tube socket tabs. Resoldering is required on the component side only where excess heat has caused solder to flow through the eyelet while working on the dip side, or when electrical test shows evidence of open or intermittent connections.

Equipment and Materials

A. The soldering iron to be used in this repair procedure has to have certain characteristics. The iron must have the following requirements:

1. Tip temperature must not rise above 600°F to maintain proper soldering control. Excessive heat will cause solder to melt completely down through the eyelet and create an unreliable connection on the component side of the chassis. This will be discussed in detail under "Soldering-Precautions".
2. Tip temperature must be above 500°F to assure adequate heat for proper fusion, and to permit making the repair rapidly enough to avoid over-heating the materials adjacent to the eyelet. Such overheating will cause destruction of the adhesive bond between the copper conductor and the phenolic base laminate; i.e., blistering of the conductor or within the laminate itself will occur.
3. The tip length must be adequate to facilitate access to the socket connections and between wire leads and components. Tip extension should be between 2 to 2½ inches. The semi-chisel or screwdriver shaped tip affords good conduction and the least obstruction of the work area. Inadequate tip extension will increase the likelihood of scorched insulation on wires and damage to components.

   Note: The particular iron used at Du Mont is the HEXAGON style P-30, 70 watt, 110 volts with the HEXAGON HT-230X tip.

B. The cored solder to be used for this process is Kester #44 flux cored solder, specified as follows: 1/16″ diameter, 63-37 alloy, #40 core size and #44 type flux. This solder has been specified for the following reasons:

1. The 63% tin-37% lead alloy is a low melting alloy and has a very short melting temperature range. "Freezing" will occur as soon as the temperature drops below 360°F. With other alloys, cold solder joints can occur if a wire or component in the eyelet is moved while the solder is still in a "plastic" state.
2. The #40 flux core contains .5% flux by weight — an amount adequate for complete fluxing; yet it will not produce an unsightly ring of resin around each resoldered eyelet. All commercial cored solders are supplied with approximately 3.5% flux, unless otherwise specified, which will leave so much resin on the chassis that a cleaning operation is required. Functionally, it is not known that excessive flux residue is harmful but it will definitely detract from the appearance of a serviced instrument.
3. The size, 1/16″ diameter, is adequate for a good rate of operation and is small enough to maintain control of the amount of solder being applied. A larger solder size makes appearance more difficult to maintain and a smaller size will result in overheating caused by holding the iron on the eyelet long enough to build up the required solder deposits.
4. The Kester #44 flux provides good wetting on all but badly oxidized or contaminated surfaces.

   Warning: Use of any other solder-flux combination for this procedure is not recommended.

C. Solvents for use in cleaning the chassis prior to resoldering and for flux removal are limited to the following: Isopropyl Alcohol or LN-10 Flux Remover (manufactured by the London Chemical Company, Melrose Park, Illinois). LN-10 Flux Remover may be used in cleaning or for flux removal. It is claimed to be "non-flammable and non-toxic". Other solvents may introduce contaminants to the chassis surface which may cause performance aberrations.

D. Acid brushes or similar stiff bristled brushes should be used with solvents for cleaning and flux removal.

E. Clean, absorbent cloths for blotting up solvents.

F. Watchmaker's loupe or magnifier to detect the presence of cracked joints.

Preparation

Both sides of each printed circuit chassis must be accessible for resoldering and cleaning. The dip side of the chassis shall be cleaned, if necessary, to remove any dust, wax, or other soils which will reduce solderability. Solvents must be used sparingly and must not be allowed to contact the following components: variable resistors, precision resistors, and Sprague wire-wound resistors. For soldering, the chassis shall be positioned horizontal within 15° and supported to provide a firm working area. Provide adequate light to illuminate the work area.

Soldering

The procedure outline below must be followed exactly for reliable and uniform results. Figure 4 represents an ideal resoldered joint. This cross section illustrates the required solder build-up on the eyelets. The importance of producing a solder build-up, as shown, by this procedure cannot be over-emphasized.

At those joints already outlined, apply the solder iron tip to the junction of the eyelet and pad or eyelet and tube socket tab. Simultaneously, apply solder to the junction of the eyelet and the solder iron tip. With solder being fed to the eyelet in this way, heat will be conducted into the eyelet through molten solder as well as through the contact point of the iron tip. Do not permit the iron tip to contact the phenolic board or the printed conductor outside the pad area. Feed enough solder to build up a deposit which will completely cover the eyelet and flow over the pad area. See Figure 4, above.

Note: A useful variation in feeding the solder is to lay the solder wire down on the eyelet and apply the iron tip to solder wire itself with a rolling motion. A more uniform length of solder can be added to each eyelet by this method and the flow of heat will be faster. The operator may find further improvement in technique can be effected by bending the tip, so that the flat side of the tip can be applied to the work area. Bending the iron tip may also improve visibility of the work area.

Keep the iron tip in contact with the work only long enough to complete the build-up process. Withdraw the iron immediately after solder flow around the eyelet is complete. If the tip temperature is close to 600°F it may be necessary to withdraw the iron just before complete flow occurs. It will be found that the heating time between eyelets will vary, depending on the presence of component or wire leads in the eyelets. Do not allow the iron tip to remain in contact with the eyelet after complete flow has occurred. If additional solder is required for adequate build-up, allow the eyelet to cool before continuing.

If excessive flux is accumulated at a joint, allow the connection to solidify, brush the flux residue with solvent and wipe up the area with a cloth.

Observe The Following Important Precautions:

1. There must be no bubbling of solder during application or after the iron has been withdrawn. (Bubbling will leave pock marks in the smooth solder surface.) Bubbling is due to overheating and will result in any one or all of several undesirable conditions:
   a. Movement of solder in the eyelet and adjacent areas at the time of "freezing", as evidenced by bubbling, can result in a cold solder joint.
   b. Complete melting of solder down through the eyelet, which may or may not be evidenced by bubbling, can result in opening the connection on the component side of the chassis between the eyelet and conductor. Solder on the underside of the chassis can be put under tension at a time when it is partially molten and is mechanically weak.
2. If bubbling or flow through of solder has occurred, the operator must:
   a. Wait until the joint has cooled.
   b. Examine the underside of the eyelet for fluxed solder. If an excess of solder has accumulated, remove it by draining with the iron and again allow the area to cool.
   c. If flow through has occurred, resolder both sides of that eyelet, following the above procedure, allowing the area to cool after heating each side.
   d. If flow through has not occurred, do not disturb the underside of the eyelet in question.
3. Do not move or disturb component leads or wires within an eyelet before the solder has set. This movement will also cause "cold" solder connections, an everpresent source of intermittent connections.

Definitions

eutectic — lowest point at which solder combination will melt.

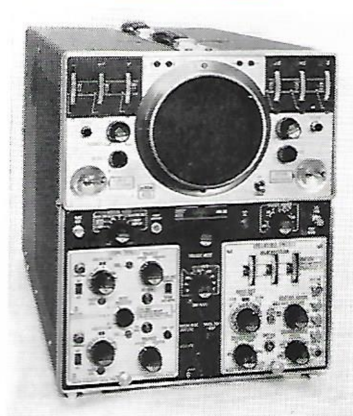
dip side of the printed circuit chassis is that side which has been dipped into the soldering pot; circuit conductors and eyelets are coated with solder.

The *component-side* conductors have the original solder-plated surface and the eyelets on this side are coated with solder which has risen up through the eyelet during dip soldering.

The *eyelet pad* is that circular portion of conductor which surrounds each eyelet.

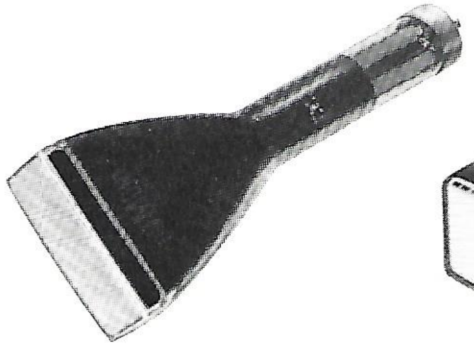
Next Issue

A detailed story on the technical aspects of entirely new concepts in oscilloscope design — as used in the new Du Mont Type 425. Just unveiled this month, after three years in development, the 425 includes such features as: front-panel direct-reading digital ReadOut of measurements; new two-dot system of precision measurements on both axes; joystick control of traces; replaceable modular construction; use of multiple plug-ins simultaneously; new mechanical concepts. For reasons and theory behind the latest state-of-the-art designs in cathode-ray oscillography

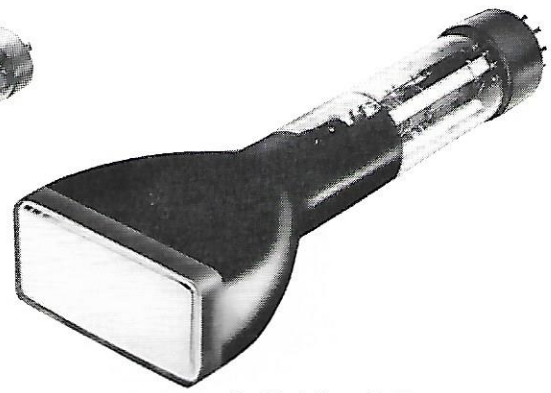


— see Issue 9 of the *Du Mont Instrument Journal.*

FOUR NEW CATHODE-RAY TUBE DEVELOPMENTS



Du Mont Type 3AYP-



Du Mont Type 3BDP-

Four new cathode-ray tubes have been released by the development laboratory of Du Mont's Electronic Tube Division. Types 3AYP-, 3BDP-, 5AQP-A and 5AMP-A have been designed to provide higher performance replacement tubes for existing equipment and to set higher standards for new equipment designs.

Types 3AYP- and 3BDP-

The Du Mont Types 3AYP- and 3BDP- are the improved versions of the earlier Types 3XP- and 3SP- respectively. The new features are completely redesigned envelopes, and new glass-rodded construction of the electron guns and deflection plates. The faceplates of the new tubes are extremely flat and uniform, increasing the distortion-free usable screen area by more than 20%. The annoying effects of parallax are reduced, and an evenly distributed display is presented. This *true* rectangular faceplate, combined with the sidewall shape of the bulb, permits "stacking" of these tubes for multichannel oscillographic presentations. Specifications for mechanical rigidity, alignment of parts and tolerances of the gun have also been stepped up to improve electrical stability and performance.

Types 5AQP-A and 5AMP-A

The Du Mont Types 5AQP-A and 5AMP-A have all the highly regarded features of their predecessors, the Types 5AQP- and 5AMP-, but now include a 20% decrease in angular alignment tolerance between horizontal and vertical traces — now held to 90° ±0.8°, and very tight tolerances on pattern distortion. The Type 5AMP-A has less than 1.1% distortion in the horizontal and less than 1.6% in the vertical scan direction at 100% of useful scan. The Type 5AQP-A has less than 1% in either direction at 100% of useful scan.

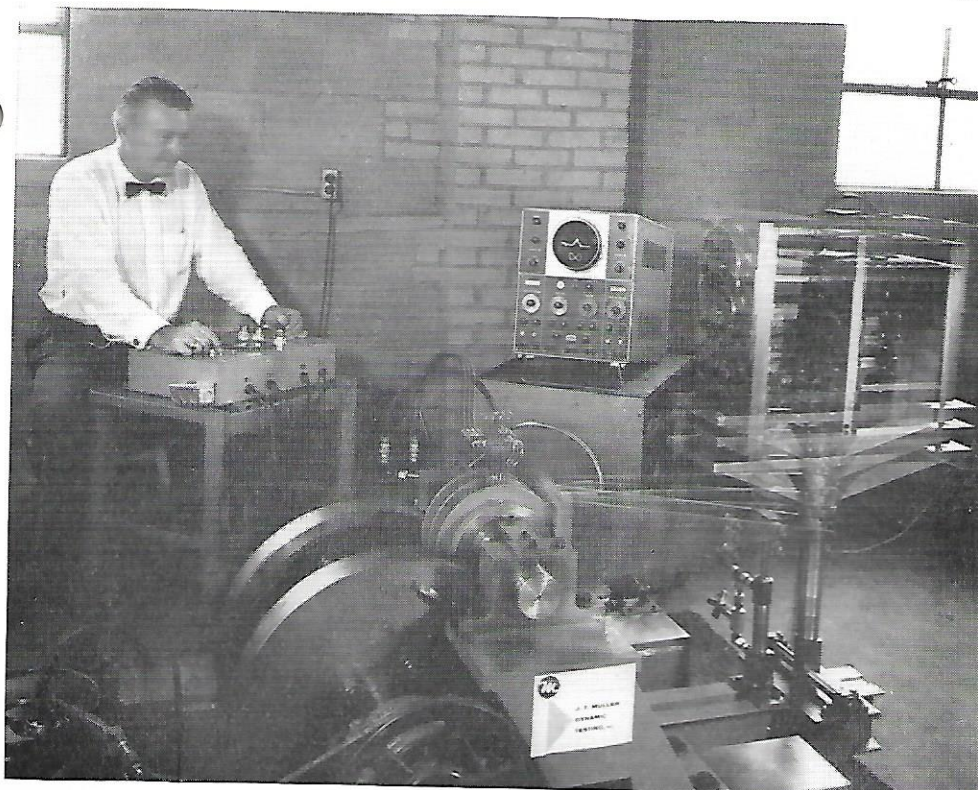
In addition, screen specifiications in respect to dead areas and blemishes have been tightened, and the glass envelopes are made to higher quality standards to extend their usefulness in scientific applications where freedom from any distortion is a necessity.

SIMULATION TESTING FOR RELIABILITY

Much to do about reliability has been headlining technical and semi-technical writings ever since the first attempt to orbit a missile was made. The reason is a good one — such missiles are extremely expensive systems, and a malfunction in even a minute component could cause a complete system failure. This is equally as true in other complex systems as it is in missile systems.

To offset dangers of such failures, or to be more positive — to more accurately forecast reliability, industry has been seeking devices of all sorts to simulate the actual dynamic conditions that destroy. These devices must simulate conditions for testing components and sub-systems, for example, such as those encountered in space flight.

One such simulating device, a controlled motion machine, has been developed by J. T. Muller Dynamic Testing Inc., of Hanover, New Jersey. The prime objective of the machine is to detect equipment faults of mechanical origin, and to supply information for ruggedizing structural designs to preclude or correct these faults — the information being obtained under dynamic conditions. It has been found that a very important adjunct to the controlled motion



The output, "G's", created by the Muller Dynamic Testing machine is depicted on the upper trace of the Du Mont Type 411 Dual-Beam Oscilloscope. The lower trace is the comparison of a known signal to the output signal of the unit under test. Ideally, the amplitude and width of both sides of the lissajou will remain equal, indicating that the unit under test is performing as it was preset to do.

table is a dual beam oscilloscope — such as the Du Mont Type 411.

Principle of Operation

The motion table utilizes a flywheel-cam assembly of considerable mass to define the displacement-time history of each cycle of the test table. The rpm of the flywheel and the table arm length can be varied independently in order to give a wide range of impulse in terms of peak "G" and time interval.

The machine creates a strong "G" field by controlling motion or whip over short periods. It can do this intermittently to simulate shock, or continuously to simulate vibration. The power of the machine is great enough to create, for example, in a distance of a few inches, the impact of an object striking a solid wall at 50 miles per hours.

In contrast to static safety factors, which are determined from steadily applied loads with no rapidly occurring deviations, the unit enables the engineer to setup a dynamic environment — providing information vitally important for designing equipment to cope with vibration and shock. These conditions are analogous to the severe, rapid, reversible loads encountered in space flight — which quickly destroy or damage equipment. The test method enables the engineer to observe and study the normal function and behavior of equipment by operating and monitoring it while known mechanical transients are being fed into its system. In this way an accurate conclusion can be drawn as to its readiness to function in a specified environment.

Dual-Trace Scope As Part Of The Testing System

The test instrument most useful to the efficient use of the machine is a dual-trace oscilloscope. The scope provides two independent beams, or channels, for simultaneously observing the performance (or output) of the test machine and behavior of the object being tested.

Definite correlations between the severity of the abuse and functional performance can be directly observed with this type of instrumentation.

A Du Mont Type 411 Dual-Beam Oscilloscope is ideal for such use. As shown in the photograph, a Type 411 is monitoring the testing of another scope which is a component part of a larger system. The upper trace depicts the motion ("G's") created by the dynamic testing machine, and can be calibrated to read directly from the scope scale. The lower trace (lissajou) depicts the frequency and amplitude of the output signal being produced by the scope under test, compared to the frequency and amplitude of a known signal. As long as the lissajou is equal in length and height on both sides of the "figure 8", the output of the unit under test is equal in every way to the known signal — for which it was preset.

Du Mont Tubes Now Available Locally

Du Mont Cathode-ray Tubes for replacement purposes, and Du Mont Multiplier Phototubes, are now available from stock at local sources. A nationwide group of authorized industrial distributors has been established by Du Mont's Electronic Tube Division to provide extra-fast service to firms requiring small quantities of these tubes. For a complete listing of these distributors and available tubes, write to the Advertising Department, Electronic Tube Division, Allen B. Du Mont Laboratories, Inc., 750 Bloomfield Avenue, Clifton, N. J.

ABOUT CATHODE-RAY TUBE SCREENS

by: Nicholas Williamson
Technical Coordinator
Allen B. Du Mont Laboratories, Inc.

This discussion of cathode-ray tube screen characteristics has been prepared to assist the increasing number of users of industrial type cathode-ray tubes in understanding the theory, application, and the selection of the phosphors used for screens. This information will be of particular use to the consumer in judging whether his existing equipment will accept a screen with different properties than the one being used, and will guide the designer of completely new equipment in choosing the proper screen for his application.

Part I

Theory of Screen Emission*

The screens used in cathode-ray tubes are solids, usually crystalline in form, which are deposited on the back of the tube face plates. These screens, called phosphors, are materials that exhibit the property of light emission when they are bombarded by charged material particles or forms of radiant energy such as photons.

According to the Quantum Theory, the energy of light is conveyed in packets, or quanta, and radiation is absorbed or emitted as particle-like photons which have discrete amounts (quanta) of energy. This energy is defined as $E = hv(nu)$ where h is equal to Planck's constant and v(nu) is the oscillation frequency of the radiation. It is this energy that gives radiant fluxes the power to energize phosphors, and the frequency of oscillation of the emitted power determines whether it is visible light.

While the exact mechanisms and physical relations that take place in phosphors are very complicated and not fully explained, a brief semi-technical expression of how this process occurs is presented to aid in understanding the characteristics of the various materials used for making screens.

Every atom has its own distribution of electrons whose number is fixed by the atomic number of the specific atom. These electrons occupy certain energy levels referred to the nucleus of the atom, again, fixed by the specific atom. When two or more atoms are chemically combined, the number of electrons generally associated with the individual atoms are also held at discrete energy levels termed bands — if the solid is at a state of equilibrium. If, in the case of the phosphors, sufficient energy is supplied (by charged electrons or photons) to the equilibrium electrons, they can be transferred from the equilibrium "electron-filled" bands up to the conduction bands — which are usually unoccupied by electrons but are capable of accepting them. When these electrons return to their unexcited state, they give up their stored energy in the form of photons which radiate as light.

There are literally thousands of materials which have been experimentally found to have the prop-

*The screen data presented is for currently used JEDEC registered screens.

erties of phosphors, but the preparation of pure crystals of these materials is extremely difficult. When the crystals are precipitated, impurities and excess reactants are mechanically and substitutionally held in the crystal lattice. However, these impurities can be desirable in a phosphor because they provide a means for trapping holes (spaces created by the migration of equilibrium electrons) and for furnishing electrons to fill temporary vacancies.

This trapping action is responsible for the observable changes in a phosphor subjected to a radiant flux. Some of the electrons can and do return to their original states while being excited. Other electrons are held in various trapping centers and their return is delayed even after the excitation is removed. The deliberate introduction of excess materials, called activators, will alter or vary the properties of the crystal in both emitted light color (frequency) and the duration of the trapping action.

The energy used to excite phosphors may come from any of several forms of radiation such as photon, electron, ion, or thermal emission. When the phosphor is bathed in any of these fluxes, it can absorb one form of energy and transmit another form, or reproduce a different frequency of the same form (photons).

Because the cathode-ray tube produces a convenient and highly controllable supply of high energy electrons for exciting phosphors, it was logical that a number of phosphors would be developed solely for this purpose. These phosphors are highly reproducible in their characteristics and have been assigned phosphor numbers by JEDEC — as each was brought into being to perform a specific function.

Although each of these screen phosphors has been designed to work efficiently with cathode-ray electron emission, the presence of other forms of radiant energy can affect them. The most serious offender is thermal radiation — which is often present and can alter the duration of emission and/or the light output. The effect of heat and other stray radiation is further detailed later in the article.

Definitions of Screen Terminology and Data

Frequently, in applying the characteristics of cathode-ray tube screens, confusion results from misunderstanding of the terms and in interpreting the data given to show these characteristics. To avoid misconceptions, the terms and methods used in succeeding sections are defined.

luminescence — the physical definition of luminescence is the emission of light from a material not ascribable to incandenscence and, hence, occurring at a low temperature. In describing the light output from a screen, it is necessary to restrict the term to light emission originating from the sub-atomic reactions discussed earlier. Even with this restriction, the term is still broad because light emission can occur during excitation of the phosphor and continue after excitation. Therefore, two other terms are introduced to further distinguish light emission.

fluorescence — the light emission occurring while the screen is excited, and *phosphorescence* — light emission after the cessation of excitation. These definitions are arbitrary and may not agree with the strict technical definitions.

The above terms, also, carry the implication of only visible light radiation, but many uses of cathode-ray tube screens involve objective detectors rather than the subjective human eye. The term light will then include radiation on either side of the limits of visible light such as ultraviolet and infrared.

spectral-energy response — is the method used to give one of the two most important characteristics of cathode-ray tube screens, that of color emitted by a screen during fluorescence and phosphorescence.

These measurements are made with a spectoradiometer from the unbombarded side of the screen when the phosphor is excited by a cathode-ray beam according to the test conditions set by JEDEC. Most of the curves plotted from such measurements are normalized to show the maximum response wavelength as 100%, although the same characteristic may be expressed by giving two coordinates on the International Commision on Illumination Color Chart. It should be noted that these are average responses and that minor differences in preparation of a screen may cause very slight shifts in the screen's response.

Generally speaking, screens will exhibit the same color during fluorescence and phosphorescence. There are exceptions to this, and a spectral-energy response curve will show two peaks when a phosphor has a different color during phosphorescence and fluorescence.

persistence — is the time it takes for the light emitted by phosphors to decay from initial brightness (reached during fluorescence) until the light is no longer detectable. This characteristic is the second of the two most important properties of a screen. The maximum light output is not measured until the screen has attained a steady state condition where further repetition of the exciting signal will not increase the brightness level. The values of the test conditions may be found in JEDEC releases. When the screen has a fluorescent color component that differs from the phosphorescent color, a color selective filter will be used to eliminate the fluorescent color light output from the peak phosphorescent value.

Screens are classified as having short persistence if their period of useful phosphorescence is between a few microseconds and one millisecond, medium persistence if between 20 milliseconds and 2 seconds, and long persistence if over several seconds. The rate of decay of phosphor has been found to be defined by one of two formulas: t^{-n}, or e^{-kt}, where n and k are time constants of the particular phosphor.

buildup — this term is applied to screens which require repeated pulses of excitation before they attain their maximum light output efficiency. In screens of this type, some of the primary energy is absorbed by deep trapping centers — which eventually reach an equilibrium state when they no longer need energy. Then the full amount of energy in the primary source is devoted to producing light emission. This effect is transitory and will depend on the intensity of excitation, the duration of the pulse, and the time between a regularly repetitive signal and random signals. In general, screens of the long persistence type show slow buildup — and vice versa.

halation — is a distortion of screen light emission occurring from light producing crystals in actual contact with the face plate glass. The rays of light emanating from the crystal glass surface are transmitted through

(*Continued on page* 16)

the glass until they encounter the opposite surface. When the angle of incidence reaches the critical angle of the glass, some of the rays are reflected internally in the glass — producing a secondary source of light. If the cathode-ray beam is at rest, evidence of halation is indicated by a circle of less intense light surrounding the point of contact of the cathode-ray beam on the screen. If the beam is in motion it is evidenced by parallel lines of diminished intensity on either side of the main trace. Control of halation can be effected by phosphor application techniques when the screen is originally laid, by phosphor crystal size and by varying the operating conditions of the tube to minimize the contrast.

stopping power and crossover potential — refers to the effects of metallization utilized to increase the light output of a specific phosphor. A portion of the primary energy in the cathode-ray beam is diverted to penetrating the metal layer, and the energy expended is defined as stopping power. After the accelerating potential has been raised enough to supply this power, the metallized screen will begin to emit light. At this point, the light intensity will be much lower than would be obtained from an unmetallized screen operated at the same conditions. As the beam potential is increased to a value known as the crossover potential, the metallized screen light output will increase until it is equal to that of an unmetallized screen under identical operating conditions. From here on, the light output of the metallized screen will always be greater than that of an unmetalized screen (see Figure 1).

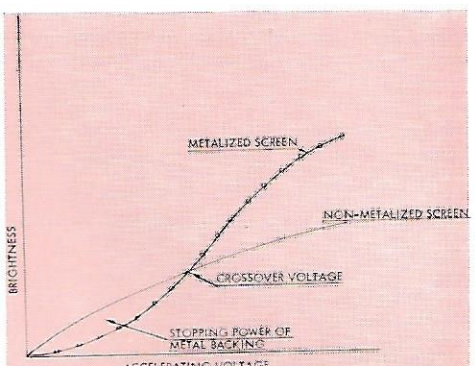


Figure 1. Graph of brightness vs. accelerating potential for metallized and unmetallized screens.

saturation — screen saturation can be caused by excessive values of either of two operating factors — accelerating potential and screen current density. If the screen accelerating potential is raised to a point where the electrons are driven right through the screen material, the excess electrons can have no further effect on light production and the screen is said to be voltage saturated. On the other hand, it is possible to raise the screen current density to a point where there is not sufficient phosphor volume to absorb all the electrons for conversion to light, and the screen is said to be current saturated. In the latter case, the electronic collisions with the screen material and face plate will raise the temperature until it actually causes physical and/or chemical damage to the phosphor — creating a screen burn.

Types of Cathode-Ray Tube Screens

The ordinary cathode-ray tube screen is usually composed of a single thickness of phosphor which is homogeneously and uniformly applied to the face plate of the tube. This type of screen is designated as a *single layer screen* and the excitant used to activate the screen are charged material particles (electrons) from the cathode-ray tube gun.

In the investigation of materials to be used for screens, certain phosphors were discovered to have very desirable properties of color and persistence, but were found to have very poor efficiency of light output when activated with the normal beam of electrons. It was also discovered that these materials were much more efficient light producers when an ultraviolet radiant source was used to excite them. It was apparent that a second phosphor could be selected which was rich in ultraviolet light output when excited by cathode-rays, and then the ultraviolet radiation could in turn be used to supply energy to the first phosphor with the desired color and persistence.

An attempt was made to use a mixture of the two phosphors — with very poor results because of the disturbing simultaneous two-color light emission and the lack of uniform excitation. A second type of screen was devised, known as the *cascaded* or *two layer screen* (Figure 2). In this type of screen, the phosphor sensitive to photon excitation is laid on the face plate glass in a single thickness, and this layer is backed by second layer of photon producing phosphor that is sensitive to electron excitation. By this means, it was possible to filter out most of the blue flash produced by the electron phosphor and provide uniform excitation for the glass layer phosphor.

Another common type of screen that has been developed is the *color selective screen,* where three phosphors, each with different spectral-emission properties (generally primary colors), are deposited on the face plate glass in contiguous areas where they can be excited by a single cathode-ray gun, or simultaneously by three separate guns. Obviously, the principal use for this type of screen is in color television, but it may find applications in oscillography and radar where a two or three color presentation might be used to show separate but related signals.

New Screens

The most recent developments in the art of applying screens have produced two radically new screen types. The first of these is the *evaporated phosphor* screen. In this process, screen material is evaporated on an internal plate mounted behind the

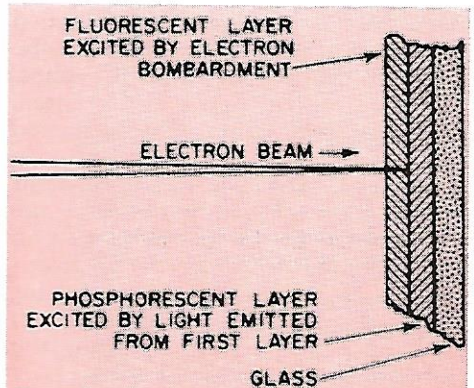


Figure 2. Diagram of cascaded or two-layer screen.

faceplate. A high degree of control in both the thickness and composition of the screen is possible with this method, producing a phosphor layer which is usually transparent and thin enough to resolve the finest of electron beam spots. Because of their transparency, these screens are commonly backed with a conductive black coating to increase the contrast in the presence of high ambient lights, to eliminate stray light emitted back of the faceplate, and to equalize charge effects on the screen.

The second of the recently developed screens involves a method of depositing the screen material to give an extremely fine grain screen. This method not only retains the advantages of crystalline structure, but makes it possible to resolve very fine electron beam spots. These screens are available from Du Mont in the JEDEC Types P1, P11 and P16. With these fine grain screens in tubes with magnetic deflection, and either magnetically or electrostatically focussed, spot sizes of less than 1 mil diameter are feasible.

Light Output Efficiencies of Screens

A very important property of a screen is the amount of usable light it will produce under certain specified conditions. A quick look at the mechanics of a cathode-ray tube will indicate that the most efficient production of light is on the bombarded side of the screen, and that as the electron beam penetrates the phosphor its irradiant power is decreased. Also, as the light is transmitted through the screen, its transmittance is reduced. However great the light output is on the bombarded side, the significant light production is seen on the unbombarded side of the screen when a cathode-ray tube is used for image display. Therefore, data on light output is measured from the front of the cathode-ray tube.

Since this measurement is strongly dependent on the type of tube, the operating conditions of the tube, the raster size, the accelerating potential, the current density and the instrument used for detection, these facts should be clearly stated on curves used to indicate light output values. Before using such data, make certain that the measurement conditions are compatible with the conditions under which the tube and screen selected will be operated.

Scotophor

The phosphor number assigned to a screen (JEDEC P10) is not a true phosphor. This screen, known as a *scotophor* (dark bearer), differs from a phosphor in that exposure to radiant flux does not produce light emission — but rather changes the absorption properties of the material when the screen is viewed with reflected light; the path of the beam will first appear as a magenta trace. This phenomenon is known as tenebrescence, as opposed to luminescence which occurs with true phosphors. The principle advantage of this type of screen is very long persistence, but it is offset by exceedingly high power excitation requirements and relative difficulty in observation.

Screen Detector Characteristics

It is impossible to obtain the maximum usefulness from a cathode-ray tube screen unless the properties of the detector used with the screen are carefully analyzed and related in turn to the properties of the screen. In the common applications of cathode-ray screens there are three principal means of detection; visual, photometric and photographic.

1. *Visual Detection*:

While the human eye is undoubtedly the most remarkable device for the detection of light in adaptability and in range, it is subject to physiological and psychological differences between one observer and another. It is possible to have different reactions to color and intensity of light between two observers and even to have the identical observer react differently at other times to the same stimulus. For this reason, many studies of this subject have been carried out and standards based on statistical averages have been established to express the characteristics of the eye as a light detector.

One of the differences that exists in the *average* individual observer is an adaption of the eye under varying levels of retinal illumination. If the eye is light adapted, it is defined as having "photopic vision", if it is dark adapted as having "scotopic vision", and if the retinal illumination is between these two extremes as having "mesopic vision". In Figure 2 two curves are shown giving the *average* spectral response of the photopic and scotopic eyes and the colors associated with that response.

The photopic eye is characterized by being better able to detect color differences, by having much higher visual acuity, by being more sensitive to flicker, and by being able to detect smaller changes in light intensity than the scotopic eye. As can be seen by the curves in Figure 3, the *average* photopic eye is more sensitive to colors in the yellow-orange wavelengths and the average scotopic eye is more sensitive to the blue-green range.

Although the scotopic eye is less able to detect minor changes in luminous intensity than the photopic eye, it is able to detect a much lower intensity of light, that is, at 5100 A° —

100% response point for the scotopic eye, it requires 1/10 the power to produce an equal sensation of brightness as it does at 5600 A° — the 100% response point of the photopic eye. The scotopic eye is practically "color blind". It can detect the presence of light but is usually unable to recognize the color.

The photopic and scotopic eyes also differ in the time required to reach a state of adaption. The photopic eye can become light adapted in a few minutes, where it may take as long as 10 hours for it to become fully dark adapted.

The ability of the eye to detect a difference between two images depends on luminance level, the object size and the distance between the two images. The differences in these variables is known as contrast. If the two images are located in separate areas, it is defined as spaced contrast. If the two images have common borders, it is defined as detailed contrast.

The factors that effect visual contrast in cathode-ray tube screens are (1) the adaption level of the eye, which is determined partly by the illuminance of the screen and partly by ambient light; (2) halation, which are reflections in the face plate glass; (3) the distance of the observer from the screen; (4) the concentration and the diameter of electron intensity in the cathode-ray beam; (5) the luminous scattering of light through the phosphor crystals; and (6) the differences in light intensity emitted by the images.

Resolution is a measure of the eye's ability to determine discernable differences in detail. The limiting factor in this characteristic as far as cathode-ray tube screens are concerned is the size of the screen crystal in relation to the diameter of the beam.

Persistence of vision is another characteristic of the eye which defines the length of time the eye will retain the sensation of brightness after the source has been extinguished. This will vary with the individual but the range is approximately a tenth to a twentieth of a second.

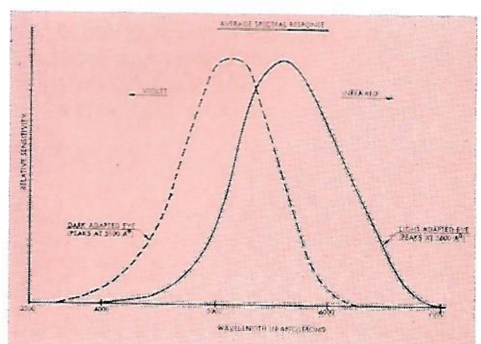
Finally, the last important characteristic of the eye to consider is fatigue. If the eye is required to look at images for prolonged periods of time, conditions must be avoided that will strain or distract the observer's attention. Continued exposure can change any or all of the foregoing characteristics. In any application of a cathode-ray screen involving eye detection, tests should be made under conditions simulating the actual use of the tube to make certain that the desired results are obtained.

2. *Photometric Detection*:

Although photometric devices such as photocells, phototubes and multiplier phototubes are less selective in their individual range and adaptability than the human eye, they have the advantage of being objective rather than subjective detectors. Their characteristics can be matched to a specific application. If another set of characteristics is desired, a different photo device can be chosen to match the desired properties. Their spectral response can be altered by a proper choice of filters, and their sensitivity can be altered by their operation.

Photometric devices also have the characteristic of persistence. In the case of a multiplier phototube, this is approximately 10^{-7} seconds.

To be continued in Issue 9



product of the pioneer

DU MONT

425

the most significant advancement in the state-of-the-art since DU MONT introduced the first commercial oscilloscope

the new

DU MONT 425

Only the very latest concepts known in the art of cathode-ray oscillography have been incorporated in the Du Mont 425 High-Frequency Oscilloscope. This new scope will outperform any commercial oscilloscope in its class—now, yet its entire design concept is based on the future—the 425 will always be a modern scope.

By ease of operation, and elimination of chances of human error in making measurements, the 425 becomes simplified enough for a non-technical person to use. At the same time, with the extreme versatility provided by a series of plug-ins, and replaceable module construction, the 425 will satisfy every laboratory or scientific need within its range.

Such features as: simultaneous use of two plug-ins; digital ReadOut of measurement parameters; joystick control of traces; a unique, highly-accurate "two-dot" measurement system; replaceable, modular construction; a new "tailored" cathode-ray tube; output facilities to feed information to external recorders or systems—all of these features and more help establish the fact that the 425 will always be the most advanced, versatile oscilloscope commercially available.

Write for technical details

the result of 44,000 engineering hours!