MILITARIZED PRODUCTS DIV

# TEKTRONIX, INC.

# THE 945 STORY

BY
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M.P.D. ENG. DEPT.

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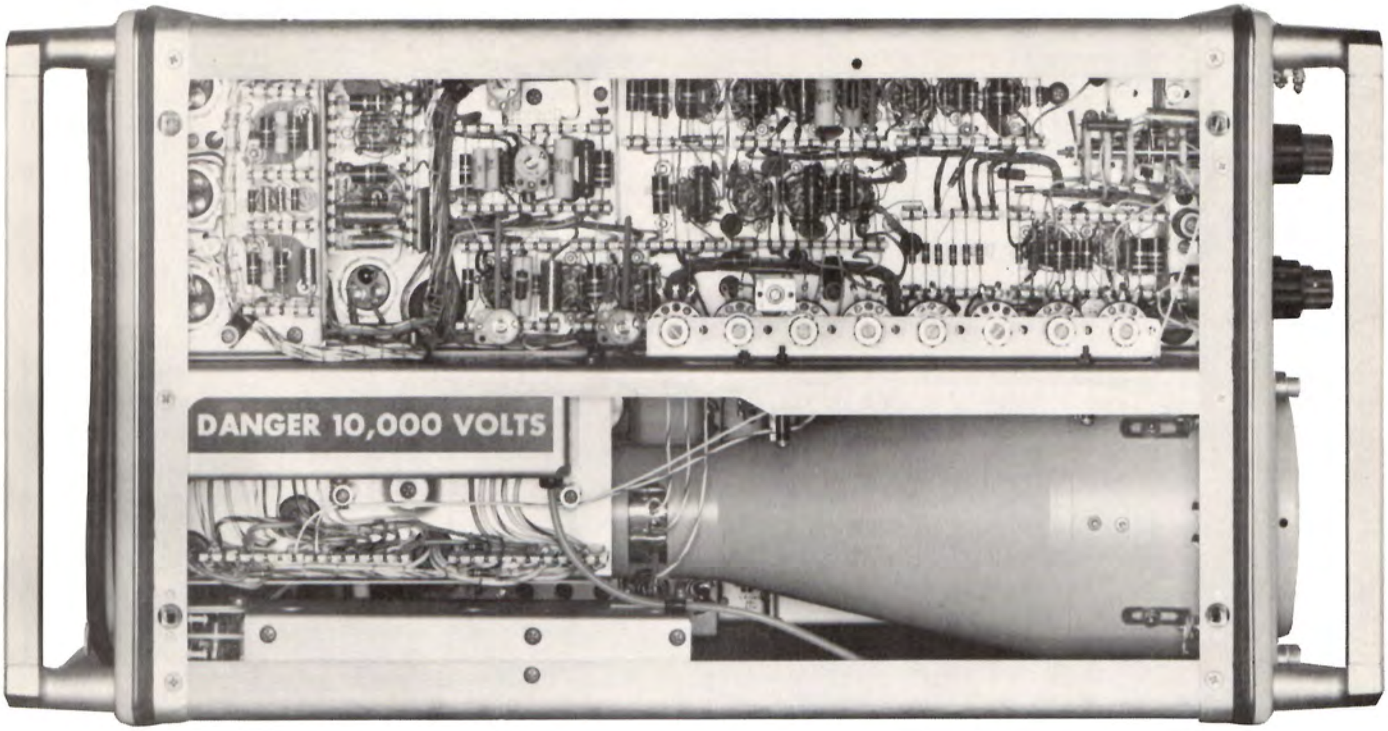
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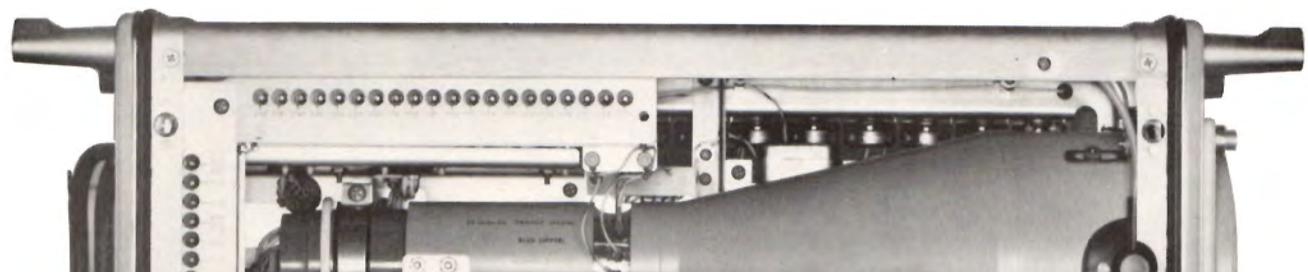

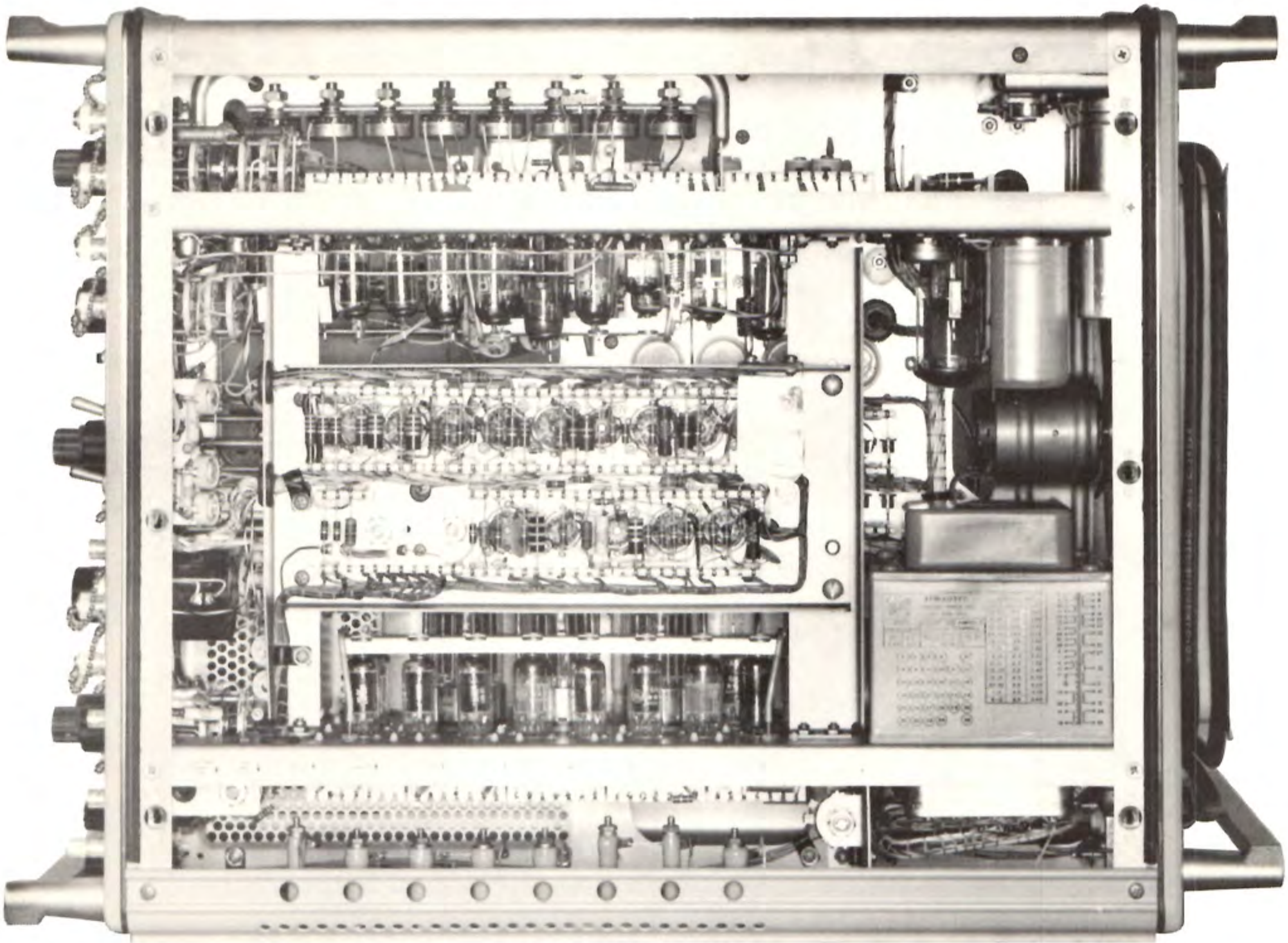

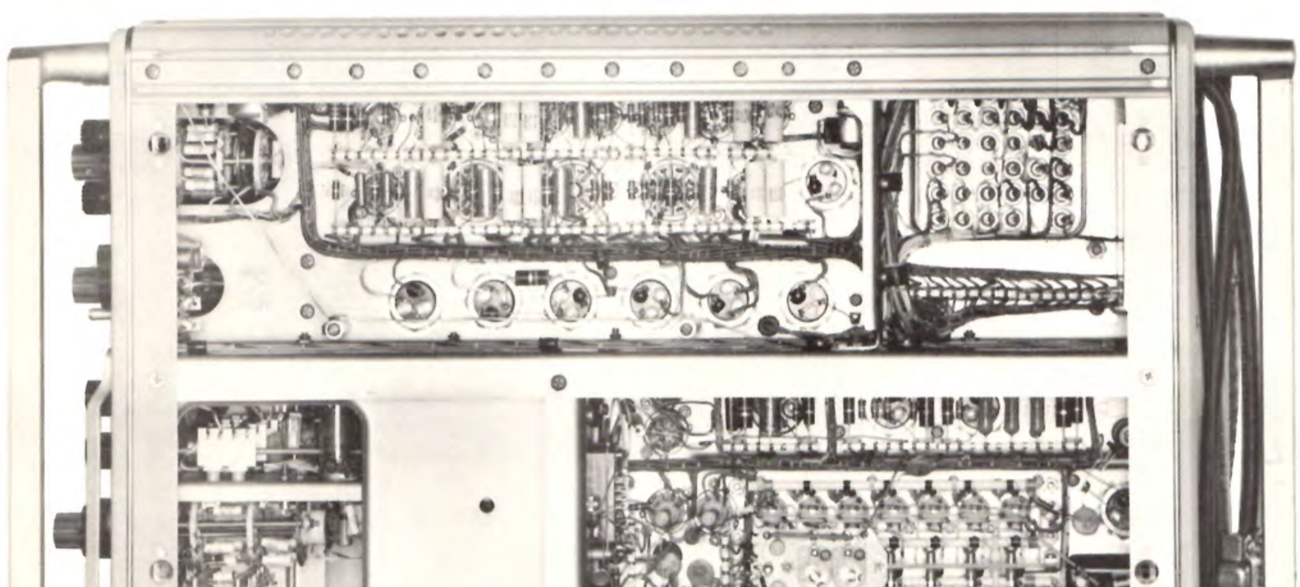

# PREFACE

There comes a time in the course of human events when an engineering report can't be avoided any longer. The burning desire to tell someone (just anybody who will listen) what you've been doing for two years, overshadows all the hours of hair tearing and gnashing of teeth that goes into putting the story on paper.

Seriously, Tektronix has become so large that it is becoming increasingly difficult to bring about an effective exchange of technical ideas. The written word requires considerable thought and effort to convey an idea concisely and clearly; however, once accomplished, it can be disseminated to a wide audience and referred to as often as necessary and of equal importance at a convenient or opportune time.

One might question the lack of the face to face contact, but this is not lost. Anytime questions need to be answered or ideas need discussing, it's pretty easy to gather interested persons for a good go-around.

This report does contain information that is best kept within the confines of the company. Assuming the reader will treat this as confidential, all reservations are lifted as to what should or should not be said.

The reason for all of this is to tell what we have done on the Type 945/MC project so that other people meeting similar situations and problems can profit from our experiences to further the technology of building oscilloscopes.

Bob Poulin

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## INTRODUCTION

Historically the Armed Services have attempted in one way or another to persuade Tektronix to build an oscilloscope which could survive outside the laboratory and maintain the accuracies so associated with Tektronix equipment. Just as historically we continually parried with our off-the-shelf item. Somewhere along the line, the glimmer began to come through. Maybe these people really are in dire need and who could best do the job but the leaders in the oscilloscope field.

In 1958 management began to gather a nucleus of people called Militarized Products Division. The first job was to contact key persons in the Armed Services. Soon, a pattern began to form that indicated the direction.

The 545/C was the clear candidate for the first militarized project. Not only does it include maximum performance and versatility but the services have many of them. They are familiar with capabilities, operation and maintenance. In contrast, the "A" version was still unpublished at that time.

The concensus was that this should be a Tektronix R & D project to provide an instrument most useful to all services, if possible, and to maintain our proprietary position.

Each service has its own general electronic specification. One which looked most reasonable and acceptable by all services (on paper anyway) is MIL-T-945A: Test Equipment, for use with Electronic Equipment; Gen. Spec. for. Using this as the framework of electrical, environmental and military parameters, the engineering began.

Any similarity between number of the Tektronix Type 945 Oscilloscope and the Mil. Spec. is purely intentional.

## DESIGN PARAMETERS

One of the initial steps is to develop a basic philosophy to guide later decisions. Attitude is all important when working with the military. There seems to be a maximum of red tape and unnecessary requirements to the extent of bordering on the ridiculous. However, after the first reaction, if one tries to appreciate the headaches the armed services have because of their supply and stocking problems, he can be more sympathetic with their methods of doing things. The military specifications are essentially a media of systematically providing a uniform commodity. There is considerable inertia in changing specs to keep up with the state of the art. This is one of the areas in which it is the responsibility of the designer to take an exception to antiquated or unreasonable requirements. In this way the need for up-dating is emphasized and the modification is brought about. There is a continual effort on the part of the armed services to modernize specifications. On the other hand, there are certain specifications that are several years old which are still as meaningful and accurate as the day they were written.

The customer (the military) might be described as a very large complex organization that has particular electrical, environmental and stocking requirements. He also is quite positive about these requirements and states them emphatically (Mil Specs). This customer is also aware of costs of maintenance and is greatly interested in promoting reliability.

With an attitude of desiring to serve this customer and all of his idiosyncrasies, the way is cleared to create a product to do his job.

The job was, fortunately, well defined by the wide acceptance in the services of the Tektronix Type 545 and C preamp. Using this as the breadboard, so to speak, several design parameters were established:

A. The basic electrical specifications remain the same. The improvements will be in the direction of meeting the environmental requirements.

B. Leave unchanged the front panel layout and functions to be the same as the 545/C. This provides universatility so that the operator using an already existing 545/C in the system, can walk up to the 945 and have a minimum of operating trouble.

C. MIL-T-945A is the general equipment specification that guides the design of the scope. It will be followed wherever possible. Military sources may be consulted for advisement about deviations.

D. The environmental requirements will be of foremost importance. Exceed the environmental requirements if it looks practical without excessive costs and there is a need. The various environmental tests will be the final criteria of the design. The scope should be thought of as not only militarized but environmentalized.

E. Ease of maintenance and reliability along with functionability will guide decisions where alternate choices exist.

F. The circuitry will lean towards that of the 545/C where we have the most history, unless the history points out the need for better reliability. The general approach is to hybridize Tek circuitry as the needs dictate.

G. Tube and semiconductor line-up will change to meet preferred types (MS200) or Mil types (MIL-E-1) wherever the circuit performance is not deteriorated or the circuit can be modified to accept the different type.

H. Mil Standard components, materials and finishes, will be used unless a more reliable item can be found, or the commercial part cannot be duplicated reasonably.

I. Tek made components should be capable of performing to applicable portions of the component specs. The transformer will be processed through qualification tests in our environmental Lab.

J. The physical layout of sub-assemblies to remain essentially the same to minimize building in new bugs. However, the structure is not particularly sacred.

K. Costs are to be considered on each decision just as any design. This customer recognizes that MIL parts are more expensive. It doesn't mean that costs can be allowed to get out of hand, but some things are simply not done cheaply. As long as the function vs. cost is explored and considered, the final compromises will set the product price.

## GENERAL APPROACH

With the goals and limitations fairly well in mind, the general approach of solving the engineering problems was tackled.

The electrical and mechanical groups worked very closely together, each appreciating the others point of view. In this way, a parallel and integrated effort was very profitably obtained. Designing for environment requires that the mechanical and electrical concepts be developed as one. Along with the electrical and mechanical efforts, an environmental testing facility was created. Here, preliminary evaluation of ideas and mock-ups could be made and later, testing of complete instruments.

It was planned to first evaluate a representative sample of commercial construction then design and build a mechanical model to be mocked-up with heavy components for a vibration test of the structure. While the mechanical design was being worked out, experimentation was performed on needed circuit changes. Also, miscellaneous ideas on things like heat distribution and cooling were evaluated. The guinea pig was the 1535, an earlier attempt at a partially militarized 535. A vibration test was performed but other environmental tests were not because of the differences between the commercial parts and the Mil parts that would be used in the Type 945/MC.

A complete working "X" model was the next step to determine how good the first guesstimates were. After this, ten prototypes were planned to firm up the design and provide enough units to work with, i.e. electrical-environmental evaluation, construction samples, show samples, demonstrators, and one each to the Navy and Marine Corps. After each of these units performed its original job, a series of life tests were run to obtain reliability information. The prototypes were practically all model shop fabricated, except for some special parts for which partial tooling was made.

In contrast, the pilot run of 50 was set-up for the Fabrication and Molding Division to tool for conservative runs for all Tek made parts. MPD manufacturing group was established to do the assembly work as they would for future production.

Evaluation is one of the key endeavors to the successful outcome of the entire project. Not only are the electrical performance characteristics important but performance in, during and after exposure to severe environment. Much effort has been and will be expended on testing to obtain history to demonstrate that we meet specifications.

Herein lies an important thought. We as a company are entering a relatively new area of instrument performance. Now our specifications will not only say X mc bandwidth but at Y temperature or after Z vibration. Some of these environments are destructive and it isn't practical to make 100% checks as we do electrical characteristics. Other tests are not deteriorating; however, even these become prohibitive in cost. So how do we assure ourselves and the customer that the scopes that he buys will do the job when the chips are down.

There are three directions to be taken:

1. Careful evaluation and qualification tests of first units from the production line.

2. Sample testing of instruments to certain important non-deteriorating environmental requirements.

3. A well established and thorough quality control function that will guarantee that parts, materials and processes remain within acceptable limits.

This may seem costly and overly ambitious for a specification assurance program. However, it seems the only logical course. After all, the environmental features of the Type 945/MC are the basic reasons for the higher price tag.

Another facet of the engineering problem is to describe accurately the capabilities of the Type 945 without minimizing the product but also not draw such a fine line that normal manufacturing tolerances will make the specs difficult to meet. This means a reasonable amount of performance data in environment and a very round crystal ball.

A specification assurance record has been generated to show that each scope has been tested for each electrical specification and that it meets the limits.

Specifications have been written so that acceptable limits are clear: Plus or minus or max/min. This leaves little room for interpretation by acceptance agencies.

Close attention to specifications is important in this project because of the spec minded military buyer. He will try to substitute a cheaper lower performance equipment unless we can close all possible gaps to have him buy the Type 945/MC or a true equivalent.

Reliability is an interesting characteristic about which there is much talk, both in and outside the military circles. More and more procurement contracts are indicating in one way or another that the equipment shall have "reliability". This is fine, but how do you measure this most desirable thing. The classic method in the big systems design is to treat the problem statistically based on the component by component application and their failure histories. Practically no one has enough data for the myraid parameters and characteristics established in a complex equipment. Large scale assumptions are made about circuit end-of-life criteria.

The long range but more certain method is to perform life studies on a number of sample instruments to produce enough history to be able to have a reasonable confidence level. Few assumptions are necessary, and exact environmental parameters can be established with end-of-life criteria defined.

This is the reliability program for the Type 945/MC. It is planned to have at least 50,000 scope hours of experience at room conditions cycled three time/24 hours. At least 5 of the prototype scopes will eventually be involved. Maintenance checks are made every 500 hours. Only when a characteristic is out of spec is it considered to have failed.

## DESIGN DETAILS

MIL-T-945A describes most of the parameters in detail. In place of a several day session of reading specifications, here is a list that outlines the basic environmental requirements:

| | | |
|---|---|---|
| Temperature | -40°C to 55°C/71°C<br>-65°C to +85°C | (operating)<br>(storage) |
| Humidity | 10 days, 95% RH 18°C to 65°C | |
| Fungus | 28 days | |
| Vibration | 5 G's, 55cps, 0.030 pk-pk | (operating) |
| Shock | 400 lb drop hammer | (operating) |
| Altitude | 20,000 ft<br>50,000 ft. | (operating)<br>(storage) |
| Radio Interference | 15 kc to 400 mc | |
| Salt Atmosphere | 100 hours. | (finishes) |
| Rain | 5 min. drip test | |

It's difficult to describe the design in a nice neat logical order. The circuits, components, structure, materials, finishes and cooling are so interrelated that it's unreasonable to treat each completely independently. The development goes along in much the same manner. Mechanical problems are often electrical and vice versa. The circuitry and active components (tube and transistors) go hand in hand and probably should come first, then the "passive" components followed by the structure to support them. Materials, finishes and cooling are interwoven among all the problems.

## TUBES AND SEMICONDUCTORS

Changing to military tube types pointed out most of the areas for circuit revision. In almost every case, information was obtained from engineering in process on the A model or from work that had already been completed. The following list shows the tube line-up and the commercial tube and circuit:

| CIRCUITS | 945 TUBE or SEMICONDUCTOR | COMMERCIAL TUBE OR SEMICONDUCTOR | NEAREST COMMERCIAL EQUIVALENT CIRCUIT |
|---|---|---|---|
| MC Preamp | | | |
| Input CF'S | 2-5654/6AK5W | 2-6AK5 | C |
| Input Amp. | 4-12AU6 | 4-12AU6 | C |
| Output Amp. | 4-6AU6WA | 4-6AU6 | C |
| Output C.F. | 12AT7WA | 12AT7 | C |
| Switching Multi | 12AT7WA | 12AT7 | C |
| Trigger Coupling Diode | 5726/6AL5W | 6AL5 | C |
| Amplifiers | 12AT7WA | 12AT7 | C |
| Switching C.F. | 12AT7WA | 12AT7 | C |
| Vertical Amplifier | | | |
| Input Amp. | 12BY7 | 12BY7A | 545 |
| Driver | 6922 | 6DJ8 | 545 |
| Distributed Amp. | 6DK6 | 6DK6 | 545 |
| Trigger Pickoff Amp. | 6DK6 | 6DK6 | |
| Position Indicator Amp. | 5814A | 12AU7 | 545 |
| Trigger Pickoff C.F. | 1/2 6922 | 1/2 6DJ8 | 545 |
| Vertical Sig. Out C.F. | 1/2 6922 | 1/2 6DJ8 | 545 |
| CRT | | | |
| CRT | T945P2 (Special T543) | T543 | 545A |
| Main Sweep | | | |
| Main Sweep Trigger Input Amp. | 6922 | 6DJ8 | 545 |
| Trigger Multi. | 6922 | 6DJ8 | 545A |
| Sweep Gating Multi | 6922 | 6DJ8 | 545A |
| | 12BY7 | 12BY7 | 545A |
| Disconnect Diodes | 5726/6AL5W | 6AL5 | 545 |
| Miller Run-up | 6AU6WA | 6CL6 | 533 |
| Sweep Gen. C. F. | 6922 | 6DJ8 | 545 |
| Hold off | 6922 | 6DJ8 | 545 |
| Lockout Multi | 1/2 6922 | 1/2 6DJ8 | 545A |
| | 6AU6WA | 6AU6 | 545A |
| Delayed Trigger Amp. | 6AU6WA | 6AU6 | 545A |
| Catching Diode | 1N281 | T12G | 545A |
| Multi Trace Sync Amp. | 1/2 6922 | 6DJ8 | 545A |
| Unblanking Mixer | 6922 | 6DJ8 | 545 |
| + Gate Main Sweep | 1/2 6922 | 1/2 6DJ8 | 545 |
| Sawtooth Out | 1/2 6922 | 1/2 6DJ8 | 545 |

| CIRCUITS | 945 TUBE or SEMICONDUCTOR | COMMERCIAL TUBE OR SEMICONDUCTOR | NEAREST COMMERCIAL EQUIVALENT CIRCUIT |
|---|---|---|---|
| Delaying Sweep | | | |
| Trigger Amp. | 5814A | 12AU7 | 545 |
| | 6922 | 6DJ8 | 545 |
| Trigger Multi | 6922 | 6DJ8 | 545 |
| Stability | 1/2 6922 | 6DJ8 | 545A |
| Sweep Gating Multi | 6922 | 6DJ8 | 545A |
| | 6AU6WA | 6AU6 | 545A |
| Disconnect Diodes | 5751 (Diode Conn) | 12AL5 | 545 |
| Miller Run-up | 12AU6 | 12AU6 | 545 |
| Sweep Gain | 1/2 6922 | 1/2 6DJ8 | 545 |
| Hold Off | 6922 | 6DJ8 | 545 |
| + Gate Out | 1/2 6922 | 1/2 6DJ8 | 545 |
| Delay Pick Off | | | |
| Pickoff Comparator | 6AU6WA | 6AU6 | 545A |
| | 6AU6WA | 6AU6 | 545A |
| Constant Current Tube | 1/2 6922 | 1/2 6DJ8 | 545A |
| Delay Trig. Multi | 6922 | 6DJ8 | 545A |
| Delay Pick Off C. F. | 1/2 6922 | 1/2 6DJ8 | 545 |
| Horizontal/Sweep Amp. | | | |
| Input C.F. | 1/2 6922 | 1/2 6DJ8 | 545 |
| Driver C.F. | 1/2 6922 | 1/2 6DJ8 | 545 |
| Output Amplifier | 6922 | 1/2 6DJ8 | 545 |
| Output C.F. | 6922 | 6DJ8 | 545 |
| HF Current Booster | 6CL6 | 6CL6 | 545 |
| Calibrator | | | |
| Cal Multi | 1/2 5814A | 1/2 12AU7 | 545 |
| | 6AU6WA | 6AU6 | 545 |
| Cal Out C.F. | 1/2 5814 | 1/2 12AU7 | 545 |
| Low Voltage Power Supply | | | |
| Rectifiers | 17-1N2862 | 16-1N2862 & others | 545A |
| -150 Reg. | 1/2 6080WA | 3-12B4's | 545 |
| | 6AU6WA | 6AU6 | 545 |
| | 5751 | 12AX7 | 545 |
| | 5651WA | 5651 | 545 |
| +100 Reg. | 1/2 6080WA | 1/2 6080 | 545 |
| | 6AU6WA | 6AU6 | 545 |
| +225 Reg. | 1/2 6080WA | 1/2 6080 | 545 |
| | 6AU6WA | 6AU6 | 545 |
| +350 Reg. | 6080WA | 6080 | 545 |
| | 6AU6WA | 6AU6 | 545 |
| +500 Reg. | 1/2 6080WA | 12B4 | 545 |
| | 6AU6WA | 6AU6 | 545 |

| CIRCUITS | 945 TUBE or SEMICONDUCTOR | COMMERCIAL TUBE OR SEMICONDUCTOR | NEAREST COMMERCIAL EQUIVALENT CIRCUIT |
|---|---|---|---|
| HV Power Supply | | | |
| H.V. OSC | 6L6WGB | 6AU5 | 545 |
| Shunt Reg. | 1/2 5814A | 1/2 12AU7 | 545 |
| DC Comparitor | 1/2 5814A | 1/2 12AU7 | 555 |
| Rectifiers | 5-5642 | 5-5642 | 555 |
| Heater Regulator | | | |
| Rectifiers | 2-1N1124 | Selenium | |
| Series Element | 4-2N277A | 1-2N277 | 585 |
| Feed Back Amp. | 2N1042A | 2N301 | 585 |
| | 2N1302A | 2N1302 | 585 |
| Protective Diode | 1N281 | T12G | 585 |
| Disconnect Diode | 1N281 | | |
| Protective Diode | 1N3027B (Zener) | | |
| Fan Drive | | | |
| Rectifiers | 2-1N1124 | No Equivalent | |
| Multi. | 2-2N1375A | " " | |
| Driver | 2-2N297A | " " | |

The only tube types that don't appear in Mil Specs are: 6DK6, 5642 and T945P2. The 5642 comes with the HV power supply and is no provisioning problem since the supply is a replaceable component. There is no mil equivalent and the services recognize that it is a Tektronix special.

The T945P2 is essentially a T543P2 with a tin oxide coated face plate and a mica filled phenolic base. The tube is sample tested to a 10 G vibration spec, which the T543P design meets. Even the tin oxide was omitted at one time by using a shielding graticule; however, this wasn't as practical as the final answer.

It is hoped that sufficient use of the 6DK6 can be shown within the military to obtain type approval. We should be able to promote the control of the parameters that are critical to our circuitry.

The armed services along with our other customers, dislike stocking checked tubes. The 12BY7 is still checked for grid bias to save juggling raw stock. Otherwise, the Type 945 is tubed with non-checked tubes.

The 1N2862 is not mil spec because of the 20-25 amp surge current rating needed in some of the power circuits. This is a good candidate for a future family of medium current high surge rectifiers for the military. The 2N277 has no mil equivalent. The 2N1375 is a low frequency medium performance transistor. Anything close to its rating in mil specs is a high frequency high cost unit. It was decided this was a logical way to go. Both the 2N1042 and 2N1302 are destined for mil type approval. The 1N281 is a mil type signal diode. The Zener diode type 1N3027B is 20 volts, 1 watt and is mil approved.

The rapidly changing semiconductor field has given the armed services a real standardizing problem. There seems to be a tendancy to go along with specials if justification can be demonstrated.

## CIRCUIT CONSIDERATIONS

The "MC" preamplifier is essentially the same as the "C" circuitwise. The chopped mode blanking refinement was not incorporated because of the additional CRT cathode switching function that would be needed on an already crowded scope front panel. The CRT cathode bypass grounding is accomplished with a shorting BNC cap.

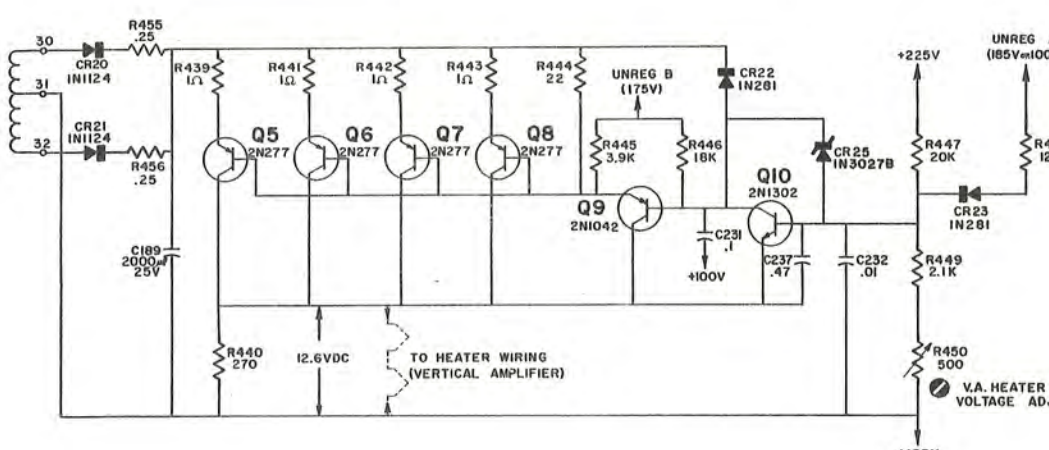
The original intent was to leave the "C" chassis layout untouched in critical signal areas. It was hoped in this way a minimum of bugs would be designed in. The ceramic turret was removed for vibration reasons, otherwise, only minor shifting was necessary. As a result, the MC performs electrically as the "C".

The vertical amplifier was approached with much the same philosophy. In spite of the various 6DK6 problems they are still the most reasonable choice. The 12BY7's are mil spec. An attempt was made to provide circuit balancing for this stage to conform with the desires of the military. No practical solution was found so they still remain as checked tubes (grid bias for fixed circuit conditions).

About 2mc of bandwidth was lost in the militarizing transition. As might be expected, a lot of experimentation was done to pinpoint the cause. The only real concrete answer was found in the delay line. First models were made with the housing spacing 0.1 inch greater than the commercial. Restoring this dimension brought back 1/2 mc. Going a 0.1 inch narrower improved the response another 1/2 mc. This left the typical response at 31mc which is certainly acceptable.

Two axial lead 1/10 amp fuses were added between the plate lines and delay line to protect the amplifier from shorts to ground at the CRT connections or in the delay line. In addition, heat shrinkable polyolefin tubing is applied to the connectors for insulation. The fuses apparently improved the typical bandwidth about 1/2mc without deteriorating the transient response.

A serious problem with the V. A. was change of gain with line voltage. Values as high as ±7% were recorded on some tests. These measurements are made at high and low line with nominal line volts as reference. Heater regulation was indicated. This was accomplished by a D. C. transistor regulator circuit similar to that used in the 585. The 6DK6's are paired in series so that 12 volts at 3 amps instead of 6 volts at 6 amps could be utilized,making the rectifier and regulation situation more practical.




Heater Regulator Schematic

The circuit is straight forward except for a few protective devices during turn on. The Zener diode saves the 2N1302 from occassional burnout if the +100 bounces just right when a plug-in is removed. Four 2N277 looks pretty husky to regulate a mere 35-40 watts until the maximum scope operating temperature of 71°C is considered. These transistors are mounted on the vertical bulkhead with anodized aluminum washer insulators. They perform comfortably at the elevated ambient.

The gain change with line voltage is reduced to ±1%. The remaining change is caused by the 6AU6 AC heaters in the MC preamp. An attempt at regulating these was made. Compatibility of plug-ins meant that regulation must occur within the preamp. A small 6 to 12 volt step-up transformer with two Amperite thermal regulators was tried. Gain change was reduced to less than ± 1/2% at the expense of 15 watts additional heat, a vibration mounting problem and some more dollars. All in all this was judged a poor trade-off. The AC heaters remain unregulated and the scope regulation specs reflect it.

A very decent bonus is realized from regulating the main V.A. heaters---longer interface life. High heater volts accelerate interface. Low volts show it up earlier. The ideal is to hold rated heater volts for optimum life. Scope life testing so far has proven this out.

Heater regulation effect in the sweep timing was also investigated. About ± 1/2% was found in the horizontal amplifier. To regulate this circuit would require a completely separate regulator from the V.A. because of a different DC elevation. It was decided to live with this amount and call it out in the regulation specs.

The main sweep is composed of 545A innovations mostly. Eliminating the 6U8 type is generally the reason for this. A 6AU6WA is employed for the Miller run-up because of its military preference over the 6CL6. It is operated without shield to get better cooling. No adverse stray pick-up has been detected.

Juggling of the sweep layout was done for several reasons; however, critical areas were changed with caution especially in the sweep generator region. An attempt was made to uncover tube sockets for better accessibility. 1/4 watt parasitic resistors were used to help unclutter the layout. This is a simple worthwhile move.

The sweep amplifier also was rearranged somewhat. The 545 circuit was held throughout. Shielding was found necessary to isolate the interference signal from the high voltage oscillator. A very small one (1.2" x 1.7") did the trick.

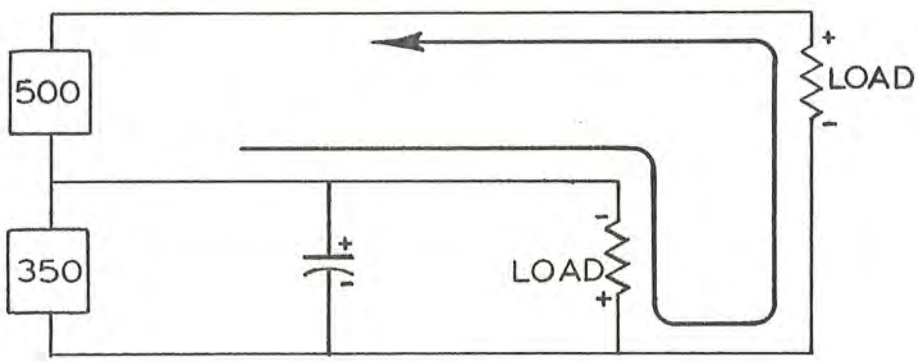
Speaking of interference, one of the sources of power line conducted interference was the capacitive coupling of the sweep amp current booster to the thermal cutout leads. Almost perfect shielding was attained by mounting the thermal cutout on the other side of the bulkhead and routing the leads in a twisted pair on that side.

The Delaying Sweep is almost all 545 circuitry except for eliminating the 6U8. A 5751 (12AX7) is used diode connected to replace the 12AL5. A delay sweep length adjust pot has been added to eliminate hand picking resistors. This was necessary for military requirements. Slightly more precision components are required as well as realistic performance specification, 4cm ± 0.5cm to 10cm -0 +1cm. This chassis was also relayed-out to try to promote better accessibility.

The 545A delay pick-off circuit is unquestionably a more dependable configuration. It was used with no changes except the CF output detail. Here again the 6U8's are eliminated.

The voltage calibrator circuit is the familiar triode pentode triode line up. It is completely 545 except the accuracy specification which has been tightened up to ±2%. This is based on the results of environmental testing and a calibration system that can be referenced to a secondary voltage standard. Ceramic to metal hermetically sealed carbon film resistors are used to provide the desired stability. The Exact Model 105 is rated at ± 3/4% but more important it has a chopper mixing circuit that allows direct comparison with a DC voltage that is monitored by a secondary voltage device such as the Fluke Digital Voltmeter. Variations of less than ±0.5% are typical for high-low limits of line voltage.

Low voltage power supplies are fairly conventional. The elimination of 12B4's and the wider regulation requirements have changed some circuit values. The "A" model bridge/fullwave circuit is used to eliminate a set of rectifiers. A protective catching diode was found necessary across a set of electrolytic in the +350 supply. After scope turn-off there is a tendency for the +350 to go negative as a result of load distribution with the 500 volt supply. The high reliability computer grade electrolytic is not designed for as high a reverse voltage as the TVL variety; hence, the protection here and not the commercial.




Current Flow at Sometime After Turn-off

Some innovations were necessary to "start" the transistor circuits properly. These are associated with the +100 unregulated relay switching. The shunt power resistors were located on the bottom rail where the dissipated heat will have little effect on other components.

One watt ceramic-metal hermetically sealed carbon film resistors have proven very satisfactory for voltage stability. 6080 triode sections have been paired off so that a section that is working near or slightly over rated power is in the same envelope with a low dissipation section. Maximum bulb temperatures recorded in heat runs have not exceeded 100° rise.

Trading the 6AU5 for a 6L6WGB high voltage oscillator was precipitated by mil specs. The 6L6 is really loafing and should rarely cause trouble. The transformer, rectifier, filter, focus and intensity portions of the high voltage supply and CRT circuit are all squeezed into one container that is potted with a flexible silicone resin. This move helps reduce space and allows the critical high voltage circuits to function after humidity exposure and at 20,000 ft. altitude.

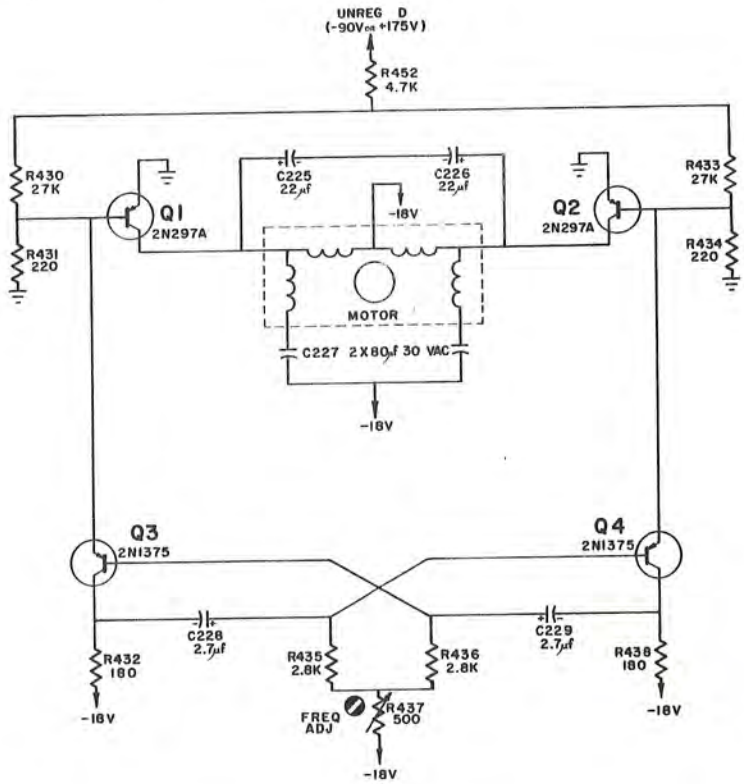
Standard ceramic capacitor values have altered the circuit constants in some cases. The unblanking time constant was changed to 0.02µF and 33K instead of the typical 0.015 and 100K. The 8.6KV has an additional filtering section to reduce the ripple that must be shielded from radiating out the front end of the CRT. Ripple of less than 1 volt is attained. In analyzing the intensity modulation of the early supply, it was realized that it was sinewave and not sawtooth. This indicates coupling from the AC secondary rather than inadequate filtering in the case of the -1350 and -1450 sections. It was finally necessary to do some lead rerouting and place the CRT grid and cathode coupling components in a separate shielded compartment within the supply package. Ripple was reduced to the 20mv region and almost equal in amplitude and in phase on the cathode and grid. Leads are brought out from the unit so that it can be easily replaced. A multiple HV connector was considered but eliminated quickly. The added cost and reliability complications make this approach undesirable. Average life of the supply should be great enough that the replacement effort is negligible in comparison.

Corona from minute air voids have plagued us for a long time. This can be observed by capacitive coupling with a scope directly on the 8.6KV lead. This corona has not impaired the scopes performance nor has it contributed to short life of the supply. However, academically it is realized that sooner or later the resin will be deteriorated and breakdown will occur. The corona isn't evident without potting resin or is it present when potted in oil. It has been concluded that the problem is strictly a physical one of removing entrapped air through a viscous media approximately 800cps. If further work proves that the method is impractical, transformer oil and silica sand in a solder sealed container will be used. The main drawback to this scheme is the messy production problems. At this time the final solution has not been determined.

High Voltage Power Supply

The fan motor drive circuit is new. The final form evolved after a great deal of deliberation. The most direct approach would be to use a transformer to couple the generator to the motor and use a feed-back winding. Only two transistors would be necessary and possibly a stock motor. The transformer was discounted for two main reasons: Cost of a MIL-T-27A transformer and the concentrated mass. The 100 cps frequency was chosen as a compromise between shaft speed and frame size. Temperature variations cause some speed changes. At 71°C,RPM drops from 2400 to 2300. Two Sensistors practically eliminated the problem at $4 each. This was judged a poor bargain.

The base circuit of the power transistors is returned to a point in the low voltage supply that provides approximately -90 volts initially then +175 after the thermal time delay period. The positive voltage assures collector cutoff at high temperatures. The $I_{CO}$ will otherwise tend to bias the base in a negative direction and slow-down the motor. At low temperatures, the positive bias in conjunction with the low $I_{CO}$ creates essentially a high emitter impedance for the multivibrator transistors. The result is excessive degeneration and a tendency towards not starting. The -90 volts at turn-on, eliminates this problem.




Fan Drive Circuit Diagram

The overheat warning light provides an operator some time to make readings without having things shut down completely. It functions at an ambient of 58°C or the equivalent in a dirty air filter. The circuit is arranged to provide a check on the warning light when the scope is energized and a convenient means of telling when the delay time is up and things are ready to operate. The different color and bulb shape was done intentionally to attract more attention when the warning goes off.

Incidentally, a 12.6V pilot lamp is used on 6.3 volts for power-on indication to give a dimmer light that is completely adequate and in addition very long life.

## "PASSIVE" COMPONENTS

The circuit design was not influenced appreciably by the "passive" components. Most of these parts were chosen with the following main parameters as guides: Function, reliability, mil standards, and cost. Other factors, of course, entered into each choice.

### Capacitors

Paper tubular capacitors used in the Type 945 are the glass to metal hermetically sealed type with oil or similar impregnant. The 125°C rating provides an added life factor since maximum air temperature within the scope with a 71°C ambient is about 85°C. Size factors are equal to or a little better than the commercial equivalent. Extended foil was used in almost every case except where space is very critical. The metal case has a vinyl sleeve to prevent shorting. This is deleted where "hook" might be a problem. The metal case offers some additional advantages for vibration-proof mounting. Both integral clamp and a screw neck mounting are obtainable. Most of the units are satisfactorily supported in a conventional manner by their leads. This type of capacitor is a military standard and is very reliable. They cost considerably more than a commercial capacitor; however, our experience so far indicates that random capacitor failure or serious deterioration with life is reduced appreciably.

The fixed ceramic capacitors are made up of the two types: Tubular and disk. Both of these are found in the mil specs. The military have standardized on the phenolic coated tubulars to provide a little more moisture and physical protection. These have been used in all but critical signal circuits where "hook effect" might be a problem. In these spots the uninsulated variety has proven satisfactory.

Mil standard general purpose disk ceramics fit the need in all cases except one value. The Mil units are generally a little larger in diameter but no difficulty occurred from squeezing them in. Short leads is the watch-word on these units because of the unsymmetrical mounting and the resulting low mechanical resonant frequency. An 0.01 600v will be resonant around 75 to 100 cycles with reasonable lead lengths.

Disk ceramics were used in the high voltage power supply to conserve space. These are good reliable capacitors but not mil standard. The supply potting material provides good mechanical support for the large capacitors. The HV unit is a replaceable non-repairable module so non-military standard parts are completely acceptable. The services will provision the entire power supply instead of components.

It is often asked if the military will accept the aluminum electrolytic. The services for a number of years have had specs covering aluminum electrolytics and recognize if they are used within limitations they are a satisfactory component. The Type 945 uses the computer grade of electrolytic that has high purity foil. This assures a longer shelf and service life. Presently the mil specs don't cover this better grade capacitor but it is only a matter of time. Vibration tests have verified that the screw neck mounting is superior to the clamp. The former is limited to two sections because of the small header. The Type 945 does use one clamp type to obtain a triple section for space reasons. Mil Standard values and ratings have been followed. Also space has been allowed to insert the taller mil standard type in the field. All electrically elevated capacitors have a polyethelene boot to prevent electrical shock. These are non-standard but can be re-installed on a replacement capacitor.

An A.C. aluminum electrolytic is used in the fan drive system on the phase shift windings of the motor. This is a special type of application. There is no excessive heat rise and there have been no catastrophic failures to date.

Temperature extremes are a problem with aluminum electrolytics. At high temperature the electrolytic will tend to boil and the capacitor deteriorates rapidly. At low temperatures the electrolyte "slushes up" and capacitance drops off. Usually ripple is the first indication of this occurance. The computer grade capacitor made by Sprague has a rating of -20C to 85°C. The Type 945 operates at -40°C with an average temperature rise of 10°C to 15°C. Even though slightly out of rating there is no malfunction of the instrument. Exceeding the spec in this manner does not accelerate failure.

Tantalum electrolytics are being used widely in military systems because of size and reliability. There are limitations to using tantalum as a general solution. Ratings above 50 volts are not readily available. Fall off of capacitance with frequency is another problem. The industry is still in a state of flux about standard designs. There are mil specs covering tantalums, so certain types are acceptable. It still boils down to using the right part for the application. We are using five in the Type 945: Two as coupling/timing units in the transistor MV for the fan drive, two are back to back across the motor for transient suppression and one in the heater regulator for response limiting. The multivibrator units were chosen for size and capacitance stability with time and temperature. These 2.7 µF 20 volts units are compatible with the transistor circuit. There was a need for about 10µF to suppress spikes on the square wave driving the motor. Two tantalums 22µF 35 volts back to back solved the electrical and space problem. Originally a 20 volts rating was used; however, the temperature rise was excessive because of reverse current. By changing to 35 volt units, the problem was eliminated. The 0.47µF, 35 volt capacitor was chosen principally for small size. All units are the solid electrolytic anodized tantalum coil type, (Sprague 150D) and are slated for mil approval soon.

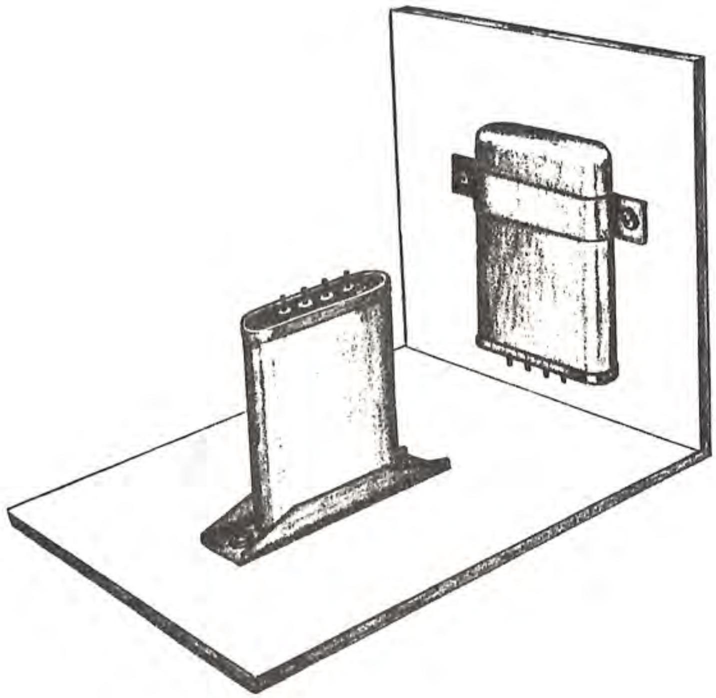
Three types of variable capacitors are used in the Type 945/MC: Ceramic disc, Polystyrene tubular and mica compression. The ceramic type is the mil style CV which is all ceramic construction. In two places: The VA termination and the horizontal input attenuator, the CV type replaced the commercial phenolic ceramic construction (Erie 577). In both cases because of higher mass, it was necessary to provide ridged support. The CV style is a dependable component. About the only problem is an adequate mounting without cracking the ceramic. Nylon cushioning washers between the ceramic and chassis have been used with negligible shrink or cold flow. A good locking device, of course, is necessary.

The polystyrene tubular caps have no exact mil equivalent. There are some glass piston trimmers of approximately the same size; however, they don't lend themselves to the design -- besides they are very expensive. The copolymerized styrene of the Erie Style 535 easily meets the environmental requirements. The screw is gold plated to prevent poor contact and electrical loss after humidity. The method of mounting by press fit in a sized hole has proven satisfactory under vibration. The component meets all of the needs of the instrument spec and is therefor an acceptable item.

The mica compression trimmer meets the electrical need of wide variation in capacitance. Any other Mil Std capacitor or system of capacitors would be costly and large. By getting the vendor to supply a mil plating system, the unit will survive the instrument humidity test (MS 170, 10 days) with no adverse effect on the circuit. This again seems to be the better choice even though it's non-mil spec.

Only a few mica caps are used in the scope and preamp. These meet MIL-C-5 and are in the amplitude calibrator, and sweep timing circuits.

The Tek made timing capacitors have proven satisfactory. The only changes necessary have been made on the mounting and finish. Hot tin dipped clamp and bracket is soldered to a hot tin dipped can. This satisfies the vibration requirements and 100 hours salt spray test. No painting is necessary. The tubular units are the metal glass hermetically sealed style.



Timing Capacitor Mounting

The temperature coefficient is positive while that of the timing resistors is negative. Neither is particularly linear but they fortunately match well enough to provide an overall sweep timing change with temperature that is very minimal. Delay time is rated at ±1% -20°C to 55°C and 3% -40°C to 71°C. Main sweep and delaying sweep timing is ±3% -20°C to 55°C and 5% -40°C to 71°C. These wider timing specs reflect the degradation caused by sweep amplifier and CRT circuitry.

Resistors

Resistors in general are covered by a variety of mil specifications. Most of these we use to some degree. Like so many of the component applications one or two vendors can supply the only "mil part" that is usable even though many more appear on the Qualified Products List (QPL). Here is one of the great fallacies of the whole scheme of things and probably why the Government often will come back to Tektronix for a ten cent item. Theoretically, for any application if a "mil spec" part is used, any qualified product should work in the circuit. The catch comes when an uncontrolled characteristic is involved--hook effect in carbon film resistors for instance. If one designed 100% towards this idea, many components would become specials or the circuit performance would be degraded to accept the lowest indicated performance level of the component specification. Obviously, neither direction is good so each case is evaluated with the stocking requirements in mind and a decision made accordingly with crossed fingers and the hope that the military won't get too fouled up. All purchased components are called out on individual outline drawings with original vendor indicated. This way a record of initial Tek QPL is retained.

The Allen-Bradley composition resistor is mil approved as are a number of other vendors. The Type 945 uses the 1/4 w and 1/10 w sizes even though they didn't appear in a mil spec initially. By this time the spec may be changed. These resistors 1/10 through 2 w are satisfactory as used in the commercial scopes. The only problem has been one of a corrosion product that develops on the leads after severe moisture exposure (humidity-fungus tests). The part is still functional. It merely looks poor. Since it does meet the resistor spec (MIL-R-11A) there is little we can do with A-B to improve this trouble.

The precision carbon film resistors contribute greatly to the accuracy of the scope. Moisture is the worst enemy of this component. Choosing a satisfactory unit was mostly choosing the best compromise on case style provided the basic resistor was acceptable in our application. The molded unit is mil spec and should give better physical and moisture protection than the painted type. It, of course, would be impractical in most signal circuits because of hook. A series of humidity tests were made on 50 samples of each style: Painted, molded and ceramic hermetically sealed. The molded resistors showed about 25% less change than the painted type which was 0.4% average. The ceramic hermetically sealed units were almost an order of magnitude better. Average change was about 0.05%. It was obvious that the ceramic hermetically sealed resistor is the best choice for this application in spite of the higher cost, (about 50 cents). In addition the ceramic is hook free enough to work satisfactorily in signal circuits. 1/4 watt units were used to replace the 1/2 watt ones in the MC attenuator. This appears to be a more reliable choice. The trade off was between an unprotected larger body resistor and a smaller body well protected. In the past, a good metal to ceramic seal on resistors has been very difficult to come by, mostly because of the difficulty in developing a good non-destructive test. A few vendors do have a very good level of quality either by large sample testing or more meaningful tests. Texas Instruments and Sprague are currently acceptable.

The Type 945 also uses some tin oxide-glass power resistors. These have been employed to replace wire wound units that have too small a wire for good reliability. The mil spec (MIL-R-11804C) was used as a guide for the cross-over point. The tin oxide unit is a mil spec resistor and is used in the axial lead and tab form. These resistors in the lower values are very stable under the most severe temperature and moisture environment.

The fixed power wire wound resistors are similar to the commercial applications; however, size factors, wattage ratings and wire sizes are more conservative. In general, by following MIL-R-26, dependable component application results. In a few instances multiple layer axial lead units as manufactured by Sprague were used to keep above the minimum wire size. The only troubles encountered with mil standard wire wound resistors have been finding space for the slightly larger parts and devising vibration proof mounting. There is no mil spec resistor that is equivalent to the Tek made low inductance precision wire wound. No provisioning problem arises from the use of this component. It is clearly a special to be supplied by Tektronix.

In the area of variable composition resistors, the A-B controls are considered to be among the best. They meet mil specs and have certainly proved reliable in our commercial scopes. The coaxial styles with and without switches are not readily obtainable from A-B so we have gone to Chicago Telephone pots that meet MIL-R-94 in basic construction. The Clarostat composition pot similar to A-B apparently has an opposite or at least widely different temperature coefficient. This has proven to be a trap in at least one instance where it was used in a HV divider string of A-B fixed composition resistors. All screw driver shaft pots are furnished with locking nuts to prevent shift of adjustment from vibration and shock. Mil Standard shaft and bushing lengths have been adopted. For a 0.25" panel shaft this is 0.875" shaft, 0.375 bushing as measured from the pot body.

The 0.5 watt miniature "G" control is a mil type that is used in a number of places for space considerations. This again is a reliable component when properly applied.

A few 5 watt wire wound pots are employed in the same circuits as the 545, -150, scale illumination and gain adjust on the MC. These are readily available as mil spec units. Two miniature mil type wire wound controls (1 watt) are used in the delay pick-off in conjunction with the 10 turn pot. These are used for stability and to save space. Clarostat is the vendor.

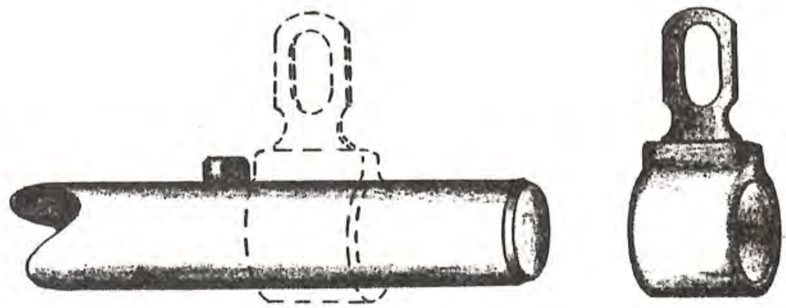
The multi-turn pot in the delay pick-off circuit exceeds MIL-R-12934A. The unit typically used doesn't have adequate wattage rating at 85°C. Helipot supplies a control with a higher temperature case and non-nutrient label. Spectrol also has a suitable control (and non-nutrient labels). The Helipot dial is still used but the knob section is replaced with one which matches the mil style of the rest of the scope.

Tektronix gain pots have been a serious reliability problem over the years. The present design has proven to be completely satisfactory in all of the environments. There is no equivalent mil spec so it is a special that meets the general requirements of MIL-T-945A.

## Inductors

There are five types of fixed coils used in the Type 945/MC: Peaking coils on 1/2 w resistor form, lumped transmission line, universal wound RF choke pi wound choke and resistive plate load, all are Tek made and need to meet the requirements of MIL-T-945A and the intent of the RF coil spec MIL-C-15305. Humidity and temperature are the most serious environmental problems. We have determined that wire coated with heavy polyurethane provides adequate corrosion protection and doesn't absorb enough moisture to significantly deteriorate the Q. Several varnishes were tried. Insul-X, and acrilic lacquer, has proven satisfactory when applied in a thin layer. The 8μhy, 2K trigger pick-off plate load resistor is coated with a silicon varnish No. A100 made by Melpar. Physical as well as moisture protection was desired in this case. Also a higher temperature capability was indicated.

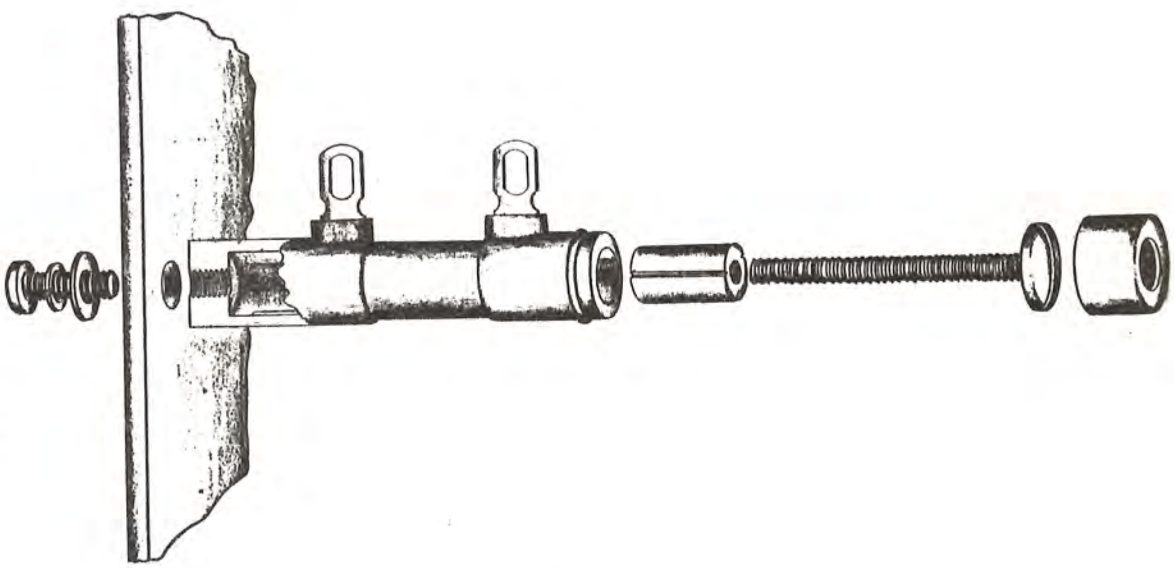
The grid, plate and delay lines are wound on a high temperature styrene, Cymac 400. This is the only material found so far that is suitable for the electrical and thermal characteristics. Thermoset plastic terminals have been added to each end of the lines to alleviate the soldering troubles that are present with the typical pressed-in pin. This is not only our idea but is directed by the RF coil spec where it calls out solderability of terminals. It doesn't cost much and is quite satisfactory.



Delay Line Termination Sleeve

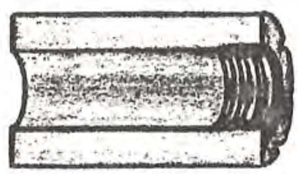
It is interesting to note that by following standard mil nomenclature any tapped coil is an RF transformer and carries a T instead of an L designation.

The variable peaking coils that we typically use in commercial instruments have been given a fairly complete face lifting. The design used in the Type 945 has evolved as a result of three problem areas: Thermoplastic body which melts during soldering; moisture absorption which changes Q and effective inductance (self-resonant frequency); and core breakage. The resulting design evolved after much effort in choosing compatible materials that withstand the environments.



Variable Coil Form

The diallphalate body has a moisture absorption in the order of 0.1% as compared to Delrin around 1%. It has good electrical characteristics and it lends itself to reasonable molding techniques. The screw is made of Delrin for a tough slippery part to work against the epoxy in the powdered iron core. Here water absorption is of little consideration. The snap-cap is made of post-cured polypropylene. It was chosen to work against the Delrin screw and be rigid enough for the snapping operation. The terminals are patterned after tube socket connectors. The necked down section provides thermal resistance. Gold plate gives good solderability. The splined and internally threaded powdered iron core is still a problem. The splines are easy but the 2-56 thread isn't. There are a number of directions being pursued. The most successful to date is a thread formed by a drop of epoxy on a metal mandrel.



Threaded Coil Core

Satisfactory vibration mounting is obtained by the conventional manner, i.e. directly to the chassis or to a tube socket with a nylon screw.

Transformers

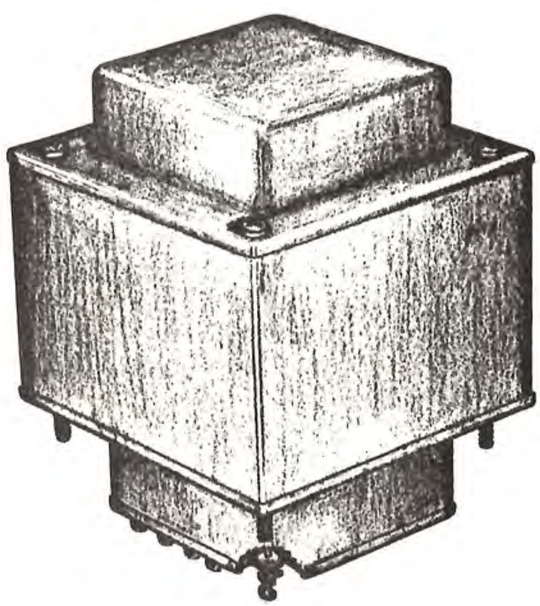
The low voltage power transformer is designed to meet MIL-R-27A. Here is one area where there exists an applicable specification for a Tektronix made part. The military has had a lot of experience with transformers and will not budge. The transformer must meet the requirements of MIL-T-27A even though the shape will be non-standard. The more or less conventional approach of epoxy encapsulation was tried first. After trying to solve some of the air leaks it was decided to see how other people meet the tests. Passing the test depends on the interpretation of results. Also, high production reject rate seems to be a continuing problem with this design.

It was decided to make a completely hermetically sealed unit, about which there would be little need for interpretation of results. The design is one of formed metal parts that conform to the shape of the transformer and are solder sealed. In this manner weight is reduced and better cooling is obtained at the added expense in metal parts. Glass to metal hermetic terminals are used to bring out the connections. These require enough tracking distance to withstand the over-voltage tests and prevent low insulation resistence after humidity.

By the way, the humidity test is performed with a polarizing voltage from terminal to case. This promotes electrolysis. A very rusty looking deposit forms but as long as IR is greater than 10,000 megohms the unit is o.k. The transformer is mounted in the normal position (terminals down). Condensed water, that forms during the temperature up swing (RH 95% constant), runs down and collects on the terminals. By forming a drip bead in the cap there is less water collected on the terminals and it passes.

The transformer is filled with a special epoxy compounded for this type of application. It has good electrical characteristics and is a reasonable thermal conductor, with minimum shrink, especially the filled varieties. There are two major hurdles to overcome with a potting system: Complete impregnation of the smallest void and good adherence to the glass of the terminal to prevent minute air voids. Proper impregnation is attained by good technique and equipment. Careful control of temperature and vacuum-pressure cycling are required. The epoxy is deaerated before pouring. The entire operation is performed in a vacuum tank. Dispelling all of the air is a physical thing. The longer the path the bubbles have to travel and the more viscous the filling material the more difficult it is to obtain 100% impregnation. The unfilled epoxies give best impregnation but promote more shrinkage and are poorer thermal conductors.

Shrinkage is the key to minute air spaces under terminals where corona is aggravated. Absolute intimate contact is required. The Type 945 transformer design solves this by having a very thin shell that can flex from shrinkage pressures. In addition, each hole for a hermetic terminal has a rolled edge that in effect is under cut. This section provides a very positive "tooth" for the surrounding plastic and prevents it from pulling away from the terminal. It has also been found that Isonel 31, a polyester varnish, applied to the glass and cured before potting greatly improves the adhesion of the epoxy.



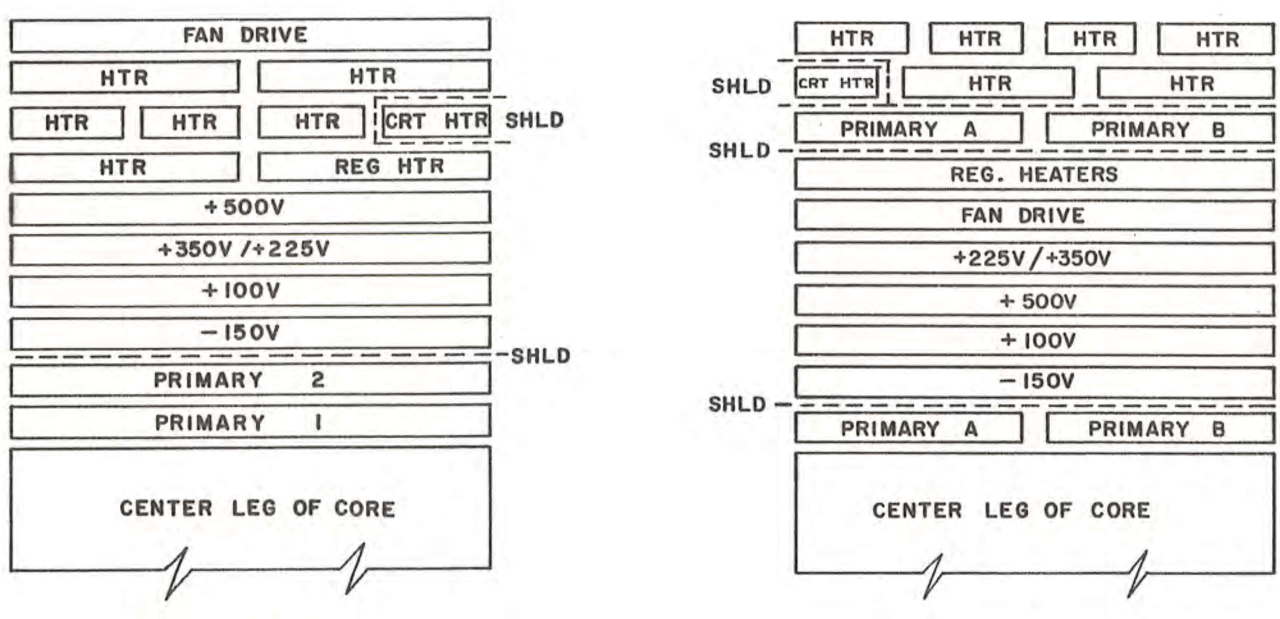
Type 945 Transformer Encasement

MIL-T-27A indicates that temperature rise tests are made with the actual load and the transformer sitting in free air, cooled by natural convection. Under these conditions, the transformer has a copper rise of 52°C average and a surface temperature of 40°C. With a maximum hot spot rating of 105°C for class A insulation, only a 50° ambient (scope internal air temperature) could be tolerated. However, the picture is much brighter when the transformer is in the scope. The copper temperature dropped to a 30° average rise and the surface temperature rise was found to be 15°C. The scopes cooling system contributes substantially to the cooling of the transformer. The temperature of the air cooling the transformer has a rise of approximately 5°C over external room ambient. This means the transformer can operate continuously in the scope with a room temperature of (105 -(30 + 5) ) = 65°C. Continuous operation for the scope is rated at 55°C, short periods (1 hour) 71°C.

The requirement of MIL-T-27A of testing for heat rise in still air is not valid for the application. This is a special transformer for a particular load and cooling situation. Therefore, a waiver on method is indicated in order to meet MIL-T-27A.

The qualification tests are performed at Tektronix with the surveillance of a government Quality Assurance Representative.

The variable line frequency requirement is 50 ±10% to 400 ±10%cps with voltage range at 115v ±10% (103.4 to 126.5v). It was found that heater voltages change as much as 3.5% from low to high frequency and DC voltages vary 10%. With the slightly greater voltage range than we call out on commercial equipment, and the frequency effect combined, almost twice as much power capabilities are called for on the part of the series regulators. This seemed to be a rather poor bargain. The transformer deficiences were investigated to see what could be done. Leakage reactance was the answer. This isn't really a true reactance but does exhibit some of the characteristics, so for want of a better name--that's it. No matter what the name, the phenomenon is a result of incomplete coupling between primary and secondaries because of winding location and geometry. To make a long story shortened, the primary is split into two sections that surround the secondaries feeding the DC supplies.




Conventional 945

Winding Methods

This method reduced the frequency effect on the heaters from 3.5% to 0% and that of the "DC winding" from 10% to 1-2%. The stack height went up 8% to reduce copper a little to accommodate the different configuration. The Type 945 transformer has incorporated this design.

The high voltage transformer hasn't been given all the treatment the power unit has received nor does it require it. The HV transformer is encapsulated in the supply to reduce environmental effect. Since the supply is an expendable module that meets the instrument requirements, the military is not concerned with the transformer or any of the parts meeting individual component specs. Somebody always says about here, "Why not encapsulate the whole scope--do away with the specs entirely?" -- believe me, we've been tempted more than once.

## Motor

The motor is one of the more expensive components in the instrument. It ranks with the transformer and CRT for cost. At first consideration it seems ridiculous to pay about 10 times the price for the commercial counterpart. Power frequency, environment and reliability all played important parts in arriving at this motor.

Available motors that can operate from 50 to 400cps are not capable of 0.01 horsepower at reasonable speeds. Or if they are, a switching operation is necessary. This calls for a relay. The specs don't allow manual switching for change in power frequency. In general, an induction motor over a range of 50 - 400 cycles was found impractical at every turn.

The DC motor approach of course, was given lots of consideration. It was discarded for three reasons: Reliability, radio interference and audible noise. We found complete agreement with these views from the military.

The final answer meets all the requirements. It is a two phase induction motor with capacitance phase shifting. It was especially designed by Induction Motor Corp. for our needs, and operated directly from a power transistor chopper at 100cps. The windings are bifilar for pushpull operation and rated at 10/10 volts RMS. A two phase induction motor was chosen over the shaded pole type for efficiency reasons. The two phase is 2 to 3 times more efficient than the shaded pole variety. This is an important factor when running from a transistor generator. The present motor on a 100cps square wave operates at 20 to 25% efficiency. The 100cps is a good compromise for size and speed. The low mass makes it much easier to mount without vibration problems and the frontal area exhibits a minimum air resistance. The 0.01 horsepower is obtained at 2400 rpm with a conservative temperature rise of 25°C. The motor is made up of class B insulating materials (130°C hot spot) so should be extremely reliable. Ball bearings are used and all finishes meet the instrument spec MIL-T-945A.

## Relays

A variety of relays are used in the Type 945 just as they are in the commercial 545. There was no reasonable way to eliminate them so every effort was made to provide maximum reliability. The main power supply switching relay was given first consideration. Looking over the history of problems for this unit, it was evident that great care must be exercised to obtain a high level of dependability. A DC hermetically sealed part was chosen. This is the "J" type manufactured by Clare. The only problem was in the hammer drop shock test, a screw came loose. As a result, tighter QC was instigated at the vendors plant. This is a military type component and meets all the environments.

A hermetically sealed thermal time delay by Dialtron was chosen. It mounts directly to the chassis and takes very little space. It functions within ratings from -40°C to +71°C ambient on the scope, and meets mil specs for environment, finishes, etc.

As might be expected, the thermal cutouts are also hermetically sealed against environment. These are important to seal since they rarely operate and need to work everytime. One is used for overheat warning and one for complete shut-off at 73°C room ambient. Stevens is the vendor for both units.

Switches

All rotary switches in the Type 945 and MC have treated ceramic insulation to withstand the effects of humidity. Kel-F rotor parts reduce friction without deteriorating electricals appreciably. Contacts are the conventional silver plated brass with corrosion inhibiting lacquer. Steel parts are cad plated and iridited (chromate conversion coating) to prevent rusting. The switches meet MIL-S-3786. The military will provision all rotary switches as special items. Shaft and bushing lengths are standardized to meet the potentiometer dimensions.

The AC-DC slide switch gave trouble in humidity early in the project. Serious hook was apparent when using a X10 probe. The paper base phenolic was changed to paper base epoxy and the knob changed from a wood flour filled phenolic to acrylonitrile styrene. The moisture problem disappeared but electrostatic charges on the high quality styrene dielectric produces interference signals at maximum gain. These are present when the switch is wiggled but are undetectable during vibration test. It was judged that the improved moisture characteristics were more important.

The toggle attenuator switches in the horizontal amplifier input circuit are a mil standard part that is the same unit as used in the commercial except for terminal sealing and varnish for a humidity barrier. This circuit does have a trace of hook present. It isn't aggrevated too much by humidity. Since the problem is of secondary importance, the abberration is tolerated and the electrical specs on transient response are opened up a little.

The toggle switch used in the on-off function is a heavy duty component that comes directly from mil specs. It has a teeter totter construction internally that gives a peculiar feel and makes one wonder about how long it will last. This design is only dependable for AC and for the scope application it is quite reliable.

The main sweep reset push button is a non-snap action switch that has mil finishes and materials. Of equal importance, the contact mechanism is a wiping action and is gold plated. Mil specs on push button switches don't fit this application by any stretch of the imagination. It is a non-standard component that meets the environmental requirements of MIL-T-945A.

Connectors

This category of components include: Front panel signal jacks, power plug, preamp multiple connector, tube sockets, CRT connectors, probe tips and fuse posts.

MIL-T-945A requires BNC coax connectors and all signal jacks and controls must be on the front panel. Covers for every jack has been added to shield against radiated interference. The CRT cathode shielding cap incorporates a grounding pin to by-pass the cathode when Z axis modulation is not is use. The BNC connector is mil standard and is a very satisfactory component. Dage supplies these with a transparent coating that retards corrosion of the silver plating.

The power plug is a military type with a complete spec written around it. It looks clumsy but is rugged and functional. It can be used in either 2 or 3 wire recepticals.

The amphenol blue ribbon connector on the plug-in is very satisfactory. It meets mil material and finish requirements. Fortunately, no change was required. All letter type plug-ins fit the Type 945.

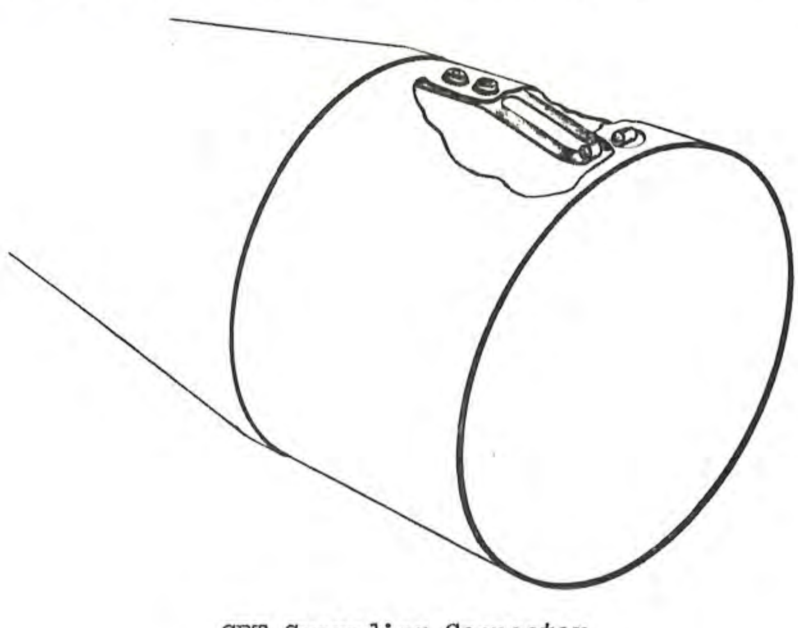
Considerable attention has been given to the various tube sockets. With some 71 tubes in the indicator alone, most of which have socket connections, the probability of connector failure is rather high.

Early humidity tests with commercial sockets readily demonstrated why the military sockets call out silver plating. Very random intermittent connections are evidenced in all circuits during vibration. After going to the mil spec socket with silver plated berrilium copper connectors, no such trouble has been experienced. The mica filled phenolic insulating material is the same as our commercial instruments. Saddles are cad plated and iridited for corrosion resistance.

FEP Teflon insulation was found necessary in all of the vertical amplifier and preamp signal circuit sockets. This was done to reduce the deterioration of bandwidth with humidity.

The CRT neck pin connectors are still the tapered AMP type. They are gold flashed for better reliability under humidity conditions. Shrinkable Polyolefin sleeving is used to insulate the pieces to reduce short and shock hazards. No trouble is experienced from vibration when the connector is properly applied with reasonable insertion force.

The tin oxide coating on the CRT face is grounded by a double finger spring contact arrangement mounted on the CRT shield. The shield is in turn grounded to the front panel by external toothed star washer. The contact finger is made of nickle-gold plated phos-bronze. The double finger provides extra dependability by redundancy. The CRT is surfaced with a fired silver coating in the contact region. The fingers extend through the shield to provide a greater spring throw and also allows a physical check of the contact force.



CRT Grounding Connector

The brush type HV anode connector basic design is adequate. The brush is gold plated. Some of the plastic pieces are changed to post cured polypropylene to prevent things from falling apart during temperature cycling.

Probe pincer tips required gold plating to prevent intermittent contact after humidity. The pincer tip insulation is now Delrin which is much more physically stable than nylon and prevents mechanical interference after humidity. The other probe tips are also gold plated.

Fuse posts are spelled out by MIL-F-19207. A hole in the cap is required so line volts can be checked. The fuse holder in the Type 945 is the type FHN 20 G. Pressure is being applied to the vendor to qualify the part for more than just materials and finishes.

## Wire and Cables

Mil specs thoroughly call out hook-up wire. The 105°C vinyl insulation we normally use is essentially mil spec. In the beginning of the project it was judged worthwhile to pursue irradiated polyethylene and polyolefin. The higher temperature capabilities is attractive for soldering problems; also, the low moisture absorption and low hook characteristics are advantageous. Like most new products, there are drawbacks: Cost, toughness, adherence and color coding. The three latter problems have been solved. The cost is still about 4 to 5 times that of vinyl. This is a result of lower quantity buying and small runs by the manufacturer since it is a new product. The color coding or striping process is a trade secret presently, so we can't buy a jillion feet of a background and stripe as needed. The Type 945/MC uses the irradiated polyolefin in places where hook or water absorption is a consideration. Both VA and Preamp are cabled with this wire, mostly for humidity. All timing circuits use it. The mag off-on circuit in the grid of the second CF uses the irradiated wire because of temperature co-efficient. Timing was off as much as 10% at 50°C at fast sweep rates with vinyl.

A flat nylon lacing twine is indicated by MIL-T-713. It is a non-nutrient for fungi. The flat material tends to slip less at the knots.

A wire color code system has been developed that fits the needs of the scope and follows Military Standard 122. Red background is B+, Violet is B-, Brown is heaters, Green grids, Yellow cathodes, Black ground, etc., etc. It turns out to be fairly easy to work with.

Solid and stranded wire attributes have been debated internally and with the military. The first prototypes were made up completely of stranded wire to see if the services had valid arguments. There is no question that the stuff is more difficult to work with. Their main point is a small nick won't destroy the connections. This is not necessarily true with a soldered joint because the solder wicks up and forms a fairly solid conductor. When fatique does occur it breaks at the transistion point from soldered to stranded. Two even more serious drawbacks were uncovered: Random shorts from clippings (there are many times more than solid wire construction), low mechanical resonance of a tied wire bundle. After pointing out these experiences in actual wired instruments, they went along with our thinking!! The Type 945 uses stranded wire only in places where a single lead or bundle may be flexed in normal maintenance, or during vibration. Firm anchoring of the bundle is necessary in most cases.

The power cord is a mil spec type and is permanently attached with a nylon Heyco strain relief grommet.

RG 58C/U is used for all signal connecting leads. This is a small flexible 52Ω RF coaxial cable. There is no mil equivalent to the coax used internally for shielded signal leads so the regular product supplied by Amphenol is satisfactory.

The probe cable as usual has been a bit of a problem. Proper vinyl must be used to prevent cracking at -65°C. The stranded glass center absorbs moisture during humidity to the extent of being a serious hook problem. Deleting this portion promotes early failure from flexing. Work is still going on in an attempt to solve this trouble.

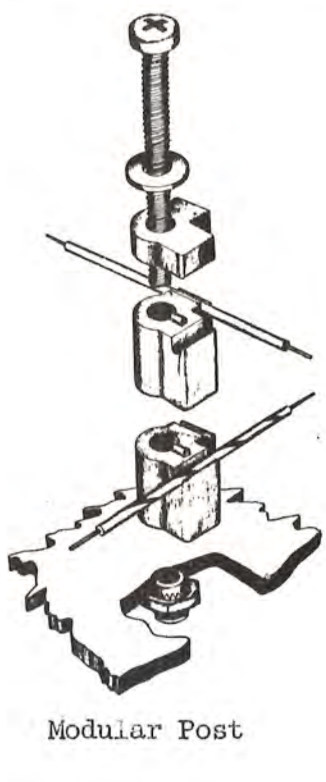
## Radio Interference Conduction Filter

The line filter is purchased as a complete package from Sprague. It was designed as a result of tests performed in their screen room in Los Angeles. It is certified to meet the requirements of the filter spec MIL-F-18344. The parameters are set by the three radio interference specs of the Army, Navy and Air Force as interpreted with regards to MIL-T-945A. This assembly is necessary because transformer shielding and noise source isolation aren't completely effective.

## Other Tektronix Made Components

A few other Tek made parts should be mentioned at this point: Ceramic strips; knobs and modular posts. Ceramic strip mounting is often asked about in reference to vibration problems. This design was originally tested on a shake table. They are completely acceptable for the Type 945 application for vibration or any of the environments. They are still soldered with silver bearing solder but it is a type that meets Federal Specification QQ-S-571. There is no applicable spec for the strips themselves.

The modular post is an outgrowth of a need to keep signal wires tight to eliminate breakage during vibration. In effect the resonant frequency is raised above 55cps. It is made up of two acrylonitrile styrene pieces.



Modular Post

The front panel control knobs are patterned after mil specs. There are no coaxial knobs in the spec so we followed the shape and dimensions in keeping with the application. Molded-in anodized inserts with two set screws is required. A thermoplastic material seemed most promising for molding in the insert. The mil spec plastic acylonitrile styrene was finally chosen. Several other directions were tried but this was most satisfactory for water absorption and low/high temperature cycling.

## MECHANICAL CONSIDERATIONS

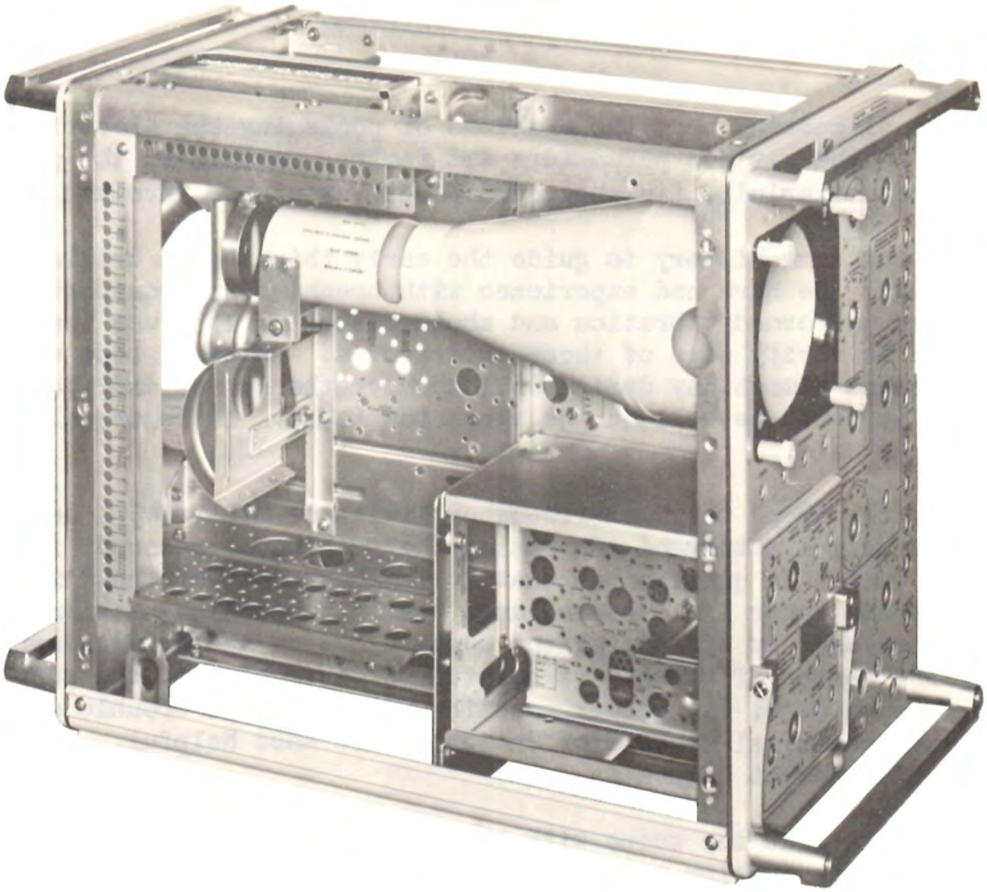
We are discussing here the problems of packaging the electrical components and conforming to the various parameters set forth. Basically, the problem is one of structure; but materials, finishes, and panel layout are involved.

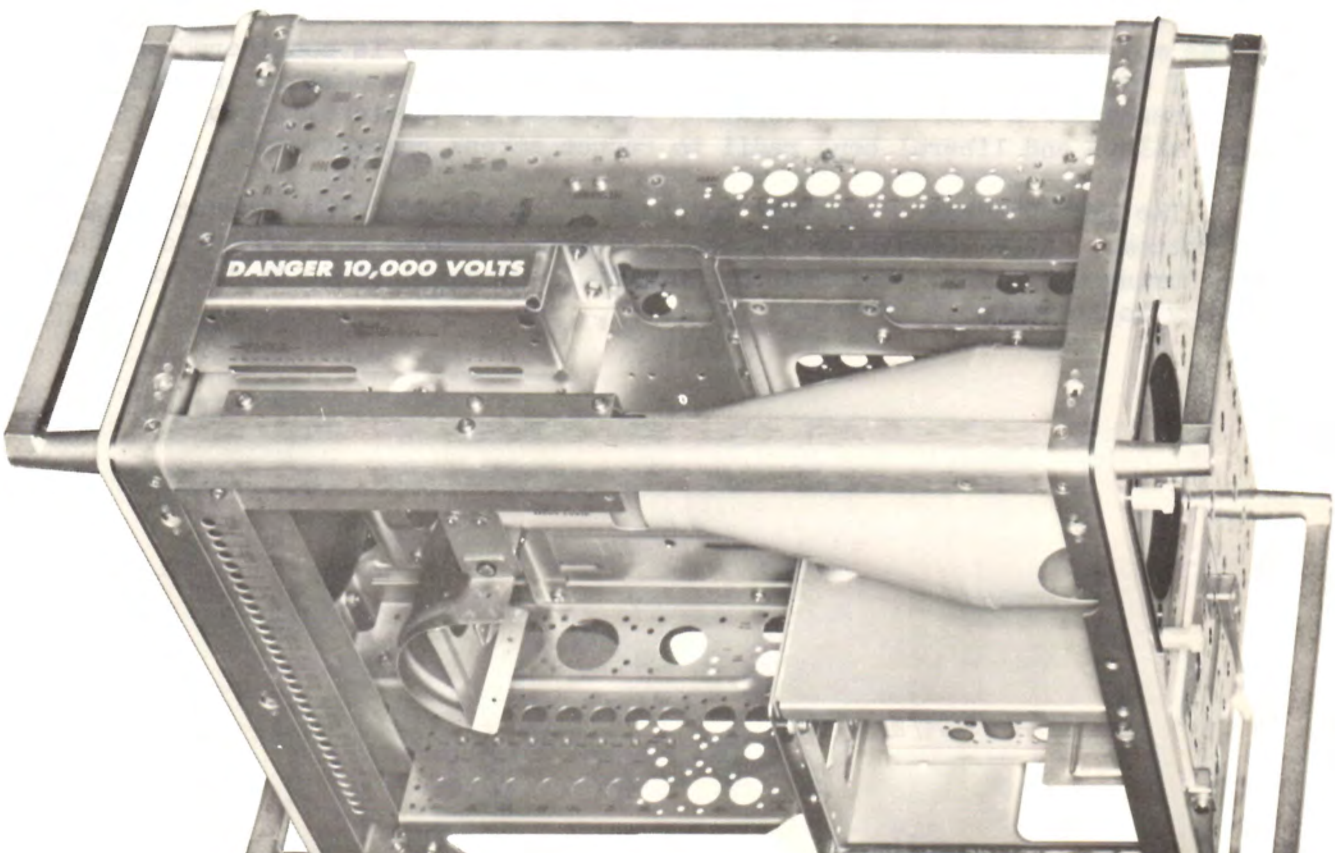
There was some history to guide the early thinking on critical areas of mechanical design. We have had experience with breakage in transportation as well as some customer performed vibration and shock tests. A 1535 was tested on our vibration table to verify some of these experiences. No shock test was necessary at this point since almost any design will survive the hammer drop, a correlated shock test, if it performs well on the vibration table. There are always a few exceptions to the rule.

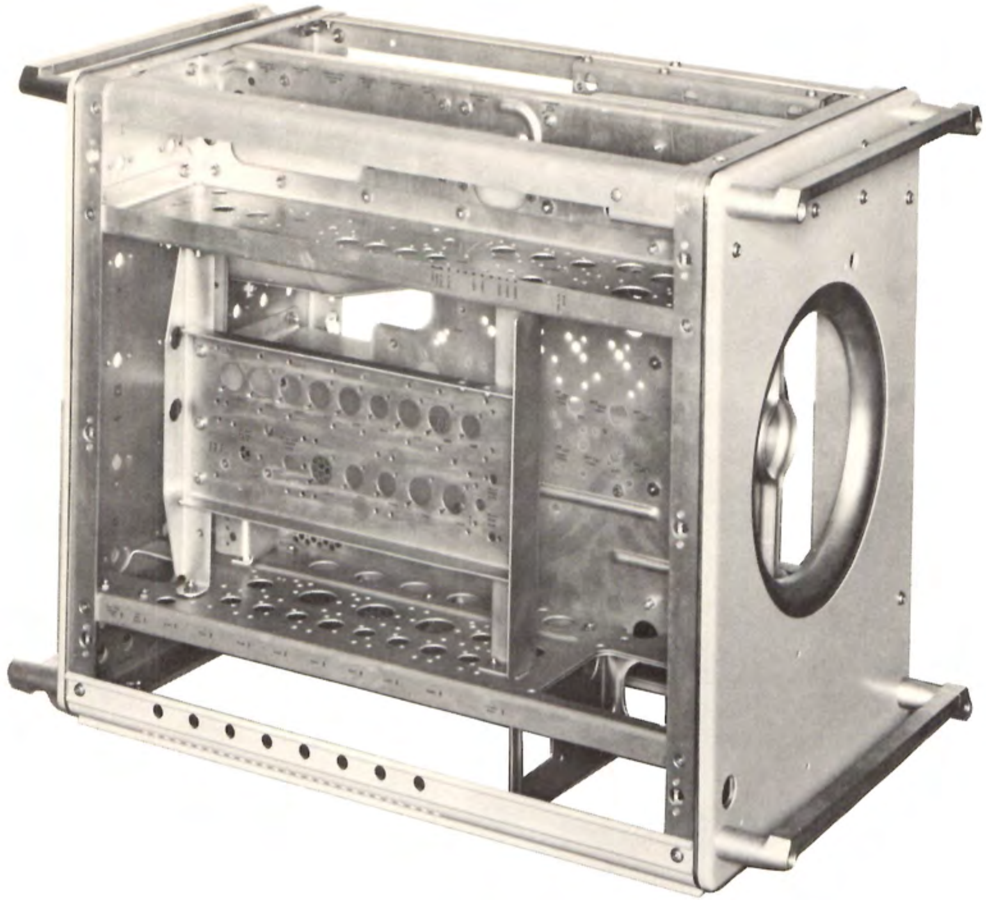
Within the 10cps to 55cps frequency limits of MIL-T-945A, designing for vibration is largely a matter of increasing the mechanical resonant frequency of the particular system in question so that it is above that of the driving force. Setting a realistic upper limit has a large bearing on optimum design. Mechanical resonance is increased by stiffening the support system and/or decreasing the mass. In addition, low center of gravity is helpful, or even better, the support plane should pass through C. G. Cantilever mounting usually means trouble and should be avoided. Lossy mechanical systems or dampening are most helpful. Fastener points is an example of inherent dampening.

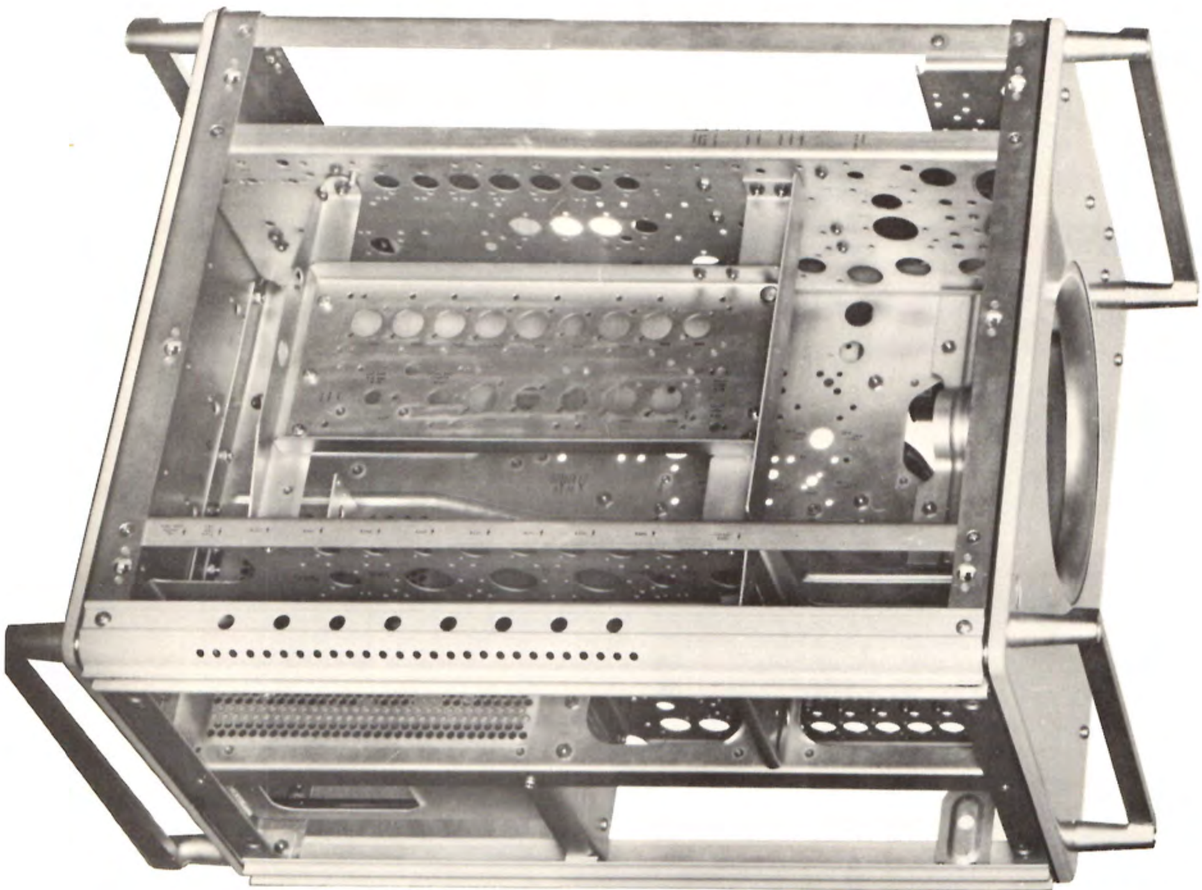
A quick look at the scope with these ideas in mind results in some early conclusions about the problem areas. The power transformer, fan motor and electrolytics are the heavy mass component mounting problems. The need for improved cross bracing to prevent racking from front and back was very evident on the 1535 test. Mechanical amplification of the entire frame work was in the order of ten to one. The test was performed at about 0.025 peak to peak amplitude. The top of the scope was moving about 0.235 inches. A figure of 2 to 2.5 is considered maximum mechanical amplification. Cracked sweep vertical and power chassis in addition to other braces after a short time vibration indicated the advisability of high fatigue strength alloys and liberal bend radii to reduce stress concentration.

The Type 945 has a vertical bulkhead which extends from front to back and top to bottom. Large cutouts are flanged and some sections are ribbed to reduce flexing during vibration. This is the largest sheet metal piece in the scope and is the key to the support system.




DANGER 10,000 VOLTS





The transformer is even heavier than the commercial counterpart because of MIL-T-27A and the extra power for heater regulation and fan drive. Some serious thought was given to splitting the transformer into two separate parts to distribute the mass. This turned out to be impractical. The general three dimensional layout of the commercial 545 is hard to improve on, especially with the limitation of keeping front panel the same. The transformer was moved back to the corner of the chassis for better support. A doubler plate was incorporated to distribute the load, and formed to provide a column to the rail. A column was also formed by flanging between two cutouts in the bulkhead. All in all a box section was developed that supports the entire mass.

Electrolytic capacitors are good examples of a Cantilever mounted compenent. The C. G. is far away from the mounting point. This proved to be a serious problem especially on the power deck where they are lined up in a row and tend to act entotal and cause diaphram resonance (oil canning) of the chassis. Ideally a snubbing system at the top end would solve the problem and several ideas were worked on. The one that showed most promise was a silicon rubber sponge strip. This did a good job but cost $1 for a piece 12" x 1". There was also a cementing problem that environment made even worse. The final answer is a compromise that meets the requirements satisfactorily with no appreciable increase in cost.

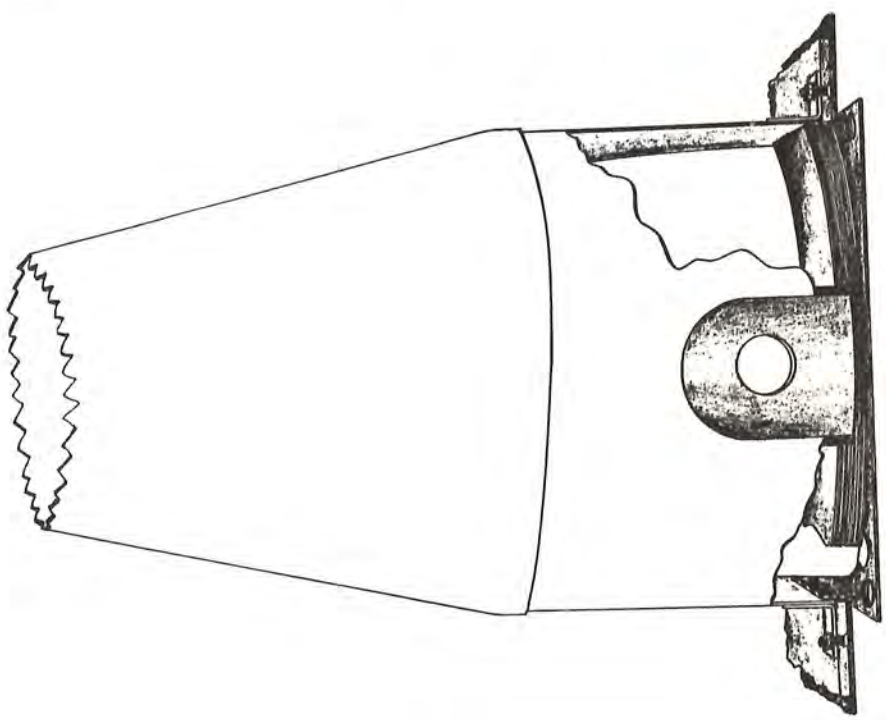
A stiffening bead is run parallel to the line of capacitors on the power deck. Another bead is formed in the bulkhead behind the capacitors. The clearance between the polyethylene insulating covers and the bead is nominally 0.030. A resilient excursion limit is established that prevents destructive movement. There is still a little working of the power deck so that care must be taken in dressing leads from ceramic strips to tube sockets. In fact, a curve of slack from strips to sockets is good practice throughout the scope.

The beading technique has been employed in several spots to provide stiffening by increased depth of section.

The fan motor mounting was solved after several attempts. Good vibration isolation strives for a mechanical resonance below the interference frequency. This is fine except to do this and make it compatible with the scopes, vibration environment from 10cps to 55 cps the resilient support for the fan motor must be moved from the typical 18cps to somewhere below 10cps. Static deflection of the mount would have to be nearly 0.5 inches. This makes a difficult thing to snub for shock environment. The first approach was to support the fan so that resonance would be around 20-25cps then use close tolerance snubbing to prevent excessive excursion and blade striking the venturi ring. It was finally decided to see how badly the ballbearing motor would vibrate the scope if high frequency mounting was used. The new rigid scope structure paid off. With a statically balanced fan blade, no low frequency vibration could be detected in the signal or by "feel". The only isolation necessary is for bearing noise. The resultant mount with high durometer neoprene rubber cushioning has a resonance around 75cps, high enough to prevent mechanical resonance and low enough to provide bearing noise isolation.

The plug-in preamplifier posed an interesting problem. The usual attaching method is floating to such an extent that very destructive hammering results. It was obvious that secure fastening in three directions was needed. Yet the answer should be such that any commercial plug-in will fit. A bail latching handle developed. Also, two close tolerance locating pins were added on the back. The mechanism has proven very satisfactory functionally. It also imparts a distinctive rugged appearance. In addition a convenient carrying handle is provided.

CRT support was given careful thought. The CRT is still the most expensive single component in the scope. The tube as now produced will pass a 10G 55 cycle vibration test by itself. The mounting system must not impart additional excursion or promote hammering. A flexible plastic ring was designed that supports the tube just rear-ward of the face plate. A black post-cured polypropylene material is used to withstand the temperature extremes and exhibit sufficient flexibility to encompass bulb diameter tolerances and also be slippery enough to allow reasonable insertion forces. The rear of the tube is supported by a stainless steel clamp around the tube base. Cushioning at this point is provided by a polypropylene "U" shaped extrusion. Both plastic surfaces (front and rear) serve to give a smooth but firm action when the CRT is rotated by the conventional nylon wrench. Other rotating and support methods at the rear were investigated but the final answer proved to be simple, functional and adequate. Random tube rotation is no problem because of this mounting system and the over-all rigidity of the scope structure. Earth's magnetic field is still an influence and it was hoped to use an electromagnetic beam rotator; however, a new magnetic shield was indicated because of the uncertainty of CRT glass dimensions in the region the coil is installed. It was decided to stay with the commercial shield for cost reasons.



CRT SUPPORT

The overall shape of the scope was set by the knob function layout and desire to maintain the familiar 545 panel. In addition, MIL-T-945A requires panel protecting handles on the front and "feet" on the back. Traditionally, bar handles on the side are used. The multitude of signal jacks along the right hand side require that a bar handle would be off-set far enough to allow good accessability. This is feasible except for anchor points top and bottom. Wrenching from the inside of the panels is virtually impossible even with special wrenches. The scope could be widened if it weren't for fitting on the scopemobile. The next step was to try handles across top and bottom. The height had to be increased to provide mounting space. Even with the increased space, wrenching from behind is unreasonable. The final answer is a very strong three piece handle fastened by Allen head 1/4 - 28 screws from the front. Floating Rosan nuts take care of the tolerance problems. The "feet" requirement in the rear was met by two more handles fastened to the back panel. The arrangement is very convenient for one or two people to carry the scope or just for manipulation on the test bench without getting into "hot" spots. A very high abrasion resistant finish was chosen. This is a brushed chrome plating on the Zamac posts and steel tubing. Tests show that it is at least 10 times more abrasion resistant than the gray alkyde enamel first tried.

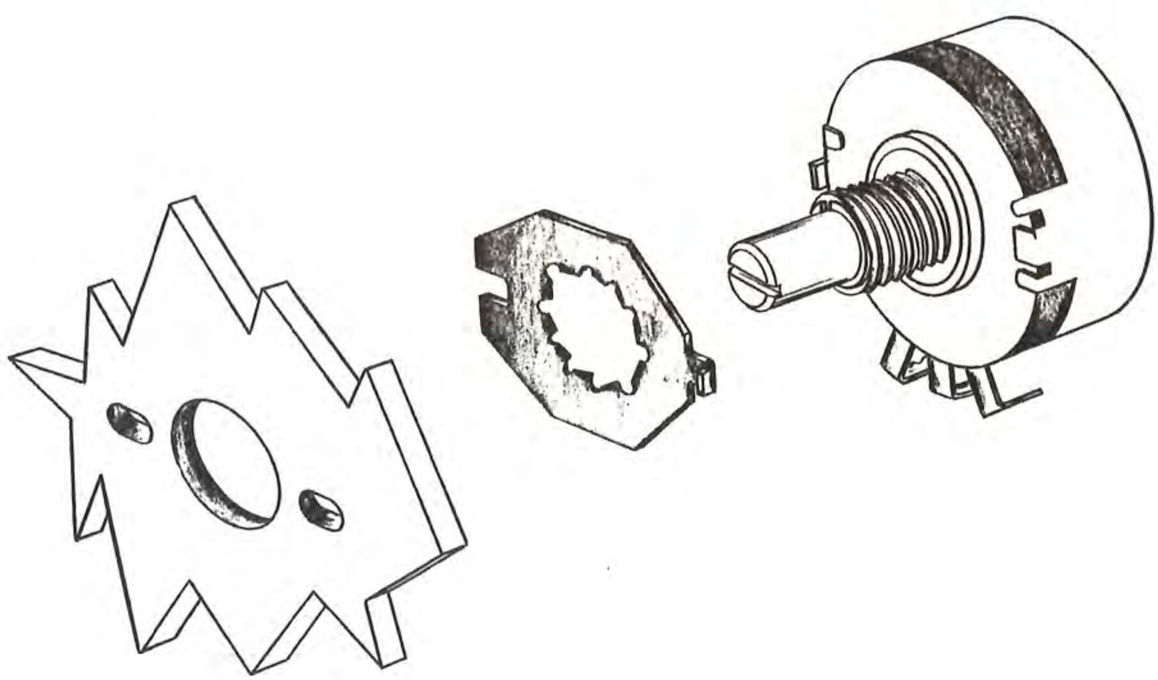
Protecting Handle

Some other items of interest should be mentioned in passing. The fan drive chassis is situated above the rear portion of the sweep deck. The electrolytics associated with the circuit are mounted on this chassis rather than the sweep to distribute physical load. Flanged clearance holes in the sweep deck are large enough to allow tipping the fan drive assembly at an angle for removal. Both top rails are easily removed for maintenance work. The lower rails are specially designed extrusion to provide a rugged deep sectioned support for the scope. It is made and attached so that multiple punching can be done in fabrication to reduce production costs. This part is typical of the thinking that went into the instrument design. It first needs to be functional but in addition it must be as reasonable as possible to fabricate with conventional tooling. The parts are based on low level mass production. Some of the tooling investment may take awhile to amortize but the fact that the military is very reluctant to modify, leaves us in the envious position of making the same item ten years from now. At that time it will still be a useful tool. Many 511's are continuing to do worthwhile jobs in the service.

The high voltage power supply mounting is a subject that seems rather innocent until it is realized that it weighs 2 lbs. and is located high above the scope C. G. It contributes appreciably to the instruments racking during vibration and needs in itself strong mounting points. By fastening in the corner of the rear panel and the bulkhead with the line of support passing almost exactly through the supply C. G., a very satisfactory mount was obtained.

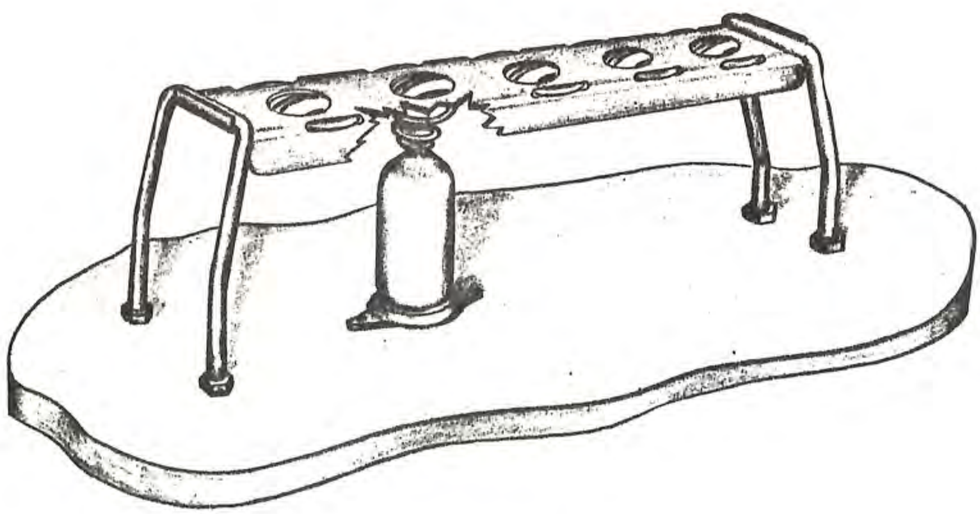
Fundamental practices were followed throughout the design. Avoid sharp transitions in sheet metal or any other parts. When stress builds up, a sharp inside corner is the point where fatigue first starts. Along this same line, a tear or orange peel from improper bending will start cracks. This is true for ragged cutouts also. All bends are made with a standard radius depending on alloy. Practically every aluminum sheet metal part in the Type 945 is made from 5052-H34 and a 2X metal thickness radius is used for structural pieces. Four standard metal thicknesses are used: 0.032, 0.050, 0.063 and 0.090. Chassis corners are relieved to prevent tearing. Standard fastener tear-out allownace is about 1.5 times screw diameter. Structural chassis minimum flange height is approximately 10 times metal thickness.

Standardizing on a few materials and hardware pieces is not only an economy move but gives better assurance of a uniform product. All aluminum sheet stock is branded to insure proper material. The wrong alloy could abort an acceptance test and be very costly. No. 8 - 32 Phillips recess style screws are used for all final assembly. Careful control of the hardware quality is necessary to reduce screw burring problems. The Phillips head is good for power driven tools and magnetic screw drivers. Self locking pem nuts are used profusely. They cost a little more but should be an over-all saving because of speed in assembly. The military specifies flat washers under screw heads to prevent scratching finished surfaces. Loctite is an acceptable (and very effective) locking method for screws that are not removed for ordinary maintenance; otherwise, a split ring lock washer is necessary. Internal tooth or external tooth washers are not acceptable locking mechanisms. The external toothed washer is principally a grounding device. The internal toothed washer is used only in rare instances. One example is the special small diameter pot lock developed for locking pot nuts on the front panel side and serving the purpose of a flat washer. A key locking washer was evolved as a result of using Mil. Std. shafts, bushings and knobs on pots and rotary switches. The standards were orignally set for a thicker panel than we are using. The special key washer is an answer that best fits all the ramifications.



Key Locking Washer

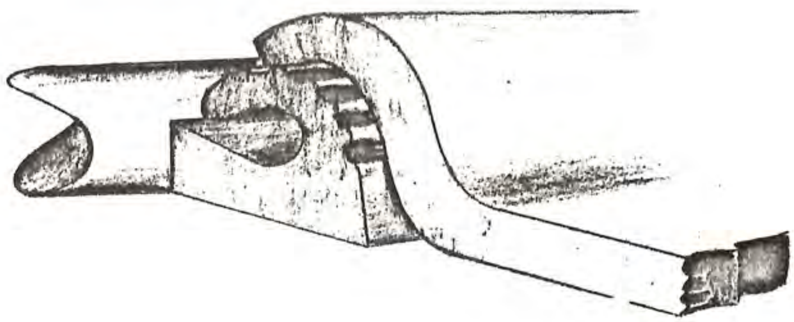
Tube clamping is another area where special hardware was developed. The Birtcher clamp for 7 and 9 pin bulbs and the Times Tophat for octals are good answers; however, cost, clutter and impossible situations led us to the multiple clamping approach. Any grouping of similar tubes lends itself to a multiple holddown mechanism. The illustration probably describes this better than any other way. Careful checking of V. A. performance, revealed no mal-performance as a result of this clamping. Forty-one tubes in the Type 945 and 7 in the C are clamped in this manner. At approximately 30¢ per Birtcher clamp -- a few dollars were saved.



Multiple Tube Clamp

The cabinet panels have been somewhat of a problem. RF tightness is handled well by screening louvers and a number of fasteners to assure frequent grounding. The nylon dog fastener was first tried but they turned out to be pretty inhuman. 1/4 turn pretensioned twist locks have proven to be much more satisfactory. A screw driver is provided in the protective covers for panel removal.

Obtaining a dripproof seal is where things got sticky. In reading the spec, one soon appreciates that here is another area of interpretation. The scope has to operate after a 5 minute exposure to a perscribed drip with no puddling or water collection. The problem is solved by performing the test with front panel covers in place (storage condition) and using a weather stripping neoprene extrusion around the front and rear sub panel. The matching panel bead insures a dripproof seal. The dripproofing also explains the reason for the one piece top design that overlaps the side panels.



Dripproof Cabinet Seal

The painted and etched panel is specified by the military. It gives a G. I. appearance that is worthwhile if only as a selling gimmic. Speaking of appearance, it is promoted by some factions of the military to design a rugged structure capable of rough treatment, but retain a slightly fragile or delicate look. This is for the sailor or soldier that is human after all. If he thinks it will take a beating he will handle it accordingly. Don't invite trouble by making the equipment look like a battleship.

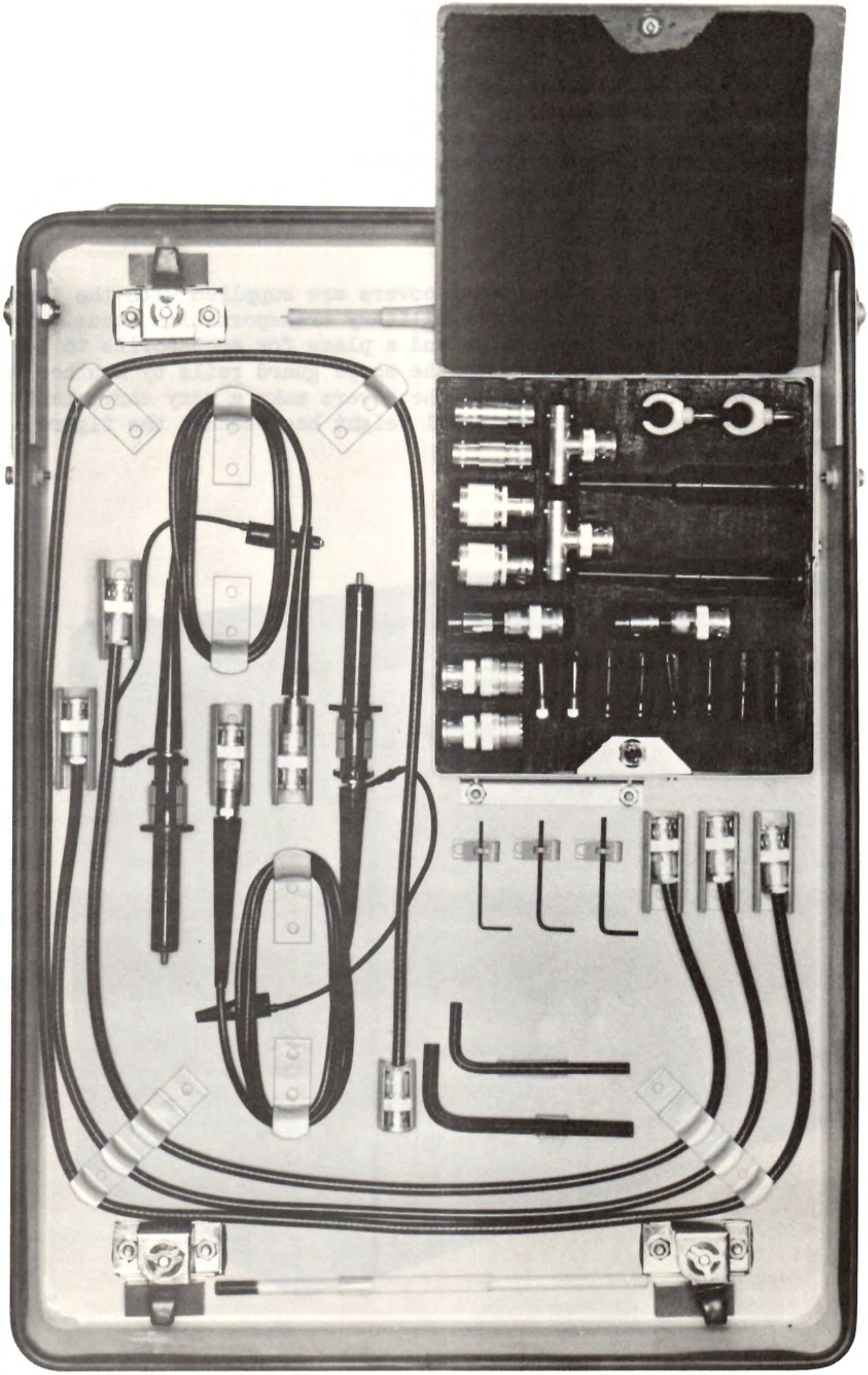
The gold chromate conversion coating (Iridite) that is used on all aluminum parts and cadmium plated surfaces is certainly distinctively military looking. It's real purpose in life is to provide corrosion protection which is in the order of 10 times better than plain or lacquered aluminum. Also the coating is very thin and electrically conductive. No problems have been encountered involving poor contact between surfaces. In fact, the cabinet sides make good enough electrical contact to provide shielding against radio interference.

All finishes, not covered by a subsidiary spec, must withstand 100 hours of salt spray without evidence of destructive corrosion that in any way interferes with mechanical or electrical performance. This doesn't imply that the scope must operate after 100 hours of salt spray. But it does mean that after thorough cleaning of salt residue and drying the instrument would still function. Very few specs spell out salt spray tests on a complete instrument. The intent here is to test any finish system or part of a stystem to demonstrate that the requirement is met.

Galvanic corrosion is one of the big headaches that must be thought of each time a metal or plating is chosen. The military galvanic charts are very explicit about which metals can and cannot be worked against each other. There are exceptions that can be made but must be proven or justified. Examples of exceptions in the Type 945 scope are: Passivated stainless steel against iridited aluminum, silver plated BNC connectors or iridited aluminum, chrome plated plug-in rods on iridited aluminum. Galvanic corrosion from incompatible metals may seem rather remote but inspection of samples after humidity or salt spray demonstrate conclusively that it is a very real problem even with mild environments.

Front and rear protection panel covers are supplied with the Type 945/MC as an accessory. These are required for military transportation needs. The deep drawn pans provide panel protection and a place for accessories to be stored as shown. They are attached directly to the scope guard rails by Southco Pawl type fasteners. The slide-up handles on the covers make a very convenient carrying means for two people. By now the total weight has reached the figure of 97 lbs. (Including the kitchen sink).

Panel Protecting Covers



Front Panel Cover

The problem was tackled early and with vigor. The importance of adequate cooling can't be emphasized enough.

Experimentation was performed to determine if improvements could be made on air distribution to better utilize available CFM. The rule is don't spill cool air. Make it work before it's exhausted. As a result, some interesting air flow patterns were turned up. Exhaust louvers were placed so they provide best air utilization. The pattern externally is less pleasing, but is certainly functional and worthwhile. Even the air scooped over the transformer was proven beneficial as mentioned earlier. The average temperature rise of the instrument is 10°C to 15°C above ambient. With a flow rate of 225 and 250 CFM the cooling efficiency is something like 50%. Best scouring of the stagnate air layer on all surfaces is accomplished by turbulent as opposed to laminar air flow. Some work was done to evaluate heat dissipating tube shields for better tube cooling and turbulence influence. The shields were determined not worthwhile. The heat dissipating tube shield is only effective when bulb temperature range above 100°C. The cooling observed at bulb temperatures around 50°C is only a degree or two. This is verified by the vendors.

An air deflector mounted above the Vertical Amplifier was found necessary to get more air over the VA tubes and into the plug-in housing. The rear opening of the plug-in was increased about 25% for better air flow. The temperature rise in the MC is approximately 15°C. The bulkhead between the preamp and right side of the instrument is perforated. This provides a maximum of air flow with good structural strength and adequate shielding.

Mounting regulator shunt resistors on the lower rail provides dissipation of about 75 watts in an area where it has practically no effect on other components. These are cooled by air that has already traveled through the instrument but they are used conservatively and can cope with high temperatures without effecting life or performance.

The 6 1/2" fan diameter was chosen to be compatible with the 2400 RPM motor. The inherently higher speed of the motor called for a smaller blade with somewhat more CFM as the typical commercial design. The smaller orifice in the back panel provides larger anchor areas for the bulkhead.

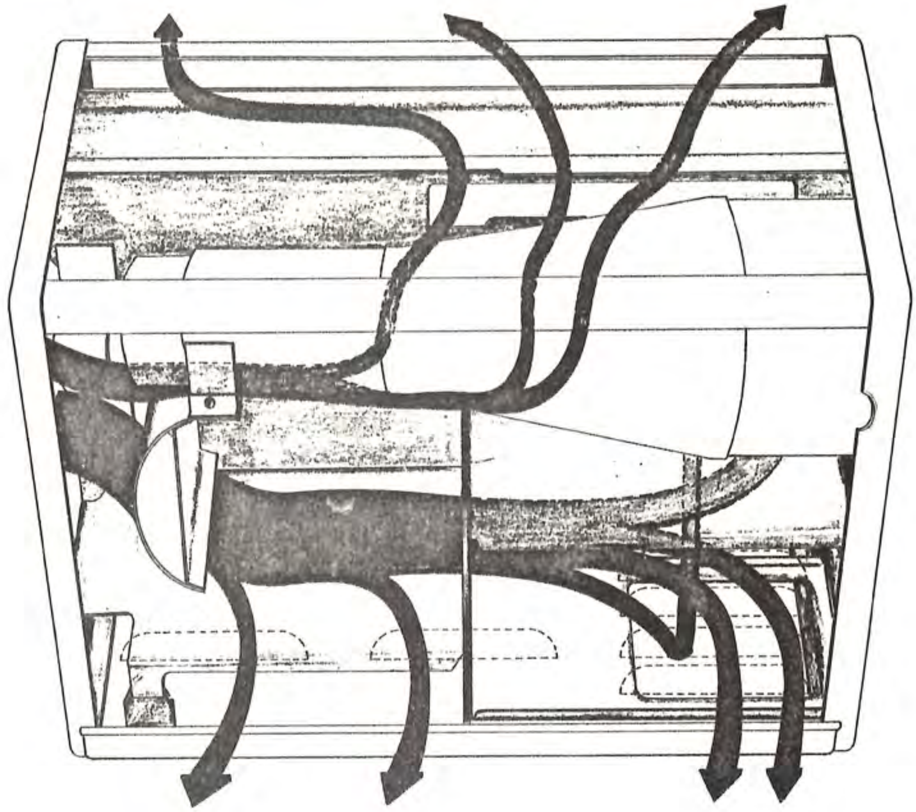
The venturi shape and clearance was first established by the design methods suggested by Torrington Fan Co. This was modified slightly by experimenting with the variables. Several tricks were tried to get consistent air flow measurements with the vane type flow meter (Velometer). Finally we purchased an anemometer type that has given consistently repeatable answers.

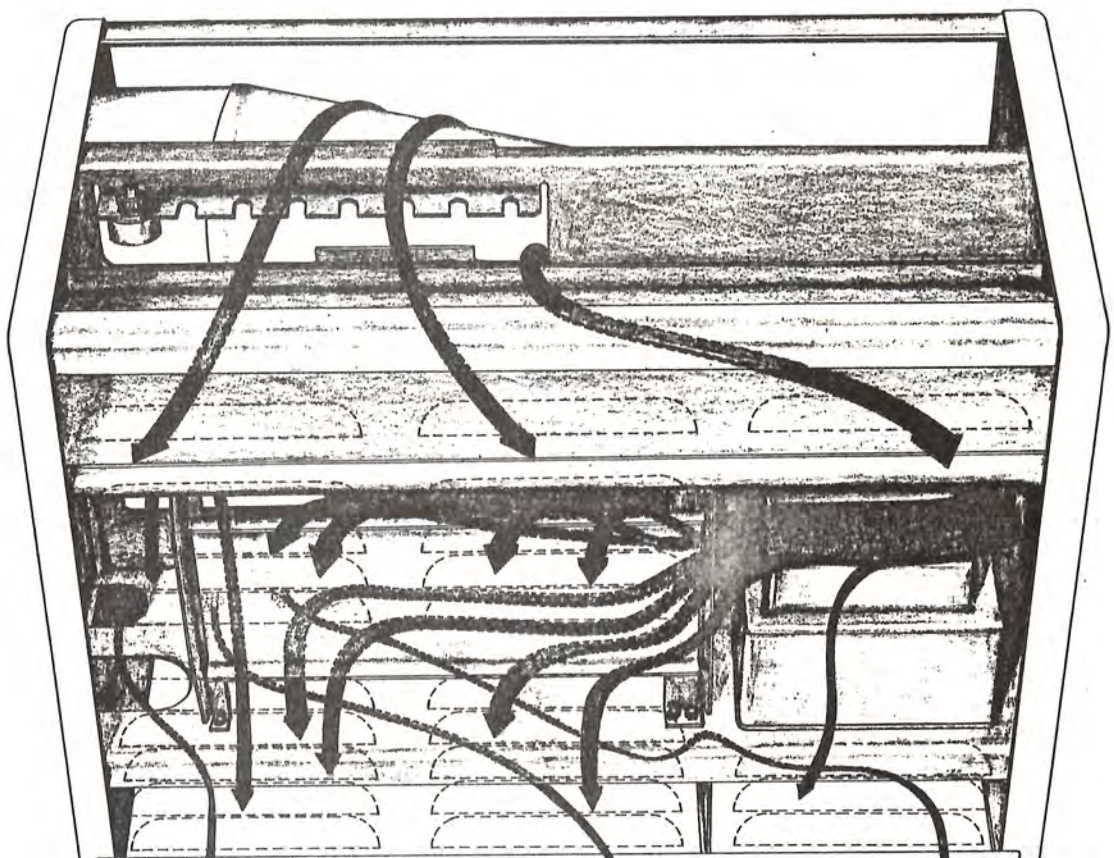
The air filter is the permanent aluminum type normally found on Tek scopes. Mil filter specifications are fuzzy. Somewhere we are supposed to test this for quality of filtering under specific test conditions with 43% fly ash, 48% lint and 9% lamp black. After several attempts to get materials, we have decided to wait and see what happens. We know the filter is adequate for the application.

Two changes are made to the existing filter. It is iridited for corrosion resistance and good electrical contact to provide radio interference shielding. Three cross rods are added to prevent mechanical resonance during vibration.

Heat runs were performed at room temperature and maximum ambient conditions. Extrapolation of temperature rises is good rule-of-thumb practice; however, final runs need to be made at actual rated ambients. Some areas go up faster than anticipated, others not as fast.

Maximum altitude specs need to call out ambient temperature limitations. For the Type 945, maximum ambient was dropped from 55°C to 50°C at 20,000 ft. This was determined by heat runs in the altitude chamber.





Air Distribution

## ENVIRONMENTAL TESTING

Aside from the Military Provisioning aspect, the Type 945 is an environmental scope. The performance in environment has equal importance with the electrical characteristics. For this reason, considerable effort and equipment has been assigned to environmental testing. The right approach and attitude is necessary to obtain good results.

The tests need to be thought out carefully before actual work begins on a specimen. Many tests are irreversible and specimens are hard to come by, especially when it's a $3K scope. Firm test parameters need to be established. For the Type 945 these were called out essentially by MIL-T-945A. Equipment must be capable of performing the test and remain calibrated. Hidden errors should be anticipated or ferreted out. Unfortunately, these bugs are often found too late, and inconclusive data is obtained. This is where experience is invaluable. Uniform environmental tests are helpful in eliminating bugs and points out one of the advantages of following military tests. These have evolved over the years. They may seem extreme to the uninitiated; however, they do reflect service conditions. Deteriorating tests such as temperature, humidity, fungus, vibration and shock are accelerated to some degree, so that results can be obtained in a reasonable length of time.

The test once agreed on, should be followed to the letter. Short cuts can give bad answers. There are always exceptions, of course. For component or small assembly tests sometimes only part of an answer is needed to continue on with the design. Here again, experience helps to know when the partial answer is valid. To illustrate the thoroughness that was found necessary on the Type 945, almost 100 readings are taken and recorded for each stopping point, i.e. end of vibration, etc. Every circuit performance is measured. This is the only way to be sure something isn't over-looked. At least 10 stopping points are included in a qualification test and requires about 60 days.

Interpretation of test results as to passing or flunking is one of the most important attitudes to be emphasized. This may sound ridiculous; however, when one gets wrapped up in a project it's all too easy to sluff off a gray area over-optimistically. A great aid is to have very clear criteria of pass or fail. Mil specs are sometimes fuzzy. If a service interpretation can't be obtained, then a pessimistic view point is taken. Usually these failures are little things that can be verbally minimized but in fact do reject the specimen. Certainly a broken lead can easily be repaired but it does prevent complete operation of the instrument. Occasionally a simple failure of this nature requires design changes, or it may point out the need for better quality control. Random failure of components like a tube or resistor is not reason for reject unless it is a direct result of the testing.

After the results are in and the failures are evaluated, there are three general directions open:

1. Improve quality control
2. Change the design
3. Change the specification

The particular project situation will determine the best route. Specification change is not impossible with the military. They recognize that waivers are necessary for a practical product. Here experience really counts.

One other thought: Plan at least twice the time you estimate.

The conclusions from environmental tests are influenced by the manner in which they are performed. If the military requirements aren't clear or we are writing our own specs, careful attention should be given to spelling out methods of testing. Also, non-destructive tests should be done first so that understandable electrical specs can be written. It's much easier to call out limits (± x%) then measure percent changes in a characteristic after several deteriorating tests.

The Type 945 is tested under two temperature conditions: -65°C to +85°C at 50,000 ft. and -40°C to +55°/71°C. The first is non-operating and is intended to demonstrate ability to be stored. An altitude capsule is placed inside a larger hot-cold chamber to simulate the required conditions. Simultaneous -65°C and 50,000 ft. is maintained. It takes about 8 hours to get thermal stabilization of the transformer. Four complete hot-cold cycles are required.

The -40°C to +55°C is continuous operating range. It has to do with change of accuracy with temperature. The +71°C tests is a short term accelerated type that is meant to induce catastrophic failure. We operate the scope one hour and measure primary characteristics and check to see that all circuits function.

Operating temperature tests require a large chamber for valid results. Recirculation of cooling air before it has cooled to ambient can give pessimistic results. All of the operating temperature tests on the Type 945 were performed in a 64 $ft^3$ chamber cooled by $CO_2$ and heated electrically. A large circulating fan maintains air movement. It's turned off 1/2 hour before any above room temperature measurements are made. 20,000 ft. altitude operating is also performed in this set of chambers. Air recirculation is more restricted in the altitude capsule, but it is not quite so important.

In altitude there is no access to the front panel. So it is a matter of making a setting, closing the door, pulling a vacuum and taking readings. Primary characteristics only are measured. A port is supplied in the main hot-cold chamber for convenient manipulation when not using the altitude box. Incidentally, at -40°C there is no question about what type of glove is used. The knob spec says, "it shall be operable with a gloved hand". A heavy insulated glove is about the only thing that is comfortable.

The temperature-altitude tests sound pretty straight forward, however it has its problems -- just try to resolve timing at 0.2% through 7 panes of thermal glass (14 reflections).

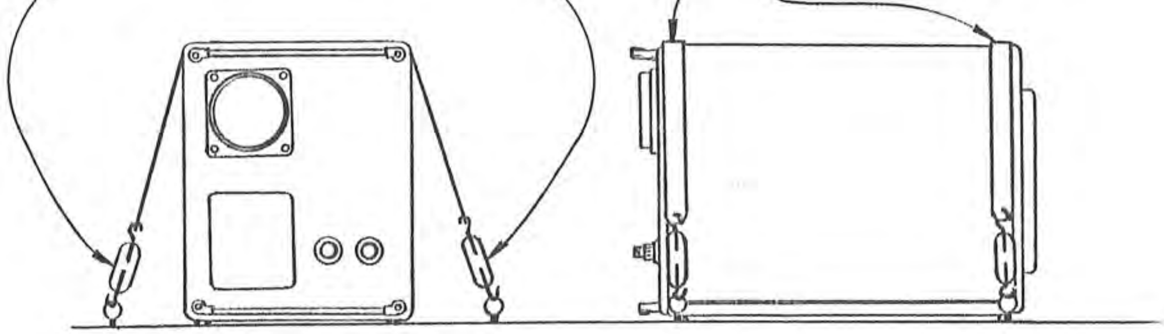
The water drip test is non-destructive and is performed by placing the scope on a cart so that it can be maneuvered in all positions to obtain a stream of water on every surface. A "domestic" nozzle is 3' above and tipped at a 15° angle from vertical. A 1' head is maintained. After 5 minutes of sprinkling, the panel protecting covers are pulled and the unit turned on. It must meet all electrical specs. Small amounts of residual water is discounted.

Primary power frequency is not generally considered an environmental condition. However, it is a variable that must be checked thoroughly. A complete set of measurements is recorded at 45cps and 440cps. Wave form distortion can be a real trap. An audio type distortion meter was used to assure less than 1% distortion. Just looking at the shape on a scope is not sufficient. An electronic amplifier has proven the best variable frequency generator for our work.

MIL-T-945A refers to MIL STD 170 for Humidity. This is definitely a deteriorating test which simulates tropical conditions or a summer day in Washington, D. C. Temperature is cycled from +18°C to +65°C with 95% constant relative humidity. Ten days of cycling goes on. The scope is checked every other day and is supposed to meet specs within 5 minutes after energizing. It takes about 2 hours for a complete electrical test during which some drying does occur. A 5 minute test is made every day except the 9th. At this time, a complete check is recorded. Immediately after the 10th check the scope is placed in the fungus chamber. This follows the spec instructions and assures ideal conditions for the fungi to grow.

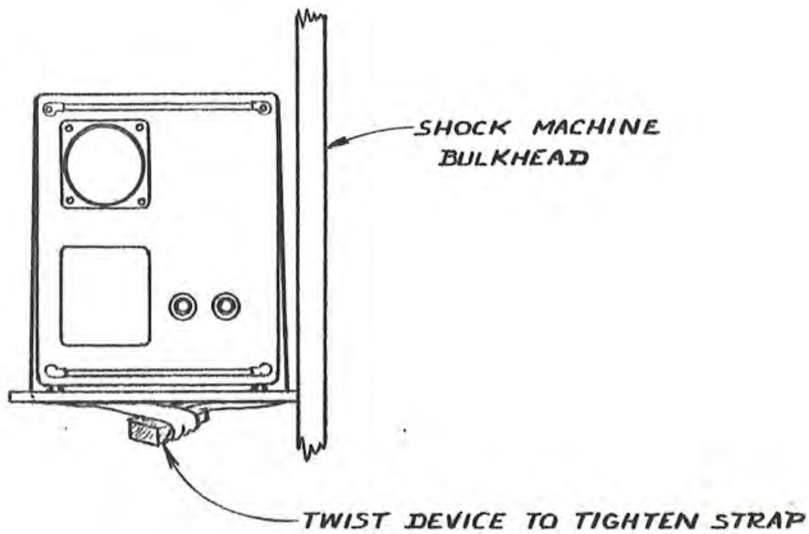
There are four species of bugs called out. They represent typical fungi encountered in the field and are vigorous growers. So, if there is nutrient available they will thrive. The instrument is sprayed with a solution of growing fungi and the chamber is closed for 28 days. A saturated atmosphere is maintained at +30°C. The test proves to be a fairly rough humidity test as well. It is allowed to dry 48 hours at room conditions before testing. Any violent growth or one that causes malfunction is reason for failure.

The vibration test proves ruggedness for transportation. The scope must operate during the test to prove that it has no catastrophic failures. The two thoughts may seem inconsistent, but proving electrical functionability removes some of the interpretation from borderline failures. The method of mounting effects the outcome considerably. Our interpretation is that metal straps over the subpanels is the intent of the spec. Some people feel nylon strapping should be used; however, this gives vibration isolation and results in unrealistic answers. Also, some factions say to use a bracket that supports the frame of the scope. This only shakes the insides and eliminates the racking problem that is so difficult to prevent. Testing with a five sided box type cabinet is also questionable since the spec says to determine the four most severe resonant points and hold constant frequency at each for 3 minutes. Visual and audible determination is necessary to do this. Our tests are all run with side panels removed. We have placed a limit of 5mm maximum microphonics during vibration. This is attainable and looks like we have finally arrived at a decent micro spec for oscilloscopes.




Vibration Mounting

Nylon strapping is the universal hold-down for the hammer drop test. The specimen is mounted on a bracket to a bulkhead. The 400 lb hammer hits this bulkhead in pendulum fashion for horizontal blows. Another 400 lb weight is dropped for vertical deflection. The instrument is operating but can malfunction during the blow. It must be o.k. afterwards. The spec says it will continue to perform its major functions. We go a step further and indicate the amount of electrical deterioration which is surprisingly small. Incidentally, the bouncing after the initial blow is almost as violent and destructive as the first shock, which is approximately 500 G's for 1 ms.



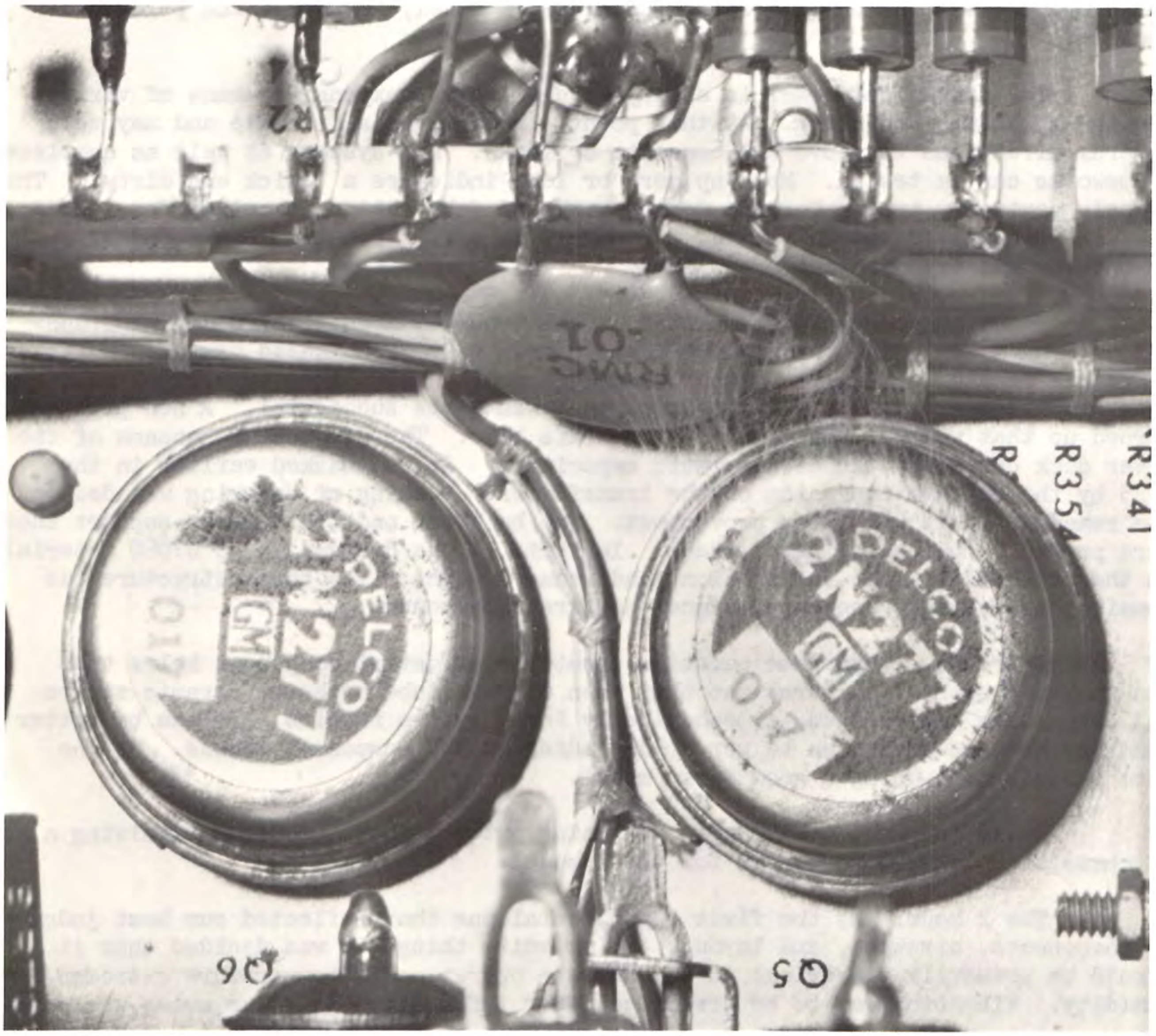

Shock Mounting

Various types of shock machines are required in the Mil Specs. Hammer drop, sand drop and anvil drop. The last two are guillotine type. Each produces a different type of shock wave form. The anvil drop can even control rise, fall and duration. Correlation between types of tests is not very good. Passing one doesn't assure meeting the others. This is one of the reasons we have not invested in such a device, so far. The anvil drop has the best chance as an engineering tool but we still would have to qualify an instrument with the called out machine.

The radio interference requirements of MIL-T-945A are unrealistic in some places. They talk about 5 microvolt level for CW but don't define bandwidth for broadband interference. After consulting with people in the interference business we have decided to meet a spec for each service for broadband radiated and conducted interference. The susceptability test of MIL-T-945A is used.

The sweeps are set to free run, amplitude cal at 100 volts, and the MC preamp is in chopped mode. At each check point the sweep range switch and variable multiplier controls are functioned. Most interference is detected at fastest sweep rates. All BNC covers are in place. These tests are tied closely with particular test equipment which changes from time to time. Until we see the economical need for investing in a screen room and equipment we will continue to utilize external facilities. The Type 945 was tested at Sprague Labs in Los Angeles.

As mentioned previously, the salt spray is for testing finishes. This is performed in the same polyester glass lined box as the fungus test. A fog of saturated salt solution is continuously sprayed for the prescribed period, 50, 100, hrs., etc. Parts are suspended from cross supports. Care is taken to prevent drops from forming at the specimen hanging point. This causes a stream of salt water that constitutes excessive testing. The salt box is a very corrosive function and is placed in a separate room with an exhaust fan to prevent rusting of other laboratory equipment.




Fungi Growth on Paper Labels, Penicillium Funiculosum and Aspergillus Flavis.

## EVALUATION OF MODELS

The foregoing discussions perhaps imply that we sat down and solved all the problems and then put the instrument together. This isn't very accurate. Each phase of development as represented by the evolution of models, brought the project closer to a satisfactory product. Each model was a base from which to proceed to the next. At this point, it would be repetative to discuss in detail the results of each test. However, the briefness of this section should not be interpreted lightly. Many, many hours have been spent on checking performance and trying to solve problems in the environmental lab. Evaluation is one of the best yard sticks for measuring design. There were four distinct models during which development was carried on: Mechanical, X model, prototype and pilot production.

The mechanical model is a simple relatively inexpensive means of verifying the structural thinking. At this point, the design is flexible and may take several directions to prove out concepts or ideas. Sub-systems as well as complete frameworks can be tested. Mock-up more or less indicates a "quick and dirty". This is only partially true. Careful design work and fabrication is called for. Once the direction is set after testing the model, it may be too time consuming or costly to back-up and try some other new idea.

Heavy components were mounted on the Type 945 mechanical model -- Transformer, fan motor, electrolytics, CRT and pots. A 0.090 bulkhead was used. Since there was no die to form the taller front and rear panels, they were rivet spliced from other scope blanks. The vibration test was quite successful. A new problem turned up that was not recognized before this time. The diaphram resonance of the power deck caused by the electrolytic capacitors. It was masked earlier in the 1535 by the extreme excursion of the transformer. Beading or snubbing was deemed the remedy -- this was later proven out. The bulkhead and transformer support ideas were proven to be on the right track. In fact, it was decided to go 0.060 material on the bulkhead to ease fabrication, and reduce weight. The basic structure has remained essentially unchanged since the first go-around.

There is always some question about the effect of component holes that can weaken chassis. It turns out that when all the tube sockets, ceramic strips and components are mounted, a mechanically lossy system results. It can be better than the mock-up or it can be worse, depending on the component masses. So the bare chassis mock-up is a good first model.

While the mechanical model was being put together, sections involving a lot of chassis chess were worked on for the X model.

The X model was the first experimental one that reflected our best judgments on components, circuits, and layout. To expedite things it was decided that it should be primarily electrical to demonstrate operation in temperature extremes and humidity. Vibration was to be performed after information in other areas was obtained.

The usual bugs were encountered. One that took considerable time was the high voltage supply and associated CRT circuitry. It became necessary to shield the grid and cathode circuit to reduce capacitance coupling to the transformer. Some lead re-routing also was needed. Bringing the CRT cathode lead out the front was solved by a parasitic resistor. It was found necessary to use an electrostatic shield around the CRT heater winding to reduce 60cps intensity modulation.

Room temperature heat runs were about what was anticipated except in the V.A. At this point the air foil was incorporated. These tests were performed with an interim fan motor also without regulated V.A. heaters. This wasn't to significant except the extra power was not being dissipated. Higher air volume rates were later attained by juggling orfice variables so things averaged out eventually.

Many things were learned on the first few runs in the environmental temperature-altitude tests. As much of this had to do with measuring techniques as scope performance. The present instrument console had its beginning during these first tests. Preliminary information was gathered that indicated very careful thorough measurements were needed on each characteristic.

Temperature coefficients of components were found to be reasonably satisfactory. The sweep timing was found lacking at faster ranges, but not all of the final timing capacitors were used. The need for low T. C. wire insulation also was demonstrated in these tests. Quite a bit of trouble with hum at -40°C was encountered. Here again the final electrolytics weren't used. Since then, the Compulitic cap has given no trouble. Another concept was formulated. Don't worry about ripple on the supplies but let the front panel indications govern the results.

The 10 turn delay multiplier pot was found with a cracked case. Investigation turned up that it is out of dissipation rating at the 80to 85° internal ambient when the scope is running at 71° external ambient. Complete heat runs at maximum rated ambient were not performed on the X model but a few thermocouples pointed out the definite need on the next model to be sure there are no hot spots.

The humidity test began to show up the real advantages of high quality components. The problems encountered were largely insulating materials and less expensive components. Transient response and bandwidth were the first to suffer. Large changes in tuning resulted, also hook was evident. Each dielectric system was scrutinized to determine what the best approach might be. The input AC-DC slide switch was changed at this point, also the various water absorption and corrosion problems in the probe showed up. Peaking coils from better plastic were experimented with. Irradiated polypropylene wire insulation and teflon tube sockets were thought of but hoped against. Timing changes and attenuator changes readily indicated the best in the way of resistor hermetic sealing. Parts that were not finished properly showed without doubt the importance of care in this department.

The humidity tests were encouraging even though it showed a number of areas that needed more work. It demonstrated the humidity for what it is -- one of the worst enemies of electronic equipment.

The vibration test was approached gingerly because of a few known weak spots resulting from a hurried up program. It was shaken energized with the developmental CRT mount. Nothing catastrophic occurred. The plug-in attachment hadn't been finished so the preamp orbited unless held down. Then, almost a year after the beginning stages, it was felt that the design was proven, even though still in rough form. Optimistically, the prototype models were planned for the IRE Show March 1960. They would represent the scope as it would be finally produced if the unknown problems could be solved by minor changes. Shock, radio interference and drip tests had not been performed at this point but it was decided to go ahead anyway and squeeze these tests in the next seven weeks.

Ten units were planned in the prototype group. At least two to be complete before the show. One for shock and radio interference testing and the other for the show. Fabrication was a mutual effort of the MPD model shop and the Fabrication and Molding Division. Both models were finished on time. The ten were meant for evaluation work, field demos and for selling to early customers. Scopes that had seen their usefulness in evaluation and field demos were to be placed on life test to get a measure of reliability. At least 50,000 scope hours was set as the goal.

It turned out the Navy and Marine Corps bought one each. Three went to the field as demos and five remained for "working on". S/N I, II, III and IX have been run through most of the environmental tests to obtain statistical data. From these results the electrical environmental specs have been established.

The first shock test on S/N I in Los Angeles, was quite thrilling. The Type 945 passed with tremendous stamina which was, to say the least, gratifying. The only falter was the power supply relay holding contact, which flipped open momentarily. The scope re-cycled and continued to run. This was not considered a failure. Of course, a vibration test had been run before trying the shock test.

During the vibration tests several minor problems evolved which were fixed rather easily. One thing did occur that was very significant and has had its effect on fabrication efforts ever since. S/N III through X had a different batch of bulkheads than I and II. When III was put on the vibration table the amplification in the front and back direction was up to 0.1", this was considerably more than the 0.065 of the other two models. In spite of this magnitude, complete cycling to MIL-T-945A was carried out. The scope passed, but a couple of hairline cracks verified that something was wrong. The instrument was dismantled piece by piece. The most significant finding was that the bulkhead was considerably out of tolerance in size and hole locations. Only by pushing and shoving was it possible to assemble. A new bulkhead was made and checked to be in tolerance. The scope was put back together and the vibration test re-run. It acted like a different instrument. The racking excursion returned to the normal 0.065.

The hard proven moral is that tolerances are set for a good reason and should be met. If they aren't in tolerance, the scope might be in as much trouble as not meeting bandwidth. The result of this incident is that vibration testing will be done on production scopes. After a little experience it's easy to know if an instrument is passable by running it up to 55cps in the racking direction. A quick vibration test easily spots untightened hardware, miscellaneous washers, wire clippings, solder, excessive microphonics, loose or unsoldered connections, and on and on. This is a very worthwhile step, not only to meet mechanical specs but to reduce the "dead on arrival" figure to insignificance.

The temperature and humidity tests on the first few prototypes brought into sharp focus the plastics problems. A number of plastic parts are made for the Type 945/MC each one has its peculiar problems. It was proven emphatically that once a material is chosen and a fabrication process developed, don't alter either without first thoroughly checking in the environment. Physical distortion from temperature and humidity extremes was most of the problem. Different materials, post-curing, and redesign were all avenues to successful results.

The humidity verified, earlier findings on the need for good insulation in the vertical amplifier. A scope was rebuilt with teflon tube sockets and irradited polyolefin wire insulation. About 3 mc was brought back on the MC preamp, and was considered worth the price. Other electrical characteristics settled down in the later prototypes. This was largely from solving each little problem along the way and finally getting in all of the desired quality components.

A fungus test was first run on S/N I. This test was approached with optimisim since evaluation at the component level had already been made and some materials already changed. In the testing business it's always nice to have something fail just to show the test was valid. Also, a perfect pass is so unsensational that emotionally its hardly worth the bother. The fungus test was very gratifying, a few paper labels grew fungus profusely. The test was a success. The scope worked with some minor deterioration in transient response and accuracies. These were moisture, not fungi, induced. The electrical environmental specs reflect the areas of deterioration and the paper labels have been eliminated.

The operating temperature tests have firmed up the confidence in performance. Some of the X model problems were caused by inferior components as suspected. Operation at -40°C is no longer any trouble. Accuracies deteriorate somewhat but are typical catalog specs at -20°C up to +55°C. Complete heat runs were performed at +55°C and +71°C on one of the instruments. Things are naturally hot but well within design rating for good reliability. Thermal relays were checked for cutout values and tolerances tied down.

Several drip tests were made on prototypes. These were in way of creeping up on the solution with the least cost. The final answer is the neoprene extrusion and matching beading in the cabinet covers. Also the gasketing on the front and rear panel covers are necessary.

Piece meal testing can be misleading. One environment may deteriorate without notice and the effect will not appear until a later test. Temperature cycling may crack or loosen a part that comes loose during vibration and falls off in shock. It's important to continue through the complete series of test in prescribed order and without adjustments or repair. S/N III and IX were handled in this manner except only one was carried through shock. The results were so good, there was little reason for the added expense of a third shock test at that time.

Even after all of this testing, it is still necessary to qualify at least one of the 50 pilot production models. This is to prove the instruments made by production people processes and quality control will perform as well as the prototypes about which the electrical-environmental specifications are written. At the date of writing this has not been done.

The pilot production is that awkward stage of development where it moves from engineering to production. The last design details are to be wrapped up and the production routine established that will not only be economical but build the product intended. It's sort of a dress rehearsal for the real thing. Here is where the engineering philosophies and ideas get instilled in the production people. Cooperation and tenacity of purpose are needed by everyone.

Evaluation work will continue in the way of life tests to measure the reliability of the Type 945/MC. This is a lengthy program but has already begun to show that the scope is capable of long life with a minimum of maintenance and catastrophic failures. S/N I presently has 3500 hours with one tube in the preamp replaced at 196 hours, two more in the preamp at 1112 hours, and a disconnect diode and miller tube at 2016 hours. The preamp and VA were retubed and retuned at 2524 hours. Nothing else has been done and it still meets specs. These are certainly very decent results when one remembers this scope has been through all the environmental tests before going on life tests.

S/N II had a 6AU6WA fail at 776 hours and the delay line was retuned for a 2% interface in the vertical amplifier at 1021 hours.

## CONCLUSIONS

A commercial Type 545/C Oscilloscope has been militarized to satisfy the requirements of MIL-T-945A with few exceptions. An examination of the Type 945/MC electrical-environmental specifications will convey the full extent of performance under extreme conditions.

Environmentalized is an equally good term to describe the Type 945. This leads one to thinking about uses other than strictly military. It might be used any place an oscilloscope is needed that is capable of performing with good accuracy and reliability in extreme conditions. By reducing the environment severity, even better reliability is realized.

Since this military, environmental, reliability concept is new at Tektronix, it remains to be seen what portion of the market is far sighted enough to appreciate its particular need for better equipment and be willing to pay the initial cost.