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TEKSCOPE

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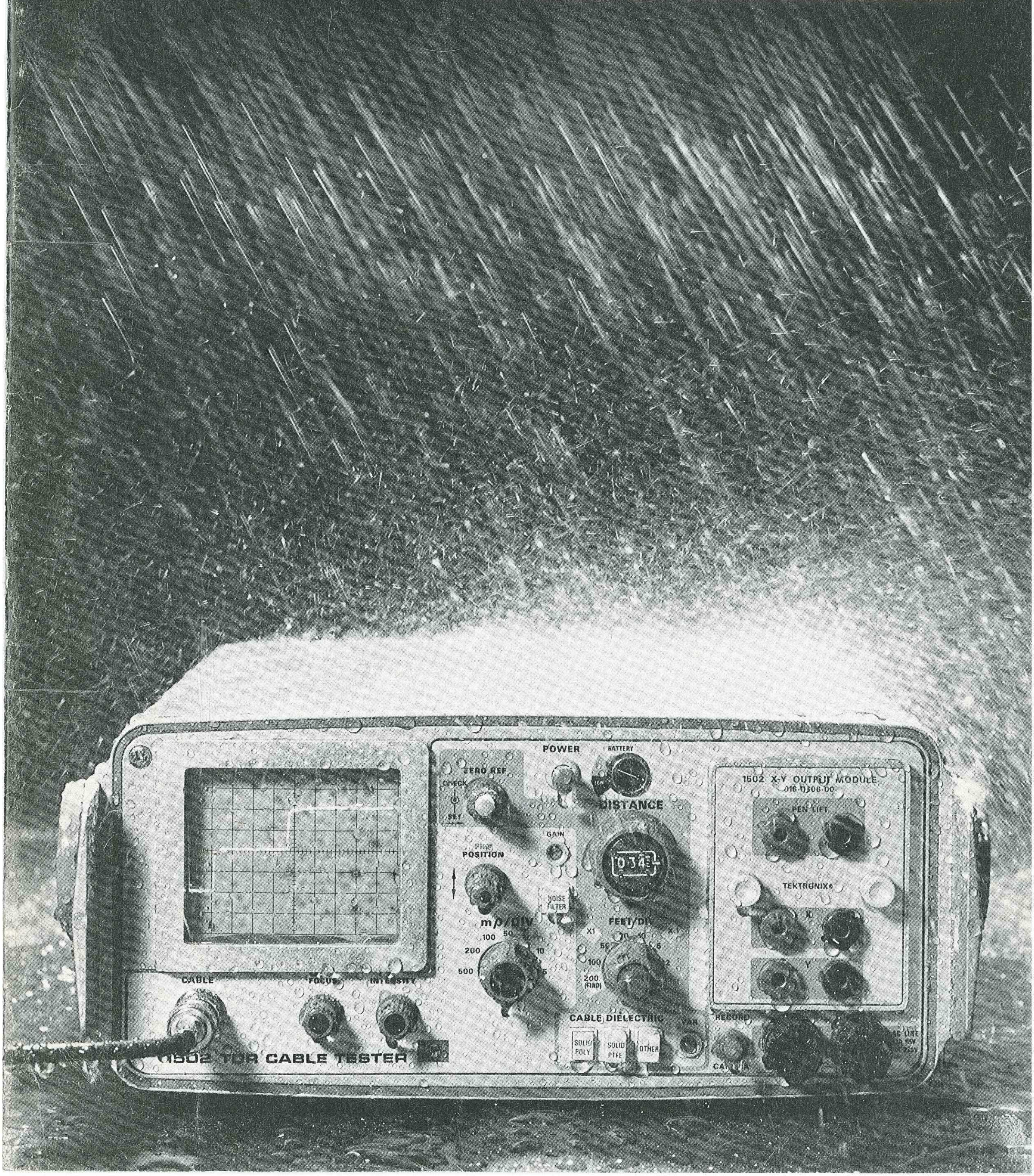

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TEKSCOPE

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Beaverton, Oregon 97077

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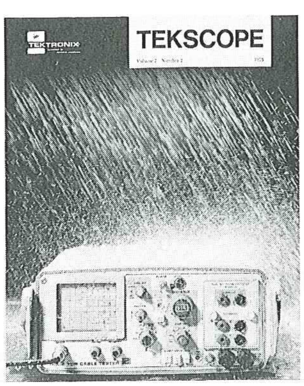
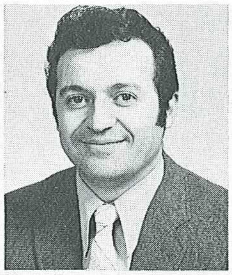
Cover: We hope you won't have to work on cables under the conditions shown on the cover. But if you do, the 1502 and 1503 TDR cable testers will work right with you. And they won't need an umbrella or a rain coat.





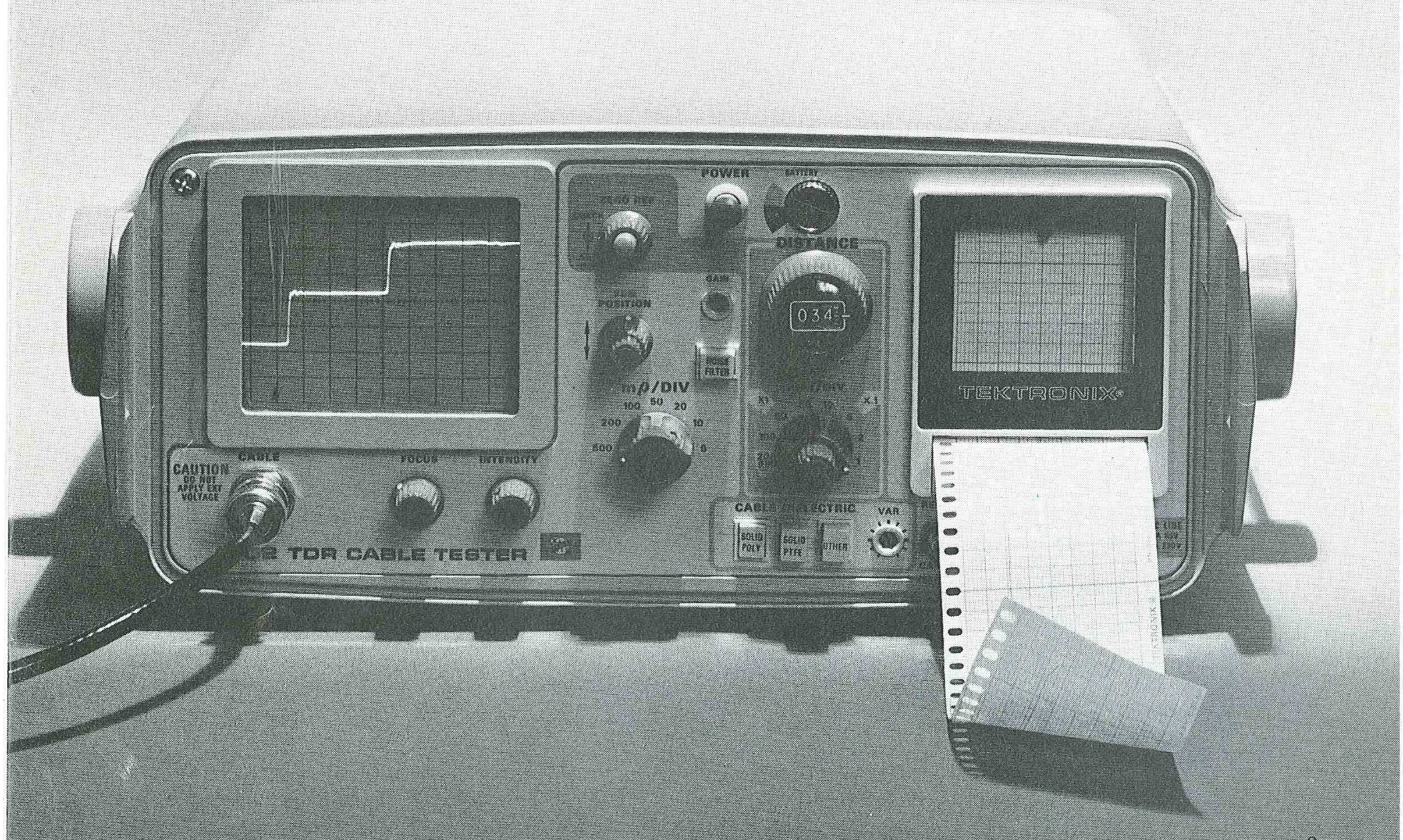
Ivan Ivanov

Two weatherproof TDR cable testers for field use

Electrical transmission lines and cables go most everywhere. You see them on poles and towers and coming out of the wall. But mostly they are out of sight. Like the arteries and capillaries that carry blood to our body cells they lace our cities, ships and airplanes and keep the parts perking, healthy and unified. Some are more vital and critical than others. Some have to be carefully placed and cared for. Others need to be fixed only when they fail. But whether you are testing a new installation, guarding against deterioration, or finding a fault, the need for quick, simple diagnostic cable testing is the same. Here is the story of the development of two new state-of-the-art TDR Cable Testers for the field.

Why two testers

The need for a high resolution (100 ps to 150 ps risetime) battery operated, portable TDR cable tester of moderate price was recognized shortly after introducing the 1501 TDR for the CATV market in 1971. Market studies then also showed the need for a portable TDR tester for lines longer than 2000 feet, where 150 ps risetime is too fast for their bandwidth. Therefore, we developed two reflectometers at the same time . . . the 1502 for high resolution and the 1503 for long range. The two instruments resemble each other physically but have some important electrical performance differences.



Exceptional ruggedness and complete protection from bad weather are vitally important in the field. The 1502 and 1503 are both designed to be operated outdoors in the worst kind of weather . . . wind, rain, sleet, snow, ocean spray, or dust storms.

For guidelines on safety, ruggedness and weatherproofing, we used the detailed criteria in a U.L. Safety Standard and in the new US Military document MIL-T-28800A for Type II, Class 2, Style A Test Equipment. Equipment of that Type, Class, and Style qualify for use on aircraft flight lines, for example, and, incidentally, aircraft cable testing is one of the foremost applications for the 1502. The 1503, mechanically equivalent to the 1502, is primarily for testing telephone lines and communications cabling. Both reflectometers meet practically all of the requirements specified in MIL-T-28800A. The table to the right is extracted from that document to show the requirements specified for Class 2, Style A Test Equipment.

The weatherproof package

Style A instruments are ones which have a case that serves for storage and shipment, as well as adverse environments. Called a combination case, it has to be very rugged to withstand all kinds of weather and the shocks of rough handling and shipment. What material is best for such a case? After careful consideration of various metals and plastics, CYCOLOY KHP® plastic was chosen. That material is 41% ABS plastic and 59% polycarbonate. It combines the outstanding strength and resilience characteristics of ABS, with the flame retardant characteristics of some polycarbonates. Although MIL-T-28800A does not specifically require the case material to be flame retardant, a consciousness of UL safety standards convinced us of the value. The main thing favoring a metal case was that it is a good shield against electro-magnetic interference, either due to radiation from the Reflectometer or radiation into it. But that problem was solved by using metal shielding around the chassis and frame of the instrument, inside the plastic case. Both the 1502 and 1503 meet the Electromagnetic compatability requirements of MIL-T-28800A.

To operate either Reflectometer you must remove the watertight cover. Two easily operated, spring loaded, over-center latches are built into a recess in the cover. They engage notches on the inside of two front panel knob-protecting guards that are part of the front panel casting. The latches, being recessed, can't be accidentally released. When snapped into place, the cover makes a water-tight pressure seal against the panel with a gasket surrounding the edge of the cover. When unsnapped, the cover contains useful accessories for operation and a small, waterproof, operator's manual. These items are kept secure by a hinged door and latch inside the cover. The cover matches the one-piece case and is made of the same material. The cover and case form the entire enclosure for the waterproof instrument. Four screws attach the case to the instrument chassis and hold pressure against the seal on the back side of the front sub-panel. The one-piece, metal handle is attached to the sides of the case by adjustable allen-screws that apply smooth, friction-loaded pressure so the handle may be used as a tiltable support. It also lets you rotate the handles out of the way for stacking several instruments.

CLASS 2 REQUIREMENTS		1502/1503 PERFORMANCE
Temperature Non-operating (degrees Celsius)	—62 to 85	Same; batteries excepted.
Temperature, Operating (degrees Celsius) at Relative Humidity to 100%	—40 to 55 (Portable: —15 to 55)	Same; battery hours reduced at extremes
Altitude Non-operating	50,000 ft.	Same
Altitude Operating	10,000 ft.	Same
Vibration Limits (Maximum)	3g	Same
Minimum Vibration Test Time/Axis	45 min.	Same
Shock, Pulse (Level)	15g	Same
(Test Shocks)	18	Same
Bench Handling	Yes	Same
Crash Safety (Mounting Base)	N/A	Same
Fungus Inert Material	Yes	Same
Salt Atmosphere Structural Parts	Yes	Same
Explosive Atmosphere	Yes	Same
Sand and Dust Resistance	Yes	Same

STYLE A REQUIREMENTS		1502/1503 PERFORMANCE
Transit Drop	30 inches	12 inches
Watertight (3 feet)	Cover On	Same
Splashproof	Cover Off	Same*
Dripproof	Cover Off	Same*
Salt Atmosphere Exposure Salt Solution	48 hours 20 Percent	Same Same
Sand and Dust Resistance	Yes	Same*

*Not with optional chart recorder

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Battery pack pocket

Because the 1502 and 1503 are battery-operated there will be occasions when continuous use for more than 6 hours requires substituting a fresh battery pack for one that is discharged. A discharged battery pack is easily removed by loosening two thumb screws on the rear of the case and unplugging the entire pack. The battery compartment is an integral part of the plastic case, a waterproof pocket that contains the entire pack and isolates the instrument circuitry against the possibility of contamination from chemicals leaking from defective cells. When plugged-in, with the thumb screws tightened, the battery pack is isolated from the weather by a waterproof seal.

Putting the battery pack in its own pocket posed a problem to calibration and maintenance people, however. How do you power the instrument with the case off? Although the reflectometers may be operated from AC line voltage, the battery pack is used for filtering rectified voltage so it must be connected. The problem was solved without requiring a special adapter cable by making the cabinet pocket connectors a feed-through type with plugs on one side and matching receptacles on the other. That way the chassis mounted connectors have the correct spacing, style, and sex to mate directly with the battery pack connectors. Standard banana plugs and jacks were combined and used to maintain watertight integrity.

An identical problem applies to the power cord receptacle. You would like to be able to power your instrument with the case off, using the same power cord as stored in the front cover. A special feed-through power cord receptable-and-plug was designed and mounted in the rear of the case.

Prepared for the worst

With the front cover off, a 1502 or 1503 is ready to go to work. But it may have to work in the rain and wind without water getting inside, so all front panel openings had to be sealed. Some special seals were developed for the push-buttons, crt, and power switch shaft, but conventional commercial seals were available for the rotary controls. The POWER switch must be pulled to turn the instrument on and pushed to turn it off. The instrument is totally sealed by attaching the front panel cover, and that automatically turns the power off by pushing the switch in. Good waterproofing measures keep sand and dust out with no additional attention.

Portable maintenance equipment has to withstand inhuman treatment and the MIL-T-28800A test sequence required the instrument to maintain its water tight properties after being subjected to a sequence of 26 twelve-inch drops.

The main problem withstanding drops was supporting the crt. At no point is it rigidly connected to the chassis. Instead, its faceplate is forced against a silicone-

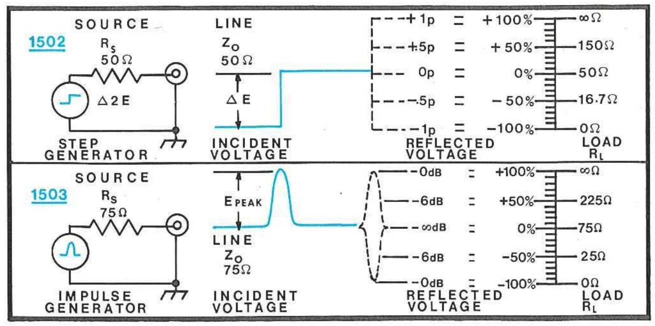


Fig. 1. Test signals generated by the 1502 and 1503 and how reflections are measured and expressed.

rubber cushion by pressure against a thick cushion at its base. The crt neck is protected against lateral shock by a doughnut-shaped plastic piece supporting it. A weak point in the crt gun structure itself was discovered and corrected while conducting the drop tests. The bench handling drop tests were mild compared to the other drop tests. Now let's take a look at some of the measurement capabilities of the 1502 and 1503.

1502 . . . widest bandwidth battery-operated portable TDR

The step-pulses generated in a 1502 have the shortest risetime of any known battery-operated portable TDR. And the bandwidth of the instrument is greater than any other portable TDR. The displayed risetime of a (nearby) reflection is 140 ps or less and that defines the limit of distance resolution. Since transmitted pulses propagate at a rate close to 1.5 ns per foot in cable having a dielectric of solid polyethelene, it takes 3 ns to go one foot and return, or 300 ps to go 0.1 foot and return. The shortest distance scale on the 1502 is 0.1 foot per division so the scales and the bandwidth are adequate to accurately diagnose all cable faults and imperfections that are not so distant that they are masked by high frequency attenuation of the cable itself. Faults separated by as little as 0.6 inches can be resolved over short distances.

Common cable faults are opens, shorts, kinks, frayed shielding, poor splices, bad connectors, wrong impedance cable, water soaked sections, defective loads, etc. The 1502 lets you examine up to 101 feet of cable at 0.1 foot per division or up to 1010 feet at 1 foot per division. To get a preview of where to look for a fault, the FIND position of the FEET/DIV switch lets you see a full 2000 feet at one time. Optional models of the 1502 may be ordered that are calibrated in METERS/DIV.

The vertical scale of the 1502 is calibrated in dimensionless units that correspond to the ratio of the amplitude of the reflected signal to that of the test pulse. The Greek letter ρ (Rho) represents the fractions. The knob that controls the vertical scale is labeled mρ/DIV (millirho per division) rather than ρ/DIV so the units may be whole numbers. The seven position switch goes from

500 mρ/DIV to 5 mρ/div, covering a 100 to 1 difference in sensitivity.

1503 . . . long range impulse TDR

Time Domain Reflectometers use step-signals, impulse signals, or bursts of RF sinewaves. Step-signals have signal components covering the widest bandwidth and, therefore, offer the best diagnostic stimulus to a fault for responses in graphic form. But long lines typically attenuate high frequency components so much that high peak power must be transmitted or the attenuated reflections will be buried in noise. Step-signals with high peak power suitable for testing very long lines require such high average power that a light, portable TDR cannot be operated very long without discharging the battery pack. For this reason and others, narrow half-sine shaped pulses (impulses) are generated in the 1503 and applied to the transmission line being tested. You have a choice of 10 ns, 100 ns or 1 μs impulse width.

Narrow pulses are attenuated more than wide pulses over a given length of transmission line, so wide pulses are used where narrow pulses would be attenuated too much. Very long transmission lines usually call for use of the wider pulses. Fortunately the accuracy of fault location is not significantly degraded by use of wider pulses as long as the width is only a very small percentage of the two way propagation time of the distance measured. Somewhat shorter but lossier lines, like twisted pair phone lines, may also require the wider pulses.

Impulse return loss

Sinewaves of a given frequency are attenuated by a predictable amount in a given type of transmission line. Such losses are usually expressed in dB per unit distance, as dB/100 ft. That figure lets you easily calculate how much signal amplitude to expect at any point along the cable and how much a reflection will be attenuated before arriving back at the input, knowing only the kind of cable. Impulses of controlled width and shape are also attenuated by a predictable amount, although calculating the amount is not as simple as for a single-frequency sinewave. Use of a table or graph corresponding to the kind of cable and the character of the impulse is a practical solution. Any signal energy that gets reflected back doesn't have the opportunity to go directly through, so is "lost" by being returned. Since reflectometers indicate reflected energy it has become common practice to express the relative magnitude of such reflections in terms of dB of Return Loss. You should keep in mind, however, the distinction between the measured amplitude of a reflection and the original amplitude of that reflection. Reflections undergo attenuation coming back to the signal source the same as the original signal is attenuated going down the cable.

Impulse amplitude in the 1503 is 5 volts into a transmission line having an impedance that matches the selected source impedance of the 1503. A choice of 50, 75, 93, or 125 ohms is selected by pushbuttons on the front panel. In some applications such as testing long antenna cables, where RF pickup may be very large, the 1503 may be used in place of the 1502 because the high amplitude pulse helps override the stray pickup. Also the input circuits of the 1503 are protected from most accidentally introduced external signals of high amplitude.

Set your own zero reference

The multi-turn DISTANCE dial on the 1502 and 1503 has 3-digit readout, with four graduated divisions between the digits of the least significant row of digits. Distance measurements made with this dial are like differential time measurements made with the multi-turn delay time dial on some oscilloscopes. However, the dial can be set to zero (000) and the zero-distance reference point in the TDR waveform positioned to the desired graticule line on the crt. The ZERO REF SET control is used for that purpose. It is especially handy for making distance measurements that begin at the end of an interconnecting test cable instead of at the CABLE connector on the front panel of the reflectometer. In other words, distance measurements don't have to start where the TDR pulses emerge from the reflectometer, they can start where the pulses emerge from the output end of a patch cable and enter the cable being tested. That way the propagation velocity of the patch cable doesn't need to match that of the cable or transmission line being tested. Nor do you need to remember to subtract its length from the distance measured. The impedance of the patch cable should match that of the cable being tested, however.

To complete the measurement, the DISTANCE dial is rotated until the fault or imperfection of interest moves to the selected graticule reference line. Then the distance to the fault is indicated directly by the numbers on the dial. The decimal point position for the indicated distance will depend on which multiplier and scale is used.

Zero reference check—something new

The multi-turn DISTANCE dial really doesn't have to be set at 000 before positioning the starting point in the TDR waveform to the reference graticule line. Pushing the ZERO REF CHECK button does the same thing as setting the dial to 000. If you think you may have bumped a knob or changed the setting of the FEET/DIV switch since positioning the beginning point to the reference line, or don't remember for sure which graticule line was chosen for reference, you only need to push the ZERO REF button to be sure. Should there be an error it may be corrected while the button is pressed, rather than rotating the multi-turn dial all the way back to 000.

Chart recordings, easier, easiest

What may be viewed on the screen of the 1502 or 1503, may be easily and inexpensively recorded by an optional plug-in strip chart recorder. Or an external X-Y recorder may be used.

The standard plug-in module supplied with a 1502 or 1503 supplies standard amplitude X and Y deflection signals and a pen-lift signal to drive an external commercial X-Y recorder. But the simplest way to make a recording is with the plug-in strip chart recorder. No skill is required, no external equipment is required, and the cost of a recording is less than that of a photograph. Any time the condition of a cable should be documented on the scene, this recorder is recommended. A strip chart 4 cm wide by 25 cm long is available in about 20 seconds after moving the RECORD-CAMERA switch to the RECORD position.

In the optional strip chart recorder the duration of the scan is automatically adjusted to correspond with the speed of the paper. The recorder makes a momentary pause while the stylus heats up, counts holes in the edge of the paper to adjust the crt beam scan speed, turns off the stylus heat when the right number of holes pass a photo-cell, turns off the paper drive motor when the chart has completely emerged from the recorder, and electrically brakes the motor so it stops in the right position to draw the next graph.

CRT phosphor flooded for taking pictures

It is important for some customers to take pictures of TDR "signatures" of cables and terminations in good condition. That is so they may prepare documented instructions on how to recognize faults and gradual deteriorations for technicians using the 1502 and 1503. But the power required to edge-light the crt graticule for photographing is excessive in some battery operated portable instruments. Total operating power required by the 1502 and 1503 is only 2.5 watts, one third of the power of one small Christmas tree bulb! So a new idea was perfected—flood the crt phosphor during retrace instead of blanking the crt beam. By gating on a high frequency oscillator connected to the vertical deflection circuits, and controlling the retrace speed, all the phosphor crystals on the entire crt screen may be excited by the one crt writing beam during retrace. The effect is to illuminate the phosphor so the parallax-free internal graticule lines stand out in good contrast. A three-position toggle switch on the front panel, labeled CAMERA in one position, selects that mode of operation. An optional camera bezel adapter accommodates the TEKTRONIX C30A oscilloscope camera.

Low amperes, long hours

Several techniques were used to extend the battery operating time. Using sampling principles conserves power because the fast, wideband circuits are operating only a small portion of the time and low bandwidth circuits generally don't require much power. Extensive low power CMOS IC technology was used in the design. In addition current for the circuits requiring high peak power is turned off most of the time and turned on only shortly before being required each sampling cycle. That helps reduce power requirements further. The 1502 and 1503 will operate on batteries for at least 5 hours, including twenty strip charts.

Battery pack protection

Nine rechargeable size C cells are connected in series to make the battery pack. Complete discharge of any one of the cells in a series-connected pack can be a serious problem because further discharge of the other cells tends to reverse the polarity of the charge for the weakest cell and ruins it. Then, because there is no practical way to replace one cell at a time in a battery pack, the whole pack must be replaced. That is expensive. To protect the battery pack, a voltage-sensing circuit automatically switches power off when the battery pack voltage drops below a safe level. A battery charge meter on the front panel gives you an indication of when the charge level is getting low.

In summary

Design of the 1502 and 1503 Time Domain Reflectometers combined several divergent fields of highly technical expertise to provide practical, rugged, exceptionally easy to use instruments capable of coping with the installation and maintenance problems of a vastly increasing number of cables and transmission lines. The designs have been completed after extensive consultation with some of the most knowledgeable of our potential customers.

Acknowledgments

Packaging the 1502 and 1503 so they would be very rugged and waterproof was a pioneering enterprise led by Darrel Pfeifer, mechanical design, with help mainly from Larry Tucker and Brent Anderson. Circuit layout and prototype support, with all the repeated revisions, were patiently provided by Bob Culver and Lena McIntosh. Bob Conchin and Dean Hager chased production evaluation and coordination problems with their special but different ways of unraveling knots and tying up loose ends. Jack Piercy did our documentation and manual writing. Special credit should go to Hans Geerling, presently on leave of absence, who did most of the circuit design on the 1502. Our various trials in completing the project have been matched by good humor and hard work at every turn.

Ivan Ivanov
Project Engineer

R. Michael Johnson

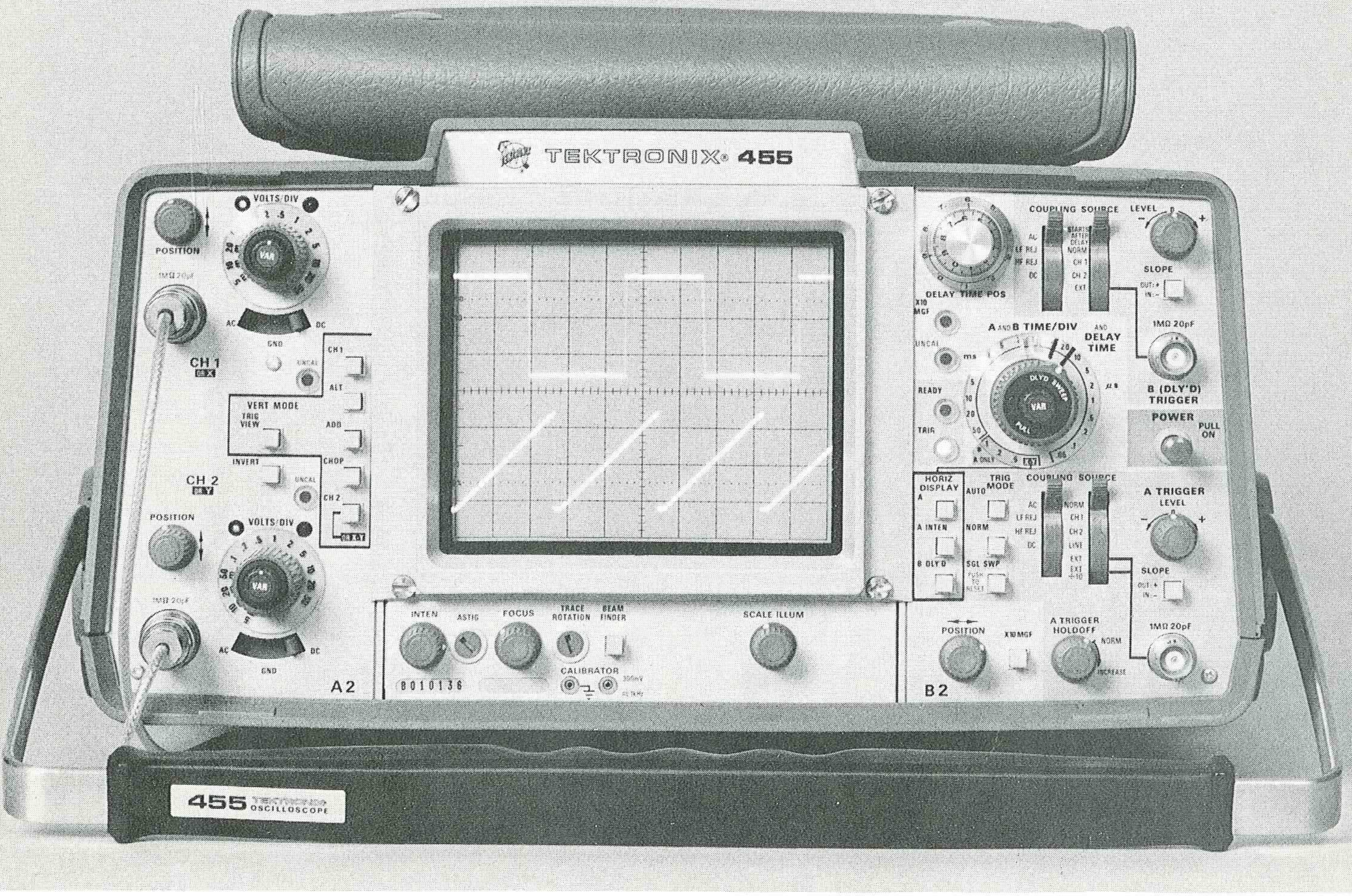
A new 50-MHz oscilloscope

New things should be exciting. But what can be exciting about a 50-MHz oscilloscope — we've had this measurement capability for a long time. Removing the cabinet from the TEKTRONIX 455 uncovers much that's new, and much that is exciting when we consider the impact on the 455 and instruments that will follow.

From an exterior viewpoint, the all-plastic cabinet, and its shape, is new to the 400-series portables. The contoured design and tough, glass-filled, shock resistant plastic result in a light, exceptionally rugged case. The material is CYCOLOY KHP®, the same as that used in the field-proven 200-Series instruments.

While newness is exciting, some things are better left unchanged — front panel layout, for instance. The controls on the 455 are just where you find them on the popular wider-bandwidth 465 and 475 oscilloscopes. There are some subtle changes, such as smaller pushbuttons, giving the front panel a more open appearance. Included are the same operating conveniences found on the wider bandwidth portables — automatic indication of the deflection factor, whether the signal is applied directly or through a 10X probe, and the ability to view the external trigger signal simply by pressing a front-panel pushbutton.

The vertical and horizontal sections look as though they may be plug-ins. They are not. Rather, they are bolt-in modules for ease in manufacturing and servicing. Both result in lower cost for you.



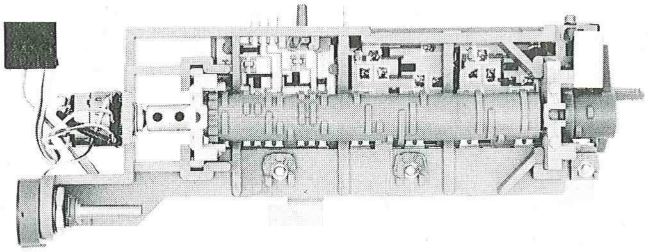


Fig. 1. Vertical attenuator switch used in the 455. Two-piece plastic frame and laser-trimmed thick-film attenuator resistors greatly reduce assembly and test time.

It may be appropriate at this point to discuss the 455 design goals. The key target was to build a quality 50-MHz portable oscilloscope at minimum cost. Serviceability was high on the list of priorities. Two major alternatives were available: 1) use existing components from wider-bandwidth instruments, thereby shortening engineering time but increasing component cost, and 2) design new components specifically for the 50-MHz bandwidth. The latter approach was adopted with one major exception — the cathode ray tube is the same as that used in the 465. Newly designed, the crt offered little room for improvement in cost savings.

The vertical section

Wideband attenuators are typically difficult and expensive to build. Here was a prime candidate for attention. The vertical attenuator assembly in the 455 is radically different from that used in other TEKTRONIX instruments. The actuator assembly, contacts, and attenuator components are mounted in a two-piece molded plastic frame. The attenuator components are assembled on two ceramic substrates. One substrate contains the 1X, 10X and 100X attenuators; the other, two 2X gain-switching attenuators. The attenuator resistors are thick-film, laser trimmed to the precise attenuation ratio. Using the new construction techniques, assembly and calibration time is reduced substantially, and the ability to service the attenuator once it is installed in the instrument is greatly enhanced. The ten-step attenuator provides calibrated deflection factors from 5 mV to 5 V per division in a 1-2-5 sequence. The two vertical channels can be cascaded by feeding the output of channel 2 into channel 1, giving a sensitivity of 1 mV/div at 20 MHz bandwidth.

A glance at the vertical amplifier section reveals a large ceramic substrate (1" x 1.5") and relatively few discrete components. The substrate is a hybrid containing twenty thick-film resistors and two chips comprising about 60% of the vertical amplifier circuitry. Both vertical channels are accommodated on the single substrate. Channel switching, variable gain, and positioning circuitry are located on the substrate, with the switching logic supplied external to the hybrid.

In addition to providing these functions, the hybrid provides an output signal of 0.4 mA/div to the delay

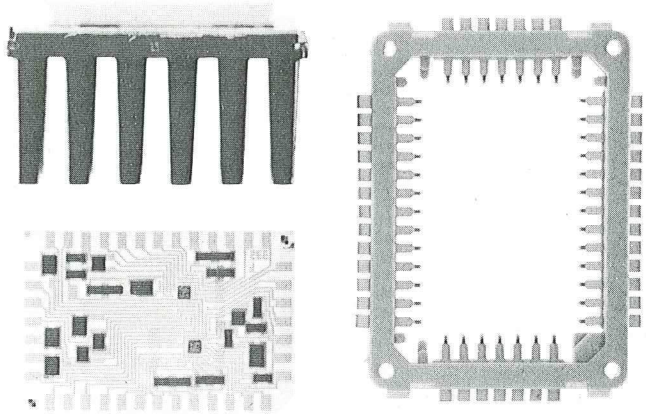


Fig. 2. The hybrid at lower left contains about 60% of the 455 vertical amplifier circuitry. At top left is the completed package. The 40-pin mounting socket is at right.

line driver transistors, and a 50 mV/div trigger output signal from each channel. It is interesting to note that a dc level change of only 3 volts occurs between the input and output of the hybrid. It is powered by +5 volts and −5 volts, and consumes about 2 watts. Thermal dissipation is accomplished by an aluminum multi-spoked heat sink bonded to the hybrid. The spoke design assures adequate cooling regardless of the scope's position.

Some of the techniques used in manufacturing the hybrid are of interest. High-frequency processes are used to achieve a clean amplifier response without the need for numerous peaking adjustments. After the chips are mounted on the substrate, the unit goes through a series of burn-in cycles to stabilize the circuitry and weed out marginal units. Following this operation, laser trimming is performed to match channel gains to within 0.5 per cent. Trimming takes place with power applied to the hybrid, eliminating time-consuming trial and error.

With the increasing popularity of integrated circuits one may logically ask, "Why isn't the entire vertical integrated?" It could be. But it would not be compatible with the design goals for the 455. Some circuits are difficult to fabricate with current processes, hence expensive. Providing optimum performance at minimum cost dictated the use of discretes for some portions of the circuitry such as the FET input source followers and the output amplifier.

The horizontal section

The horizontal section consists of five circuit boards: one each for trigger, sweep, horizontal, time base A, and time base B. The boards interconnect directly without the need for cabling.

Several new components are used in this section. Most prominent is the new timing switch (Fig. 3). The timing boards for time bases A and B are integral parts of the switch. The actuator is mounted between the two boards, with the entire assembly removable as a unit. Accessibility to all of the timing components is excellent even with the switch in place.

Four new integrated circuits were developed for the horizontal section: trigger, sweep control, sweep generator and horizontal preamplifier. Identical units are used for both time bases, with slight variations in function for delayed sweep operation. The Miller integrator uses discrete dual FET's in a run-down configuration. The horizontal preamplifier IC converts the sweep to push-pull signals and provides the X10 magnifier and positioning circuitry. The horizontal output amplifier, located in the main module, provides the final signal amplification to drive the horizontal deflection plates.

Twenty-two calibrated sweep rates for time base A range from 0.5 s/div to 0.05 μs/div in a 1-2-5 sequence. Time base B ranges from 50 ms/div to 0.05 μs/div in nineteen steps. The X10 magnifier extends both sweeps to 5 ns/div.

The power supplies

The low-voltage power supply provides three of the regulated low-voltage sources (+5 volts, −5 volts, +32 volts) used to operate the main, vertical and horizontal modules. High-gain amplifier cells with differential inputs monitor variations in the output voltages and provide correction signals to the series regulating transistors. Short-circuit protection is provided for each of the supplies. A fourth low-voltage supply (+95V) is produced in the crt circuit.

The crt circuit contains the Z-axis circuitry, crt intensity, focus and astigmatism controls, and high-voltage supply. A unique high-efficiency type supply is used to generate the high voltage. Energy from the unregulated +32 volt supply is stored in an inductor during a portion of the oscillator cycle, and then discharged into the primary of the high-voltage transformer later in the cycle. The supply operates at the resonant frequency of the high-voltage transformer, which is about 45 kHz. Accelerating voltage is 12 kV, providing a bright trace even when the faster sweeps are running at a low rep rate.

An available option includes a dc to ac inverter permitting operation from either a 12 or 24 volt dc source, such as the TEKTRONIX 1106, or from standard ac line voltages.

Mechanical innovations

Much of what's new and exciting in the 455 is the result of mechanical innovation. The vertical attenuator, timing, and trigger switches were designed to minimize production and assembly time, and maximize serviceability. The modular construction also simplifies assembly, testing, and servicing. The seven printed circuit boards comprising the entire unit interconnect directly, eliminating extensive cabling. As a convenience in servicing, extender cables are available for remoting the horizontal and vertical sections. Ready

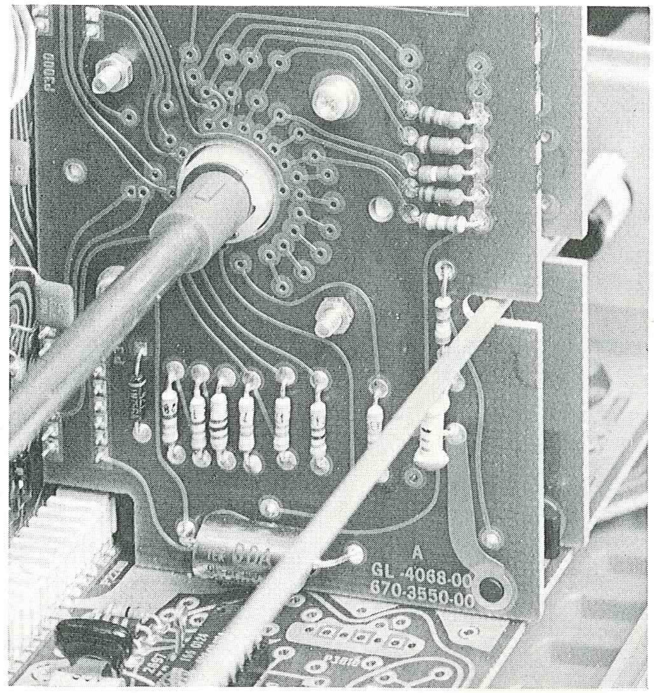


Fig. 4. The timing boards for both time bases form an integral part of the TIME/DIV switch.

access to the power supplies is provided by removing just four rear-panel screws.

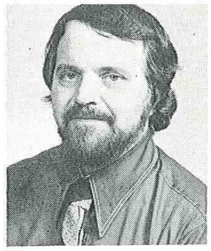
Modularity was even extended to the 10X attenuator probes supplied with the 455. The probe body, cable, and attenuator box are separate assemblies that plug together. Accidentally yanking the probe cable causes no damage. The probe tip, often damaged from extensive use, is easily replaced without disassembling the probe body, or use of a soldering iron.

These, and other innovations in the 455, are the result of an intensive engineering effort to provide you with state-of-the-art 50-MHz measurement capability at the lowest possible cost. We are pleased with the results and confident you will be, too.

Acknowledgements

Encouragement and direction were provided by Leon Orchard. Electrical design was done by Jim Woo, George Reis, and Ken Holland, vertical; Jim Godwin, Larry Gagliani, and Al Schamel, horizontal; Walt Strand and Dennis Bratz, low voltage and crt circuit. Mechanical design leader was Glen Sorum with contributions from Bob Leith, Bill Cottingham, Len McCracken, Dave Curtis, Dave Hargis, Scott Long, and Ric Meyer. Al Hill and Jerry Wrisley were the industrial designers. Pat Simonson constructed numerous prototype instruments and kept the parts list correct. George Ermini and Dennis Fuhrman evaluated the instrument.

Many other people deserve to be mentioned. They know who they are. Unfortunately space is limited, so to all of you I say thank you and congratulations on a job well done. — **Bob Johnson, Project Manager**



Dick Brown

The TM 500 mobile test lab

In 1949 Tektronix designed and offered the first Scope-Mobile®, our registered trade name for a mobile cart for oscilloscopes. It was an instant success. Later models have a tilt-top, making them convenient to use whether you are sitting or standing. They are functional, rugged, and good-looking. We are proud to say they have been almost universally preferred to other makes and are probably the most widely used kind of cart made especially for electronic test instruments. Scope-Mobiles have a historical significance in the development of the TM 500 Mobile Test Lab.

The right kind of mobile cart does more for you than you might imagine. Even if you have used a Scope-Mobile, and like it, you may not have stopped to consider all the benefits. Let's take a look at a few. Keep in mind that what the right kind of cart can do for a scope it can do for other test instruments.

Bench space savings is fairly obvious. Any instrument you can wheel up to your bench you can power while still on wheels. But a cart is an extra bench that doesn't take *extra* floor space permanently. It won't crowd you except when you want to be surrounded by your work. Properly barricaded you can even avoid some of the friendly conversation that interrupts you when you least want to be. And it's easy to wheel the cart out of the way when you don't need it.

A mobile test bench

When you can't bring the work to your bench a mobile cart lets you bring the bench to the work. There are numerous instances when you would like to test somebody's work with your own instruments, even if inspecting is not your job. Maybe you're uncomfortable with someone's conclusions, diagnosis or test methods. They won't think kindly of any challenge that requires direct substitution of your instruments for theirs. A side-by-side comparison is more tactful, more scientific and more convincing.

Sometimes there is little or no choice about taking your instruments to the job. The job may be to test an X-ray machine that is bolted to the floor. Small, portable instruments usually come to mind in that situation. But if the job is within your own plant, laboratory, or institution, instruments on wheels may be more practical. You may find no bench or table available otherwise. And what if you need more instruments than you can carry in both hands?

Borrowed instruments return

Borrowed instruments come back quicker when they have wheels. Ever notice that when a cart seems a part of the instrument the two tend to stay together? People don't ask to borrow merely your cart. When they borrow the instrument, the cart goes with it, naturally. Now when somebody needs to borrow your instrument he needs it, and he would gladly tote it away himself if

Fig. 1. A TM 500 Mobile Test Lab is pictured at right being used to service an automatic component insertion machine. The lab includes a storage oscilloscope, DMM, counter, function generator, pulse generator, power supply and digital delay unit.

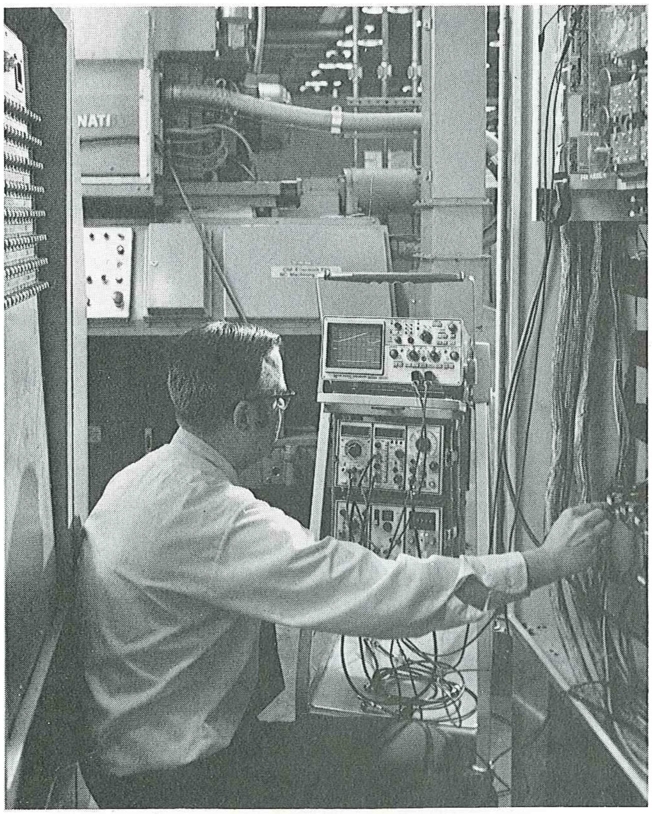


Fig. 2. Checking out a sophisticated machine control unit, using a TM 500 Mobile Test Lab.

necessary. But what about bringing it back? He never has a need to bring it back; and if that is inconvenient you may hit a snag getting it back when you need it. You are much more likely to get your instrument back as soon as his need is satisfied if it has wheels.

A mobile test lab

If you know the benefits of a Scope-Mobile you can readily understand the significance of a compact *laboratory* on wheels, having only one power cord and a built-in way of minimizing test cable clutter. For years many of our customers have designed their own mobile test labs using TEKTRONIX Scope-Mobiles. Now, with the TM 500, we can offer a whole series of plug-in test and measurement instruments that work together neatly on wheels as well as bench tops. The importance of this idea, when it embodies precisely the capabilities you have needed but couldn't afford in a customized mobile test lab, is just now becoming fully apparent. The concept is enthusiastically welcomed by a wide base of customers. They are telling us, in a spirit of discovery, how much they like what they see, how much they use what they buy.

A TM 500 Mobile Test Lab looks like an ordinary Scope-Mobile with a bunch of spare plug-ins suspended from the tilt-top tray, a familiar sight. But a closer look reveals (1) that the plug-ins don't even work in a scope, (2) that the plug-ins are basically separate, independent instruments that merely share the same mainframe and regulated DC supplies, (3) that they will work together with internal patch cords as well as front panel jumper cables to reduce test-lead confusion and clutter, and (4) that the whole mobile lab, including an oscilloscope, will operate from one AC power outlet. An available option permits coupling signals between plug-ins located in separate power mainframes, via rear-panel connectors.

Some people who need a mobile lab have given up on the idea because the variety of instruments they require is so great they don't believe they could put them all together and have a system small enough to wheel about. The small size and big variety of the TM 500 series of test instruments will surprise you. There are over 25 plug-ins to choose from at present, including signal generators, amplifiers, counters, timers, multimeters and a do-it-yourself plug-in chassis. We know we won't be able to supply every "widget" some people can't do without. And if you need a "widget" custom-designed, your designer will be far ahead by having the hardware and the DC supply voltages he needs, at the outset. The rest of the design will be the most fun for him, so you can expect quicker results as well as lower cost. Speaking of costs—the modular idea behind the TM 500 plug-ins is like that two edged sword: one edge lets you do your job better, the other edge cuts our costs so we can cut your costs.

You may need a mobile test lab if you are involved with any of the following:

- Maintenance or calibration of equipment that can't be moved
- Verification of performance of equipment that can't be spared
- Production check-out of equipment on the floor
- Quality assurance at the other fellow's station
- Process control equipment that's all over the place
- Presently toting or carting armloads of miscellaneous instruments with you

A mobile medical system

A good example of a TM 500 Mobile Test Lab is one called MICS, a Medical Instrumentation Calibration System. See Figure 3. This system is ideal for the maintenance and calibration of various medical instruments found in hospitals. These include Electrocardiographs and Electrocardiographic Monitoring Systems, Coronary Resuscitation Carts, Diagnostic X-ray Systems, Infant Incubators, Electrocautery, and Diathermy Equipment.

In the six slots that are part of the two TM 503 mainframes there is a multimeter, time-mark generator, counter, function generator, ramp generator and a differential amplifier. On the tilt-top tray is a storage oscilloscope. This particular set of instruments has been carefully selected to meet the requirements of a large number of hospitals, but variations are easy to make.

An industrial mobile system

Consider another example — final assembly and test checkout of large equipment on the production floor. Here is a typical picture: A manufacturer of computer peripherals has a large production area with twenty or thirty pieces of equipment being built in place, with one or two technicians assigned to each station. A few oscilloscopes on Scope-Mobiles are already being shared between different stations. Some counters, digital multimeters, generators, etc., that you can't afford to have at every station are also shared. Where do you put them? You may stack them on top of the equipment, then on top of each other where they sometimes get bumped, fall and break. Or you may put them on the floor where you kick them, stumble over the power cords, or have to stretch the test leads to make your hook-up. Test leads get intermittent that way. Or maybe you have to unplug several pieces of equipment to find all the AC outlets you need, and turn off somebody else's equipment by mistake in the middle of a test. Not being able to distinguish between the equipment which is purchased to be shared and that which goes with each station, questions will arise about who owns which instrument and whose job it is to keep the instrument in good condition. The mobile test lab straightens out such disorder.

A large variety of combinations of instruments can be selected to make up a TM 500 Mobile Test Lab. Selecting the right combination for a given requirement takes a little thought, but not nearly as much as if you had to specify the entire requirements for a customized mobile lab. Free assistance in making such a selection is available from your Tektronix Field Engineer or Representative.

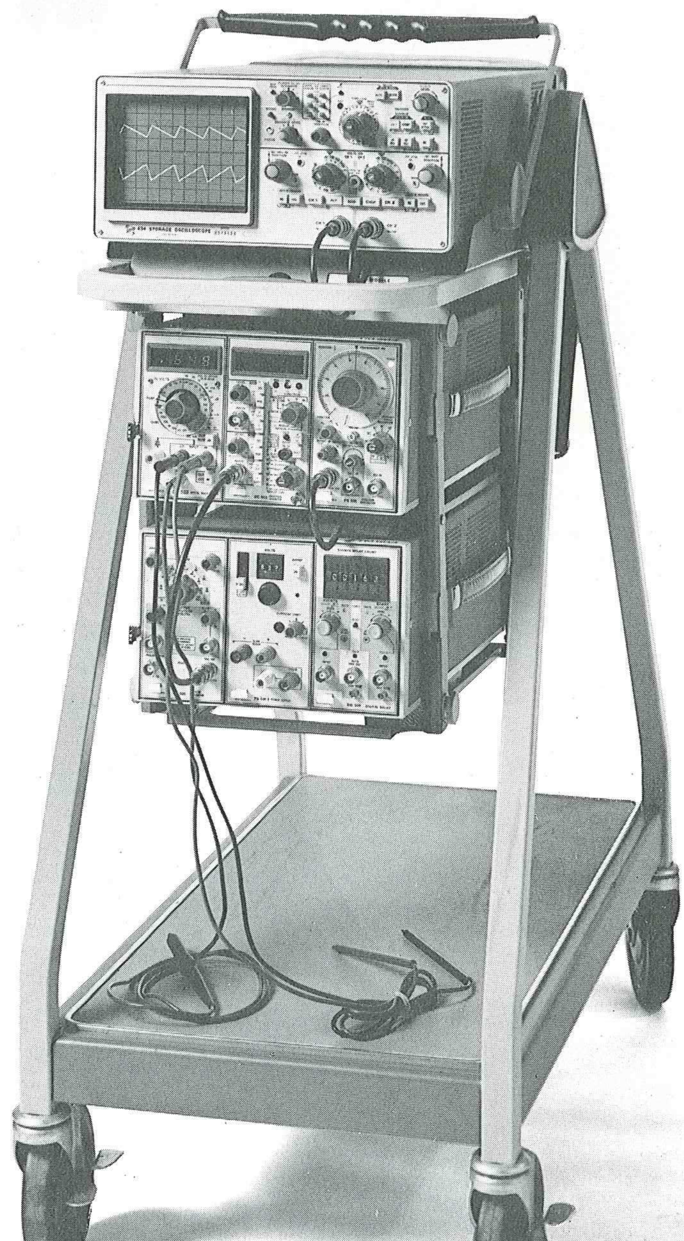


Fig. 3. Pictured at right is the TM 500 Medical Instrument Calibration System (MICS) with test instruments selected for servicing the instrumentation used in hospitals and other medical facilities.

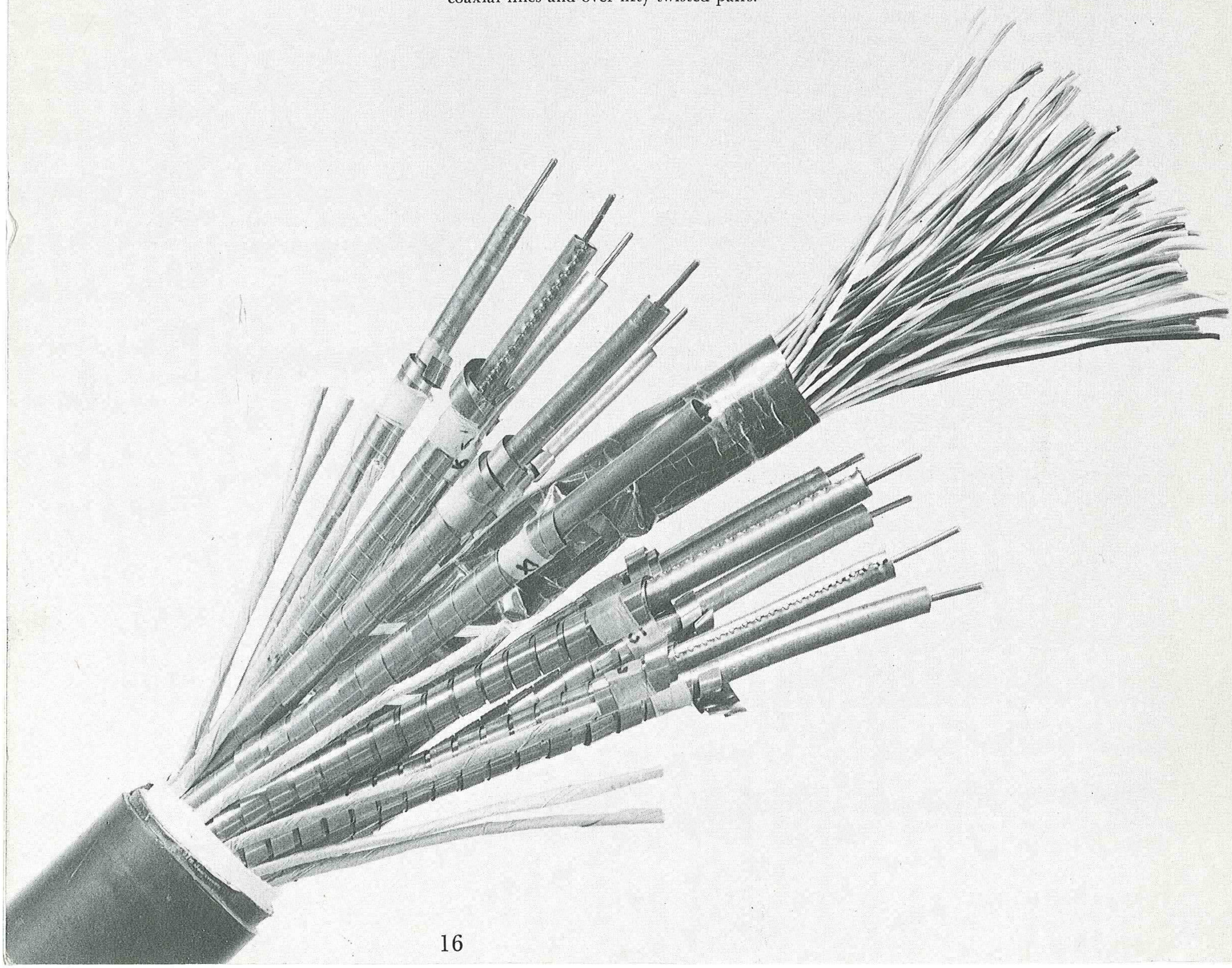
Servicescope

Transmission line characteristics ...a review

All electrical transmission lines have what is called characteristic impedance, or Z_O. We're aware of the importance of this characteristic when we want to assure maximum transfer of energy between a transmitter and antenna, or some other signal source and its load. However, we may not all be aware of the significance of this characteristic in locating faults in transmission lines, or may not have developed a clear understanding of the differences between transmission lines, and why they behave as they do. This review of basic transmission line characteristics may help.

Use of the term "impedance" usually implies a frequency dependence, so it is a little surprising that the characteristic impedance of a cable is not a frequency dependent characteristic. To say characteristic "resistance" would be erroneous, however, because power is dissipated when current passes through a resistance, and there is no power loss in a transmission line that may be attributed to its characteristic impedance. The term "impedance" is a better choice, because its value is determined by the inductance and capacitance of the cable, as we shall see later.

Fig. 1. Underground cable used in wide-band data transmission systems contains twelve coaxial lines and over fifty twisted pairs.



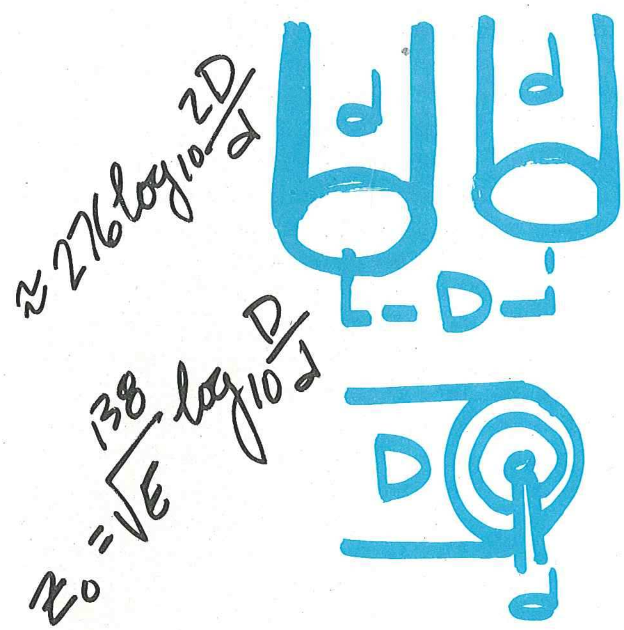


Fig. 2. Formula at top yields characteristic impedance of parallel lines with air dielectric; bottom formula is for coaxial lines.

Consider what takes place if we apply a step function of voltage to a cable. If we suddenly apply 50 volts across a 50-ohm cable, one ampere of current starts to flow. All of this initial current is used to charge the capacitance between the conductors of the transmission line. That capacitance exists uniformly along the entire length of the line, and a change in voltage on one end of the cable cannot cause a change at the other end any faster than a voltage wave front can propagate down the cable. The cable is charged at a uniform speed to a uniform voltage as the wave front moves through. This speed ranges between 66% and 100% of the speed of light for common dielectric materials, depending on the dielectric used between the conductors. The speed of light is 30 centimeters per nanosecond so the propagation velocity is between 20 and 30 centimeters per nanosecond. Since 30 cm is very close to 1 foot you can also express the speed as 1 to 1.5 ns per foot. After the capacitance in the entire length of cable has been charged, voltage is available to apply across the load. You might say that is when the applied voltage arrives at the load.

Factors determining Z_O

Since even straight wires have inductance, and every inch of cable capacitance is charged by current passing through the two cable conductors, it is not difficult to visualize how inductance and capacitance are the two factors that determine the characteristic impedance of a cable. As you would expect, cable impedance increases as the inductance per unit length increases. And, as you would expect, cable impedance decreases as capacitance per unit length increases. These two factors jointly determine how much current will flow when a given voltage is suddenly applied.

Characteristic impedance is equal to the square root of the L/C ratio ($Z_O = \sqrt{L/C}$), where L is the inductance of a given length of cable, and C is the capacitance of the same length. The actual length doesn't matter because capacitance and inductance are directly proportional to length.

Two things determine the capacitance per foot of a coaxial cable: the dielectric constant of the material separating the conductors, and the ratio of the diameter of the conductors. The inside diameter of the outer conductor and the outside diameter of the inner conductor are the dimensions of interest. Inductance per foot is determined only by the ratio of the diameters when the conductors are non-ferrous. Therefore, usually only two physical factors determine the capacitance and inductance and, consequently, the characteristic impedance: (1) the ratio of the diameters and (2) dielectric constant. Their relationship is expressed by the formula $Z_O = (138/\sqrt{\varepsilon}) \log_{10} D/d$, where Z_O is the characteristic impedance, D the inside diameter of the outer conductor, d the outside diameter of the inner conductor, and ε the dielectric constant.

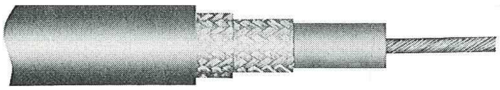
You can't tell the impedance of a coaxial cable by its appearance but you can be sure its impedance is comparatively high if its inner conductor is relatively small. In a similar way parallel twin-lead and twisted-pairs which have conductors that are widely spaced, compared to their diameter, will have a higher impedance than if the same conductors are closely spaced.

Propagation velocity

We touched briefly on propagation velocity earlier in this article. It is interesting to note that propagation velocity is not dependent on the physical size of a cable, the impedance of the cable, or the capacitance per unit length. It is dependent only on the dielectric material, or materials, separating the conductors. Polyethylene is the most common dielectric material used in coaxial cables and underground power lines, and the material that reduces propagation velocity most . . . to 66% of the speed of light in air. Polytetrafluoroethylene (PTFE or TFE) is even more stable than polyethylene and will not melt or flow at temperatures up to 200°C. This material is also known as Teflon®, a DuPont trade name.

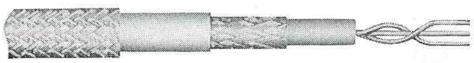
Velocity is inversely proportional to the square root of the dielectric constant ($V \propto 1/\sqrt{\varepsilon}$). Cables with mostly air or gas for a dielectric have a propagation velocity close to the speed of light. When the dielectric is a mixture of two materials, such as polyethylene and air, the propagation velocity is between that for the two materials. Polyethylene foam is an example of such a mixture. When the electrical field between parallel conductors extends into the surrounding air the effective dielectric constant is also some value between that for air and that for the solid material. Twin-lead TV cable and twisted pair phone lines are examples.

Single Braided Shield and Stranded Center Conductor

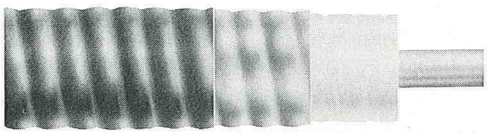


Double Shield and Stranded Center Conductor

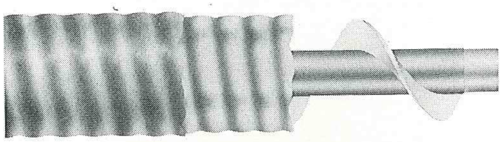
Double Shield and Solid Center Conductor



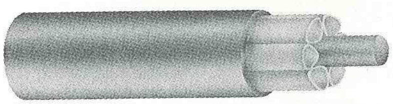
Armored Jacket over Single Shield—Solid Center Conductor Supported in Hollow Polyethylene Tube by Twisted Polyethylene Threads



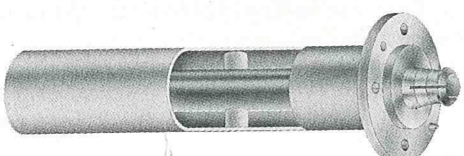
Polyethylene Foam-Filled Corrugated Copper Shield



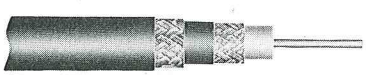
Polyethylene Helical Support for Center Conductor



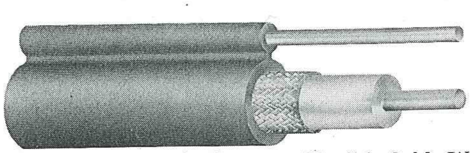
Hollow Polyethylene Tubes Support Center Conductor



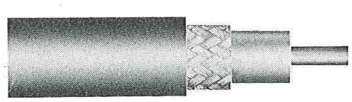
Pressurized Rigid Line 7/8" to 6 1/8"



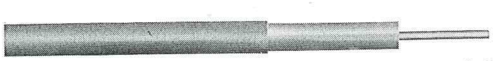
Two Insulated Shields for Better Shielding or "Guard" Voltage on Inner Shield



Steel Messenger Wire Supports Flexible Cable When Suspended Between Poles



Flat Ribbons Instead of Round Wires for Shield Reduce Losses Above About 1 GHz



Solid Shield Over Solid TFE Insulation—Rugged, Stable, Gigahertz Cable

Characteristic impedance and TDR

The capacitance of 50-ohm coaxial cables using non-ferrous conductors and solid polyethylene for a dielectric material is close to 1 pF per centimeter (30 pF per foot). That is true regardless of the size of the coax because it is the ratio of the conductor diameters that determines the capacitance per unit length once you have settled on the dielectric material and the kind of conductors.

If a coaxial line is sharply bent or compressed in some region there will be an increase in capacitance in that region and, consequently, a reduction in characteristic impedance there. If part of the outer conductor is worn away there will be an increase in impedance at that point. Anything that causes the characteristic impedance of the transmission line to deviate from its normal value will cause a signal passing through the cable to be partially reflected at that point. It is at this point that Time Domain Reflectometry or TDR enters the picture. If we know the propagation velocity of the line, we can use a TDR to measure the distance to the fault, greatly simplifying the task of locating the problem. A good deal of information about the nature of the fault can also be determined by even a relatively inexperienced operator. Now let's look at some other cable characteristics.

Signal attenuation factors

Voltage and power losses in a cable are caused principally by the resistance of the two conductors, at low frequencies, and by skin-effect and dielectric losses at high frequency. Losses due to skin-effect increase as frequency increases, and so do dielectric losses.

Skin-effect is a high frequency phenomenon which limits current to the surface region, or skin, of a conductor. As frequency is increased, less and less of the available metal does any conducting. In effect, the skin gets thinner, increasing the series resistance of the conductors as frequency increases. In coaxial cables the inner surface of the outer conductor and the outer surface of the inner conductor carry most of the current at high frequencies. Some large diameter coaxial cables have a hollow center conductor to avoid wasting the metal in the middle. Dielectric losses are relatively small for most dielectric materials and usually can be ignored for frequencies below about one gigahertz.

Attenuation of a high frequency signal passing through a transmission line is proportional to the square of the length of the line. Therefore, attenuation is usually expressed in decibels per unit length, as dB/100 feet. The frequency must also be stated because attenuation increases with frequency and is approximately proportional to the square root of frequency. When expressed in decibels, attenuation may be easily calculated for any specific length. For example, a kind of cable which attenuates a 100 MHz signal 2 dB/100 feet could be expected to attenuate the same signal 0.2 dB if it were ten feet long. When wideband signals are carried over a transmission line the waveform is distorted by the greater attenuation of the higher frequency components. The distortion may be mostly corrected by passing the signal through an amplifier having complementary characteristics. Cable TV line amplifiers and telephone relay amplifiers provide such a function.

Coaxial cables have a practical upper frequency limit, the frequency at which the cable starts to act like a waveguide. Waveguides will propagate signals with much less attenuation than coax but they are narrow band transmission lines. When wideband signals are applied to a coax and some frequency components extend beyond the frequency where the coax behaves like a waveguide, the coax begins to act a little like a frequency selective filter.

The cutoff frequency is inversely proportional to the sum of the conductor diameters ($f_{co} \propto 1/D+d$) for any given dielectric, so the smaller the cable the higher the frequency. Since high frequency signals and small diameter cables produce the most signal attenuation, signals above about 10 GHz simply can't be carried very far over coax without severe attenuation. The cutoff frequency for a 50-ohm cable with polyethylene dielectric (a D/d ratio of 3.6 to 1) and a 1 cm diameter (D), is close to 10 GHz. A cable having the same dimensions, but with air for a dielectric, would have a cutoff frequency close to 15 GHz, 50% higher. Some cable manufacturers are conservative in their claims and state the cutoff frequency to be 90% of these figures, or less.

Designing for minimum loss

Ordinary transmission lines range in impedance between about 50 ohms and 300 ohms. The impedance is rather critical in some applications and of only minor importance in other cases. The 300 ohm twin-lead on a TV antenna matches the antenna impedance and thereby transfers the most signal power to the receiver. However, the "neutral" wires surrounding the insulation on a power line directly buried in the ground only act as a protective shield. Although their presence makes the line a coaxial cable, these wires ordinarily carry little or no current. The impedance of the power line as a coax is nearly inconsequential unless being tested with a reflectometer. By contrast the 75-ohm, 3/8-inch diameter coaxial lines used extensively for wide band telecommunications are meticulously designed and manufactured for minimum signal loss and the most economical use of materials and equipment.

Where minimum signal loss per foot is most important, a coaxial cable having an impedance of 77 ohms, with air for a dielectric, is best. It is not possible to use air exclusively, however, because the center conductor must be supported somehow. Discs, beads or spiral windings are used to support the center conductor in many cables having mostly air for a dielectric. The optimum impedance for lowest signal loss per foot is achieved when the ratio of diameters (D/d) is 3.6 to 1. With that ratio, use of any ordinary dielectric material will result in the cable having an impedance between 51 ohms (polyethylene) and 77 ohms (air).

Loss per foot is reduced by using larger cables, of course, but then cost is also greater. Sometimes the cable diameter is dictated by the amount of current the conductors must carry, or the peak voltage that may sometimes be applied. Excessive temperature rise in a center conductor can melt the dielectric and cause a short between the shield and center conductor. Because of skin-effect, high frequency current heats up the conductors more than an equal amount of low frequency current.

Sometimes high impedance cables are chosen so that a high impedance signal source may deliver the maximum amount of voltage. For example, only about half as much voltage would be delivered over a 50-ohm cable to a 50-ohm load, as you could deliver to a 100-ohm load over a 100-ohm cable. But small diameter high impedance cables are fragile and difficult to build to a close tolerance because of the extremely small diameter of the center conductor. The D/d ratio of a 100-ohm cable with a polyethylene dielectric would be 14 to 1, but a 200-ohm cable of the same sort would have a D/d ratio of more than 100 to 1.

INSTRUMENTS FOR SALE

C27, $400; Bob Oppelt, (203) 265-2361.

D43R, D42, J, G; Jerry Somer, (507) 835-5235 (home) or (507) 353-2050 X320 (Work).

D67 (2), Bob Heim, Delta Bsns Mach, 1723 Hancock, Gretna, LA, (504) 368-3402.

FM122 (4), RM125 for FM122, rack mount, $100; Barry Fox, Optronics Int'l, Inc., 7 Stuart Rd, Chelmsford, MA 01824, (617) 256-4511.

H unit (2), $35 ea.; T unit, $45; Don, Washington Avionics, Seattle, WA, (206) 762-0190.

P6013, $75, Jim Crites, CH Electronics, 5300 Castlebrook Dr., Raleigh, NC 27604, (919) 833-2250.

R149A Op 1, $3,375; Harold Dougherty, Satterfield Electronics, (608) 257-4801.

RM567 w/6R1A, 3T5, 3S2 w/o sampling heads, trade for 25 MHz realtime scope; C. B. Wilson, Box 32, Richardson, TX 75080 (214) 826-4503.

S54, $300; Arthur G. Albin, 18209 167th Ave. NE, Woodinville, WA 98072, (206) 486-0618.

TLS54, $350; Joe Lucas, Seattle, WA, (206) 655-3331 (Work), (206) 746-9435 (Home).

TLS54; Syro Steel Co, Mr. James Raynish, 1170 N. State St., Girard, OH 44420.

1L5, $995; Charles Black, 3138 Fairview Ave East, Seattle, WA 98102, (206) 324-3950.

3S1, $400; Bill McCune, (408) 736-1060.

7B51; Jerry Foster, Mangood Corp., Streeter Amet Div., Grayslake, IL 60030, (312) 223-4801.

7B53AN, $725; A. V. Center, 6116 N. Lincoln Ave., Chicago, IL 60659, Attn: Mr. Paul Roston, (312) 539-7700.

114; L. L. Glemser, 6829 Shenandoah, Allen Park, MI 48101, (313) 381-5708.

122; G. W. Ewing, Seaton Hall Univ., Dept. of Chemistry, South Orange, NJ 07079.

211, $500; Mr. Stanley Lester, Boice Div., Mech. Tech., Inc., Hyde Park, NY 12538, (914) 229-2171.

262, 190A, 105, 130, S30, 291, P6046; Bill Groschen, Circuit Supply Co., 15109 Minnetonka Industrial Blvd., Minnetonka, MN 55343, (612) 933-2281.

310A; call Joe Lucero (208) 342-2711 X446, between 8:30 to 5:00.

422, $1000 w/std. access.; John Smith, Columbian, PO Box 180, Vancouver, WA 98660, (206) 694-3391.

422, $900; Robert Gardner, Times Publishing Co., 205 W. 12th St., Erie, PA 16501, (814) 456-8531.

422, $900 - $1200; R. Corley, Baird-Atomic, Inc., 125 Middlesex Tpk, Bedford, MA 01730, (617) 276-6202.

454, $2000; George Jannery, Ridgefield, CT, (203) 438-5226.

465/DM43; Ronald M. Lord, 110 Ilima Lane, APO San Francisco, CA 96553; (808) 423-1104.

465, $1850; Terry Melinder, (916) 258-2661.

491 Mod 139L; David Hostetler, Antenna Specialists, 12435 Euclid Ave., Cleveland, OH 44106, (216) 791-7878.

TM501 (2), DC502 (2); L. Giovannangelo, GE Co., 2379 John Glenn Dr., Chamblee, GA 30341, (404) 458-2231.

INSTRUMENTS FOR SALE

503, $350; Larry Myhre or Bob Custer, Hallidie Machinery, 4975 3rd South, Seattle, WA 98134, (206) 762-7600.

507 (3), Surge Scope $2,300 ea.; A. R. Miller, eci, 1124 Dorchester Ave., Dorchester, MA 02125, (617) 825-0980.

514D; Warren King, Rt. 3, Box 27, Silverton, OR 97381, (503) 873-4959.

517A, pwr sply, Scopemobile, $600; Jeremy Seeger, Hancock, VT 05748, (802) 767-5152.

519 w/access., $2250; Mr. Lizec, R & D Consult, Inc., 3133 Hodler Dr., Topanga, CA 90290.

519, $2500; Paul Thomas, High Voltage Eng., Burlington, MA 01803, (617) 272-1313 X283.

531A, E, CA; Howard Gourneau, Medtronics, (213) 843-1770.

531, 53/54C, $450; Steven K. Roberts, Cybertronic Systems, PO Box 18064, Louisville, KY 40218.

531, B; Geo. Breindel, 3518 1st Ave. NW, Seattle, WA 98107.

531 plug-ins: D, G, R, S (12 ea); Jim Knoall, El Camino College, Hawthorne, CA 90250.

535, K, $450; Jay Staiger, Jerrold Electronics, 200 Witmer Road, Horsham, PA 19044, (215) 674-4800, X454.

547 w/cart, 1A1, IL40, 132 pwr. sply, P6008 (2), P6028 (2), 115 (5), Mr. J. Johnson, General Research Corp., 7655 Old Springhouse Road, Westgate Research Park, McLean, VA 22101, (703) 893-5900.

547, 1A2, cart, Pat Phillips, Data 100 Corp., 7725 Wash. Ave So., Edina, MN 55435, (612) 941-6500.

549, 547, 546, 1A1; Wes Miller, 3845 Birch Ave., Newport Beach, CA 92660, (714) 540-5231.

545B, $1000; Mr. Peterson, Remote Recording Services, #19 Hillcroft, Cherry Hill, NJ 08034, (609) 547-4796.

551, CA, D (2); 605; 502A; Norman Altman, B.A.I. Corp., Magee Ave., Stamford, CT, (203) 348-4277.

561A/3A72/2B67, cart, hood, manuals, Mr. Johnson, (617) 583-0160.

561A, 3A6, 3B4, $900; Fred Wong, Kaitronics, 870 Mahler St., Burlingame, CA 94010, (415) 697-9102.

564, RM567, $300 ea; 2B67 (2) $100 ea., C. W. Jenkins, 2231 W. 4520 South, Salt Lake City, UT 84119, (801) 299-4262.

567 w/3S76, 3T77, $2,395; 565, $595, 532, $365; Lee Lab, 13714 So. Normandie Ave., Gardena, CA 90249.

INSTRUMENTS FOR SALE

575 w/adapters, $580; Fred Davis, Yale Univ., (203) 436-8949.

585, 81, K, $1000; 661, 5T3, 4S3, $1000; Pete Edwardson, DAB Associates, 312 9th Ave., Haddon Hgts, NJ 08035, (609) 547-4796.

602, w/std or P7 phosphor; Mr. Norman Lantz, 22234-1 James Allen Circle, Chatsworth, CA 91311.

611 (2), $2,000 ea., 4610; Ron Kocher, Process Control, PPG Industries, POB 11472, Pittsburgh, PA 15238, (412) 362-5100.

611 (2), 4601, $2,100 ea.; Dr. S. J. Mustric, Denver, CO (303) 255-4677.

1401A-1, $1,582.50; Mel Jenschke or Jim Lancaster, Big Springs Cable TV, Box 1871, Big Springs, TX 79720 (915) 263-6259.

4010-1; Dr. Willard Graves, Towson State College, Towson, MD 21204 (301) 823-7500 X611.

4010-1; Thelma Trageser, Johns Hopkins Univ., Baltimore, MD (405 Ames Hall), (301) 366-3300 X319.

5103N/D10, 5A18N, 5A21N, 5B12N, Dennis Luther, Wilhite Instruments, 7685 Wash. Ave. So., Edina, MN 55435 (612) 944-2535.

7313, 7A18N, 7B53AN, probes (2), $2,800; Chuck Ullman, 13130 S. Yukon Ave., Hawthorne, CA (213) 973-4191.

7704, 7A16A, 7A15A, 7B70, 7B71, list less 25%; John Newby, Union Drug, 136 Bus Terminal Rd., Oak Ridge, TN 37830 (615) 483-8429.

INSTRUMENTS WANTED

3B4; Paul Laramee, Tektronix, Inc. 31, Haight Ave., Poughkeepsie, NY 12603 (914) 454-7540.

3L5, Dr. Ray Hefferlin, Southern Missionary College, Box H, Collegedale, TN 37315, (615) 396-4363.

3L5; Mr. Bentov, I. B. Development Co., 241 Glezen Lane, Wayland, MA 01778 (617) 358-7619.

53/54C, 1A1, CA; Walt Williams, 14585 Berry Way, San Jose, CA 95124 (408) 337-2850.

556 w/ (2) M; Larry Traylor, 733 E. Edna Place, Covina, CA 91723 (213) 966-7431.

4701, 4501, 4551; Dr. Krause, Medical College of Penn., 3300 Henry Ave., Philadelphia, PA 19129 (215) 839-1645.

5403, 5A48, 5B42; Andy Samchuck, Balsom Grove, NC 28708 (704) 655-2970.

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