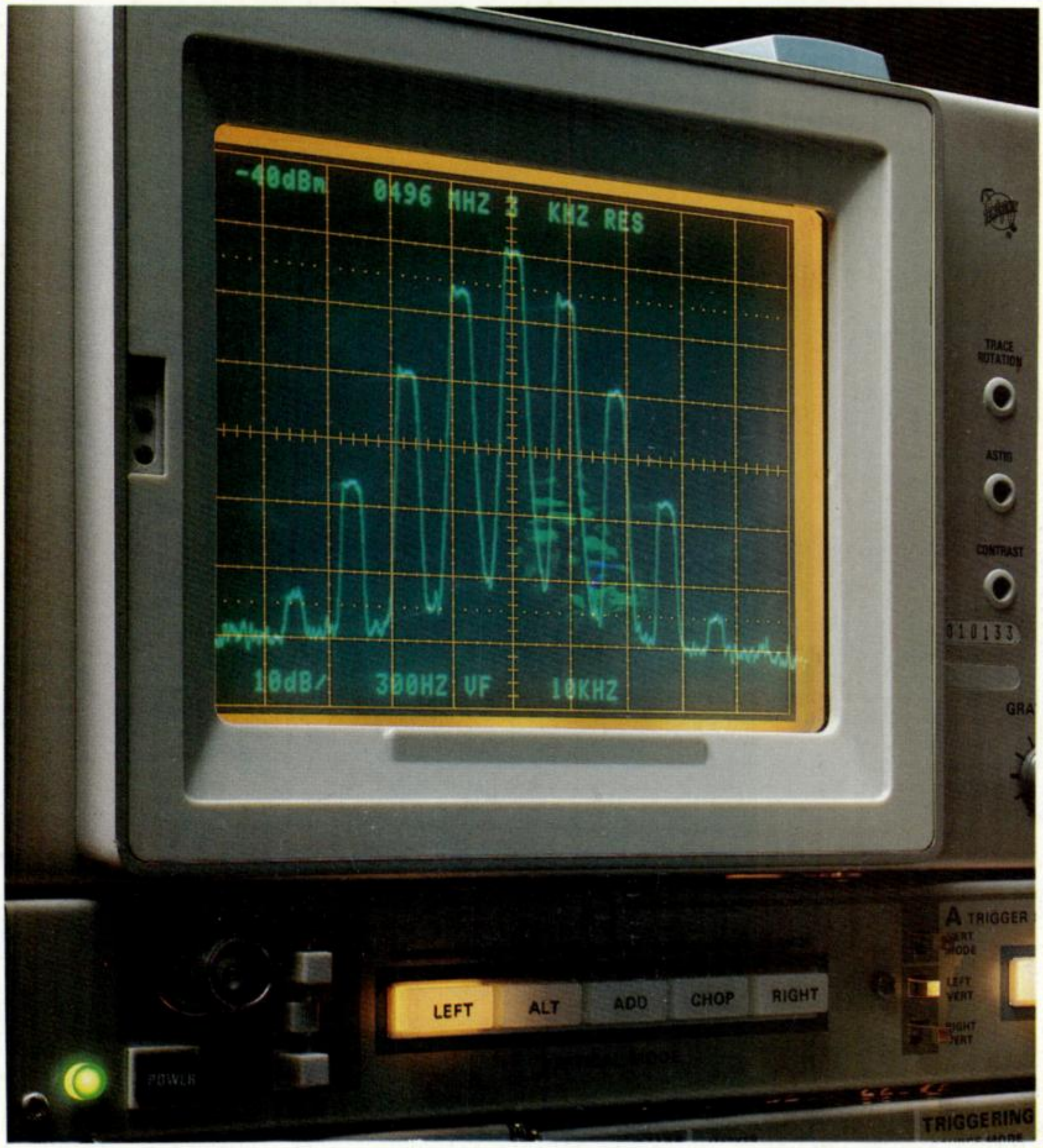
March/April 1981

A Cardiff Publication

rf design



SAW Devices
Wideband Monofilar Autotransformers
Spectrum Analysis Basics
Automated Spectrum Analysis

Now Available...

1W AMPLIFIERS

0.05-1200 MHz from $199

- Broadband ... each model multi-octave (see table)
- High linear output ... up to 30 dBm (1 W)
- Gain ... available from 16 dB to 27 dB
- Very flat gain response ... ±1 dB
- Connectors ... BNC Std; SMA, TNC, N available
- Compact ... 3.75" × 2.60" × 1.92" (ZHL-A Models)
  4.75" × 2.60" × 2.22" (ZHL Models)
- Self-contained heat sink
- One-week delivery

ZHL-2-8

If your application requires up to 1 watt for intermodulation testing of components ... broadband isolation ... flat gain over a wide bandwidth ... or much higher output from your frequency synthesizer or signal/sweep generator ... MiniCircuits' ZHL power amplifiers will meet your needs, at surprisingly low prices. Five models are available, offering a selection of bandwidth and gain.

Using an ultra-linear Class A design, the ZHL is unconditionally stable and can be connected to any load impedance without amplifier damage or oscillation. The ZHL is housed in a rugged ⅛ inch thick aluminum case, with a self-contained hefty heat sink. BNC connectors are supplied; however, SMA, TNC and Type N connectors are also available. Of course, our one-year guarantee applies to each amplifier.

So from the table below, select the ZHL model for your particular application now ... we'll ship within one week!

ZHL-1A

MODEL NO.	FREQ. MHz	GAIN dB	GAIN FLATNESS dB	MAX. POWER OUTPUT dBm 1-dB COMPRESSION	NOISE FIGURE dB	INTERCEPT POINT 3rd ORDER dBm	DC POWER VOLTAGE	DC POWER CURRENT	PRICE $ EA.	PRICE QTY.
ZHL-32A	0.05-130	25 Min.	±1.0 Max.	+29 Min.	10 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-3A	0.4-150	24 Min.	±1.0 Max.	+29.5 Min.	11 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-1A	2-500	16 Min.	±1.0 Max.	+28 Min.	11 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-2	10-1000	15 Min.	± 1.0Max.	+29 Min.	18 Typ.	+38 Typ.	+24V	0.6A	349.00	(1-9)
ZHL-2-8	10-1000	27 Min.	±1.0 Max.	+29 Min.	10 Typ.	+38 Typ.	+24V	0.65A	449.00	(1-9)
ZHL-2-12	10-1200	24 Min.	±1.0 Max.	+29 Min.*	10 Typ.	+38 Typ.	+24V	0.75A	524.00	(1-9)

Total safe input power +20 dBm, operating temperature 0° C to +60° C, storage temperature −55° C to +100° C, 50 ohm impedance, input and output VSWR 2.1 max.
*+28.5 dBm from 1000-1200 MHz
For detailed specs and curves, refer to 1980/81 MicroWaves Product Data Directory, Gold Book, or EEM.

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World's largest manufacturer of Double Balanced Mixers
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MINI-CIRCUITS LABORATORY
A Division of Scientific Components Corp   R46 REV F BL

INFO/CARD 1

Fluke introduces two new synthesized signal generators that you can specify with confidence.

With 20 years experience in RF instrumentation, we're driving down the cost of advanced technology.

Until now there has been a critical gap in the signal generator market — the gap between $10,000 synthesizers with limited capabilities and more accurate and sophisticated units priced over $25,000.

The Fluke 6070A and 6071A have been designed to bridge this gap, offering users the highest performance value of any RF instruments available.

Innovative design makes these most-wanted features affordable.

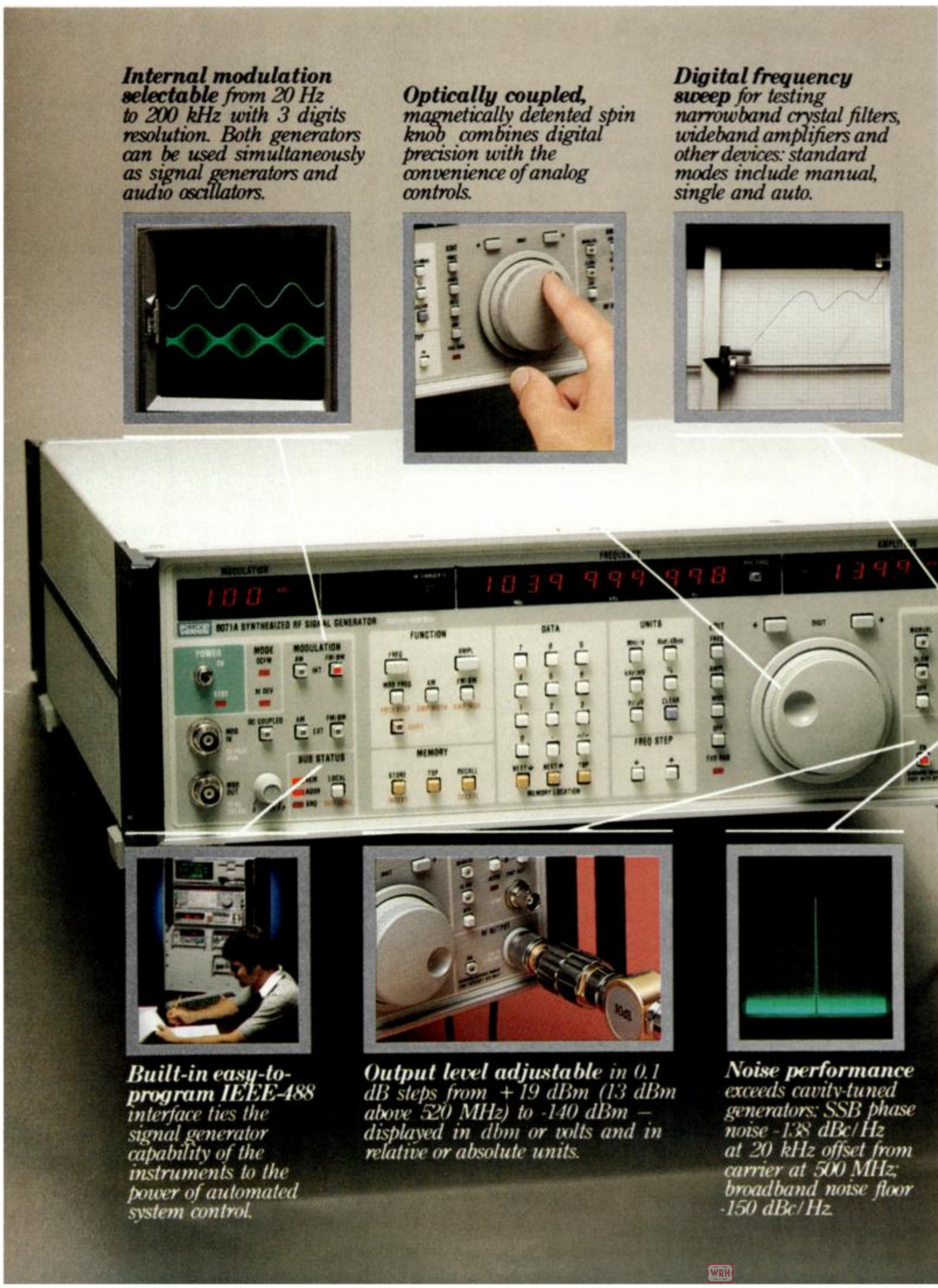
New, cost-effective synthesis techniques have been developed to deliver a high degree of spectral purity without sacrificing frequency range. And both the 6070A and 6071A are controlled by powerful microprocessors.

The 6070A covers the range from 200 kHz to 520 MHz; the 6071A range extends to 1040 MHz. Yet both feature noise performance that equals or exceeds the best cavity-tuned generators on the market, with precision resolution and settability.

Versatile modulation control of AM, FM and ØM — internal or external, simultaneous or separate — increases the applications flexibility of the 6070A and 6071A. And because the internal modulation signal can also function as an independent audio source, the user gets two instruments for the price of one.

Additional benefits of advanced Fluke technology include pinpoint frequency tuning with the optically coupled spin knob, simplified keyboard data entry, digital frequency sweep, a learn mode memory, self-diagnostics and error code flagging. Both instruments are fully programmable for use in IEEE-488 systems. And a relative units feature lets you define any center of interest as a zero point.

For more information on these new signal generators from Fluke, call toll free **800-426-0361**, use the coupon below or contact your nearest Fluke sales office.



Internal modulation selectable *from 20 Hz to 200 kHz with 3 digits resolution. Both generators can be used simultaneously as signal generators and audio oscillators.*

Optically coupled, *magnetically detented spin knob combines digital precision with the convenience of analog controls.*

Digital frequency sweep *for testing narrowband crystal filters, wideband amplifiers and other devices: standard modes include manual, single and auto.*

Built-in easy-to-program IEEE-488 *interface ties the signal generator capability of the instruments to the power of automated system control.*

Output level adjustable *in 0.1 dB steps from +19 dBm (13 dBm above 520 MHz) to -140 dBm — displayed in dbm or volts and in relative or absolute units.*

Noise performance *exceeds cavity-tuned generators: SSB phase noise -138 dBc/Hz at 20 kHz offset from carrier at 500 MHz; broadband noise floor -150 dBc/Hz.*

FLUKE®

INFO/CARD 2

Fast-Response Coupon

RF 3/4-81

IN THE U.S. AND NON-EUROPEAN COUNTRIES:
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Telex: 152662

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☐ Please send complete 6070A specifications.
☐ Send information on other IEEE products.
☐ Have a Sales Engineer contact me for a demonstration.

Name

Title Mail Stop

Company

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Telephone ( ) Ext.

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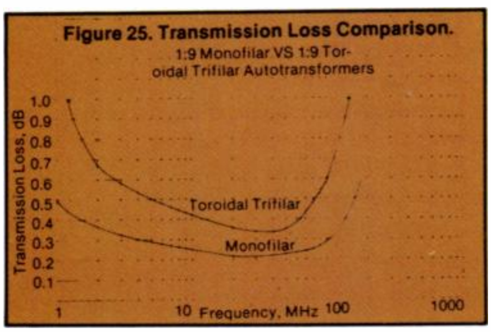
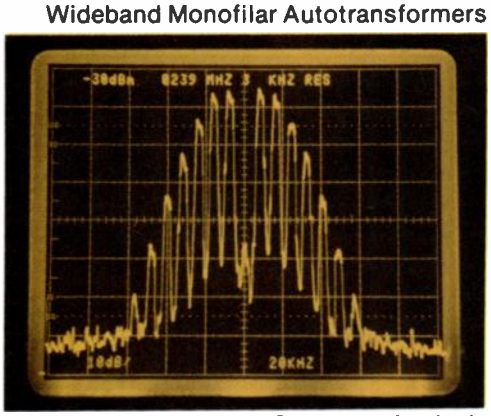
March/April 1981

SAW Devices



Wideband Monofilar Autotransformers


Automatic Spectrum Analysis

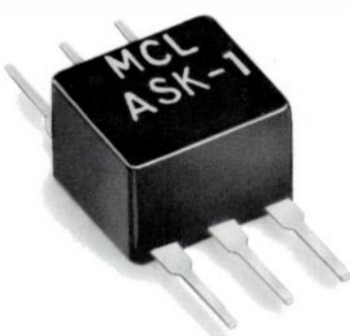
March/April 1981. Volume 4, No. 2. **r.f. design** (ISSN 0163-321X) is published bi-monthly by Cardiff Publishing Company, a subsidiary of Cardiff Communications, Inc., 3900 S. Wadsworth Blvd., Denver, Colo. 80235 (303) 988-4670. Controlled circulation postage paid at Denver, Colorado. Please address subscription correspondence and Postmaster, please send PS form 3579 to P.O. Box 1077, Skokie, Ill. 60077. Subscriptions: Domestic $10, Canada & Mexico $15 per year; foreign $20 per year. Please make payment in U.S. funds only. Single copies available at $3 each.

Shown actual size

the shrinker

the worlds smallest and lowest priced flatpack mixer **shrinks size and cost.**

The ASK-1 from Mini-Circuits $5.95 (10-49)



Mini-circuits
Model ASK-1/Plastic Case

Until now, the smallest mixer flatpack available was 0.510 by 0.385 inches or 0.196 sq. inches.

Now, Mini-Circuits introduces the ultra-compact ASK series, measuring only 0.300 by 0.270 inches or 0.081 sq. inches, more than doubling packaging density on a PC board layout.

Utilizing high production techniques developed by Mini-Circuits, the world's largest manufacturer of double-balanced mixers, the ASK-1 is offered at the surprisingly low price of only $5.95 (in 10 quantity).

Production quantities are available now for immediate delivery. And, of course, each unit is manufactured under the high quality standards of Mini-Circuits and is covered by a one-year guarantee.

ASK-1 SPECIFICATIONS

FREQUENCY RANGE:
RF, LO: 1-600 MHz;
IF: DC-600 MHz

CONVERSION LOSS:
One Octave from Bandedge: 8.5 dB Max.
Mid-Range: 7.0 dB Max.

ISOLATION:
L-R: 45 dB Typ.; L-I: 30 dB Typ.

ABSOLUTE MAXIMUM RATINGS:
Total Input Power: 50 mW
Total Input Current, peak: 20 mA
Operating Temperature: −55°C, +100°C
Storage Temperature: −55°to +100°C
Pin Temperature (10 sec): +260°C

WEIGHT: .35 grams (.01 ounces) *CASE:* Plastic

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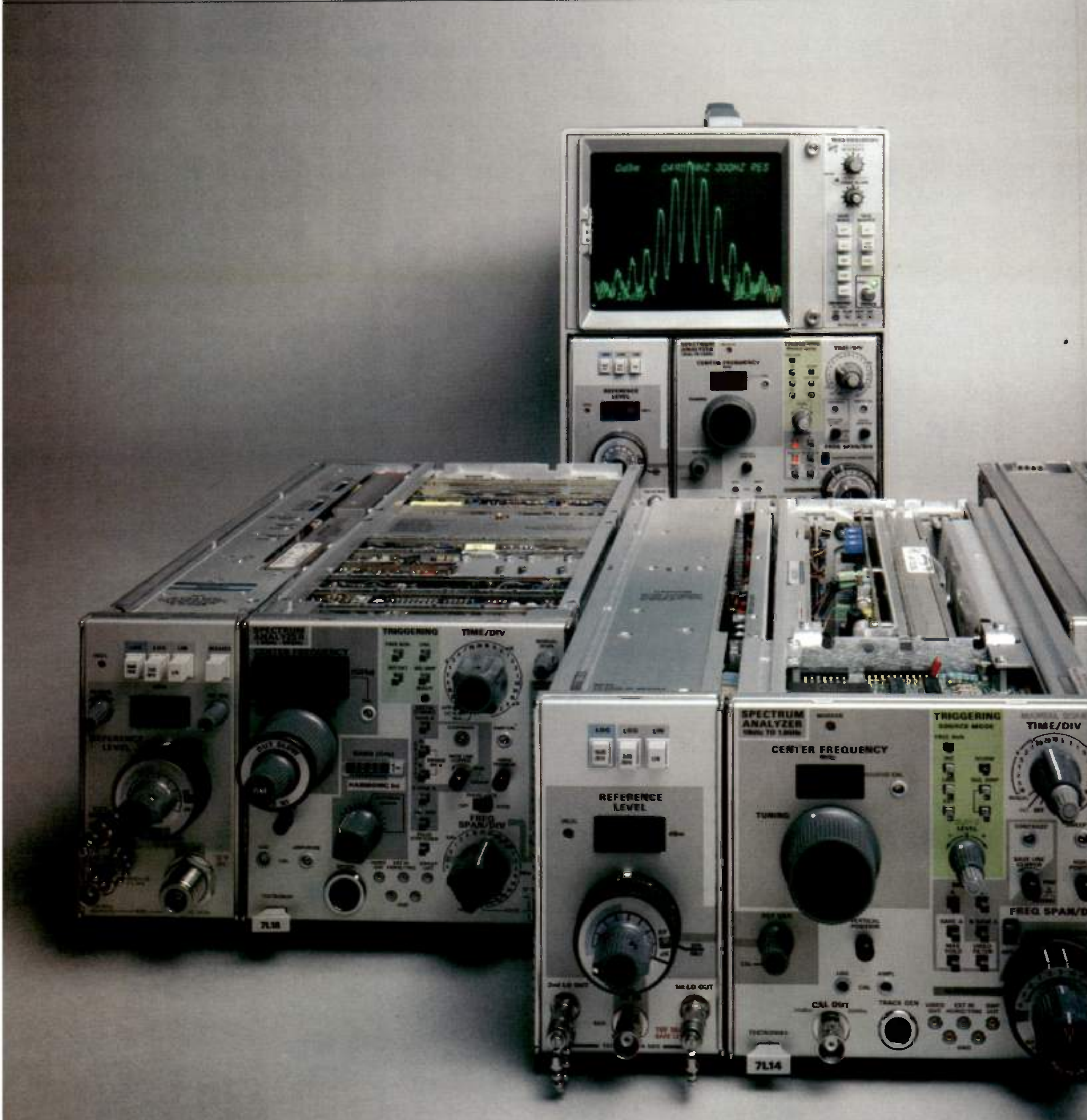
INFO/CARD 3

TEK 7000 SERIES SPECTRUM ANALYZERS



Now you can plug in an all digital-storage family of spectrum analyzers.

Three models provide laboratory performance with flexibility and versatility.

With the introduction of the new 7L14, there are now three members of the Tektronix family of digital storage plug-in spectrum analyzers. They provide frequency coverage from 20 Hz to 60 GHz. This plug-in concept brings you high performance, versatility and flexibility unmatched by monolithic instruments. At reasonable prices. They're compatible with any Tektronix 7000 Series oscilloscope mainframe, including the new digitizing GPIB 7854 for programmable solutions to complex measurements.

Family characteristics that make spectrum analysis easier.

All three instruments feature digital storage for flicker-free displays that are easy to interpret. This provides averaging and peak detection; accurate waveform comparisons; stores for long periods to measure amplitude changes and frequency drift.

The 7000 Series plug-in family displays alphanumeric readout for referencing and easy documentation. And each spectrum analyzer is protected from up to one watt input levels to save expensive front end repairs caused by inadvertent overloading.

With a 7000 Series mainframe on your bench, you select the spectrum analyzers that fit your requirements. And they interchange quickly with 30 other Tektronix test and measurement plug-ins. Use the powerful mainframe for logic analyzer, oscilloscope and other measurements.

New 10 KHz to 1.8 GHz 7L14 completes the 20 Hz to 60 GHz digital storage plug-in team.

Here it is. The new 7L14 for digitally-stored close-in, high resolution measurements from 10 KHz to 1.8 GHz. With 10 Hz residual FM, the 7L14 provides stability and jitter-free 30 Hz resolution displays. Its digital storage can be used to eliminate system errors and provide flat swept RF measurement capability. Digital averaging provides noise reduction which gives 70 dB spurious-free dynamic range. You can check broadband RF networks, filter networks, amplifiers, cables. Measure EMI/RFI and FM, navigation, two-way and other communications systems.

At the top of the spectrum you get top performance from the 7L18 Spectrum Analyzer. It provides full amplitude calibration in the 1.5 GHz to 60 GHz range and has 30 Hz resolution to 12 GHz. Displays are sharp, stable and flicker-free. Digital storage and digital signal processing make complex measurements easy with microprocessor aided controls. An automatic preselector insures spurious-free operation, giving easily interpreted displays.

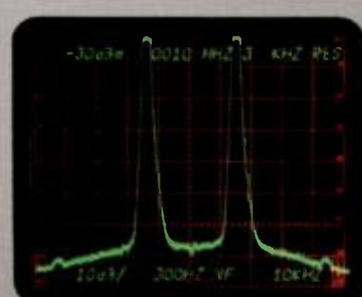
For baseband measurements choose the 7L5 for its precision and convenience in the 20 Hz to 5 MHz range with 10 Hz resolution. For a high performance analyzer, it's unusually easy to operate.

This family works together to make an outstanding value.

You get this laboratory performance and measurement flexibility at prices that point up the value of the Tektronix plug-in concept.

Call your nearest Tektronix Field Office (listed in major city directories) for complete details on the 7000 Series lab performance spectrum analyzers. Or call 800-547-1512 for descriptive literature.

Tektronix, Inc., P.O. Box 1700, Beaverton, OR 97075. In Europe: European Marketing Centre, Postbox 827, 1180 AV Amstelveen, The Netherlands.



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r.f. design Buyers' Guide

The first *r.f. design* Buyers' Guide (Nov./Dec. issue) is shaping up as follows: 3 main groups: components, instrumentation and services; 200 specific categories and 1000 RF companies represented therein.

Thank you for your cards. Each one to date has been read and considered. Keep them coming. A partial list of categories has been printed below. Which ones have I missed?

ABSORBERS
ADAPTERS, COAX
AMMETERS, RF
AMPLIFIERS, HYBRID
AMPLIFIERS, INSTR.
AMPLIFIERS, LOG
AMPLIFIERS, MODULE
AMPLIFIERS, SWEEP
AMPLIFIERS, TRANSISTOR
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ANTENNAS, DIRECTIVE
ANTENNAS, OMNI
ANTENNAS, RADOMES FOR
ARRESTORS, LIGHTNING
ATTENUATORS, FIXED
ATTENUATORS, VAR., MAN.
ATTENUATORS, VAR., PROG.
AUTOTESTERS, VSWR

BALUNS
BLOWERS
BOARDS, PC
BRIDGES, RF

CABLE, COAX
CABLE, FIBER OPTICS
CABLE, TOOLS FOR
CAPACITORS, CERAMIC
CAPACITORS, CHIP, GNRL.
CAPACITORS, GENERAL
CAPACITORS, HV
CAPACITORS, MICA
CAPACITORS, VAR., MIN.
CAPACITORS, VAR., HV, AIR
CAPACITORS, VAR., HV, VAC..
CHOKES
CIRCULATORS
COIL WINDERS
CONDUCTIVE COATINGS
CONNECTORS, COAX
CORES, FERRITE
CORES, POWDERED IRON
COUPLERS
CRYSTALS, QUARTZ

DELAY LINES, LC
DELAY LINES, SAW
DELAY LINES, ULTRASONIC
DETECTORS
DIELECTRICS
DIODES, IMPATT
DIODES, INFRARED LASER
DIODES, LIGHT EMITTING
DIODES, PIN
DIODES, SCHOTTKY
DIODES, TUNNEL
DIODES, TUNING
DIODES, VARACTOR
DISCRIMINATORS
DUPLEXERS

ENCLOSURES, SMALL
ENCLOSURES, LARGE

FERRITES
FILTERS, CAVITY
FILTERS, CHIP
FILTERS, COAXIAL
FILTERS, CRYSTAL
FILTERS, EMI
FILTERS, HELICAL
FILTERS, INTERDIGITAL
FILTERS, LC
FILTERS, MECH-TUNED
FILTERS, SAW
FILTERS, THICK FILM
FILTERS, VOLT-TUNED
FILTERS, YIG-TUNED
FREQUENCY COUNTERS

GASKETS
GENERATORS, FUNCTION
GENERATORS, NOISE
GENERATORS, SIG., INSTR.
GENERATORS, SIG., MOD.
GENERATORS, SWEEP
GROUND TESTERS

HEAT SINKS
HEAT SINK COMPOUND

INDICATORS, SWR
INDUCTORS, CHIP
INDUCTORS, METALIZED
INDUCTORS, SHIELDED
INDUCTORS, VARIABLE
INSULATORS
INTEGRATED CIRCUITS
ISOLATORS

LIMITERS
LOADS, FIXED
LOADS, VARIABLE TEST

MEGOHMMETERS
METERS, FREQUENCY
METERS, MAGNETIC
METERS, POWER
METERS, R, L, C, Z
METERS, THERMOCOUPLE
METERS, VOLT
MIXERS, ACTIVE
MIXERS, PASSIVE
MODULATORS
MULTICOUPLERS
MULTIMETERS
MULTIPLIERS, LINEAR
MULTIPLIERS, NON-LINEAR

NETWORKS, LC
NETWORKS, REJECTION

OSC., CRYSTAL
OSC., GRID-DIP
OSC., MECH-TUNED
OSC., VOLT-TUNED
OVENS, OSC.

PHASE SHIFTERS
POWER DIVIDERS
PREAMP., GENERAL
PREAMP., INT. DET. .
PRESCALERS

RCVRS., COMMUNICATIONS'
RCVRS., SURVEILLANCE
RCVRS., TELEMETRY
REFLECTOMETERS, GNRL.
REFLECTOMETERS, TDR
RELAYS
RENTALS, EQUIPMENT
RESISTORS, CHIP
RESISTORS, GENERAL
RESONATORS, CERAMIC

SAW DEVICES
SCOPES, GENERAL
SCOPES, PORTABLE
SCOPES, STORAGE
SCREEN ROOMS
SENSORS, RF FIELD
SHIELDS, SHIELDING
SLOTTED LINES
SOCKETS
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SPEC. A., SWEEPING
SWITCHES, DRIVERS FOR
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TRANSMITTERS
TUBES, HIGH POWER
TUBES, RECEIVING
TUBES, SPECIAL PURPOSE
TUNERS, ANTENNA

Alex Burwasser, Dave Krautheimer, Jeff Schoenwald and Raymond Sicotte, welcome to the editorial review board. The expertise you bring with you is appreciated.

Rich Rosen

SURFACE ACOUSTIC WAVES for the R.F. Design Engineer

Thus begins a series of articles with the intention of introducing surface acoustic wave (SAW) devices to some, reviewing it for others, and promoting its usefulness to all.

Jeff Schoenwald
Microelectronic Research and Development Center
Rockwell International Corporation
Thousand Oaks, CA

History

In the last decade of the nineteenth century Lord Rayleigh first described the propagation of elastic energy in a wave-like motion on the free surface of an isotropic medium. That was 84 years ago and makes the subject as contemporary as Maxwell's foundation work on the properties of time-variant electromagnetic fields. Back then, as now, some people were concerned with the nature of earthquake tremors, so Rayleigh gave some thought to the subject and described the wave phenomenon that now bears his name.

Why, then, did the subject fall into relative obscurity for over half a century, to be resurrected in the 1960's as a laboratory curiousity, and begin to find its way into limited application in the last 10 years?

Well, first of all, the waves associated with earthquake tremors are very low frequency — sometimes less than one Hertz. Naturally this did not ring any bells with what then passed for electrical engineers. Second, what did

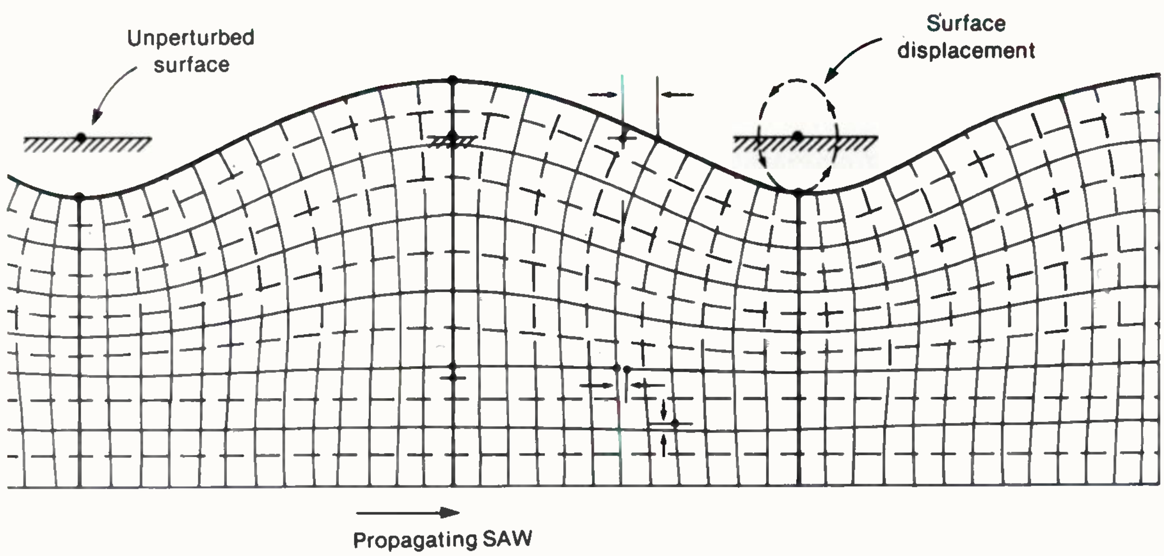


Figure 1. An exaggerated depiction of the distortion of the region adjacent to a surface over which a Rayleigh wave is propagating.

elastic vibration have to do with electricity? Until piezoelectricity was better appreciated and the value of quartz to the early days of radio transmission — remember the old quartz crystal radios? — was understood, this question went unanswered.

Then a period of development followed which produced the piezoelectric transducer and bulk crystal resonator. Suddenly we had delay lines and stable frequency sources. Later, the coupling between bulk acoustic crystal resonators (electrically) resulted in narrow band filters. Acoustic coupling led to the monolithic two-pole and four-pole crystal filter. These had the advantage of being small, low-loss and narrow-band. But because the frequency of operation varies inversely as the thickness of the crystal plate, 30 MHz became a practical upper limit for fundamental mode operation, with operation at higher harmonics leading to serious problems with impedance mismatch and bandwidth in filter applications.

The quartz crystal, naturally, was not the answer to all RF filtering and frequency source problems. There were requirements for wide bandwidth (television broadcasting), higher frequency, and spread spectrum signal coded communications, to name a few. LC, helical, ferrite, mechanical and other types of filters were developed but could not cover all bases.

Surface Wave Description

First, let's look at a brief qualitative description of a surface acoustic wave (SAW). Imagine sitting at the edge of a still pond. Toss a small pebble out into the flat water and observe the ripples that spread out. If you could excite a SAW with a point application of force in the same way you would see much the same result. Of course, bulk waves would be generated as well, but more on that later. Now imagine tossing a rod into the pond so that it lands flat on the water's surface. Instead of a spreading circular pattern, what you get are plane wave-fronts. Because solids have somewhat different elastic properties than liquids — in particular, strong shear restoring forces and lower viscosity — the details of particle motion are somewhat different. The picture, however, is still pretty much the same. In Figure 1 a schematic representation of a propagating SAW shows how the crystal structure is distorted as the wave passes by. As in most other wave phenomena, there is no net displacement of matter, yet momentum exists and energy is certainly transported.

Surface Wave Motion

What does the detailed motion in the vicinity of the surface look like? Before answering that, think about the types of vibrational motion that can exist in solids. First there are longitudinal waves, the compressional waves that air and liquids can support. Because there are transverse restoring forces in solids you can have shear waves as well. In isotropic media the two axes normal to the direction of propagation are identical so that only one shear mode is physically significant. In single crystal materials of complex symmetry, two shear waves exist, but for now lets not get bogged down in matters that need consideration later. In isotropic matter the shear and longi-

If you're looking for a sweeper in the 2.5 GHz range, the obvious choices are Wavetek's Model 2002A and HP's 8620C mainframe with an 86222B plug-in. But just look at the chart: the Model 2002A is a lot more instrument for about half the price. The only way your choice could be more clear would be if the HP instrument didn't exist. But then what could we compare our Model 2002A against? Wavetek Indiana, Inc., P.O. Box 190, 5808 Churchman, Beech Grove, IN 46107. Toll-free 800-428-4424; in Indiana, (317) 787-3332. TWX (810) 341-3226.

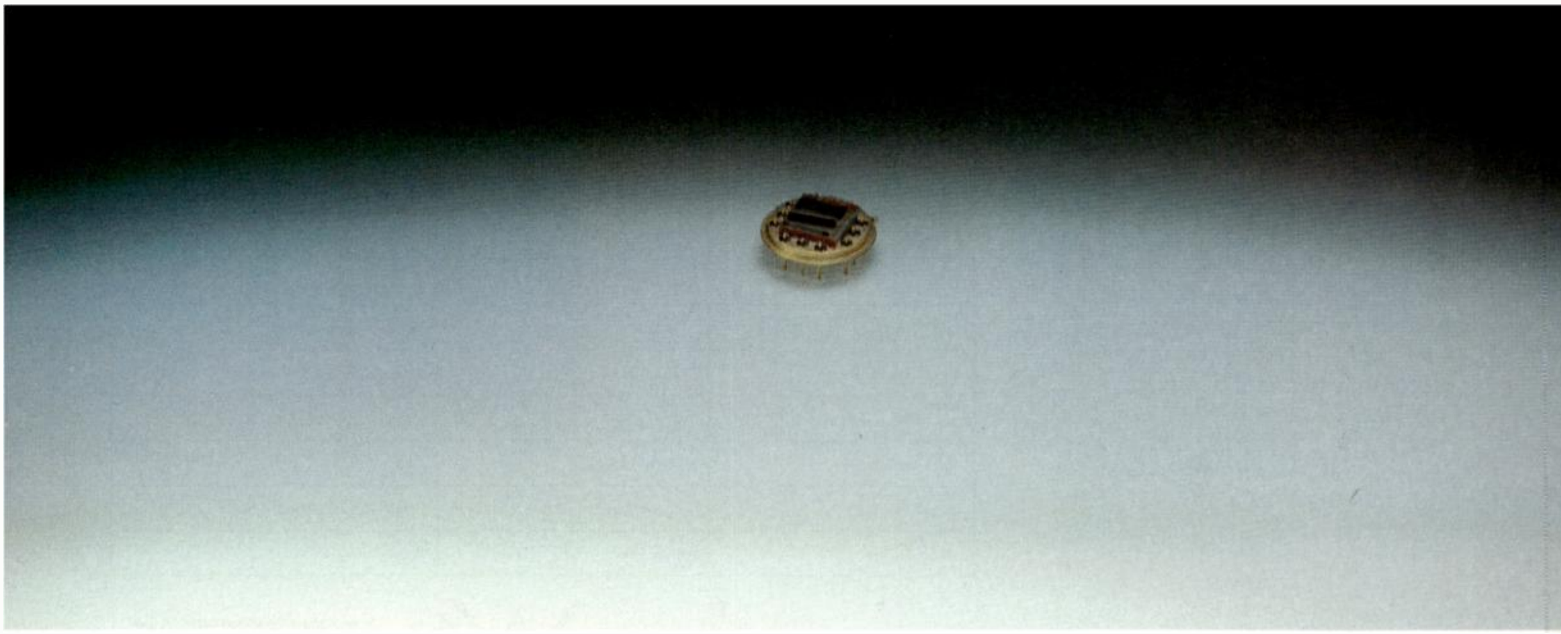
	Wavetek Model 2002A including Harmonic Markers	HP 8620C Mainframe with 86222B plug-in
Price	$4600	Plug-in $5750 + Mainframe $2850 = Total $8600
Convenience	Single, stand-alone unit	Two detachable units, mainframe & RF plug-in
Frequency Range	1 MHz to 2.5 GHz	10 MHz to 2.4 GHz
Non-harmonics at 13 dBm	None detectable (0.5 to 2.5 GHz) >35 dBc (1 to 500 MHz)	> 30 dBc (0.01 to 2.3 GHz) > 25 dBc (2.3 to 2.4 GHz)
Calibrated Output Level Meter	Standard	Not available
Step Attenuator	Standard	Optional at $400
Harmonic Markers	1, 10, 50 and 100 MHz (plus single frequency markers)	1, 10 and 50 MHz
Marker Range	1 MHz to 2.5 GHz	10 and 50 MHz markers to 2.4 GHz 1 MHz marker to 1.0 GHz
Marker Width	Adjustable from 15 kHz to 400 kHz	Fixed, Minimum width is 150 kHz
Marker Size	Adjustable	Fixed

Demonstration INFO/CARD 8 Literature INFO/CARD 9

WAVETEK®

Compare our 2.5 GHz sweeper with its closest competitor.

(The competition costs more and does less; we think that puts it out of the picture.)



Our SAW Filters give you less for your money.

Less cost.

Today, Andersen SAW filters are priced competitively with other filter technologies. We have hundreds of standard designs suitable for thousands of applications. So you save on design charges. And if you need something tailor-made, our fast, computerized design capabilities and large production volume can reduce your costs far below what you'd expect.

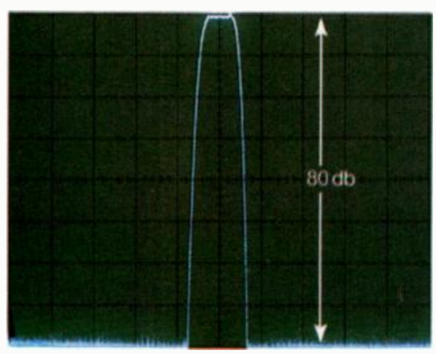
Less bulk.

Andersen SAW filter vs. equivalent LC network.

Because you get greater precision in a smaller package. See for yourself how Andersen SAW filters stack up in size against LC filters.

Less tuning.

Because there's nothing to tune. Our filters are passive analog solid-state devices. They have permanently fixed performance characteristics. Once that design is checked by our computers, it never has to be checked again. Unlike LC filters, our SAW filters need no tuning, assembly, checking, retuning, and rechecking. So you save time, labor and capital equipment costs.



Typical frequency response of Andersen BPP70-1300-3-133A of 1.5MHz bandwidth.

Less maintenance.

Because there's nothing that can ever get out of tune. Our SAW filters not only cost less than you'd think to begin with. They won't nickel and dime you to death after you buy them.

Less rejects.

Because SAW filters of the same design are virtually identical. That helps you produce a more consistent end product. And our proven designs assure top performance. You get a superior shape factor. Improved close-in rejection. Inherent linear phase. And less distortion than with conventional filter designs.

Less confusion.

Because if there's one thing we give you more of, it's information. Volume I of our Handbook of Acoustical Signal Processing will tell you everything you need to know about the right SAW filter for your application.

Plus, for a limited time, the Handbook is free. So send for your copy now.

Andersen SAW filters. We think you'll agree they're everything you've always wanted in a filter.

ANDERSEN LABORATORIES

Andersen Laboratories, Inc., 1280 Blue Hills Avenue, Bloomfield, CT 06002 Telephone (203) 242-0761 TWX: 710-425-2390

Andersen SAW products are available in the United Kingdom and Europe through our sister company, Signal Technology Ltd., Swindon, Wiltshire, UK.

INFO/CARD 10

tudinal bulk waves are uncoupled, i.e., we may excite only one or the other if we wish. But the presence of a free surface in the vicinity of the many waves occurring in the medium constitutes a boundary condition that binds the two types of waves together to form a coupled mode that is "pinned" to the surface and propagates — and dissipates! — in only two dimensions at most. That is the *surface acoustic wave.* Figure 2 shows the relative amplitudes of the longitudinal component and the shear component normal to the surface of a "site" in the crystal as a function of depth into the medium. Only in anisotropic crystals, and along particular surfaces and directions can a shear component parallel to the surface exist. Such waves are called Bleustein-Gulyaev waves.

Now, consider the surface acoustic wave velocity. In a medium that transmits acoustic energy, the surface wave velocity is typically 3×10^5 cm/sec, or five orders of magnitude slower than the speed of light. I remember when, only 11 years ago, I needed 100 nanoseconds of delay. A technician handed me 100 feet of coaxial cable. Now I can get over 3 microseconds in less than an inch of substrate. That gives you an idea of size versus delay.

Surface Wave Excitation

The next question I pose is this: How do you excite a surface acoustic wave? For years, people bonded quartz transducers to wedges and phase matched longitudinal or shear bulk waves from the wedge onto the surface of an adjacent substrate. Ditto for detection. While this made for continuously variable delay, it was not very efficient, repeatable or rugged.

Back in 1965 Voltmer and White used photolithography to define a pattern on a piezoelectric (quartz) substrate surface, now known as the interdigital transducer (idt) and demonstrated that application of an AC signal to the opposing electrodes was capable of generating an elastic surface wave (the term then in fashion). No matter that the total insertion loss was 90 dB. The concept was now feasible: If alternately connected electrodes each a quarter wavelength wide in the direction of propagation (Figure 3) and a periodicity of one wavelength were excited by a frequency given by $f\lambda = v$, where f is the frequency, λ the wavelength, and v the surface acoustic wave (SAW) velocity, then a wave would be excited, and by reciprocity, could be detected by a similar idt. The first effort was in the VHF range. Incidentally, the first Russian attempt at SAW involved a quartz substrate about one inch thick and worked at about 180 kHz. Plug that in to compute the wavelength and electrode linewidth and it makes you wonder what they used for a contact print mask aligner!

Eventually the electrical characteristics of the idt were characterized in terms of the elastic, dielectric and piezoelectric properties of the materials commonly in use (chiefly crystal quartz, lithium niobate, lithium tantalate and, for a while, bismuth germanium oxide) to the point where impedance mismatch and high insertion loss were no longer serious problems.

From there, design techniques for bandpass filters, comb filters, pulse compressors, convolvers,

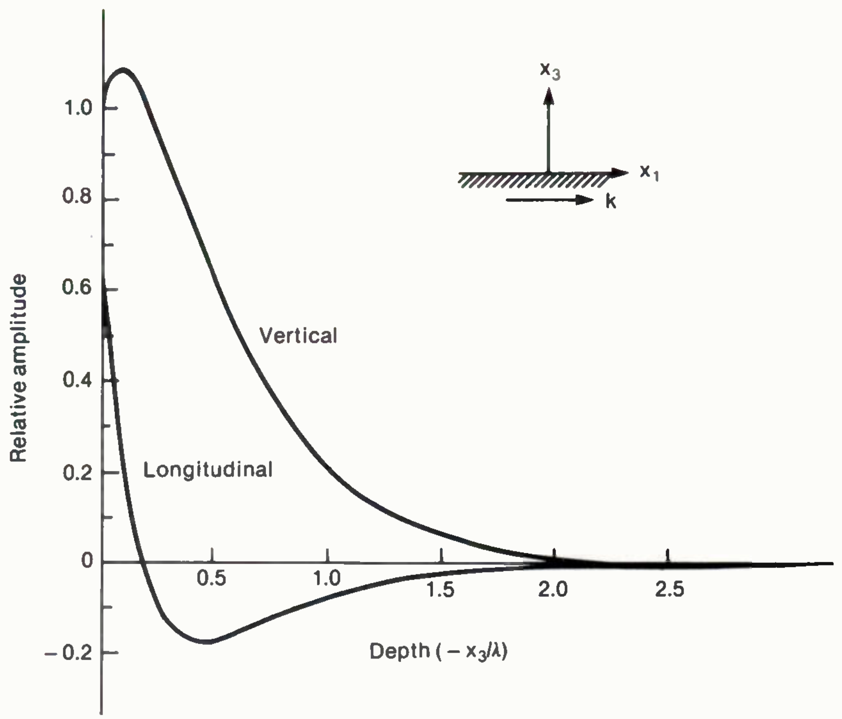


Figure 2. Normal and longitudinal displacement variation with distance into an isotropic medium.

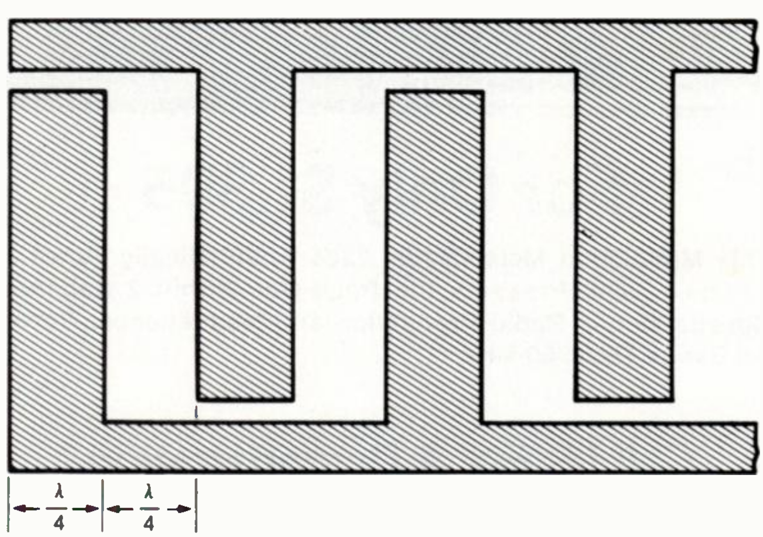


Figure 3. Interdigital transducer (idt).

correlators, and a Pandora's Box of other tricks were developed. In a series of articles to follow, I will examine a number of these applications of surface acoustic waves. Hopefully the depth will be adequate for the RF design engineer to appreciate the capabilities and limitations of these devices. Hopefully the breadth will be adequate to get a positive response from most readers who are looking for a solution to a problem and aren't familiar enough with SAW to know if a possible answer is lurking in this technology. Perhaps the two biggest prejudices that SAW has to face in the modern electronics era are that 1) it usually isn't a silicon device, and 2) it is acoustic, not electronic. Thus, having resisted circuit chip integration, it has not found a comfortable place in the current rush to electronic sophistication.

Types of SAW Devices

There are many types of SAW devices, the variety resulting from the ingenuity of SAW physicists and engineers in modifying the basic interdigital transducer, and using the material properties of the substrate to perform different tasks. A partial list of these devices consists of:

1) Delay lines
2) Bandpass transversal filters
3) Comb filters
4) Pulse compressors and expanders
5) Resonators and oscillators
6) Convolvers and correllators
7) Sensors

Future Topics

In future issues some of these topics will be explored, as well as some that aren't listed. I intend to start slowly, to get comfortable with the SAW transducer, and build our appreciation of its versatility as we become familiar with its complexity and nuance. Some aspects of SAW may get less attention than others. That may be due as much to my preference as the fact that many areas of SAW development are still premature for present systems use or are concerned with more arcane sectors of research, such as new materials or new crystal cuts of older materials. I hope the path I wind up leading you down is worth your time and patience. □

Part 2

Wideband Monofilar

This article concludes with measured performance data for 1:1.5 through 1:16 ratio autotransformers, other configurations and general manufacturing information.

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Consulting Engineer
Fair-Rite Products Corp.
Walkill, NY

In the first part of this article the autotransformer was designed in terms of its equivalent circuit. Test set-ups for measuring its transmission & reflection characteristics were detailed. Actual performance data utilizing these set-ups will now be presented and explained.

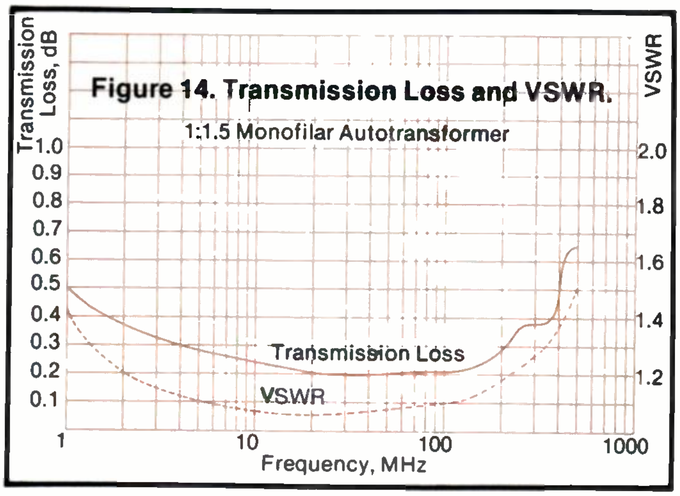


Figure 14. Transmission Loss and VSWR.

Autotransformer Performance Data

Figures 14 through 22 present the measured transmission and reflection characteristics for 1:1.5, 1:2, 1:3, 1:4, 1:5, 1:6.25, 1:7.5, 1:9, and 1:16 autotransformers. The test setups for these measurements are the transmission and reflection test fixtures of Figures 9 and 10, respectively. These measurements represent typical autotransformer performance that can be obtained from production units. The cores employed in these test autotransformers were not specially selected, but were purchased "off the shelf" from a distributor.

Figure 14 shows the test results for the 1:1.5 autotransformer. Note that even at the worst-case frequency, the transmission loss is only .65 dB, being much less over most of the frequency range. Note also that the VSWR is low (below 1.5) over the entire frequency range. Of course, the user must decide for himself how low the transmission loss and VSWR must be for the particular application at hand. For more applications, however, this autotransformer could be conservatively rated as a 1-500 MHz device.

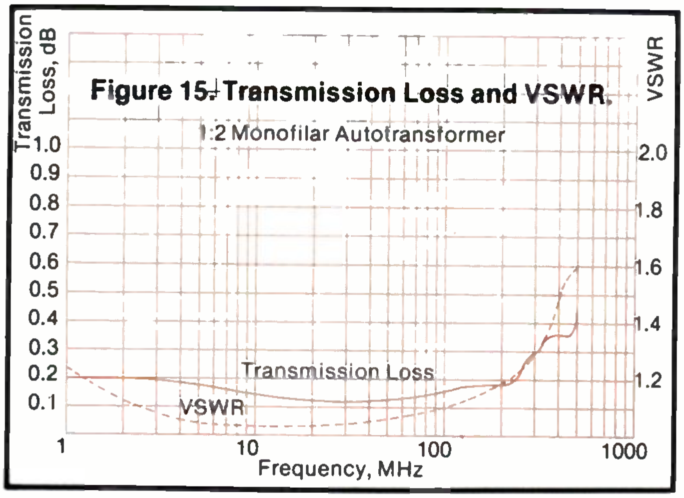


Figure 15. Transmission Loss and VSWR.

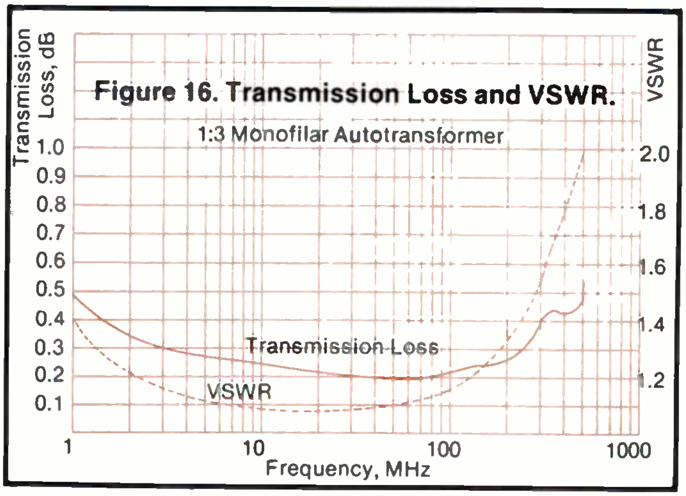


Figure 16. Transmission Loss and VSWR.

Autotransformers

Figure 15 shows the test results for the 1:2 autotransformer. When comparing the performance of this autotransformer with that of the 1:1.5 unit, two facts become evident. Note that the 1:2 autotransformer is superior at the low frequency end. Even at 1 MHz, it is not yet significantly rolling off either in terms of transmission loss or VSWR. Performance is good down to about 0.5 MHz. This improved low frequency response results from the additional primary turn, which raises the equivalent parallel inductance L_p (L_p being the parameter having the predominant influence on low-frequency performance). Note also that the 1:2 autotransformer has less mid-band transmission loss. Once again, the additional primary turn is responsible, since it has raised the equivalent parallel impedance.

The 1:3 autotransformer test results of Figure 16 provide a superb example of an opportunity to specify autotransformer performance with less-than-complete candor. Note that transmission loss is within 0.55 dB from 1-500 MHz. Looking at VSWR, however, we see significant deterioration at the high end of the frequency range. Now this isn't to say that this autotransformer may not to be usable in some applications to 500 MHz — it probably is — but to utilize this autotransformer, we need to know the reflection characteristics as well as the transmission characteristics.

The 1:4 autotransformer test results of Figure 17 are probably of particular interest, since 1:4 autotransformers are the most frequently used (probably because they are the easiest multifilar wound autotransformers to construct). As an experiment, this autotransformer was also wound with bifilar wire and tested. The results were

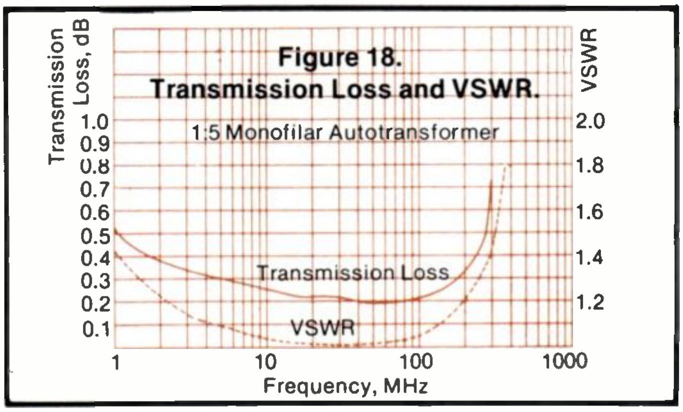


Figure 18. Transmission Loss and VSWR.

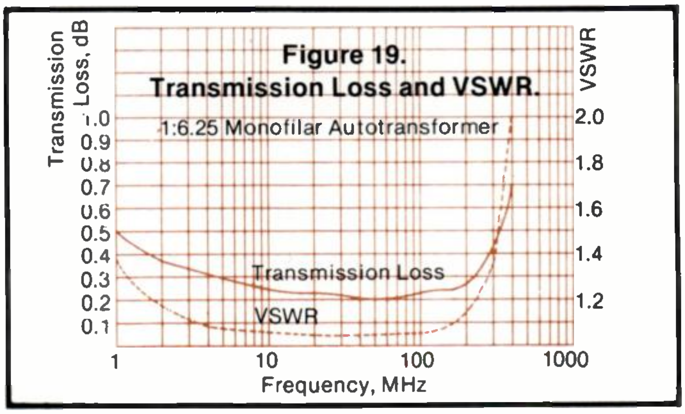


Figure 19. Transmission Loss and VSWR.

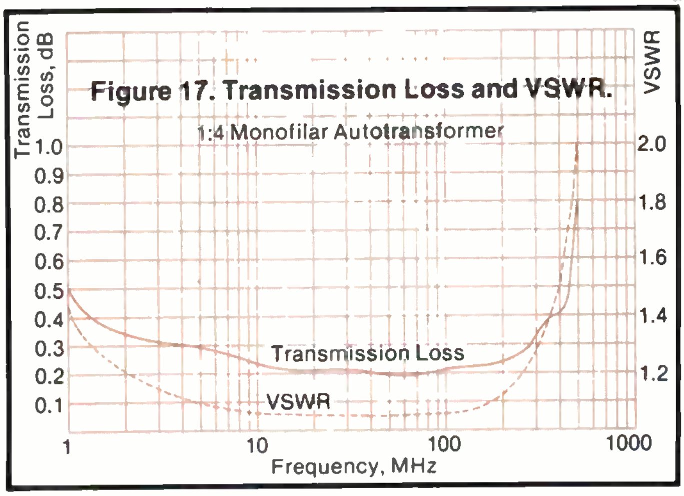


Figure 17. Transmission Loss and VSWR.

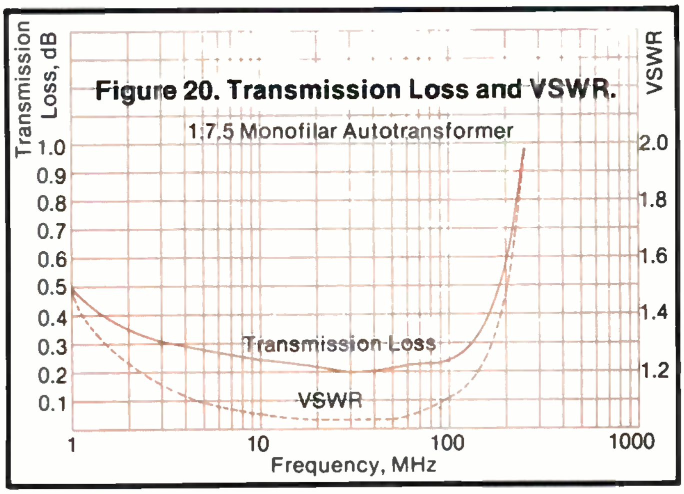


Figure 20. Transmission Loss and VSWR.

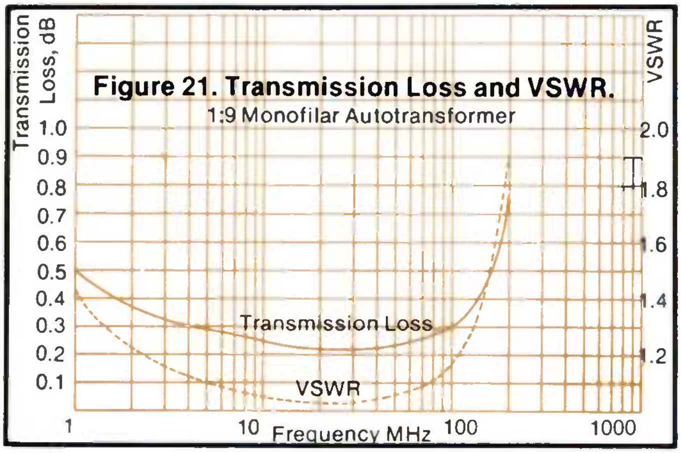


Figure 21. Transmission Loss and VSWR.
1:9 Monofilar Autotransformer

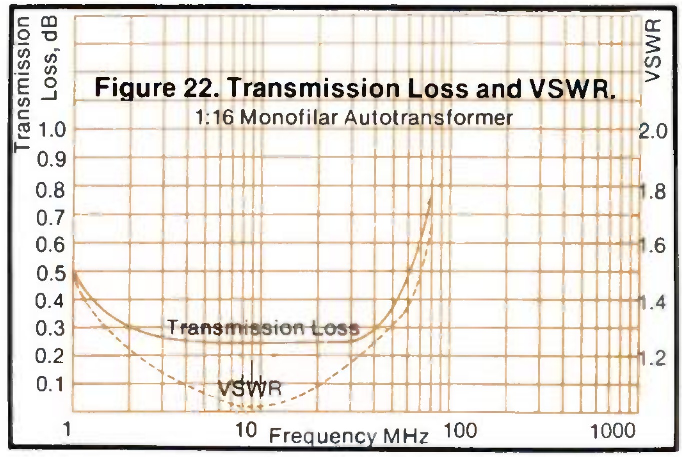


Figure 22. Transmission Loss and VSWR.
1:16 Monofilar Autotransformer

very nearly as good as those of Figure 17.

The test results for the 1:5, 1:6.25, 1:7.5, 1:9, and 1:16 autotransformers are presented in Figures 18 through 22. Note that as the impedance transformation ratio increases, the bandwidth tends to diminish. This bandwidth reduction occurs entirely at the high frequency end, and is primarily a function of the increased interwinding capacitance imposed by the additional turns.

As another experiment, the 1:9 autotransformer was compared to two other 1:9 transformers, one wound with four trifilar turns on the previously mentioned core and the other a commercially available isolation transformer (selling for $3.45). All three transformers were tested in the transmission and reflection test fixtures of Figures 9 and 10, respectively. The results are plotted in Figures 23 and 24.

The most obvious result is the tremendous difference in performance between the trifilar wound autotransformer and the monofilar autotransformer. Clearly, the trifilar wound autotransformer exhibits vastly inferior transmission and reflection characteristics. When comparing the monofilar autotransformer to the commercially available transformer, it is clear that the monofilar unit has much less insertion loss over the relevant frequency range. In addition, the monofilar autotransformer reflection characteristics are equal or superior to those of the commercially available transformer over the bulk of the frequency range. This comparison is not intended as criticism of the commercially available transformer (quite to the contrary, this transformer is very well designed and constructed). Its higher losses are not a result of poor transformer design, but rather are due to the fact

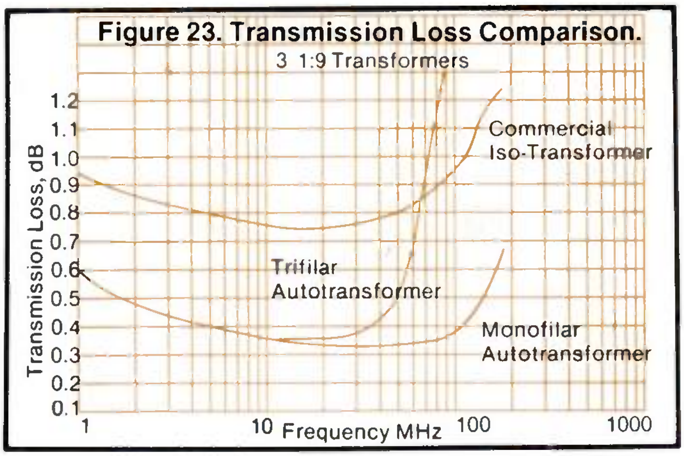


Figure 23. Transmission Loss Comparison.

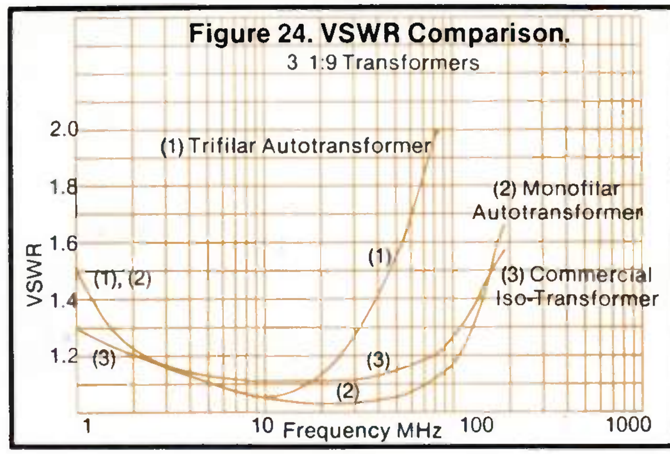


Figure 24. VSWR Comparison.

that RF isolation transformers usually exhibit more transmission loss than RF autotransformers.

To pursue the matter of autotransformer comparison further, a 1:9 autotransformer was trifilar wound on a suitable toroid** using five trifilar turns. Again, as shown in Figures 25 and 26, the monofilar autotransformer is still vastly superior, although the performance of the trifilar wound autotransformer improved markedly by replacing the two-hole balun core with a toroid.

As a final comparison, the 1:4 monofilar autotransformer was compared to a bifilar version wound with five bifilar turns on a Fair-Rite Products Corp. 2643002401 toroidal core. Figures 27 and 28 show the results.

**Fair Rite #2643002401

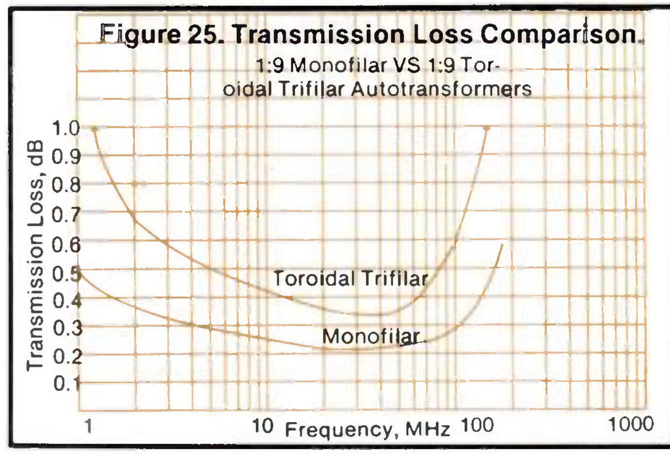


Figure 25. Transmission Loss Comparison.

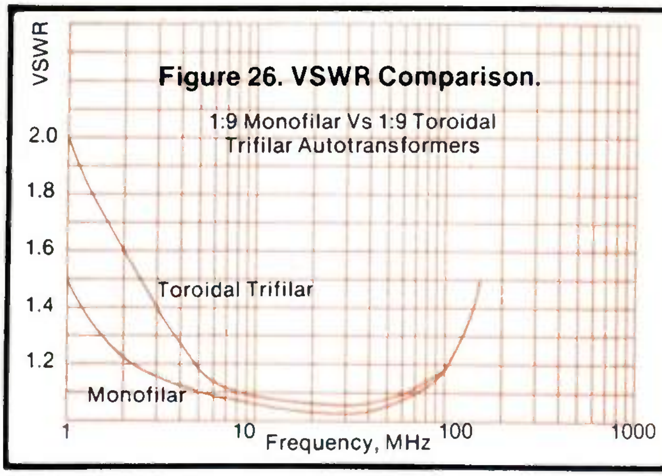


Figure 26. VSWR Comparison.
1:9 Monofilar Vs 1:9 Toroidal Trifilar Autotransformers

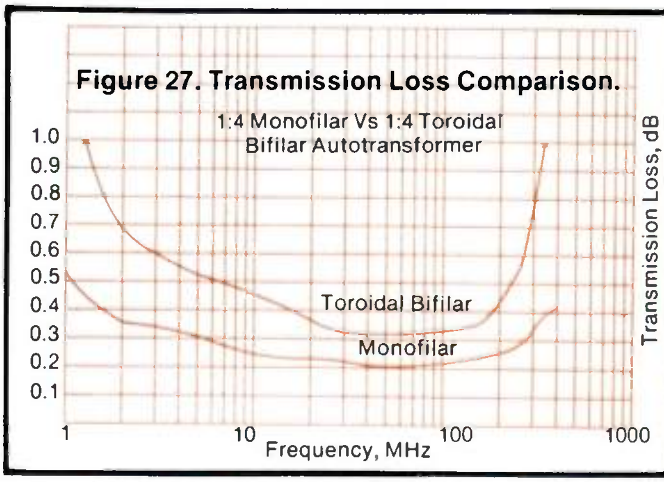


Figure 27. Transmission Loss Comparison.
1:4 Monofilar Vs 1:4 Toroidal Bifilar Autotransformer

Again, the monofilar autotransformer yields superior performance.

Baluns

A balun is a device through which a balanced source may be connected to an unbalanced load without significantly disturbing the balance of that source. Some balun configurations yield an impedance transformation. In antenna and transmission line applications, these baluns are often constructed with coaxial cables. Lumped versions of these baluns may also be constructed with ferrites and bifilar wires.

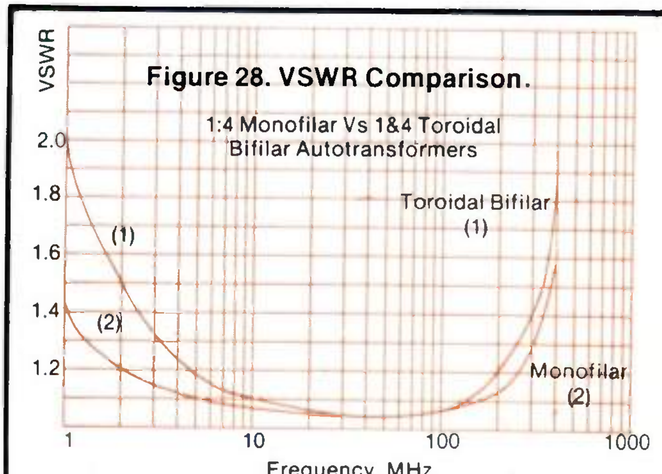
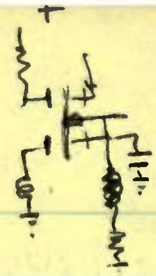
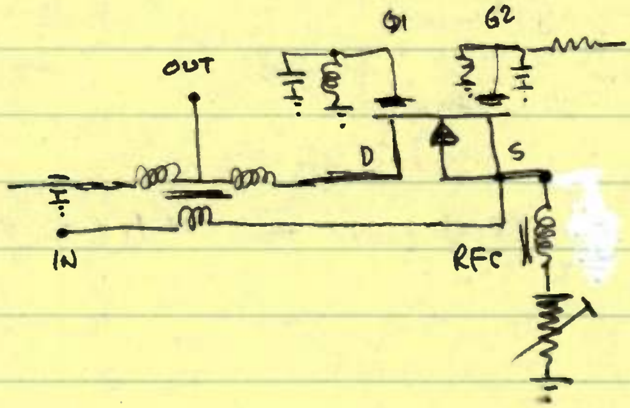
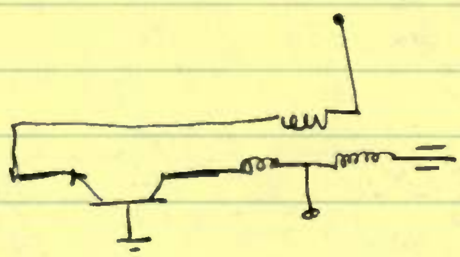
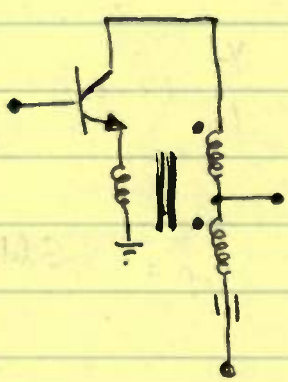


Figure 28. VSWR Comparison.
1:4 Monofilar Vs 1&4 Toroidal Bifilar Autotransformers




G1
G2
OUT
D
S
IN
RFC





$$\frac{Y(d)}{Y_o} = p + j\,\frac{B(d)}{Y_o}$$

$$p + j\,\frac{B(d)}{Y_o} = \frac{Y_T/Y_o + j\tan\beta d}{1 + j\,(Y_T/Y_o)\tan\beta d}$$

$$p + j\,p\left(\frac{Y_T}{Y_o}\right)\tan\beta d + j\,\frac{B(d)}{Y_o} - \frac{Y_T}{Y_o}\,\frac{B(d)}{Y_o}\tan\beta d = \frac{Y_T + j\,Y_o\tan\beta d}{Y_o}$$

Real

$$p - \frac{B(d)}{Y_o}\left(\frac{Y_T}{Y_o}\right)\tan\beta d = \frac{Y_T}{Y_o}$$

$$-\frac{B(d)}{Y_o}\left(\frac{Y_T}{Y_o}\right)\tan\beta d = \frac{Y_T}{Y_o} - p$$

$$+\frac{B(d)}{Y_o} = \frac{\left(\frac{Y_T}{Y_o}\right) - p}{\left(\frac{Y_T}{Y_o}\right)\tan\beta d} = \boxed{\frac{p - \frac{Y_T}{Y_o}}{\frac{Y_T}{Y_o}\tan\beta d}}$$

$$\boxed{\frac{p - Y_{Tn}}{Y_{Tn}\tan\beta d}} \quad \text{where} \quad p = G(d)/Y_o$$

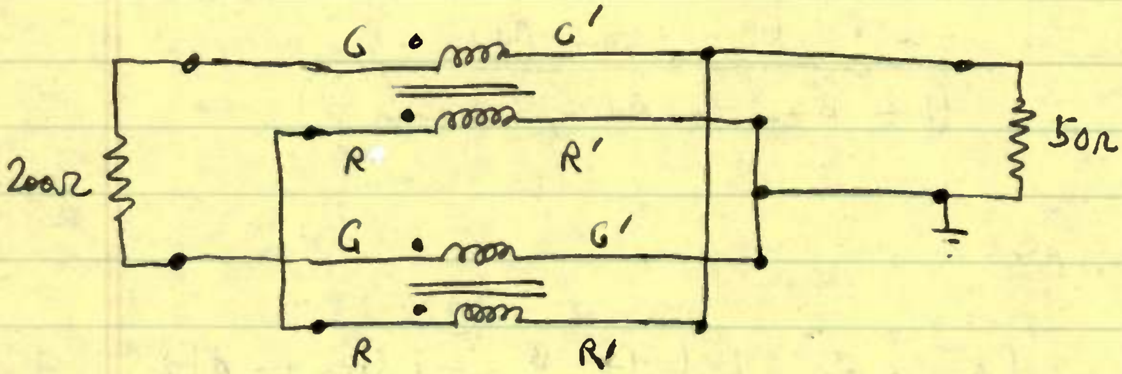
$$l_1 = .122\,\lambda$$

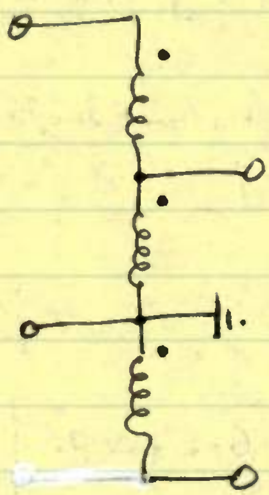
$$: \; 1 -$$

$$-\tan(.720)\,[5.214] + 2.078 + \tan(.720) - 2.078\tan[(.720)]^2$$

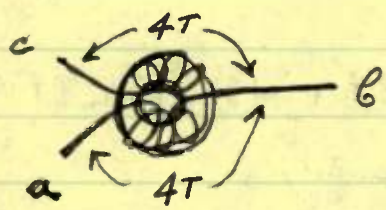
$+ \; \therefore$ add a short for this line length.

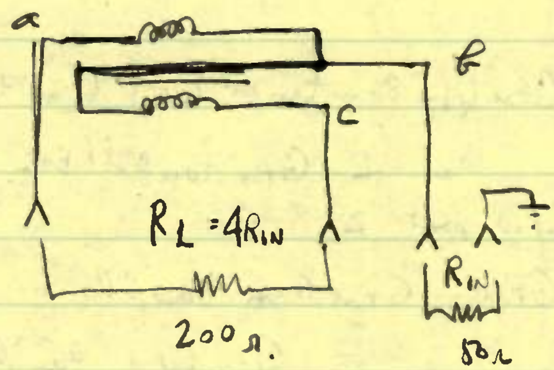
4:1





1:1 Unbal- Bal.





$\frac{\tan^{-1} x}{360} = .122$

$\frac{2\pi}{\lambda}\ .122\lambda$

$$\frac{Y(d)}{Y(0)} = \frac{G_{Tn} + j(B_{Tn} + \tan\beta d)}{(1 - B_{Tn}\tan\beta d + j\, G_{Tn}\tan\beta d)}$$

real part

$$\frac{G_{Tn} + j(B_{Tn} + \tan\beta d)\,(1 - B_{Tn}\tan\beta d - j\, G_{Tn}\tan\beta d)}{(1 - B_{Tn}\tan\beta d + j\, G_{Tn}\tan\beta d)(1 - B_{Tn}\tan\beta d - j\, G_{Tn}\tan\beta d)}$$

$$= \frac{G_{Tn}(1 - B_{Tn}\tan\beta d) - j\, G_{Tn}^2\tan\beta d + j\, B_{Tn} + \tan\beta d}{(1 - B_{Tn}\tan\beta d)^2 + (G_{Tn}\tan\beta d)^2}$$

numerator

$l = .002$

$$G_{Tn} + j(B_{Tn} + \tan\beta d)\left[(1 - B_{Tn}\tan\beta d) - j\, G_{Tn}\tan\beta d\right]$$

$$= G_{Tn}(1 - B_{Tn}\tan\beta d) - j\, G_{Tn}^2\tan\beta d + j\,(B_{Tn} + \tan\beta d)(1 - B_{Tn}\tan\beta d) + G_{Tn}\tan\beta d(B_{Tn} + \tan\beta d)$$

real part is:

$$G_{Tn} - \cancel{G_{Tn}B_{Tn}\tan\beta d} + \cancel{G_{Tn}B_{Tn}\tan\beta d} + G_{Tn}\tan^2\beta d$$

$$= G_{Tn}(1 + \tan^2\beta d)$$

$\frac{B(d)}{Y_0} = -j \Rightarrow y^2$

$\therefore$ ~~add~~ open stub

1.114

imaginary part is

$\frac{B(d)}{Y_0} = -3.307$

$$-G_{Tn}^2\cancel{\tan\beta d} + \cancel{B_{Tn}} - B_{Tn}^2\cancel{\tan\beta d} + \cancel{\tan}\beta d - B_{Tn}\tan^2\beta d$$

$$B(d)/Y_0 = \boxed{-\tan\beta d\left[G_{Tn}^2 + B_{Tn}^2\right] + B_{Tn} + \tan\beta d - B_{Tn}\tan^2\beta d}$$

$$-\tan(43.92)\left[5.214\right] + 2.078 + \tan(43.92) - 2.078\left[\tan(43.92)\right]^2$$

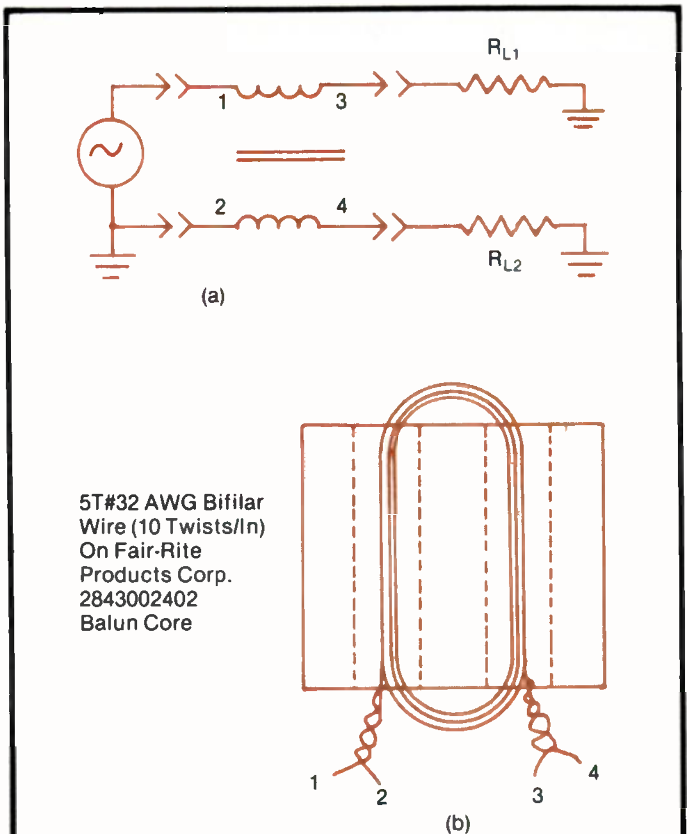


Figure 29. (a) 1:1 Balun Schematic Diagram. (b) 1:1 Balun Cutaway Drawing.

Figure 29 shows schematically and pictorially a device often employed (and loosely defined) as a 1:1 balun. This balun essentially is a transmission line loaded with ferrite. In addition to the transmission and reflection characteristics shown in Figure 30, there are two other parameters of importance here. These parameters are phase balance and amplitude balance. Phase balance is simply a measure of how closely the respective voltages across R_{L1} and R_{L2} of Figure 29 approach the ideal 180° antiphase condition, while amplitude balance is a measure of the equality of the voltages impressed across R_{L1} and R_{L2}. This 1:1 balun typically exhibits

(Continued on page 28.)

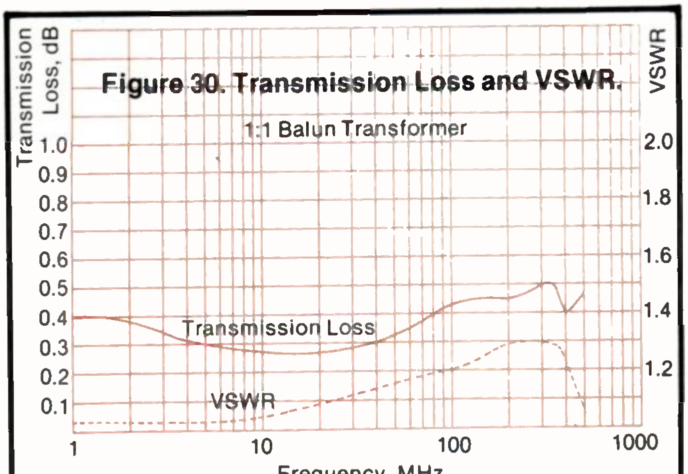


Figure 30. Transmission Loss and VSWR.

Terminations... Others are

High Power Coaxial Fixed Attenuators
Models 24, 25 & 26

50 WATTS
- dc — 8.0 GHz — Model 24
- dc — 4.0 GHz — Model 25
- dc — 1.5 GHz — Model 26
- High Power — 50 W Avg., 5 kW Peak
- Standard Values — 3, 6, 10, 20 and 30 dB
- Stainless Steel Type N Connectors — Mate with N per MIL-C-39012

Circle Reader Service 104

High Power Coaxial Terminations
Models 1426 & 1427

50 WATTS
- dc — 8 GHz
- High Power — 50 W Avg., 5 kW Peak — Model 1426 25 W Avg., 5 kW Peak — Model 1427
- Low VSWR — 1.30:1 Maximum
- Calibration Data — dc Resistance and VSWR Supplied
- Stainless Steel Type N Connectors — Mate with N per MIL-C-39012

Circle Reader Service 105

Miniature Medium Power Termination
Model 1419

10 WATTS
- dc — 18.0 GHz
- Power Rating — 10 W, 1 kW Peak
- Low VSWR — 1.35:1 Maximum
- Stainless Steel WPM Connectors — Mate with SMA per MIL-C-39012

Circle Reader Service 106

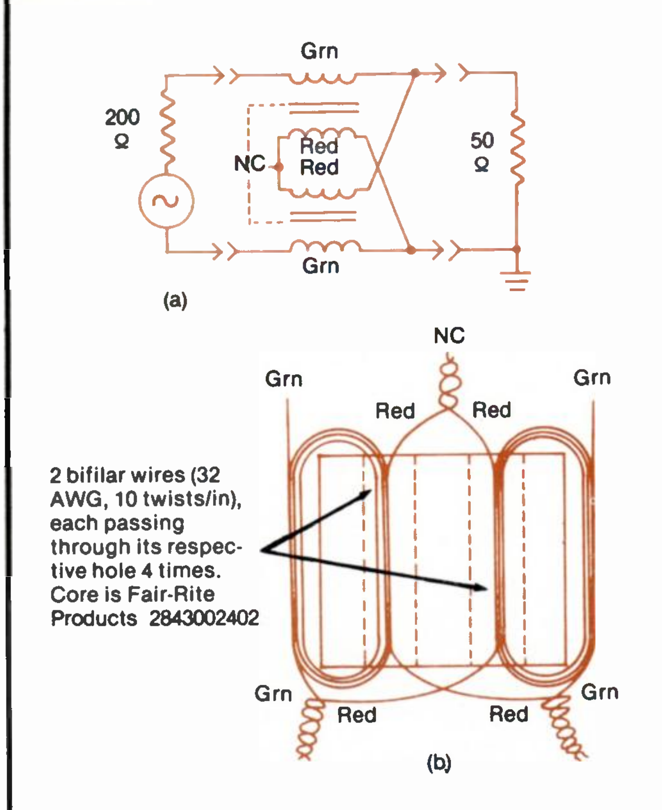


Figure 31. (a) 4:1 Balun Schematic Diagram. (b) Pictorial.

phase balance to within 3° from 2-500 MHz. Amplitude balance over the same frequency range is typically within 0.5 dB, improving to 0.25 dB from 25-300 MHz.

Figure 31 shows schematically and pictorially a 4:1 balun. Baluns similar to this have been employed for years by the television industry to match a 300 ohm balanced transmission line to an unbalanced 75 ohm coaxial cable. This 4:1 balun can be thought of as having attributes of both an autotransformer and a transmission line transformer. To clarify this point, suppose we redraw the 4:1 balun schematic of Figure 31 as shown in Figure 32a. When viewed in this fashion, the 4:1 balun appears to be a symmetrical autotransformer (although magnetic coupling between the windings is insufficient for this balun to be classified as a true autotransformer). However, if we again redraw the schematic as shown in Figure 32b and ignore the ferrite core for the moment, we see that we have two transmission lines that are series-connected at the high impedance end and shunt-connected at the low impedance end. If each of the two transmission lines has a characteristic impedance of 100 ohms, then a 200 ohm termination at the series-connected end will appear as 50 ohms at the shunt-connected end. So that these lines need not be excessively long, ferrite loading is employed. In addition, it is not strictly necessary for the transmission line characteristic impedances to be 100 ohms. Figure 33 shows the transmission and reflection characteristics of this balun. Again, phase and amplitude balance are important. For this balun, phase balance is typically within 3°, while amplitude balance is typically within 0.7 dB from 30-300 MHz. This balun works quite well in broadcast FM and VHF TV applications.

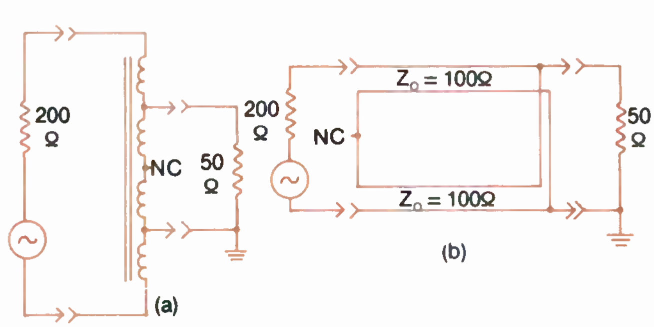


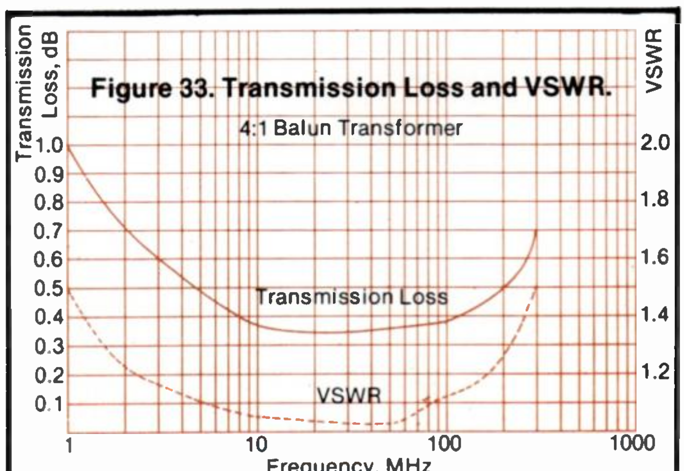
Figure 32. (a) 4:1 Balun Redrawn as Symmetrical 4:1 Autotransformer. (b) 4:1 Balun Redrawn as 4:1 Transmission Line Transformer.

Other Configurations

Although the impedance transformation ratios for which detailed performance data has been presented should cover most applications, there may be occasions when some other ratio may be required. In most cases, a suitable winding configuration may be obtained by finding a suitable turns ratio using Equation 4. There are two major constraints here. On the one hand, the winding needs enough turns to yield the desired low-end frequency performance. Four turns is optimum for the 50 ohm port if the autotransformer is not to be used below 1 MHz. A three-turn winding at the 50 ohm port raises the low-end cutoff frequency to 2 MHz, while a five-turn winding extends operation down to about 0.5 MHz.

It may be necessary in some instances (primarily in transmitting and other high-level applications) to transform a 50 ohm source to a lower impedance load, or vise versa. This can be accomplished with the monofilar autotransformers already described, but the useful frequency range will shift downward. This is usually not desirable, since there are very few requirements for wideband autotransformers below 1 MHz. The best autotransformers for these applications are the 1:1.5, 1:2, and 1:3 versions. The 1:4 performs better in these applications by employing a four or six turn (center-tapped) winding rather than the specified eight turn winding. In general, wideband downward transformations to very low impedance levels are more difficult to achieve than similar upward transformations.

Figure 33. Transmission Loss and VSWR.



(Continued from page 25.)
Although the autotransformers described in this article are intended for use in low power level applications, they will easily handle power levels in excess of one watt.

Manufacturing Information

Construction of these autotransformers is simple and straightforward. There are a few precautions, however, that can save time and trouble.

The factor most responsible for production fallouts is the assembler's failure to correctly count the number of turns during winding. Turn-counting errors can be minimized by precutting the wire to the correct length as a separate assembly operation. Another good practice is to have the assembler wind the autotransformers in an area where interruptions or other distractions can be minimized.

One edge of the core should be premarked with a conspicuous dot to designate the ground or common terminal of the autotransformer. If more than one type of autotransformer is to be constructed, color code these dots to designate the impedance transformation ratio.

Testing of the autotransformers can be accomplished by several methods. The most sensitive method is to employ the swept VSWR test fixture of Figure 10, terminating the autotransformer secondary with its correct load resistance. This method will readily indicate any abnormality, including a miscounted turn (even on the higher ratio autotransformers).

Another satisfactory method relies on the fact that the ratio of the secondary to primary winding inductance is very nearly equal to the impedance transformation ratio. Any standard inductance meter (operating below 1 MHz) is quite suitable for conducting this test.

Summary and Conclusion

Although the autotransformers described in this article are intended for use in low power level applica-literature concerning the specifics of the design and construction of practical and cost-effective autotransformers. Detailed performance data appears to be generally unavailable. As a consequence, most engineers must resort to a great deal of time consuming experimental effort in designing, constructing, and specifying autotransformers suitable for their needs.

In this article, the desirable qualities of autotransformers were discussed in terms of performance, cost, and manufacturability. A variety of different autotransformers (employing the monofilar winding technique) and baluns were then described in detail with regard to transmission characteristics, reflection characteristics, and the construction techniques.

Comparisons were made to show the superiority of these autotransformers to those employing standard toroids and multifilar windings. Finally, manufacturing and testing information was provided.

In closing, this author recognizes that autotransformers could be designed with even better performance characteristics than the monofilar units described in this article. However, the emphasis here has been placed not only on superior performance, but also on providing the design engineer the information needed to design a wide variety of low cost, easily manufactured, well specified autotransformers with better performance characteristics than can be obtained with more customary design techniques. □

Spectrum Analysis Basics

This discussion is intended to serve as an introduction to Spectrum Analyzers for the beginner and as a limitation reminder to the experienced user.

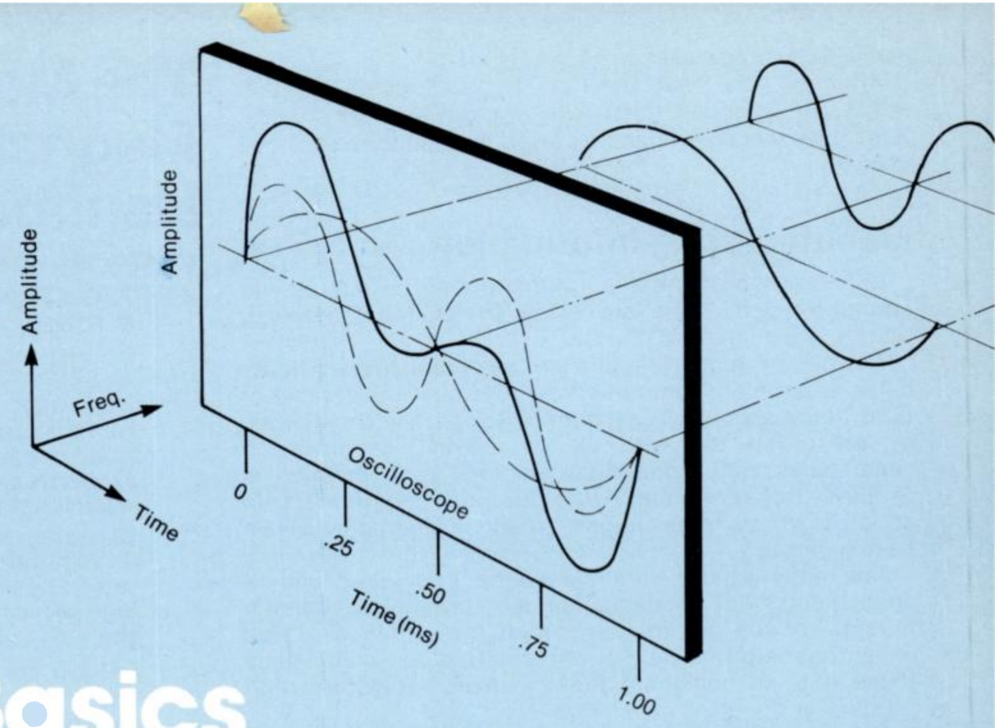


Figure 1.

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The advent of the low cost spectrum analyzer has without doubt increased the effectiveness of the modern design laboratory. As a development tool, the spectrum analyzer is an invaluable diagnostic aid. As a performance instrument the spectrum analyzer yields fast analysis of harmonic and spurious signal equipment operation.

Because of ever increasing uses of potential "radiators" i.e. electronic equipment capable of radiation in the radio frequency or RF spectrum regulations and standards are appearing which cover not only deliberate "radiators" (radio transmitters for example,) but also the incidental radiators. These include computers, electronic toys, calculators, etc. Thus the need for effective spectrum analyzers has expanded out of the RF laboratory and into many other laboratories.

Harmonic Measurement

As late as 1957, a common method was to tune a receiver to the harmonic frequencies then insert a signal generator and measure the level required for equal amplitude. With proper techniques measurements of this kind yielded 120 dB of dynamic range.

Limitations of the above system are:

1) Measurements of spurious other than harmonics is time-consuming and, in the case of transistory spurious responses, some spurious may be missed.

2) Spurious responses in the passband require a highly selective and stable receiver to recover useful data. Because of the required selectivity tuning rate would be prohibitively slow.

Panoramic Analyzers

The first spectrum analyzers to be developed were largely used for inband measurements, that is measurements close to the desired operating frequency. These instruments were often called panoramic analyzers.

One of the most interesting early spectrum analyzers is the Collins 478R-1. This unit is usable from 1.7 to 63 MHz, has a 17" CRT display and displays up to 100 kHz of spectrum at a time. To develop the sweep a variable speed motor is connected to a pot which controls the deflection voltage and a variable capacitor which controls the low frequency sweep oscillator.

Real-Time Versus Swept-Tuned Analyzers

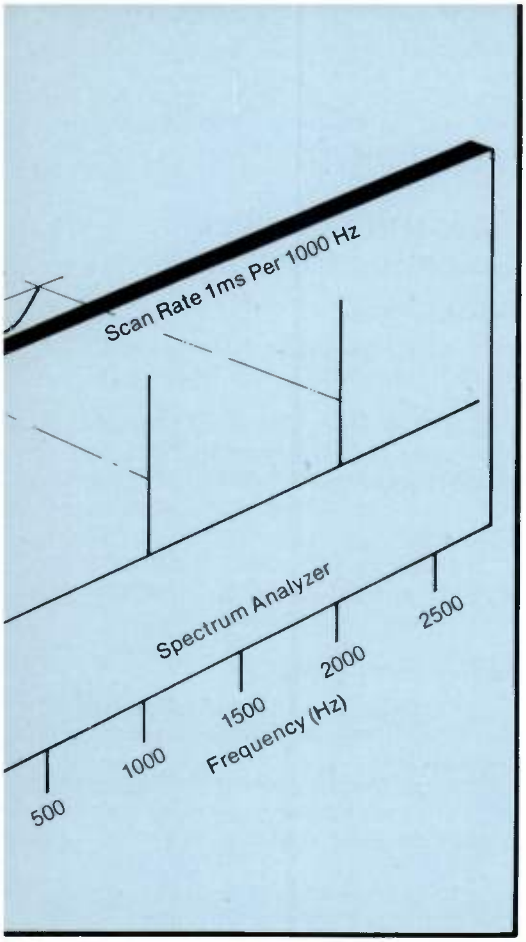
A spectrum analyzer is an instrument which displays voltage or power on the Y axis while displaying the corresponding frequency on the X axis. (See Figure 1.)

Spectrum analyzers fall into two basic types, real-time and swept-tuned. Real-time analyzers simultaneously display all signals in the frequency range, thus preserving phase information. Additionally real-time analyzers have the capability of displaying transient responses.

Swept-tuned analyzers on the other hand display the frequency of the components of spectrum sequentially. They are tuned by electrically sweeping them over the frequency range (with the notable exception of the Collins unit).

Real-time analyzers are used primarily in the subsonic, sonic, ultrasonic and electronic application areas. Examples include but are not limited to large-mass structural design and diagnostics, speech-signature analysis, magnetostriction studies and power-spectral-density measurements for modulation and FM noise studies, respectively.

Instead of a single tunable filter the real-time or Fast Fourier Transform Analyzer (FFT) consists of a bank of filters, which are all presented with the signal simultaneously. Therefore, the spectrum-data acquisition time is simply, the time required to put energy into one filter considerably faster than the swept-



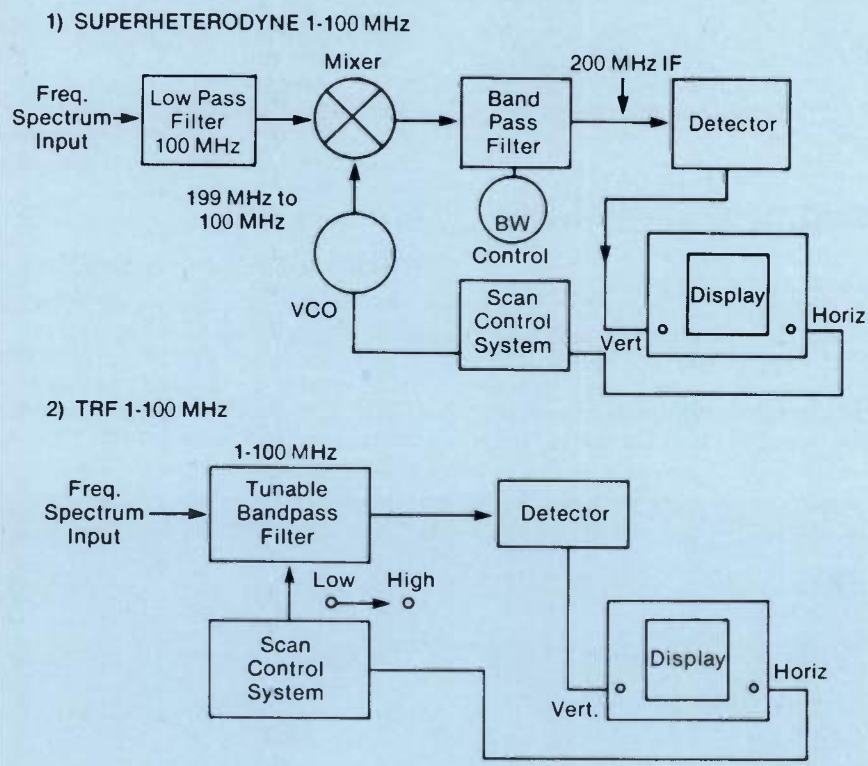


Figure 2. Swept-Tuned Block Diagrams.

filter analyzer, for a given resolution.

Swept-tuned analyzers fall into two categories: the superheterodyne and the tuned-radio frequency (TRF) type. The most common type found in the laboratory is the superheterodyne. The TRF type has several limitations that has made it unpopular:

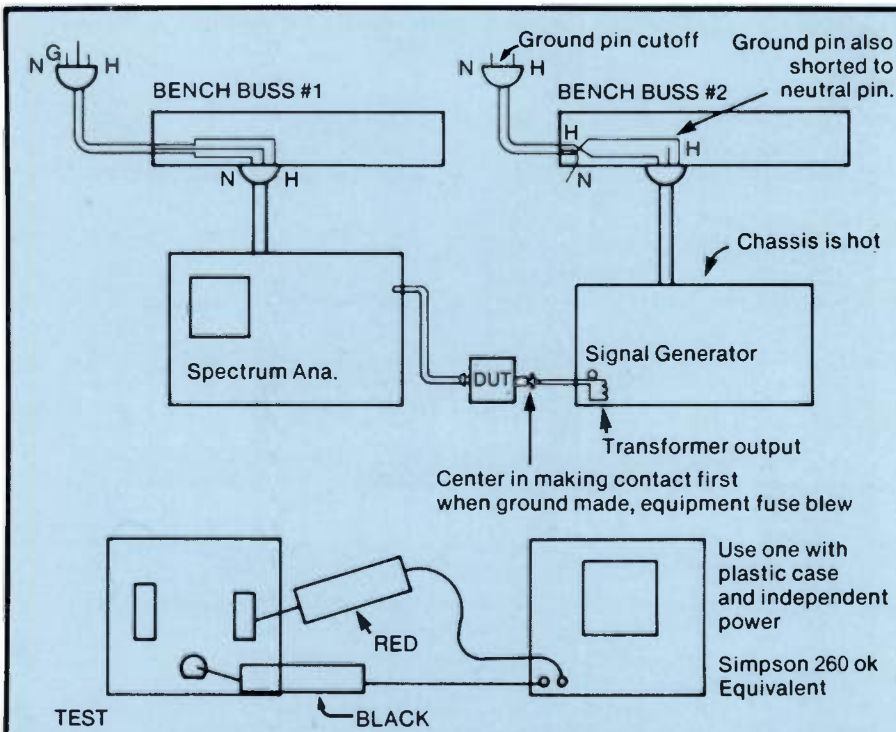
1) It is rather difficult to build an electrically-tuned filter that will tune over several decades while maintaining a constant bandwidth. (See Figure 2).

2) Changing the filter bandwidth is an uneconomic proposition at best, thus limiting the versatility of the analyzer.

Superheterodyne analyzers operate by converting the input signal to a specific IF frequency and then sweeping a voltage-controlled oscillator (VCO) to view the spectrum of interest (Figure 2). Usually the IF frequency is above the frequency of interest. This allows use of the analyzer down to VLF without fear of IF interference. Additionally, the image response may be removed by use of a low-pass filter.

Commercial instruments generally make an additional conversion to a lower frequency. This is usually done in order to make band-pass filters practical and to develop IF gain using less expensive amplifier stages.

The above covers the very basic



STEP 1: Set meter on 250 volt scale, Insert Black probe in Gnd.
STEP 2: Insert red probe in small prong hole, this will be hot (117 VAC) if socket wired correctly.
STEP 3: Move red probe to large hole (neutral), this should read zero, if so step four, else stop.
STEP 4: With red probe in neutral and black in ground switch to ohms, resistance should be <2 ohms.
STEP 5: Repeat process for all outlets on test bench.

Figure 3.

spectrum analyzer systems. Other features that help in spectrum analysis are tracking generators, display storage (both tube and digital) and input attenuation.

Equipment Limitations

In order to prevent serious damage and/or incorrect data, it is important that the operator understands the limitations of the equipment. It is very easy to damage the input attenuators and mixers in modern spectrum analyzers if design limits are exceeded.

One way that I have personally seen a five hundred dollar attenuator ruined was by the application of 117 VAC to the analyzer input. Figure 3 indicates the problem area. Additionally, this setup is potentially hazardous to personnel as there is 117 volts on the signal generator chassis.

Initial Safety Procedures

1) Insure that all power receptacles are properly wired. (See Figure 3.)

2) Ground all equipment chassis (don't depend on test lead grounds!)

3) Do not use 2 wire extension cords or cords with ground pins removed! This is common sense and may not only save a valuable piece of equipment but your life.

Spectrum Analyzer Selection Criteria

Safety Criteria

1) Inputs should be plainly labeled as to the maximum safe AC and DC levels.

2) If "safe input level" changes with attenuator settings, then this should be clearly spelled out on the attenuator switch or at the corresponding input.

3) When all attenuation is removed, a warning light or other prominent identification is highly desirable.

Performance Criteria

1) Damage Level: Level at which equipment may be damaged. (Specified in dBm.)

2) 1 dB Compression Point: Level which causes gain of analyzer to compress 1 dB. (Specified in dBm.)

3) Max Input for Specified Distortion: Input level which will yield specified spurious-free dynamic range.

4) Noise Level/Bandwidth: Level of noise floor for a specified bandwidth. Several of these may be given for a particular measurement.

The above does not take into account the switched internal attenuator that precedes the first mixer. Through the addition of attenuation damage level may change. "2" and "3" will be raised by an amount corresponding to the amount of attenuation. "4" will also be raised. .

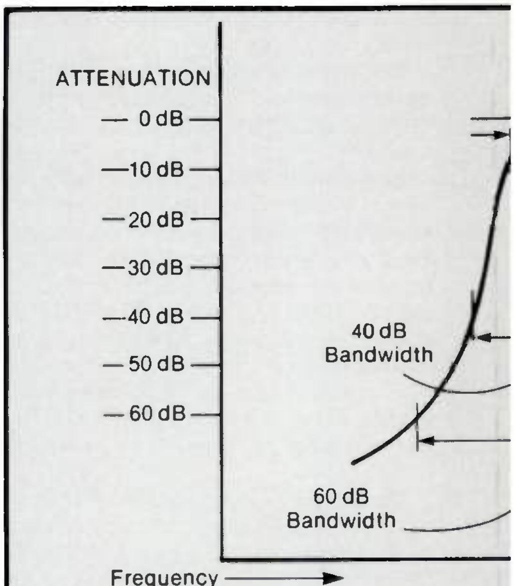
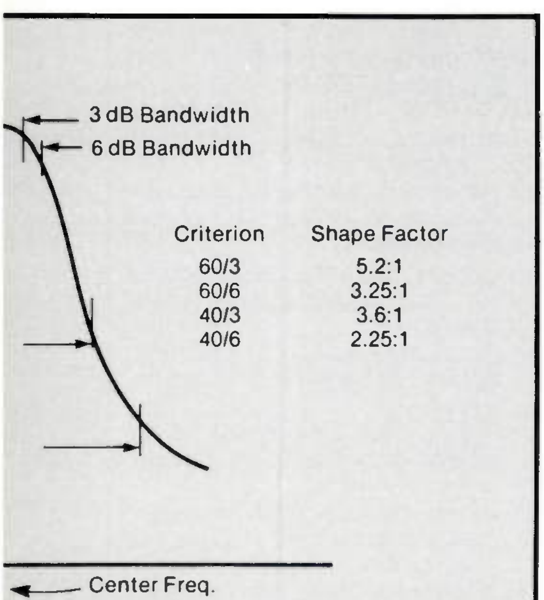


Figure 4. Bandwic

5) Resolution: This is the ability of the analyzer to discern two signals that are close to each other in frequency. This characteristic is determined by the IF filter's bandwidth and shape factor.

The shape factor is usually defined as the ratio between the 3 dB and 60 dB filter bandwidths. However, not all spectrum analyzer manufacturers adhere to this standard. It is important for purposes of comparison to establish that the measurement of the filters is accomplished in a uniform manner. (See Figure 4). Observe that this filter appears twice as good using 40:6 as compared to 60:3. The filter in Figure 4 is hypothetical and much better than ones found in practice. A spectrum analyzer with a 15:1 shape factor (60:3) is not bad. The importance of high resolution becomes apparent in this next example. Consider examining sidebands generated by a 60 Hz AC line that appears on a signal. If your analyzer has a 10 Hz filter with a 15 to 1 specification (60:3) and the 60 Hz modulation is 50 dB below the carrier, it will begin to be distinguishable on the display. A signal at 75 Hz will become apparent at −60 dB. A filter with poorer (larger) shape factor will not distinguish between these signals.

There are two other considerations that are indirectly related to resolution. The first is the noise sideband generated by the L.O. and the other mixing oscillators. Let's assume that the actual signal is perfect in this regard. Random noise exists close to the carrier frequency of the L.O. (and other oscillators). The type and quality of the L.O. will



vs. Attenuation.

determine how far down this noise is suppressed. Generally speaking the closer the L.O. frequency is approached the greater the amplitude of this noise. Thus, for close in measurements the level of this noise becomes critical. To make the above measurement the analyzer would have to have a noise sideband specification of -60 dBc when offset from the carrier by 60 Hz. This noise is often referred to as SSB Phase Noise. It is generally measured using a 1 Hz bandwidth.

The other problem is residual FM, which should be specified by spectrum analyzer manufacturers. As a case in point it is very difficult to make the 60 Hz measurements if the residual FM is 1 kHz.

6) Sensitivity: Analyzer sensitivity is a consideration during the detection of very low amplitude signals. This specification is usually in dBm or volts or both. Good analyzers range from -117 dBm for an inexpensive analyzer to -135 dBm for the high-priced unit.

The major improvement in noise performance is due to the fact that the first analyzer uses a 1 kHz IF filter while the second analyzer has a 10 Hz filter.

Noise power is based on the following equation: $P_n = KTB$ Where P_n = Noise power (watts), K = Boltzman's constant = 1.38×10^{-23} joule/°K., T = absolute temperature in degrees Kelvin and B = bandwidth of the system in Hertz. It follows then if we reduce bandwidth by a factor of 10, then the noise power will also be reduced by 10 resulting in a 10 dB improvement. Thus the expected problem is thermal noise and by reducing the economy model to 10 Hz bandwidth the performance would improve to -137 dBm. It is highly probable that other noise contributors would limit the inexpensive model even if it were equipped with a 10 Hz filter.

If you are comparing noise specifications, insure that they are measured using the same IF bandwidth!

Coming Soon

Part II will cover the following aspects of spectrum analyzers.

1) Harmonic measurements: or how to make high dynamic range measurements (>80 dB) using an inexpensive analyzer.

2) Intermodulation Distortion: Discusses techniques for two-tone generators, analyzer test sets and high-speed measurements.

3) External attenuators and cabling: Discusses performance of various attenuators and cable sets when spectrum analyzers and accessories must be located in the radiated field i.e. everything on the bench! ☐

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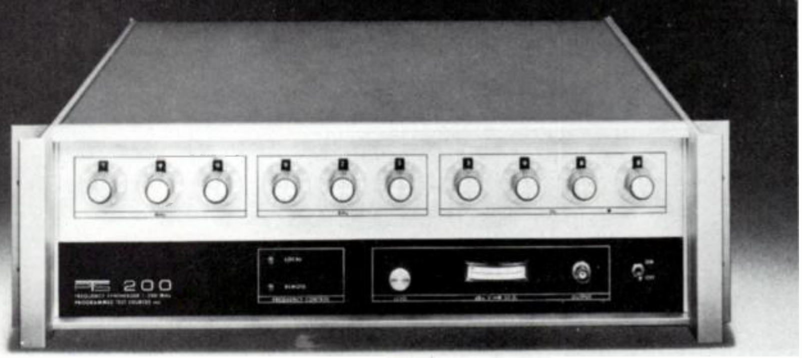

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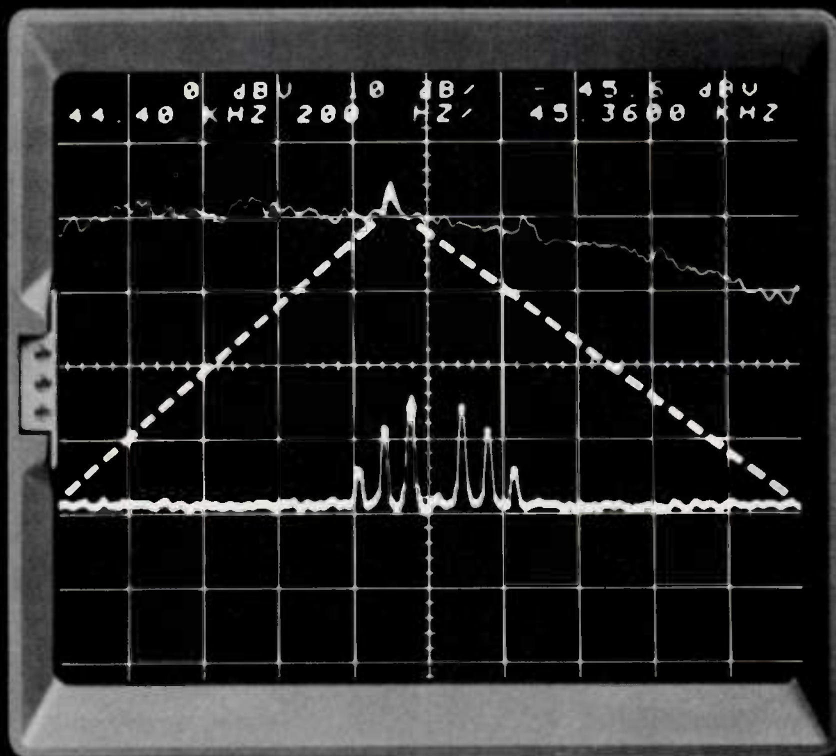

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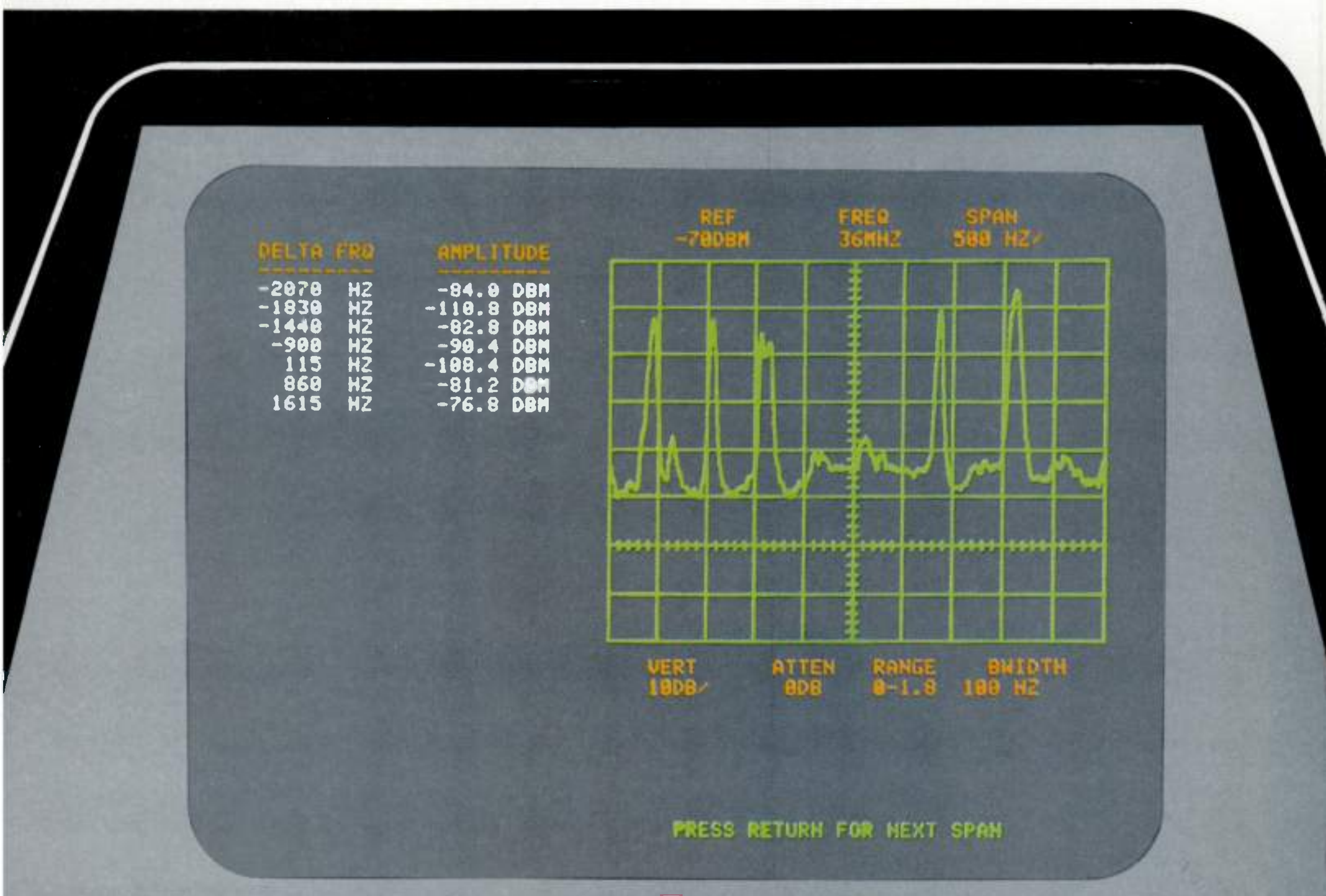
Automatic Spectrum Analysis

Total Harmonic Distortion, Impulse Bandwidth and Percentage Modulation are a few of the measurements that can be made more readily utilizing automatic spectrum analysis techniques.



Gary Mott
Tektronix, Inc.
Beaverton, OR

The modern spectrum analyzer is a relatively new test and measurement instrument. Twenty-five years ago, the spectrum analyzer was used strictly as a laboratory device by skilled engineers for limited applications. Early spectrum analyzers were little more than spectrum monitoring devices. They were not capable of making calibrated measurements. They were large and cumbersome, and their overall usefulness was limited. The engineers who used these early instruments were required to read and interpret most of the data themselves. The modern spectrum analyzer has come a long way since that day. It is used not only by the skilled engineer but by a wide range of technically skilled and unskilled people for many applications. It has become one of the most versatile electronic instruments in use today.

Automatic Spectrum Analysis

In the last several years, the spectrum analyzer has truly come of age. With the advent of microprocessors, controllers, and the General Purpose Interface Bus to couple test instruments into a system, the modern spectrum analyzer has become even more versatile. Measurements can be made with a high degree of accuracy and with greater speed than by using manual methods.

The typical automatic spectrum analyzer is a monolithic instrument dedicated to spectrum analysis. It may have some computing capability built in or it may rely on an external controller. Figure 1 is a display utilizing a desktop controller coupled to an automatic spectrum analyzer. It shows the results of running a frequency search program for monitoring signals and displaying their frequencies and amplitudes.

Another approach to automatic spectrum analysis is to use a waveform processing mainframe that accepts plug-in spectrum analyzers. Figure 2 is a display from one such instrument. It has built-in computing capability, so it can make various basic time and frequency domain measurements automatically. Some of the time and frequency domain measurements that are possible with the touch of a button are maximum, minimum, peak to peak, RMS, etc. . . amplitude of a waveform, pulse rise and fall time, and digital averaging of the display. It can be programmed to make more complex measurements automatically as well.

Many complex spectrum analyzer measurements require calculations. These are the very kinds of measurements that are most adaptable to an automatic spectrum analyzer under program control. Some examples of measurements made easier automatically are *total harmonic distortion, impulse bandwidth, percent amplitude modulation,* and *frequency deviation.*

Measuring Total Harmonic Distortion Automatically

Harmonic distortion is the rms sum of all the separate harmonic distortion components that occur when a single, pure tone is passed through any *non-linear* device such as a transmitter, receiver, or amplifier. Harmonics occur in sequence (2nd, 3rd, 4th, etc. . .). Therefore, a 1000 Hz tone would produce 2000 Hz, 3000 Hz, 4000 Hz, harmonics etc. . . The rms sum of these harmonics is the total harmonic distortion (THD).

Measurement of harmonic distortion is often done manually with a spectrum analyzer. The technician or engineer connects the spectrum analyzer to the amplifier, receiver or other device under test and notes any harmonics related to the fundamental.

The spectrum analyzer provides a quick glance at THD, and a good idea of relative distortion is quickly obtained. When THD must be precisely quantified, the automatic spectrum analyzer is an excellent tool. In these instances the amplitude of the fundamental and each harmonic is measured and then these values are used to calculate THD as follows:

$$THD(\%) = \frac{\sqrt{H_2^2 + H_3^2 + H_4^2 + \ldots}}{F} \times 100$$

where F is the amplitude of the fundamental and H_2, H_3, H_4 are the amplitudes of the second, third, and fourth order harmonics respectively.

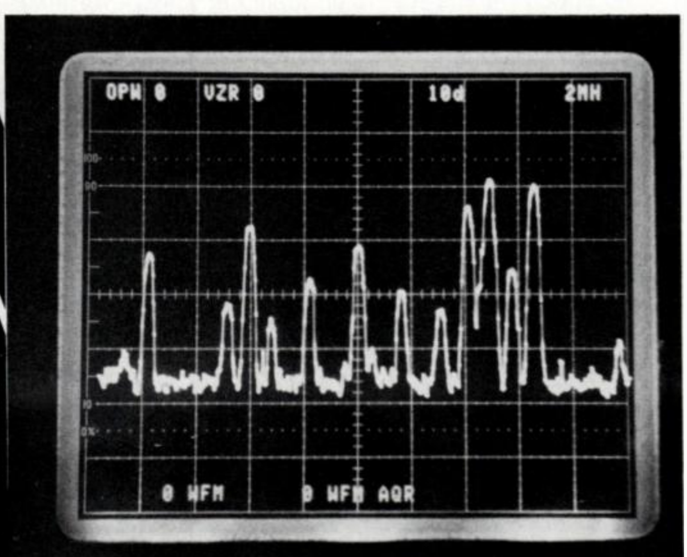


Figure 2.

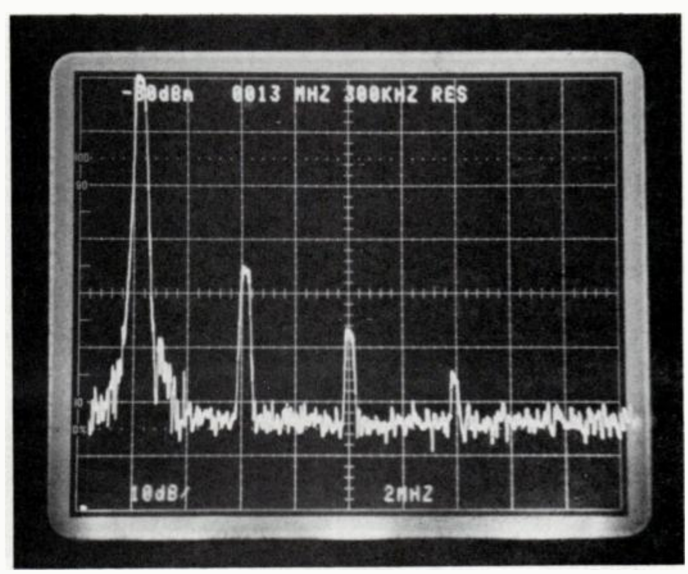


Figure 3.

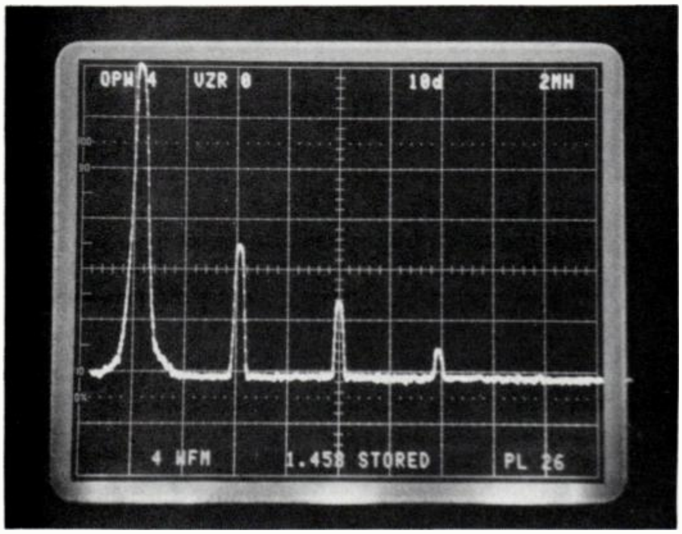


Figure 4.

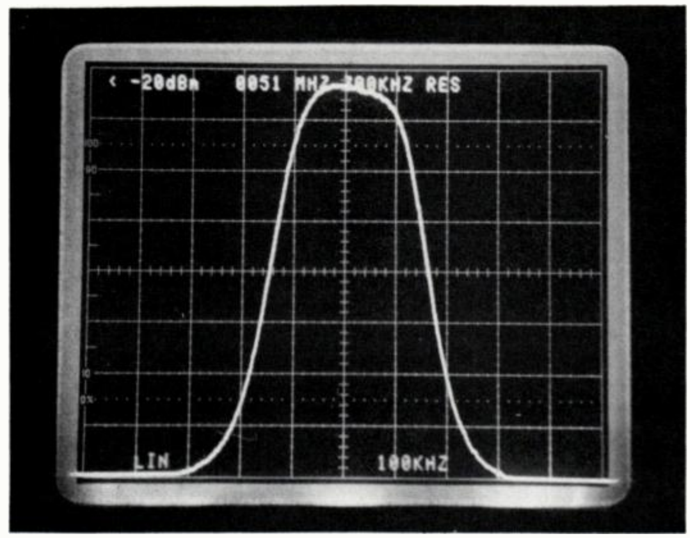


Figure 5.

By using the appropriate program, the automatic spectrum analyzer makes the calculations for you. You simply input the signal with harmonics to be measured (Figure 3), press the appropriate buttons on the waveform calculator module, and the result is calculated under program control. Total harmonic distortion in percent is indicated at the bottom center of the display (Figure 4).

Measuring Impulse Bandwidth Automatically

Electromagnetic interference (EMI) deals with the tendency of electronic equipment to interfere with each other. There are basically two kinds of EMI tests made on electronic instruments. There are tests for undesired emissions and tests for susceptibility to external emissions. The spectrum analyzer can be used for the former.

The modern spectrum analyzer has a wide selection of frequency span ranges and resolution bandwidths making it easy to evaluate entire frequency bands at a time. This makes the spectrum analyzer a desirable tool for making EMI measurements.

The spectrum analyzer, however, requires that some correction factors be applied before measurement results can be directly applied to EMI applications. One of these is the conversion of the spectrum analyzer resolution bandwidth to an equivalent impulse bandwidth. Impulse bandwidth is one of the more critical spectrum analyzer characteristics in EMI measurements and often must be measured accurately.

One method of obtaining the impulse bandwidth is to measure the area under the spectrum analyzer's linear response curve, divide by the height of the curve, and multiply by the span per division. This must be done whenever you use a different spectrum analyzer resolution bandwidth setting.

Impulse bandwidth can be more easily calculated by using an automatic spectrum analyzer. A program can be written to measure the height and area under the curve and make the necessary calculations. All you need do is display, in the linear mode, the resolution bandwidth curve you wish to convert, and run the program. Figure 5 is a linear resolution bandwidth curve from the spectrum analyzer, and Figure 6 is the equivalent impulse bandwidth program results.

Measuring AM

The spectrum analyzer is an ideal instrument for measuring and analyzing amplitude modulated signals. Because

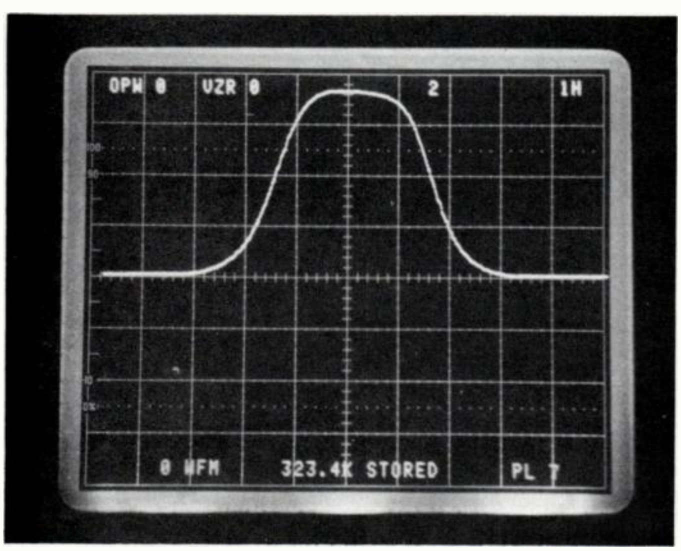


Figure 6.

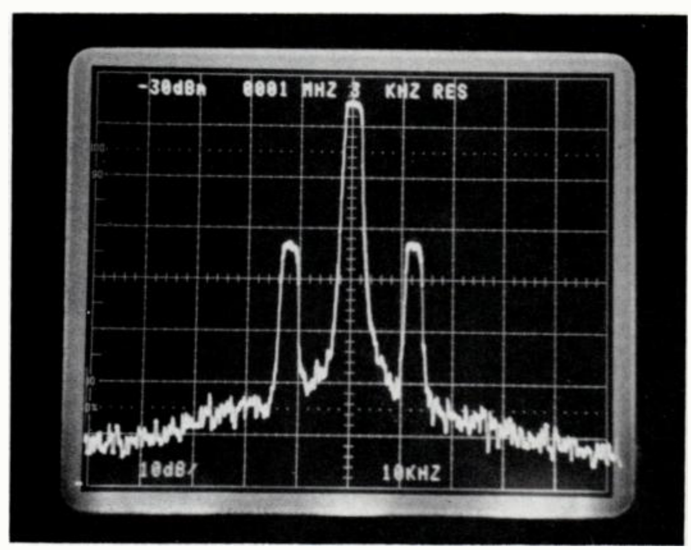


Figure 7.

of its sensitivity and wide dynamic range, it is especially useful for measuring low levels of modulation. Also, because it is a frequency domain instrument, multitone modulation is easier to measure.

Figure 7 is a spectrum analyzer display of an AM signal. Most of the characteristics are directly obtainable from the spectrum display. For example, by tuning the signal to the center of the screen, you can quickly obtain the carrier frequency and amplitude. You can measure the modulating frequency by measuring the spacing between sideband and carrier, and you can measure the sideband power relative to the carrier.

Percent modulation is a very important AM measurement that requires calculation. Therefore, it lends itself very nicely to automatic spectrum analysis.

In the frequency domain, percent modulation is calculated from:

$$M(\%) = \frac{2A_S}{A_C} \times 100$$

where A_S is the amplitude of the sideband and A_C is the amplitude of the carrier.

A_S and A_C can be measured directly from the spectrum analyzer display using the linear (voltage) vertical mode or can be converted to a voltage ratio from the logarithmic vertical mode. Figure 8 is a handy graph for conversion of sideband level to percent modulation.

If you use an automatic spectrum analyzer for the percent modulation measurement, you need not bother with the conversions and calculations. You can store a program that will do it for you at the touch of a button.

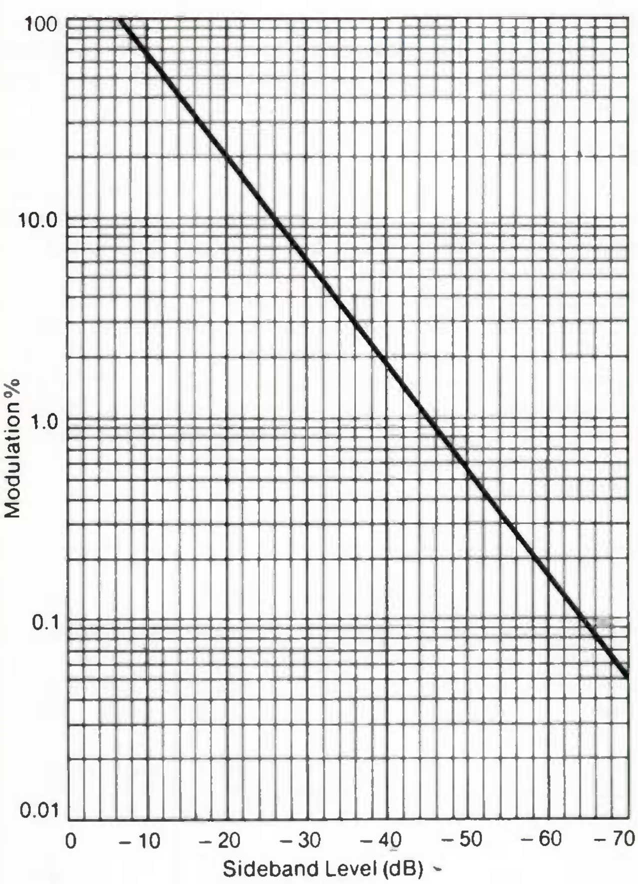


Figure 8.

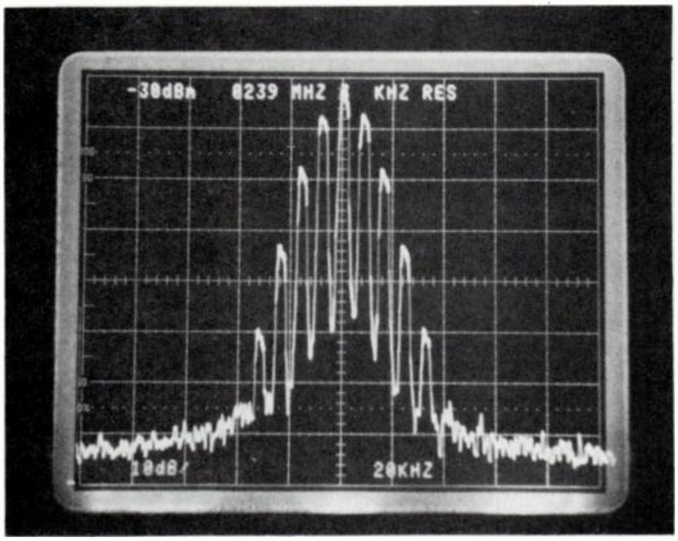


Figure 9.

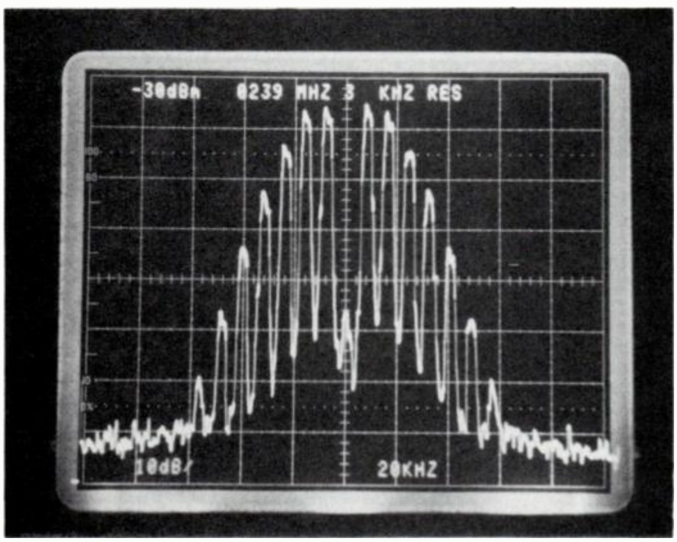


Figure 10.

Carrier Bessel NULL Number	$t = \frac{\Delta F}{f}$
1st	2.4048
2nd	5.5201
3rd	8.6531
4th	11.7915
5th	14.9309
6th	18.0711
7th	21.2116
8th	24.3525
9th	27.4935
10th	30.6346

Figure 11.

Measuring FM

The spectrum analyzer display of a frequency-modulated signal consists of a carrier and multiple sidebands spaced around the carrier. The spacing between the sidebands is equal to the modulating frequency, and from the location of the carrier on the display you can measure its frequency. Figure 9 shows a display of a typical FM signal.

Besides the modulating frequency and carrier frequency of an FM signal, the other information that is useful is deviation. FM deviation cannot be measured directly from the spectrum analyzer; it must be calculated. Thus, it is an appropriate measurement for an automatic spectrum analyzer.

Where the FM signal can be changed, the most common and also most accurate method of measuring FM deviation is the carrier Bessel null method. This method is based on the fact that as deviation changes, the amplitude of the various frequency components, including the carrier, also change. (This means that the total power remains constant, regardless of deviation). Therefore, by increasing the modulating frequency or signal amplitude from the modulator until the carrier goes to zero, you can calculate deviation. Figure 10 shows a FM carrier null display.

Deviation is calculated by using the following formula:

$$t = \frac{\Delta F}{f}$$

where t is the modulation index, ΔF is the deviation, and f is the modulating frequency.

Modulation index is determined by noting the number of times the carrier has gone through a null and referring to a table of carrier nulls such as shown in Figure 11.

All this information can be incorporated into a program to make the same measurement automatically. The automatic spectrum analyzer measures the necessary parameters and makes the calculation for you. In this instance, to avoid error, you must make certain which carrier null you have selected.

Summary

Using an automatic spectrum analyzer in one of its many forms maintains the spectrum analyzer as one of the most versatile measurement instruments today. Data and waveform storage and comparison are made easy.

Multiple signals can be displayed or held in storage simultaneously. Digital signal averaging allows you to see signals otherwise buried in the noise. Finally, with GPIB capability you can attach a controller for coordinating your spectrum analyzer with other instruments, for additional spectrum analysis, for storing spectrum analyzer data on magnetic peripherals, or for creating paper copies of analyzer data. □

References

EMI Applications Using the Spectrum Analyzer, Morris Engelson, Tektronix, Inc.

Noise Measurements Using the Spectrum Analyzer, Part Two: Impulse Noise, Morris Engelson, Tektronix, Inc.

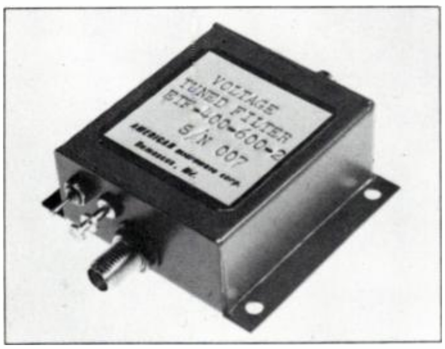
The Tektronix Cookbook of Standard Audio Tests, Clifford Schrock, Tektronix, Inc.

Measurement Variety — An Engineering challenge Featuring the 7854, Tektronix, Inc.

Spectrum Analyzer Theory and Applications, Morris Engelson and Fred Telewski, Artech House.

Voltage-Tunable Bandpass Filter

Model ETF-600-2 is a constant bandwidth, two-pole voltage tuned filter covering the band 400-600 MHz. Bandwidth is 50 ± 5 MHz at the −3 dB points. Insertion loss is 3.5 dB, maximum. Impedance is 50 ohms. VSWR is 1.8:1 maximum. Third order intercept point is +18 dBm referred to the output. Power handling is +20 dBm maximum. Linearity is ±3 percent, ±1 percent with optional linearizer. Tuning time between any two points is 20 ns, typical. Tuning



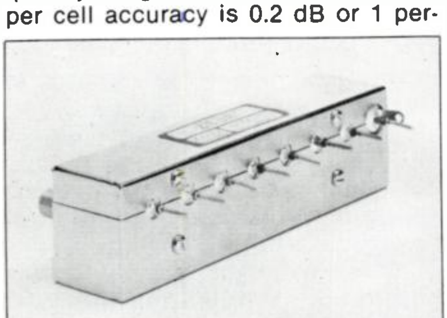
voltage is 1.5-·0 volts. Connectors are SMA female for RF and solder pin for tuning. Size is 0.75 x 2.0 x 1.5 inches exclusive of connectors.

Contact American Microwave Corp., P.O. Box 41, Damascus, MD 20750. INFO/CARD #140.

Subminiature Programmable Attenuator

Texscan announces its newest subminiature programmable attenuator, the PA-5010. This attenuator requires less than 3 cubic inches of space.

The PA-5010 provides 0-127 dB of attenuation in 1 dB steps. The frequency range is DC-1300 MHz. The per cell accuracy is 0.2 dB or 1 per-



cent at 1000 MHz. VSWR is 1.5 to 1 at 1000 MHz.

This attenuator is available with control voltages of 26.5 VDC, 12.0 VDC or 5.0 VDC. Connectors are SMA type.

Contact Texscan Corporation, 2446 North Shadeland Avenue, Indianapolis, IN 46219. INFO/CARD #139.

Weinschel Programmable Attenuators

Weinschel Engineering has just released a new brochure describing its line of programmable attenuators designed for the OEM. The four page brochure details the 3200 Series which operates over the frequency range of DC to 2 GHz. The series includes eight, five and one cell configurations and five standard attenuation ranges.

The 3200 brochure presents all the outstanding advantages including: a microstrip circuitry and special compensation techniques, a standard TO-5 type double-pole, double-throw relay that provides a minimum attenuation path for the RF signal; high speed switching; long switch life; excellent repeatability and compact size.

Complete specifications, attenuatin, curves and outline configurations are also given.

Contact Weinschel Engineering, Gaithersburg, MD 20760. INFO/CARD #138.

RF and Microwave Filter Catalog

Telonic Berkeley has just published a 40-page catalog describing its line of filters.

The catalog lists more than 23 types of filters from 20 MHz to 12 GHz, including two new standard series: highpass and subminiature. Each series of filters is represented by a description, photo, and chart of electrical and environmental specifications. To aid the customer in ordering, the catalog contains sections on: Aids to the Use of this Catalog, Ordering Information, Filter Selection Guide, Frequency and Bandwidth Tolerance Curves, Passband Relationships, and Passband Relationship

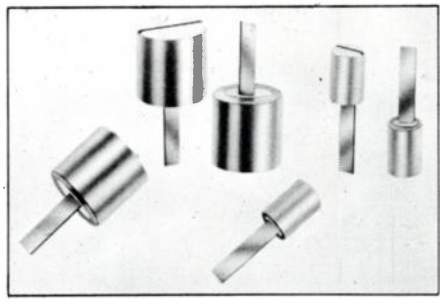
Curves. Telonic Berkeley offices and representatives all over the world are also listed.

The filters described include: tubular lowpass, tubular bandpass, cavity, interdigital bandpass, tunable cavity bandpass, combline, miniature, tunable band reject, highpass and subminiature.

Contact the Marketing Department, Telonic Berkeley, 2825 Laguna Canyon Road, Laguna Beach, CA 92652. INFO/CARD #136.

Cartridge Termination

Cartridge Terminations are designed

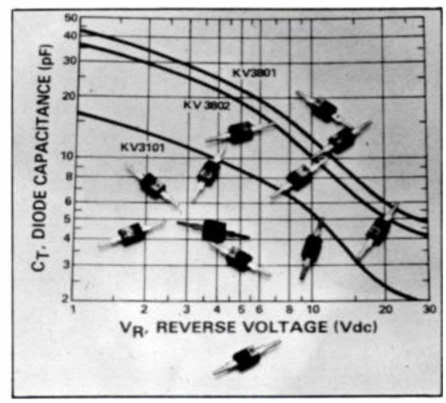


for high frequency applications. Compact in size, the PCL3-125-3 weighs less than 2 grams and will dissipate 3 watts of average power. Also available is the PCL15-250-3 15-watt Cartridge Termination. Both units have a slot to assist in the alignment of the tab and circuit. These ultra stable, 50Ω terminations are for use in devices operating in the frequency range of DC to 18 GHz and have a VSWR of 1.35:1 maximum from 12.4 to 18 GHz.

Contact KDI Pyrofilm Corporation, 60 South Jefferson Road, Whippany, NJ 07981. INFO/CARD #137.

Hyperabrupt Tuning Diodes

KSW Electronics Corp. has announced a new family of low cost, hyperabrupt tuning diodes designed for use in VHF-UHF range communications circuits. Types KV3101, KV3801 and KV3802 offer capacitance swings as high as 6 to 1 from 3 to 25 volts and allow the designer to select capacitance values at 3 volts of 11, 25 or 29 pF from the economical high Q, plastic packaged series.



These low inductance devices have typical Q values in the 300 to 400 range at 50 MHz and can be used up to 1 GHz in voltage controlled oscillators and filters. This diode family can replace popular types such as MV109, MV3102 and BB105. Delivery for production quantities is 60 days with medium quantity pricing (100 to 999) ranging from \$0.58 to \$0.63 each.

Contact KSW Electronics Corp., South Bedford Street, Burlington, MA 01803. INFO/CARD #135.

Microprocessor-Based RF Voltmeter

The new Boonton Model 9200 RF Millivoltmeter is the first microprocessor-based RF voltmeter. A separate non-volatile memory stores the calibration information for the voltmeter probe. New data for replacement probes can be field-entered.

Zeroing and autoranging are automatic with the 9200. Voltage display

in millivolts covers 200 μV to 3 V over a frequency range of 10 kHz to 1.2 GHz dB display can be referenced to 1 mV, or 1 mW at an panel-selected reference from 50Ω to 600Ω. Any dB display can be offset by an arbitrary amount.

A second input channel option allows two voltage probes to be connected to one 9200. The instrument then can display either channel or their instantaneous difference in dB. This option allows the direct dB display of voltage gain or loss.

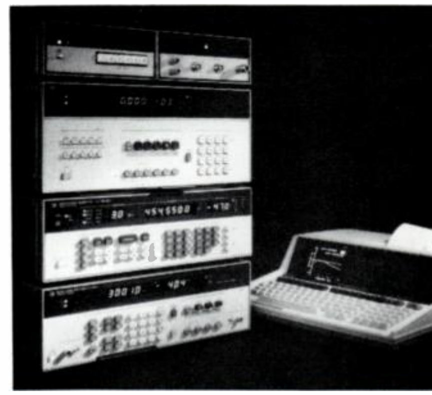
A field-installable IEEE-488 bus option allows all instrument functions to be bus programmable and provides full data outputs according to bus standards.

Contact Boonton Electronics, Parsippany, NJ. INFO/CARD #134.

Semi-Automatic Transceiver Test Set

Testing of modern communications systems requires sophisticated, high performance equipment to insure proper operation. Now, this new Hewlett-Packard Model 8903-E85 Semi-Automatic Transceiver Test Set provides that performance at low cost with flexible, easy-to-use, standard HP instrumentation. It makes in-channel tests on AM, FM and PM communication transceivers from 150 kHz to 990 MHz, either automatically under control of an HP-85F Instrument Controller, or manually using instrument front-panel keyboard entry. The test set's measurement capabilities range from simple tests such as frequency and distortion through complex measurements such as usable sensitivity and audio flatness.

Each of the test set's three key components — the HP 8903A Audio Analyzer, HP 8901A Modulation Analyzer, and the HP 8656A Synthesized Signal Generator — is itself a precision instrument with microprocessor control, full programmability and HP-IB (IEEE-488) interface for remote control by the test set's HP-85F Instrument Controller. Both manually and under



HP-85F control, these instruments perform complex measurements quickly and accurately. For example, the HP 8901A Modulation Analyzer measures AM depth or FM deviation to 1 percent accuracy in less than two seconds with a single key stroke or a single instruction from the HP 85F Instrument Controller. Under the control of the HP-85F, the test set combines the instruments' capabilities to do more complex measurements such as transmitter microphone sensitivity or receiver audio flatness.

Included in the test set are numerous features which expand its measurement capabilities beyond basic transceiver measurements. For example, the HP 8901A Modulation Analyzer contains selectable FM de-emphasis filters, post-detection audio filters and peak, peak hold, and average detectors. The HP 8656A Signal Generator has calibrated output levels with calibrated AM, FM, and simultaneous internal and external modulation. For characterizing audio signals, the HP 8903A Audio Analyzer contains selectable high-pass and low-pass input filters to remove unwanted signals such as noise and squelch tones.

Contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, CA 94304. □

Classifieds

RF DESIGN ENGINEERS

Join a company on the leading edge of technology, creating new solutions to old problems. Engineers seeking challenges in low noise amplifiers, ultra-linear power amplifiers, low noise frequency-agile synthesizers or adaptive noise cancellation techniques in the HF/VHF spectrum should contact T. Joseph Daley, **Harris Corporation, RF Communications Division,** 1680 University Avenue, Rochester, NY 14610, (716) 244-5830, EXT 3328.

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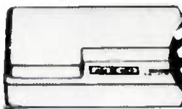

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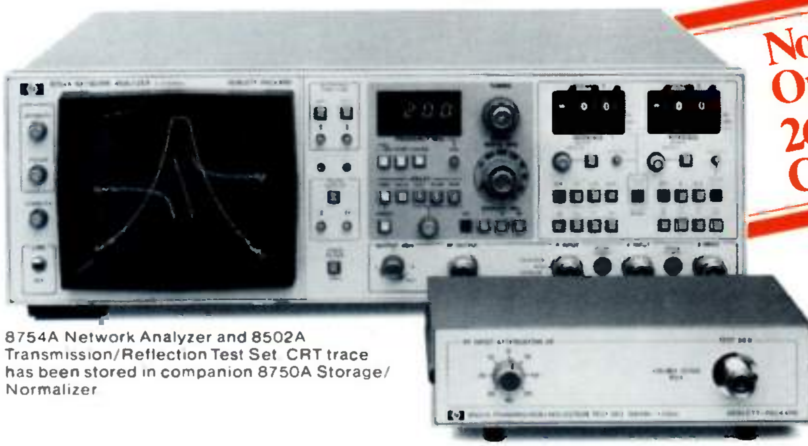
INFO/CARD 37

Advertiser Index

When your RF network measurement needs are large, but your budget isn't.



8754A Network Analyzer and 8502A Transmission/Reflection Test Set. CRT trace has been stored in companion 8750A Storage/Normalizer

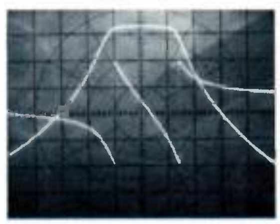
HP's 1300 MHz Network Analyzer. It brings speed and convenience to RF measurements for only $12,400.

The HP 8754A consists of:

- 4-1300 MHz swept source with +10 dBm leveled output, calibrated sweeps and crystal markers.
- Three channel receiver to measure any two transmission/reflection parameters simultaneously with >80 dB dynamic range.
- CRT display for rectilinear and polar plots with resolution 0.25 dB and 2.5°/major division.

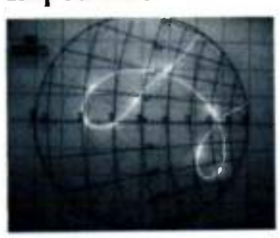
Just add the appropriate test set and you can make thorough and accurate measurements quickly and easily. Such as:

Transmission Magnitude and Phase.



Measure loss, gain and phase shift using the 11850 Power Splitter ($675). Completely identify filter passbands and skirt characteristics without misleading harmonic or spurious responses.

Impedance.



Measure and display impedance in polar form, with crystal markers to give precise frequency data. Test sets are available for both 50 and 75Ω systems.

Simultaneous Transmission and Reflection.

Use the 8502 Test Set ($2250) and see the trade offs between transmission gain/loss and input match in a single setup. For two-port characteristics of networks, including transistors, an S-parameter test set is available.

Storage/Normalizer increases the 8754A's capabilities.

Add the 8750A and you can automatically remove system frequency response variations also make comparison measurements easily. Digital storage permits flicker-free displays even for measurements requiring slow sweep rates.

A call to your nearby HP field sales office is all you have to do to get more information, or write 1507 Page Mill Road, Palo Alto, CA 94304.

Domestic US prices only.

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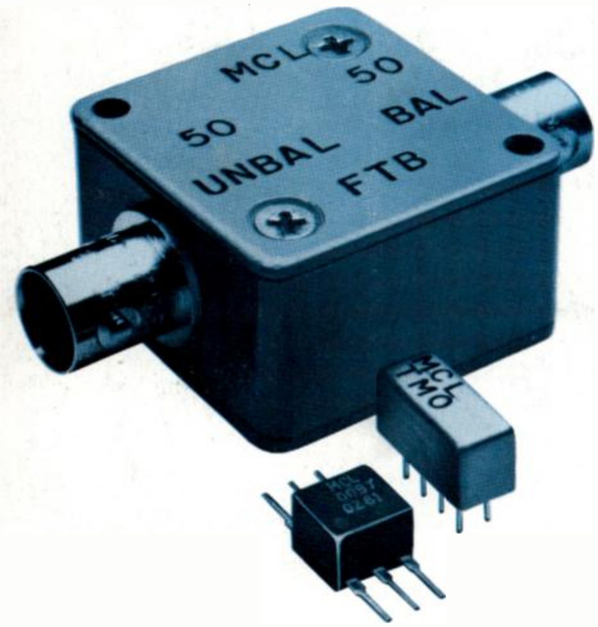

Select from the economical, microminiature T-series (plastic case) or TMO series (hermetically-sealed metal case) covering 10 KHz to 800 MHz. These models operate from 12.5 to 800 ohms with insertion loss typically less than 0.5 dB.

For large dynamic range applications, specify the T-H series which can handle up to 100 mA primary current without saturation or distortion.

Need a connector version? Select from the FT or FTB series, available with unbalanced or balanced outputs. Connector choices are female (BNC, Isolated BNC, and Type N) and male (BNC and Type N). These units operate from 10 KHz to 500 MHz with impedances of 50 and 75 ohms.

Of course, Mini-Circuits' one-year guarantee is included.

DC ISOLATED PRIMARY & SECONDARY

Model No.	T1-1 TMO1-1	T1-1H	T1.5-1 TMO1.5-1	T2.5-6 TMO2.5-6	T4-6 TMO4-6	T9-1 TMO9-1	T9-1H	T16-1 TMO16-1	T16-1H
Imped. Ratio	1	1	1.5	2.5	4	9	9	16	16
Freq. (MHz)	.15-400	8-300	.1-300	.01-100	.02-200	.15-200	2-90	.3-120	7-85
T Model (10-49)	$2.95	$4.95	$3.95	$3.95	$3.95	$3.45	$5.45	$3.95	$5.95
TMO model (10-49)	$4.95		$6.75	$6.45	$6.45	$6.45		$6.45	

CENTER-TAPPED DC ISOLATED PRIMARY & SECONDARY

Model No.	T1-1T TMO1-1T	T2-1T TMO2-1T	T2.5-6T TMO2.5-6T	T3-1T TMO3-1T	T4-1 TMO4-1	T4-1H	T5-1T TMO5-1T	T13-1T TMO13-1T
Imped. Ratio	1	2	2.5	3	4	4	5	13
Freq. (MHz)	.05-200	.07-200	.01-100	.05-250	.2-350	8-350	.3-300	.3-120
T Model (10-49)	$3.95	$4.25	$4.25	$3.95	$2.95	$4.95	$4.25	$4.25
TMO model (10-49)	$6.45	$6.75	$6.75	$6.45	$4.95		$6.75	$6.75

UNBALANCED PRIMARY & SECONDARY

Model No.	T2-1 TMO2-1	T3-1 TMO3-1	T4-2 TMO4-2	T8-1 TMO8-1	T14-1 TMO14-1
Imped. Ratio	2	3	4	8	14
Freq. (MHz)	.025-600	.5-800	.2-600	.15-250	.2-150
T model (10-49)	$3.45	$4.25	$3.45	$3.45	$4.25
TMO Model (10-49)	$5.95	$6.95	$5.95	$5.95	$6.75

FT FTB

Model No.	FT1.5-1	FTB1-1	FTB1-6	FTB1-1-75
Imped. Ratio	1.5	1	1	1
Freq. (MHz)	.1-400	.2-500	.01-200	.5-500
(1-4)	$29.95	$29.95	$29.95	$29.95

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