July/August 1979

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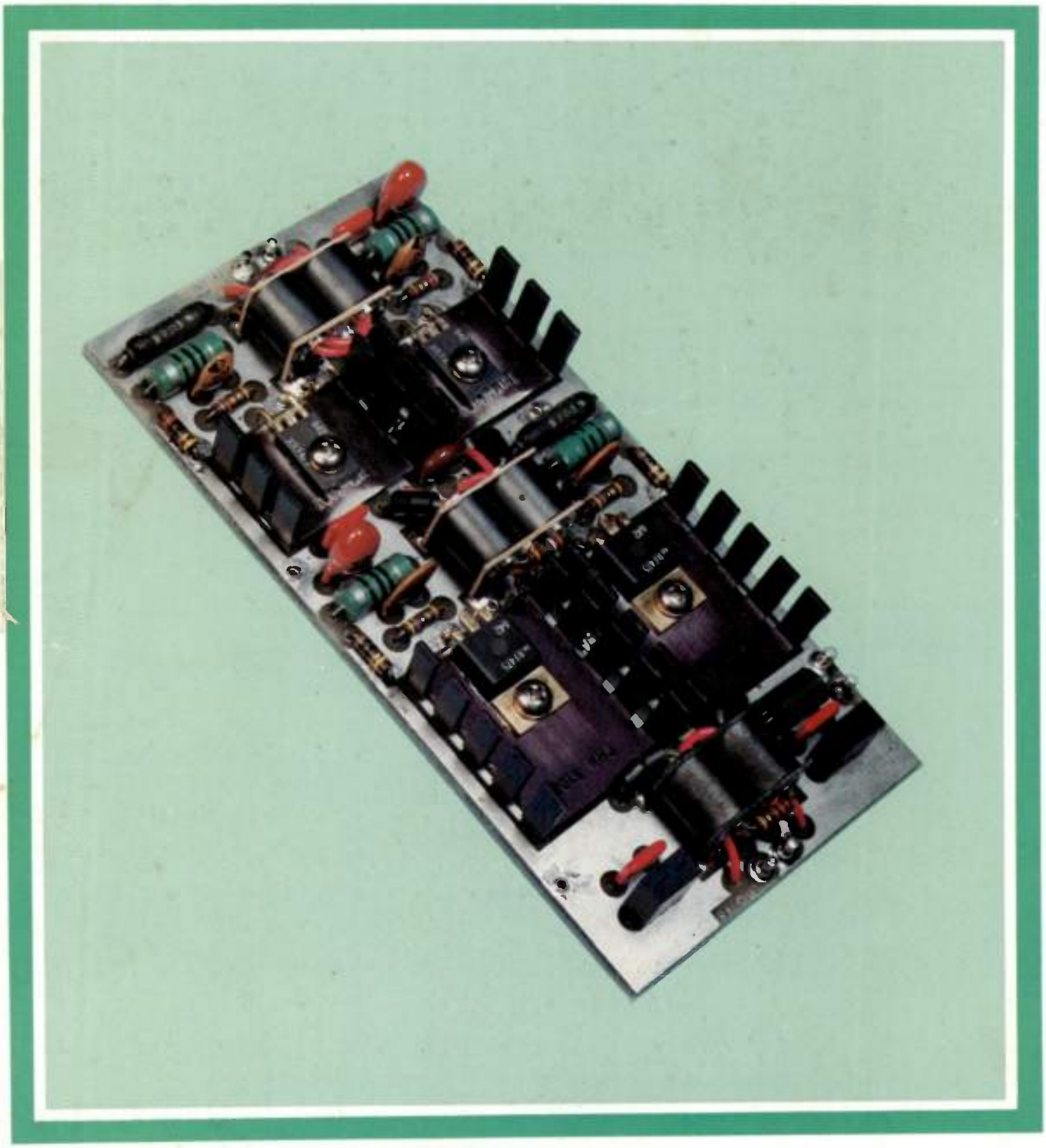
rf design



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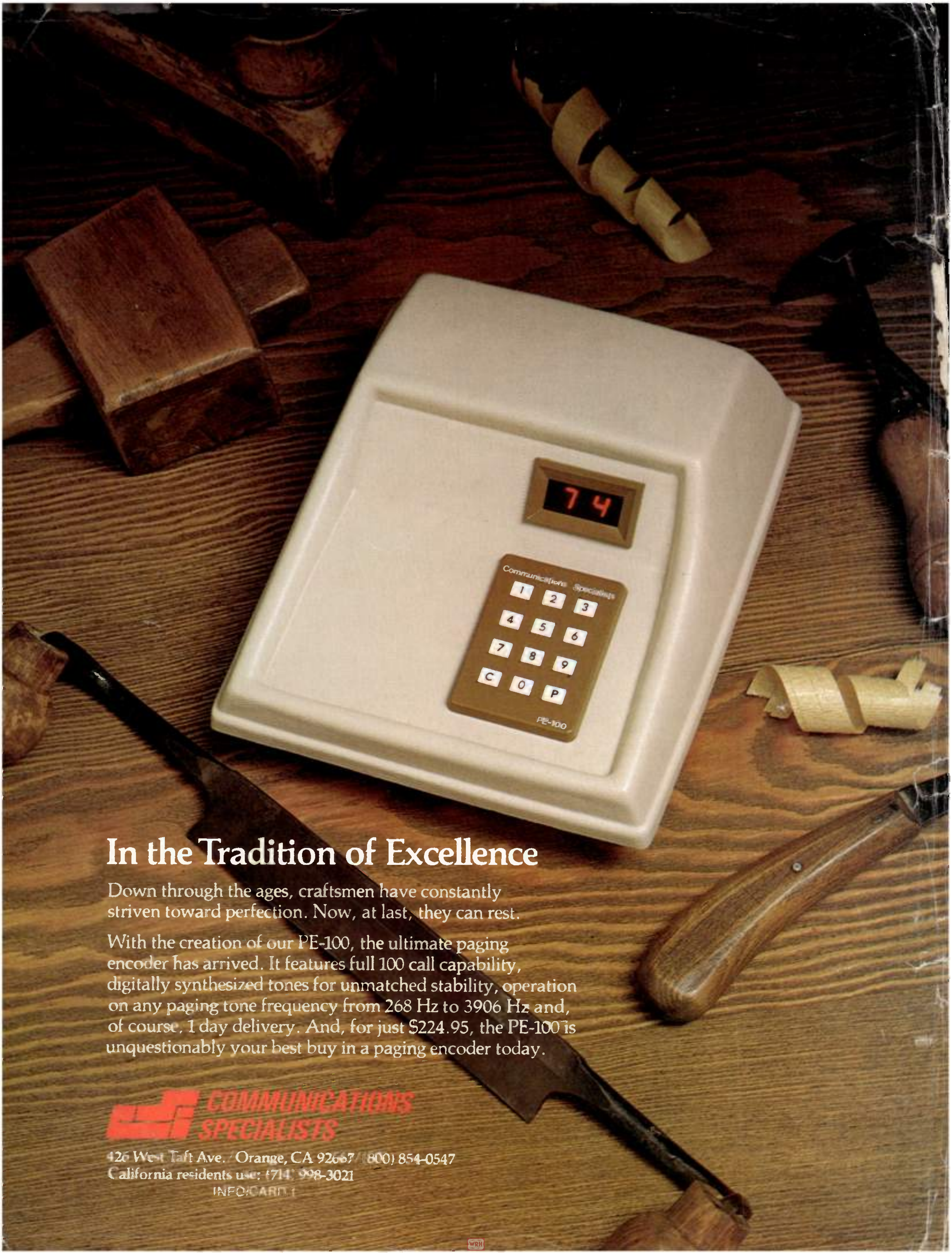

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Larry Brewster Editor

July/August 1979

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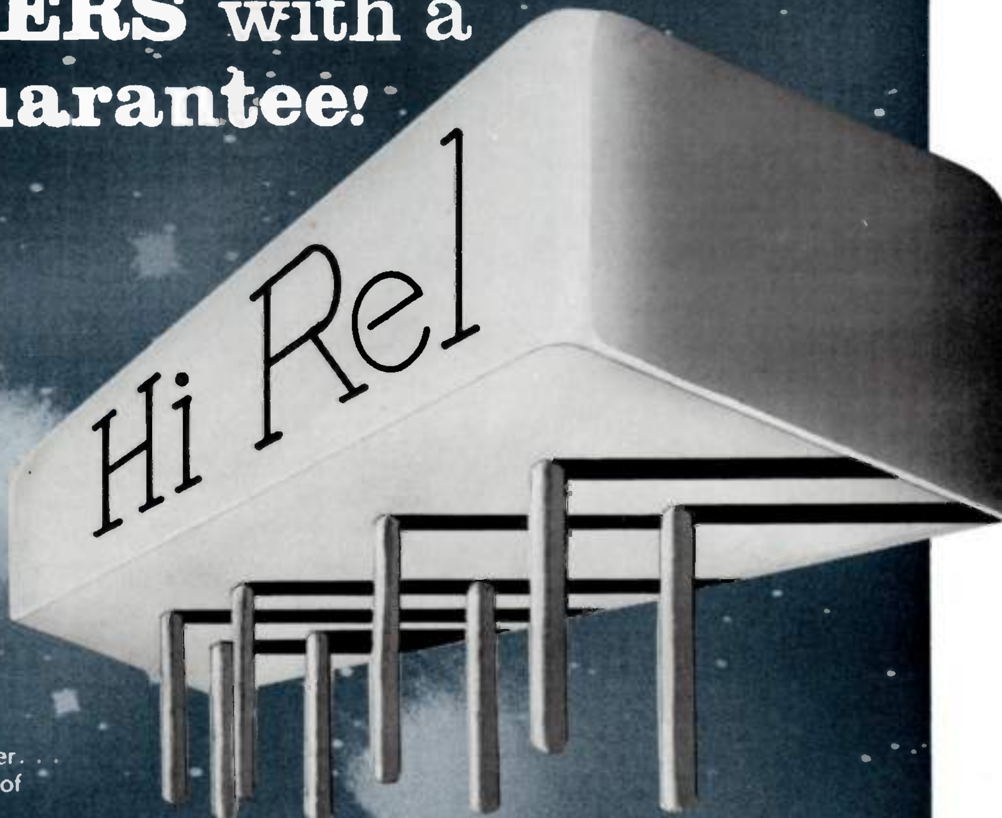

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0.5-500 MHz	6.5	8.5

Isolation (dB)		Typ.	Max.
0.5-5 MHz	LO-RF	50	45
	LO-IF	45	35
5-250 MHz	LO-RF	45	30
	LO-IF	40	25
250-500 MHz	LO-RF	35	25
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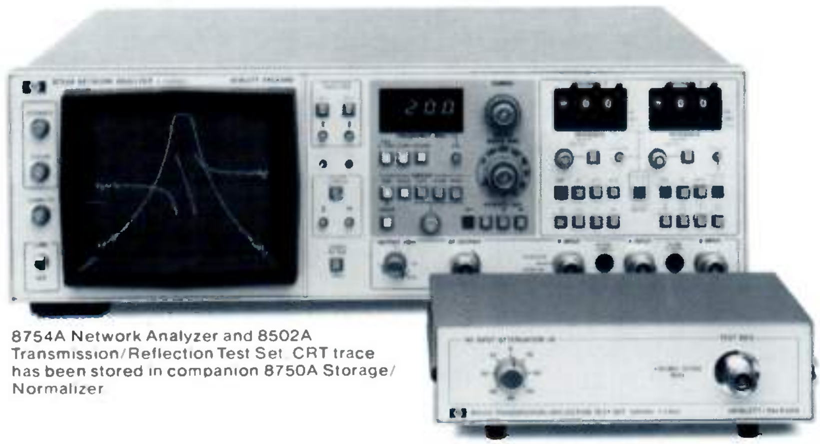

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HP's New 1300 MHz Network Analyzer. It brings speed and convenience to RF measurements for only $11,500.

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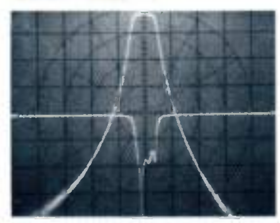

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This letter is in regards to a pair of articles by Mr. Tom Litty in the January/February and March/April issues of *r.f. design.* These articles on RF amplifier design contain an error which I believe invalidates the design information contained therein.

In the January/February article Mr. Litty treats the transmission line sections of his matching networks as though they are lumped inductive reactances. This is evident in Figure 8 of the article, where the effect of the transmission line sections is presented as moving the impedance along a line of constant resistance. If this were the case, then one may conclude from Figure 8 of the article that a quarter-wavelength of 50Ω line loaded with 25Ω would appear to be an open circuit at its input. The correct answer is that the effect of a section of transmission line is to move the impedance along a line of constant VSWR, which is a circle whose center is the center of the Smith Chart.

Mr. Litty's apparent reasoning for his mistake appears in the March/April article, "Fabricating a Microstrip RF Amplifier," where he correctly derives the equations for the reactance of open and short-circuited transmission lines and then *incorrectly* assumes that the reactance of the transmission line may be treated as a lumped component when the open or short is replaced by some other impedance. If this were the case the quarter-wavelength of shorted 50Ω line would still appear to be an open circuit when the short is replaced by a 50Ω load!

I hope this may clear up some confused reader's problems.
Mike Durkin
Associate Engineer
Motorola G.E.O.

P.S. In general, I find your publication very relaxing and enjoyable to read. M.D.

I am afraid you are correct, there appear to be a number of inconsistencies in the Litty series of articles. Thank you for bringing one of them to our attention.
Bart Gates
Managing Editor

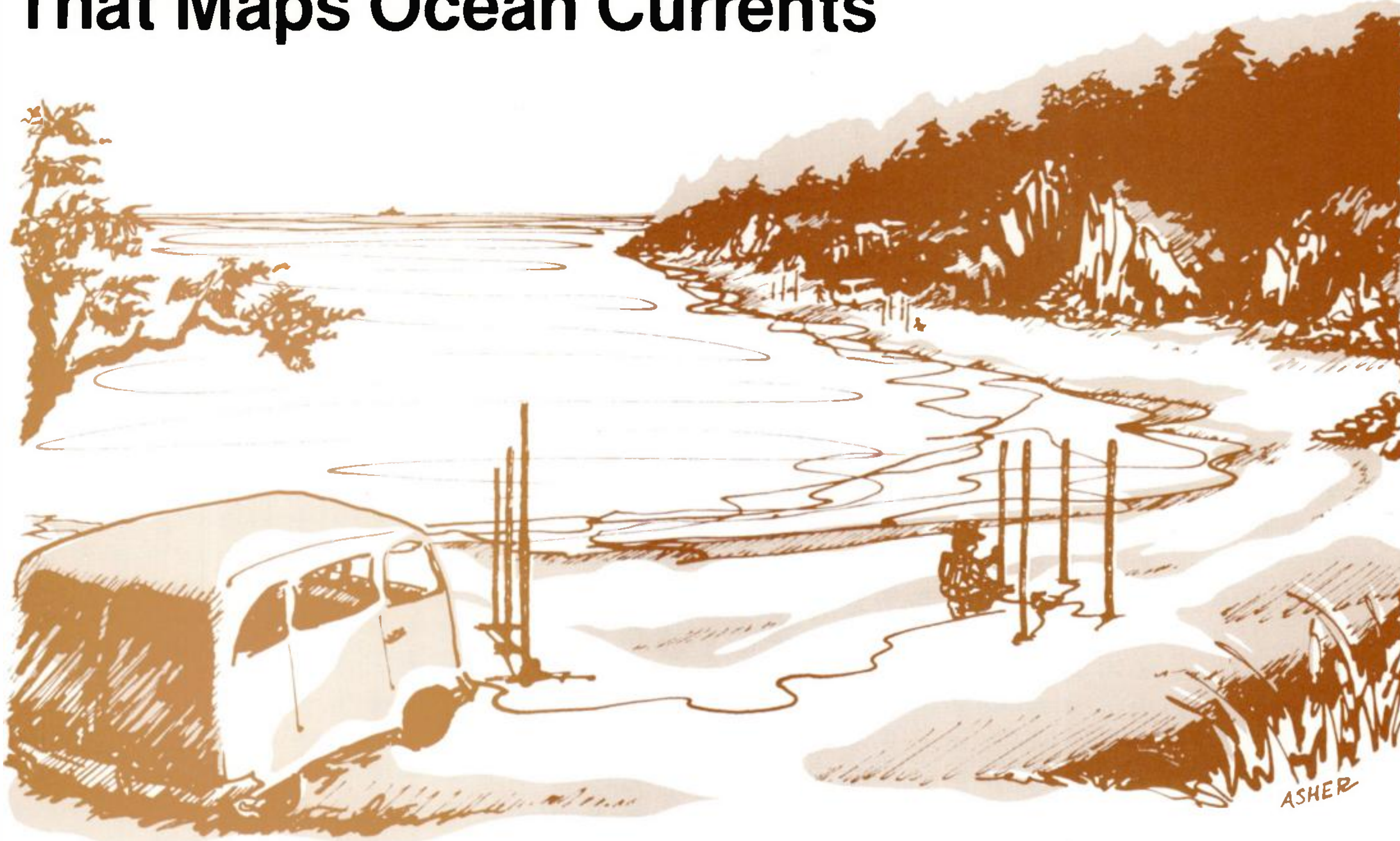
Your editorial in the May/June 1979 issue was well done. I'm responding to "then tell us your insights" about "finding and applying eloquent answers, to imaginative questions..."

Transistor RF power amplifiers are now designed by empirical art. Circuits are designed around specific transistor types purchased from specific vendors. Interchangeability of transistors from multiple vendors is difficult; generally, the design must be changed to accommodate a transistor from another vendor. Typically, the transistor power dissipation is 60 to 70 percent of the RF power output. Then the transistor junction temperature typically is 150 to 200°C, and reliability can be less than desired, at such high junction temperatures.

All that can be changed with the Class E RF power amplifier circuit (U.S. Patent 3,919,656); we bring science back to power-amplifier design! Details are in the enclosed reprint of my Electro '79 paper (I'll send copies *gratis* on request from readers of *r.f. design).*
Nathan O. Sokal
President
Design Automation, Inc.

In reviewing the "Spectrum Analyzer Analysis" article, I noticed that the sensitivity of the HP 3580A analyzer had been omitted. The sensitivity of this analyzer is – 150 dBV (3 Hz). Also, in the "Spectrum Analysis Performance" article, the photos in Figure 5 and Figure 6 are interchanged.
Ralph Fowler
Marketing Engineer
Hewlett-Packard Company □

NOAA Develops HF Radar That Maps Ocean Currents



Until now, when oceanographers wanted to measure the ocean's currents, they had to deploy drifting buoys or moored current meters, costly and time-consuming methods that provide spot current estimates at a few locations at best. Now, the National Oceanic and Atmospheric Administration (NOAA) has developed a portable HF radar system that does a much better job from the shore using remote sensing.

By measuring the Doppler shift of 25.6 MHz radar echoes Bragg-scattered from 6-m ocean waves, the radar system computes the underlying surface currents from deviations of the waves' phase speed from the theoretical 3 m s^{-1} they would have in the absence of currents. With two radar units located some 40 km apart along a shoreline, currents out to 60 km offshore can be automatically mapped under computer control in about 45 minutes. The final output of the system, called CODAR (for Coastal Ocean Dynamics Radar), is a map of some 800 current vectors in 2.4 x 2.4 km cells covering several thousand square kilometers of ocean.

Transmitter

The radar transmitter radiates 16-μs pulses with 2-kW peak power at a 2-kHz rate; the average radiated power is thus only about 60 W. The original in-house transmitter design used 16 RF power transistors, but a new design now being field tested uses V-FET devices to give the same power output using half the transistors and one-tenth the volume. The new power amplifier fits in a box 6 by 6 by 4 inches.

In applications where increased range is required, 10 kW peak pulse power has been obtained using modified amateur power amplifiers. Under development is a compact 50-kW power amplifier that uses a single 3CPX1500A7 tube. The low (3 percent) radar duty cycle permits the use of energy-pump techniques that reduce the size of the power supply to that required to meet only the average-power requirements.

Antenna Systems

A portable, vertically polarized, three-element Yagi deployed on the beach illuminates the sea by surface-wave mode. The sea echoes are received by four fiberglass CB whips arranged in a 5-m square. The four receiving antennas operate not as a conventional phased array but as a phase-measuring antenna with an angular resolution of a fraction of a degree. The received phase is sampled by a PIN-diode switching circuit that cycles through the four antennas at a 2-kHz rate, so that only one antenna at a time is connected to the receiver. The remaining antennas are terminated in a high impedance to minimize perturbations of the active element's omnidirectional receiving pattern.

The radar and antenna system can operate anywhere between 25 and 35 MHz, but the 25.6 MHz frequency normally used is a trade-off between higher propagation losses at the higher frequencies and more radio-frequency interference and less ocean-wave scattering at lower frequencies.

Receiver

In designing a receiver for sea-state-radar applications, requirements for low phase noise, low intermodulation and wide bandwidth are particularly severe. The triple-conversion radar receiver designed by NOAA not only processes the incoming echoes under computer control, but also generates the transmitted pulse stream to be sent to the power amplifier. For coherent detection, the transmit carrier frequency and the receiver local oscillators are phase-locked to a common frequency synthesizer. Receiver gain is varied with range, under computer control, to compensate for the attenuation of the radar echoes with range.

Following conversion of the incoming signal to zero intermediate frequency, its in-phase and quadrature components are digitized every 16 μs by a 12-bit A/D converter for subsequent digital signal processing.

Signal Processing

After they are range-gated and digitally low-pass filtered, the signals from each antenna and each range gate are separated and accumulated for up to 20 min (depending on Doppler-resolution requirements) for a complex discrete Fourier transform (DFT). The azimuth information is extracted from the phase differences of each frequency (Doppler) component among the four antennas, so that the final output is the Doppler shift of the echo as a function of range and azimuth.

A signal-processing interface processes all the high-speed data that comes out of the receiver at a 2-kHz rate, thus reducing the speed requirements on the digital computer. The Digital Equipment Corp. PDP-11/34 computer presently used will be replaced with an LSI-11/23 microprocessor.

The final output of one of the radar stations is an array of radial current components as a function of range and azimuth. Current components derived from two radar stations are combined via a VHF data link into a map of current vectors.

Following completion of a transition-engineering phase late this year, a production version of a complete CODAR system will be developed. Ultimately, a complete two-station system should cost no more than $75K.

*From Tom Georges and Mike Evans — NOAA.

Klystrons For Fusion Reactor

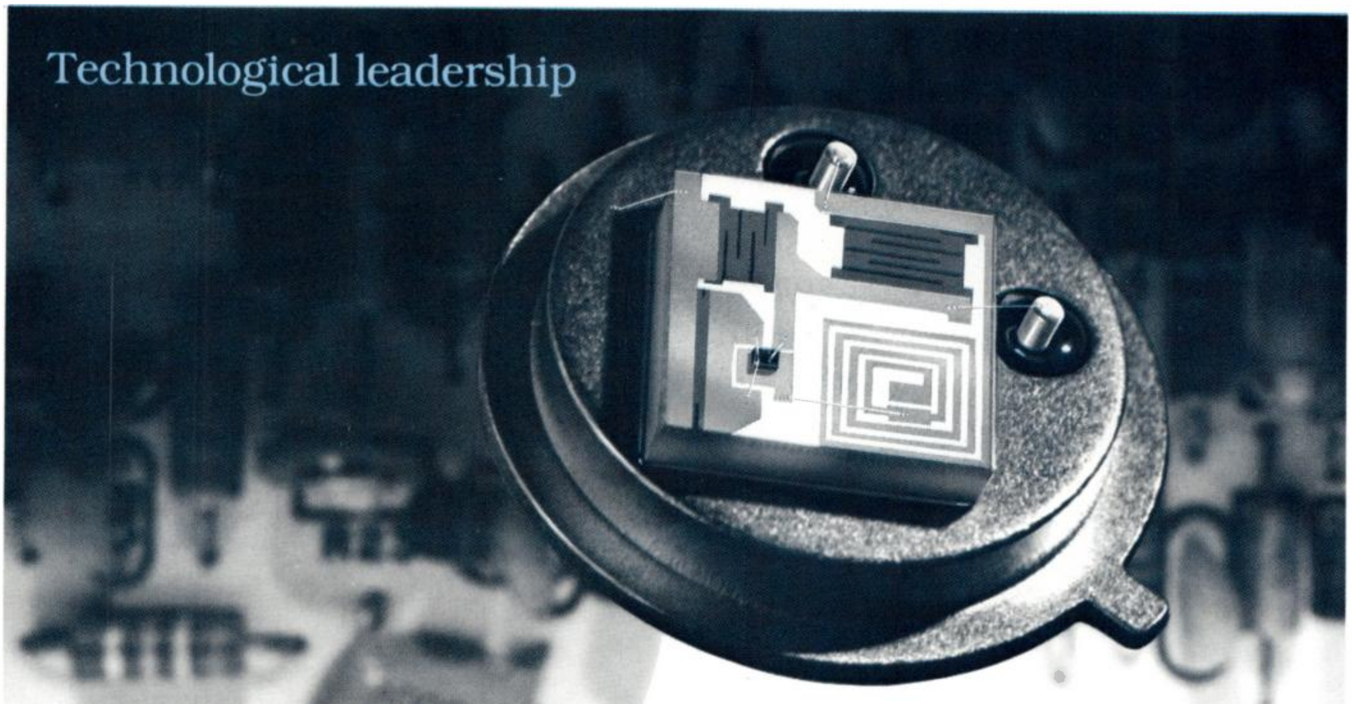
A $1.1 million contract has been awarded to Varian Associates to supply the Massachusetts Institute of Technology with 17 klystron tubes and magnets for its Alcator C project, an important step in achieving a controlled thermonuclear fusion reaction.

A fusion reactor requires temperatures up to 100 million degrees celsius — six times hotter than the sun's interior.

MIT's Plasma Fusion Center at Cambridge, Mass. will use the klystron tubes as a high-power source of microwaves which will be beamed into a plasma of hydrogen ions, already heated by resistive methods, in a Tokamak-type reactor. Research has already demonstrated that this will further increase the temperature of the plasma.

The klystrons will be specially engineered by Varian's Palo Alto Microwave Tube Division as no standard tubes are available at the required frequency and power level. Each tube will produce 250 kW at 4.6 GHz in half second pulses.

Princeton University scientists recently heated a plasma to 60 million degrees in a Tokamak — the hottest temperature ever achieved — using four Varian Eimac tetrode tubes to control and protect neutral beam sources. ☐



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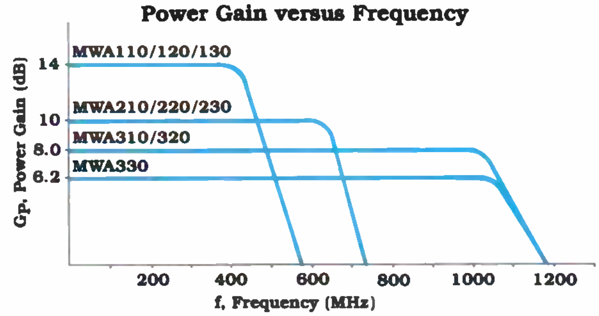
Gain response, cascades and other marvels.

The series has virtually flat response over 13 octaves. Units can be used singly or cascaded in 50 Ω systems for any gain without bandwidth shrinkage. They're flexible, functioning elements where noise, sensitivity, dynamic range and distortion are important - RF/IF stages, multi-channel power splitters, preamps, cable drivers, multicouplers, RF distribution systems, feedback loops, isolation and buffer stages. Even in digital systems, since they handle pulse trains without distortion. Typical gains range from 6.2 to 14 dB.

Other specs include 1 dB gain compression output levels from -2.5 to 18.5 dBm; I_{dc} choices of 10, 25 and 60 mA and 4 to 9 dB NF, depending on type. Hi-Rel processing similar to MIL-S-883, Method 5004.4, Class B processing, is available. And it all comes in the low-profile TO-39 case.

Power Gain versus Frequency



Contact Motorola Semiconductor Products, P.O. Box 20912, Phoenix, AZ 85036 for comprehensive, fully-characterized data. Then, instead of paying $40 or more for others, design in the MWA-series for only $5.00 to $7.00. Because Motorola produces RF technology *in volume* for

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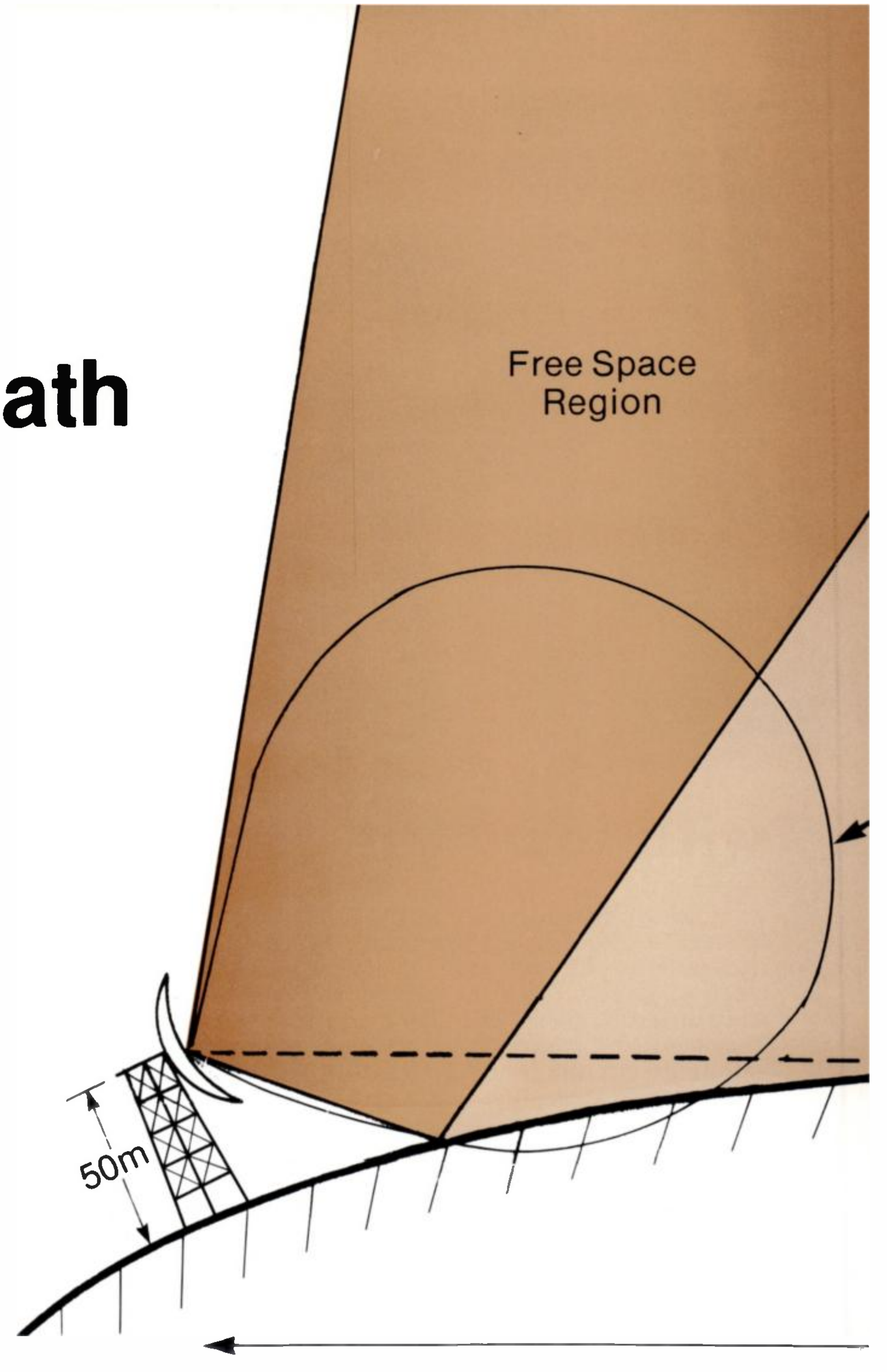
Computing Path Loss In the Diffraction Region

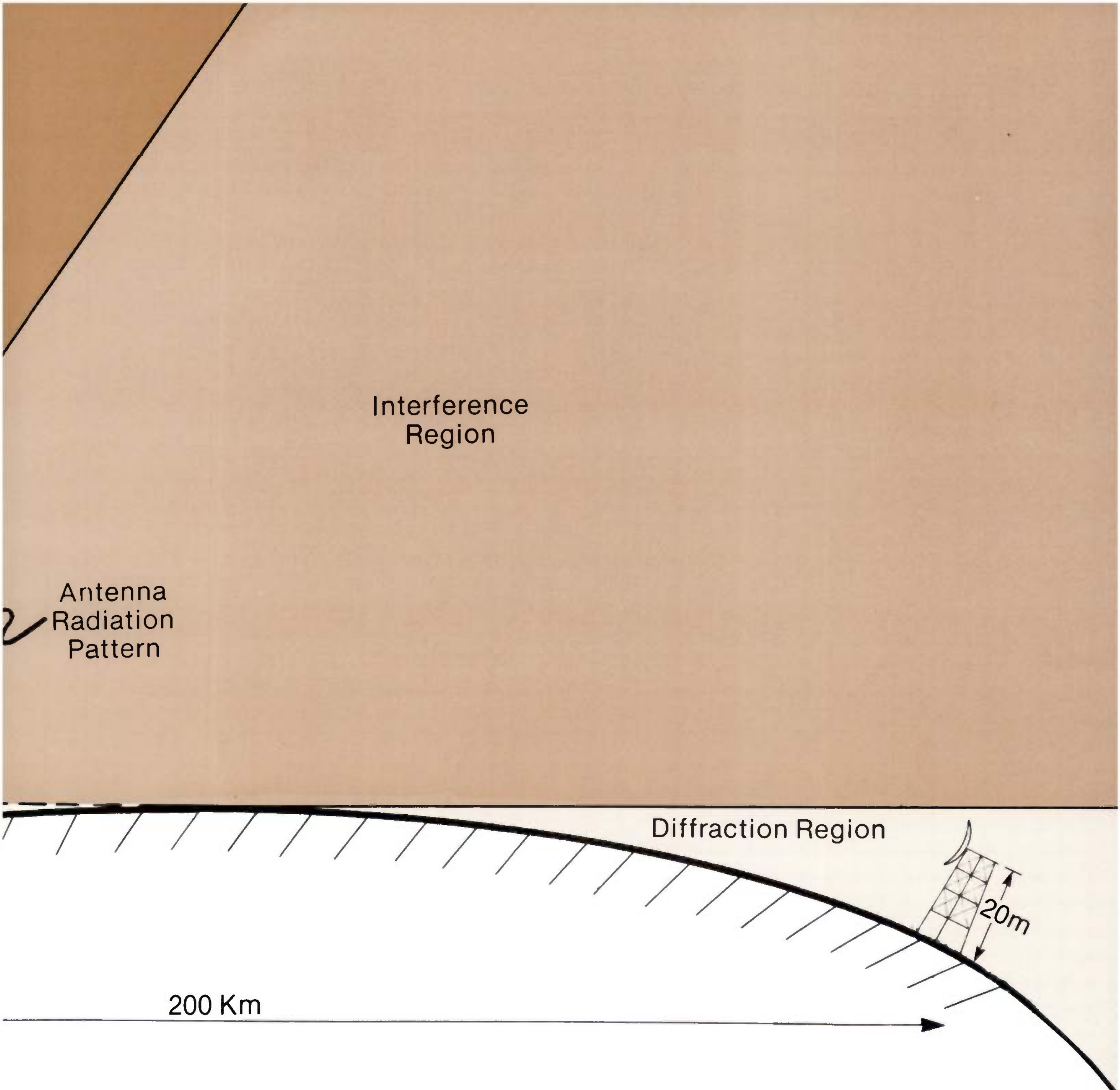


By John O. Battle
2350 East Hill Way
Norcross, Georgia

In designing communication systems, it is frequently necessary to compute the attenuation the signal will sustain when transversing the distance between the transmitting antenna and the receiving antenna. While this is a relatively straightforward problem if the antennas are located within line-of-sight of one another, many modern communication systems make use of the small amount of energy which is diffracted around the Earth's curvature in order to establish radio communications between antennas which are located well beyond the radio horizon relative to one another. Although an exact solution for this problem is extremely complex and subject to many, often time varying, parameters, a reasonably accurate estimate of the average value of the path loss can be obtained without resorting to difficult analytical techniques.

Free Space

Figure 1 illustrates the three regions of space into which the propagation modes involved are distinctly different. The first of these is referred to as the "free-space" region and is as shown in the figure. Essentially all of the energy reaching a receiving antenna located within this region does so via a direct path along a straight line* extending directly from the transmitting antenna to the receiving antenna. The path attenuation for this case is simply



equal to the fraction of the transmitted "beam" which is intercepted by the receiving antenna aperture, viz:

$$A_t = \frac{4\pi R^2}{G_t} \qquad (1)$$

$$A_r = \frac{G_r \lambda^2}{4\pi} \qquad (2)$$

*Actually radio waves follow a slightly curved path from transmitter to receiver due to the variation of the atmospheric refractive index, with height, however this curvature is accounted for by assuming a radius for the Earth which is one third larger than the actual physical size. This practice will be followed here.

$$L_f = \frac{A_r}{A_t} = \frac{G_r G_t \lambda^2}{(4\pi)^2 R^2} \qquad (3)$$

The distance between the antennas, R, and the radio wavelength, λ, are given in meters, the transmitting and receiving antenna gains, G_t and G_r, are given as a ratio relative to isotropic, and the Computed free space path loss, L_f, is a dimensionless ratio of received signal power to transmitted signal power. The parameter A_t is the equivalent surface which would be illuminated by the transmitting antenna at range R, and A_r is the effective aperture, or capture area, of the receiving antenna, both given in units of square meters.

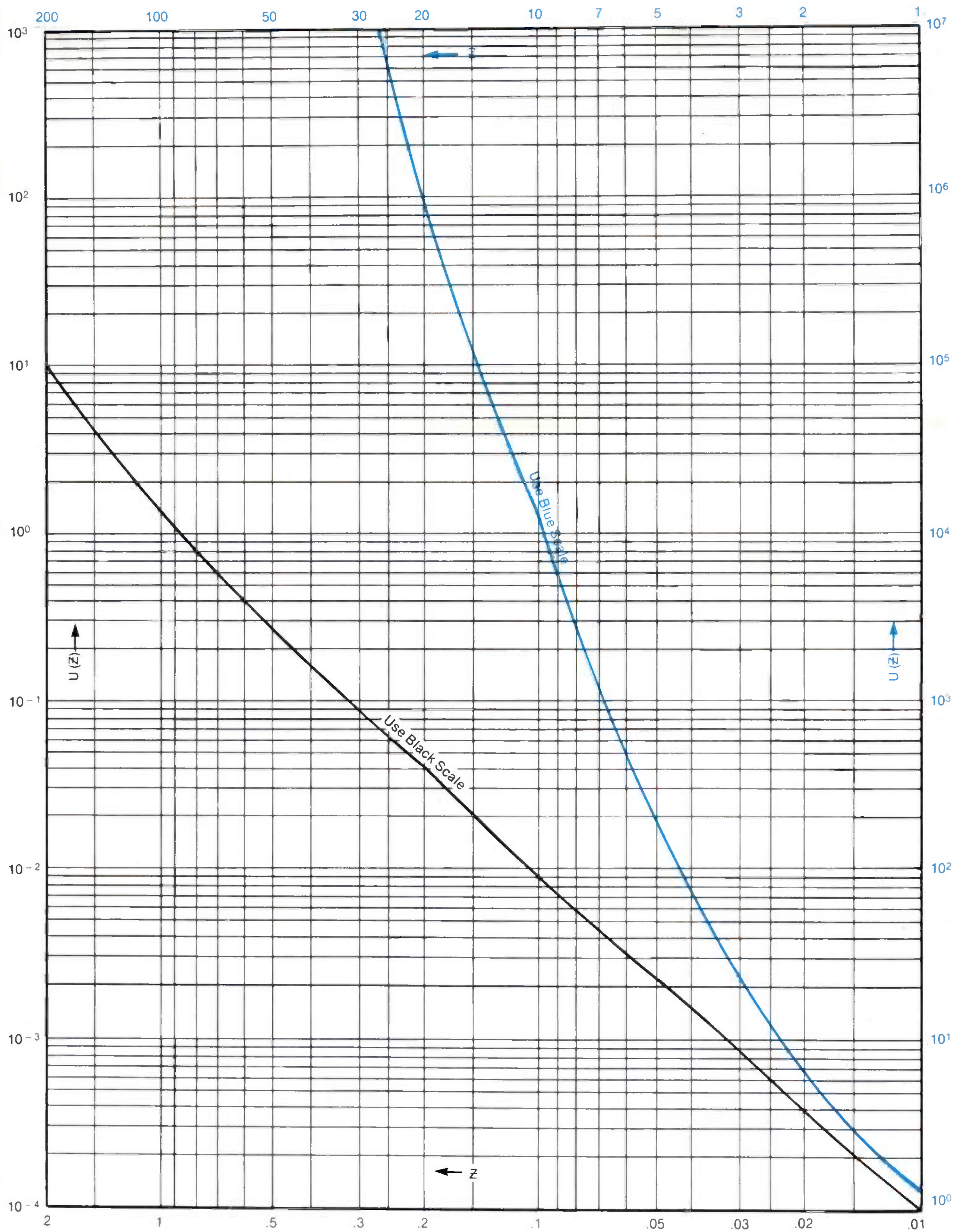

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Figure 4.

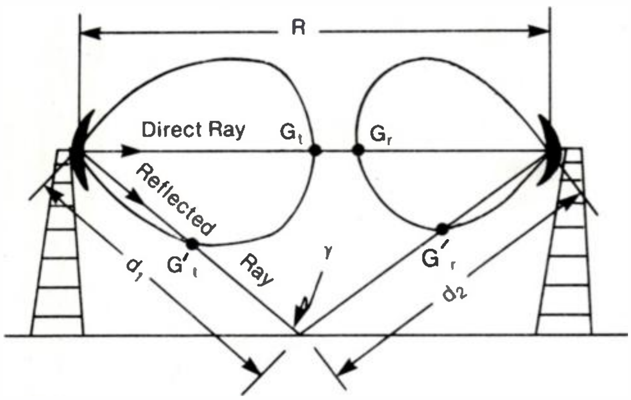

Figure 2. Propagation in the Interference Region.

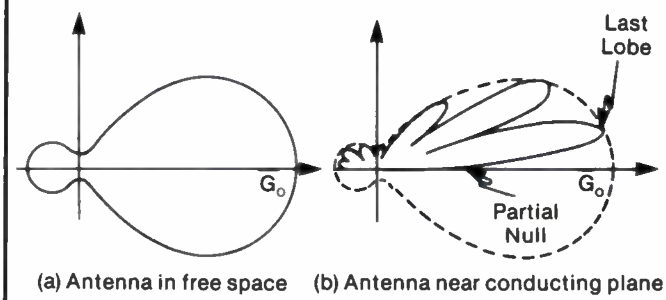

Figure 3. Effect of Conducting Plane on Elevation Pattern.

Interference Region

Referring to Figure 1, the next distinct region is referred to as the interference region and is shaded blue in the figure. In this region of space, the received signal consists of a vectoral combination of signals arriving via two distinct paths, see Figure 2. One signal arrives via a direct path as previously discussed in the free space region. The other signal reaches its destination by reflecting from the Earth's surface. Depending on the exact geometry of the situation, these signals will either add or cancel each other, a situation analogous to constructive and destructive interference of sound or light waves as studied in physics, thereby leading to the adoption of the name "interference region." The effective path attenuation in the interference region is given by:

$$L_i = L_f F^2 \quad (4)$$

The pattern propagation factor, F, is a multiplicative factor whose value depends on the phase relationship of the two components, the gain of the transmitting and receiving antennas on the two components, and the reflectivity of the Earth at the reflection point.

$$F = 1 - \xi\gamma \sqrt{\frac{G'_t G'_r}{G_t G_r}} \cos\left[\frac{2\pi}{\lambda}(R - d_1 - d_2)\right] \quad (5)$$

where:

G_t = transmitting ant gain on direct ray
G'_t = transmitting ant gain on reflected ray
G_r = receiving ant gain on direct ray
G'_r = receiving ant gain on reflected ray
γ = reflection coefficient of Earth
ξ = divergence factor

A detailed explanation of the methods of computing the value of the pattern propagation factor is beyond the scope of this article, however a complete explanation can be found in Kerr, "Propagation of Short Radio Waves," McGraw-Hill, 1951 beginning on page 112. The effect of the pattern propagation factor is to produce a series of lobes in the elevation pattern of the transmitting antenna, see Figure 3. The lowest of these lobes lies at an angle slightly above the radio horizon and is terminated by a partial null at an angle exactly corresponding to the horizon as seen by the antenna. This null marks the end of the interference region and the beginning of the diffraction region.

Diffraction Region

The diffraction region encompasses all space not within "line-of-sight" of the transmitting antenna. If the value of the parameter ϱ is positive then the point in question lies within the diffraction region and the techniques in this section are applicable:

$$0 < \varrho = R - (2a_e)^{1/2}(\sqrt{h_t} + \sqrt{h_r}) \quad (6)$$

The effective Earth radius, a_e, which is numerically equal to 4/3 of the actual Earth radius, is approximately 8.48 x 10^6 meters. The heights of the transmitting and receiving antennas are h_t and h_r.

As mentioned earlier, the energy reaching a receiving antenna located within the diffraction region must somehow "curve around" the Earth's surface in order to reach its destination. There are quite a number or radio phenomenon which will accomplish this: tropospheric scatter, auroral refraction, ionospheric reflection, and meteor scatter, to name a few. All of these modes, however, either are not functional at the higher frequencies (VHF and UHF), are very sporadic in nature, or result in extremely high losses. The mechanism responsible for most transhorizon VHF/UHF radio circuits is diffraction. It is this mode of propagation which we will discuss.

The theory of propagation of radio waves over the surface of a smooth, conducting spherical surface (the Earth) was first treated in 1937 by Van der Pol. In the early 1940's, however, it was discovered that his predictions, while correct for long wavelengths, resulted in considerable error at VHF and higher frequencies. Further investigations led to the theory put forward by John Freehaufer which expresses the solution in terms of an infinite series of circular harmonic functions. The solution, although technically correct, converges so slowly that it is extremely difficult to apply in practice. Later, Domb and Price applied a transformation to simplify the equations, and found that, for reasonable antenna heights, only one term of the new series was needed to yield a sufficiently accurate solution.

Using this approach, the formula for computing the diffraction attenuation consists of four factors:

$$L_d = L_f \cdot U(Z_t) \cdot U(Z_r) \cdot V(X) \qquad (7)$$

The functions U(Z) and V(X) are the height gain function and the range loss function respectively, and are given in terms of the normalized antenna heights and range which are computed as follows:

$$Z_t = \frac{h_t}{h_o} \qquad (8)$$

$$Z_r = \frac{h_r}{h_o} \qquad (9)$$

$$X = \frac{R}{R_o} \qquad (10)$$

The parameters h_o and R_o are the reference height and reference range and are computed as follows:

$$h_o = \tfrac{1}{2}\left[\frac{a_e \lambda^2}{\pi^2}\right]^{1/3} \qquad (11)$$

$$R_o = \left[\frac{a^2{}_e \lambda}{\pi}\right]^{1/3} \qquad (12)$$

The range attenuation function, V(X), may be computed by the following expression:

$$V(X) = 2(\pi X)^{1/2} e^{-2.02X} \qquad (13)$$

Computation of the value of the height gain function, V (Z), is done by using the curve in Figure 4. The entire process of computing the diffraction path attenuation will now be illustrated by an example.

Consider the following problem: A communication system has transmitting and receiving antennas separated by a distance of 200 kilometers and mounted on towers at heights of 50 and 20 meters respectively. Each antenna has a directive gain of 12 dB over isotropic at its operating frequency of 170 MHz. Compute the path attenuation.

The first step is to check equation (6) to make sure the diffraction region techniques apply.

$$\begin{aligned} \varrho &= 2x10^5 - (2 \times 8.48 \times 10^6)^{1/2} (\sqrt{50} + \sqrt{20}) \\ &= 1.53x10^5 > O. \end{aligned}$$

Next we compute the free space attenuation using equation (3):

$$\lambda = \frac{3 \times 10^8}{170 \times 10^6} = 1.765 \text{ meters}$$

$$G_t = G_r = (10)^{.1 \times 12 dB}$$

$$L_f = \frac{(15.85)^2 (1.765)^2}{(4\pi)^2 (2 \times 10^5)^2} = 1.239 \times 10^{-10} \qquad (3)$$

Then the reference heights and the reference range using equations (11) and (12) are calculated.

$$h_o = \tfrac{1}{2}\left[\frac{(8.48 \times 10^6) \times (1.765)^2}{\pi^2}\right]^{1/3} = 69.4 \text{ meters}$$

$$R_o = \left[\frac{(8.48 \times 10^6)^2 \times (1.765)}{\pi}\right]^{1/3} = 34313 \text{ meters}$$

Next, compute the normalized height of each antenna and the normalized range using the reference values:

$$Z_t = \frac{h_t}{h_o} = .288$$

$$Z_r = \frac{h_r}{h_o} = .720$$

$$X = \frac{R}{R_o} = 5.83$$

Now, using the curves given in Figure 4 and equation 13 compute the value of the height gain function for each antenna and the value of the range loss function for the normalized values:

$$\begin{aligned} U(Z_t) &= U(.288) = .083 \\ U(Z_r) &= U(.720) = .60 \\ V(X) &= V(5.829) = 6.58 \times 10^{-5} \end{aligned}$$

The total path loss is now computed by simply multiplying the factors:

$$\begin{aligned} L_d &= L_f \ U(Z_t) \cdot U(Z_r) \cdot V(X) \\ &= (1.239 \times 10^{-10})(.083)(.6)(6.58 \times 10^{-5}) \\ &= 4.06 \times 10^{-16} \\ L_d(dB) &= 10 \log (L_d) = -153.9 \text{ dB}. \end{aligned}$$

Calculator Design Of Microstrip Traps

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The following discussion will present a unified approach to RF trap design using microstrip techniques. While most of the analysis is applicable also to other transmission line techniques, the stress will be on application of simple microstrip circuits to everyday RF problems.

Several techniques have been tried in the past to reduce the number of mathematical calculations involved in transmission line circuit design. One, the Smith Chart approach, provides some insight into the circuit characteristics, provided you are well acquainted with its use. However, to become proficient in its use requires considerable practice, as well as a good theoretical background. The "hardware" investment is minimal, since graph paper-type Smith Charts are widely available for graphing the problems and solutions. Another technique is the computer. It can perform rather intricate operations and obtain the answers to very sophisticated problems. the "hardware" and "software" investment is rather high, however. In addition, some of us old-timers, who have managed all these years with a slide rule, do not particularly want to get involved with learning computer programming. The problems can, of course, also be solved using the slide rule and a lot of paper, but the chances for making mathematical errors are high and, after a few calculations, interest in the original problem begins to wane.

Fortunately, there is a happy medium. With the advent of the low cost, programmable pocket calculator, the engineer can now concentrate on selecting the most suitable design, simulating its operation, and optimizing it for a particular application. "Cookbook" designs are no longer necessary when design time is limited and the engineer gets a feeling of accomplishment rather than the frustration of waiting for his problem to be programmed and run on a computer. Different values can be quickly substituted to check effects of component drift, tolerances, etc. The accuracy is more than adequate, approaching that of the computer, and considerably better than that obtained using Smith Charts or a slide rule. In some cases, such as when converting the reflection coefficient to loss in dB, for instance, this increased accuracy (at least 4-5 place accuracy is sometimes needed) provides meaningful answers.

The calculator programs in this article were derived for use in the HP-19C/29C RPN-type calculator. It is comparatively low cost and has adequate (98 step) memory for general use. All the shorter programs can be also used in the older HP-25 calculator, and, of course, all the programs can be adapted to the PH-67/97. The advantage of the simpler calculator, for occasional problems, is the more intimate contact with the actual design problem, rather than the programming.

Fundamental Formulas and Programs

Some of the basic formulas and programs are not only suitable for simpler design problems, but can be combined into a program for a more intricate circuit solution. The main thing to remember, when going from a lumped constant to a transmission line circuit design, is that transmission lines can look like reactances, shorts, open circuits, resistances, and transformers depending on their *configuration, termination,* and *location* in the circuit. Every lead is a transmission line component in microstrip circuits. While some may be neglected in some cases, all become quite important at higher frequencies and neglecting them produces the "unexplainable" result. Most lumped circuit components can be represented in transmission line form at a given frequency, and vice versa. The main difference being that the transmission line reactance behaves differently with frequency, thus frequency response for an equivalent transmission line configured circuit may not be the same as when lumped circuits are used.

The following discussion and examples are for typical double-sided microstrip structures (one side being the ground plane). A 50-ohm system is assumed. The line characteristics are given in degrees (θ) for line length and ohms for characteristic impedance. The lines are assumed lossless (a valid assumption in most cases), to reduce the amount of math required.

Stubs

The simplest and very useful line configuration is the stub. It can be shorted to ground or open and is equivalent to a reactance placed across the line, as shown in Figure 1. That reactance is equal to:

$$jX_1 = jZ_1 \tan\theta_1 \qquad (1)$$

for a shorted line and

$$jX_2 = -j\frac{Z_2}{\tan\theta_2} \qquad (2)$$

for an open line. In both cases θ is the electrical line length in degrees (360° = one wavelength) and Z is the line characteristic impedance (determined by its width). The above equations show that either stub can be a capacity or an inductance at a given frequency, depending on its length; and, for a given length, they both change from an inductance to a capacity and vice versa as frequency changes. The value of the reactance is determined by both the characteristic impedance and length. Two characteristics of a stub, commonly used, become apparent: when line length is 90° (quarter wavelength), the shorted sub looks like an open circuit (jX = ∞) and the open stub looks like a short (jX = 0), for 180° (half wavelength) stubs the roles reverse. This characteristic is very handy in design of circuits such as veractor frequency doublers, where a tuned circuit has to be open at one frquency and a short at 1/2 or 2 times that frequency.

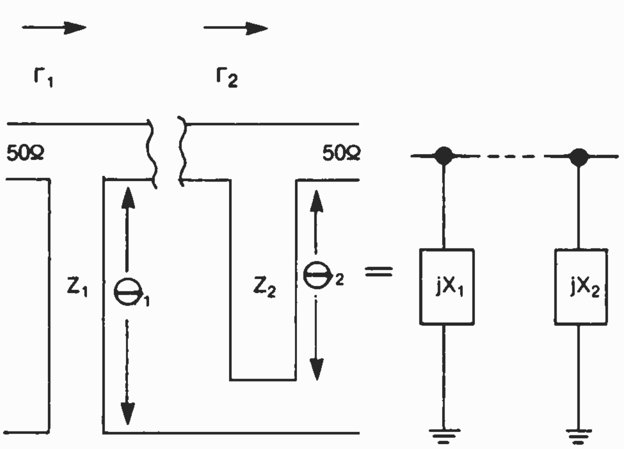


Figure 1. Shunt Reactances.

Table I

Step	Instructions	Input Data/Units	Keys		Output Data Units
1	Key in the program				
2	Store	f_o	STO	0	
		Z_o	STO	1	
		50	STO	8	
		θ	STO	9	
3	Enter frequency	f			
4	Start program				
	—for shorted line		GSB	0	f, |Γ|, dB
	—for open line		GSB	1	f, |Γ|, dB

Step	Key Entry	Key Code	Step	Key Entry	Key Code
001	(g) LBL 0	25 14 00		(g) 1/x	25 64
	STO 4	45 04		(f) →R	16 34
	PRx	65		STO 5	45 05
	RCL 0	55 00		X ⇌ y	11
	÷	61		STO 7	45 07
	RCL 9	55 09		X ⇌ y	11
	X	51		RCL 8	55 08
	(f) tan	16 44	040	—	31
	GSB2	13 02		(g) →P	25 34
010	(g) RTN	25 13		RCL 5	55 05
	(g) LBL 1	25 14 01		RCL 8	55 08
	STO 4	45 04		+	41
	PRx	65		RCL 7	55 07
	RCL 0	55 00		X ⇌ y	11
	÷	61		(g) →P	25 34
	RCL 9	55 09		X ⇌ y	11
	X	51		R↓	12
	(f) tan	16 44	050	÷	61
	(g) 1/x	25 64		PRx	65
020	CHS	22		STO 3	45 03
	GSB 2	13 02		(g) X^2	25 53
	(g) RTN	25 13		CHS	22
	(g) LBL 2	25 14 02		1	01
	RCL 1	55 01		+	41
	X	51		(f) log	16 33
	STO 6	45 06		1	01
	RCL 8	55 08	060	0	00
	X ⇌ y	11		X	51
	(g) 1/x	25 64		PRx	65
030	x ⇌ y	11		(g) SPC	25 65
	(g) 1/x	25 64		(g) RTN	25 13
	(g) →P	25 34			

Knowing the reactance, the reflection coefficient, Γ, where,

$$\Gamma = \frac{Z-50}{Z+50}, \qquad (3)$$

(Z = series equivlanet of 50Ω//jX)

can be calculated, as well as the response (insertion loss), A,

$$A = \frac{\text{transmitted power}}{\text{incident power}} = 10\log(1-|\Gamma|^2)\,dB \qquad (4)$$

caused by this reactance in a 50 ohm system. Since the calculated reflection coefficient is in absolute and not vector form, the above equations apply at any point on the 50 ohm line. The program of Table I calculates the values of the reflection coefficient and response in dB for any value of frequency. Use GSB 0 to initiate the calculation for the shorted line and GSB 1 for the open line.

Knowing the reflection coefficient, the VSWR caused by the stub on the line can also be calculated:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad (5)$$

Traps

One of the uses for a simple stub would be as a trap for unwanted frequencies. A sharp null occurs at frequencies at which an open stub is quarter wavelength long or a shorted stub is half wavelength. However, if the null frequency is close to the desired frequency, some attenuation at the desired frequency is present due to the bandwidth of the null circuit. A simple method to improve the trap performance is shown in Figure 2. Stub Z_1 provides the desired attenuation at f_1 while the stub Z_2 tunes out the undesired reactance of stub Z_1 at f_0. Either stub can be shorted or open and the undesired frequency f_1 can be below or above f_0. The program to calculate θ_2 and response is shown in Table II. To calculate θ_2 start program with command GSB 1. After θ_2 is automatically stored in register R.1, the response can be calculated by entering the desired frequency and initiating the program with GSB 0. An example of the improved performance of the double stub trap, as compared to the simple single stub is shown

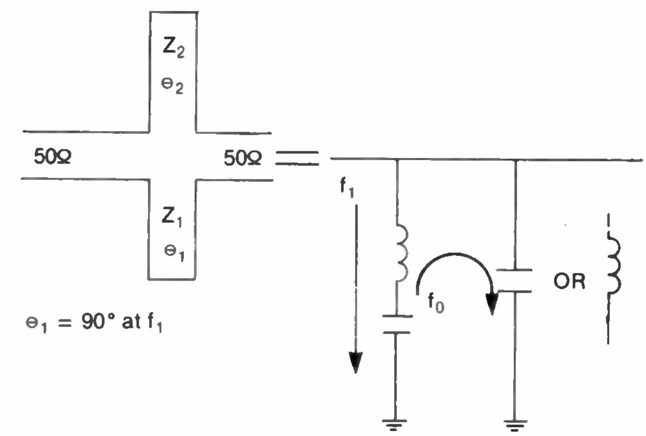


Figure 2. Microstrip Trap.

Table II

Step	Instructions	Input Data Units	Keys		Output Data Units
1	Key in the program				
2	Store	f_o	STO	1	
		f_1	STO	2	
		Z_1	STO	3	
		Z_2	STO	4	
		270	STO	.2	
		50	STO	.3	
		90	STO	.4	
		180	STO	.5	
3	Calculate θ_2		GSB	1	θ_2
4	Calculate Response	f	GSB	0	f
					$\lvert\Gamma\rvert$
					<
					dB
5	Repeat Step 4 for other frequencies	f	GSB	0	f
					$\lvert\Gamma\rvert$
					<
					dB
6	Recall (if desired)		RCL	5	X_1
			RCL	6	X_2
			RCL	7	$X_1 + X_2$
			RCL	8	R_s
			RCL	9	X_s
			RCL	.1	θ_2

Step	Key Entry	Key Code	Step	Key Entry	Key Code
001	(g) LBL 0	25 14 00		(g) 1/x	25 64
	STO 0	45 00	010	RCL 4	55 04
	PRx	65		CHS	22
	RCL 1	55 01		X	51
	÷	61		STO 6	45 06
	RCL.1	55.1		RCL 0	55 00
	X	51		RCL 2	55 02
	(f) tan	16 44		÷	61

Step	Key Entry	Key Code	Step	Key Entry	Key Code
	RCL.4	55.4		R↓	12
	X	51		X⇌y	11
	(f) tan	16 44		—	31
020	(g) 1/x	25 64		PRx	65
	RCL 3	55 03		1	01
	CHS	22	060	RCL.0	55.0
	X	51		(g) X^2	25 53
	STO 5	45 05		—	31
	(g) 1/x	25 64		(f) log	16 33
	RCL 6	55 06		1	01
	(g) 1/x	25 64		0	00
	+	41		X	51
	(g) 1/x	25 64		PRx	65
030	STO 7	45 07		(g) SPC	25 65
	(g) 1/x	25 64		(g) RTN	25 13
	RCL.3	55.3	070	(g) LBL 1	25 14 01
	(g) 1/x	25 64		RCL 3	55 03
	(g)→P	25 34		RCL 1	55 01
	(g) 1/x	25 64		RCL 2	55 02
	(f)	R		÷	61
	STO 8	45 08		RCL.4	55.4
	X⇌y	11		X	51
	STO 9	45 09		(f) tan	16 44
040	RCL 8	55 08		÷	61
	RCL.3	55.3		RCL 4	55 04
	−	31	080	X⇌y	11
	(g)→P	25 34		÷	61
	RCL 8	55 08		CHS	22
	RCL.3	55.3		(g) $\tan^{-1}$	25 44
	+	41		(g) X>0	25 41
	RCL 9	55 09		GTO 2	14 02
	X⇌y	11		RCL .5	55.5
	(g)→P	25 34		+	41
050	X⇌y	11		(g) LBL 2	25 14 02
	R↓	12		PRx	65
	÷	61	090	STO .1	45 .1
	PRX	65		(g) RTN	25 13
	STO.0	45.0			

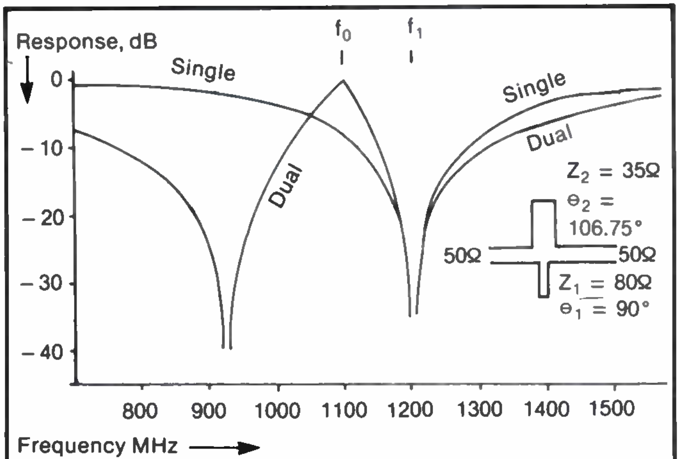


Figure 3. Comparison of Single and Double Stub Trap Performance.

in Figure 3. To facilitate making the PC board artwork, Z_1 and Z_2 are usually made 50 ohms. This is not necessary, however, and the program of Table II will calculate θ_2 and response for any desired value.

In addition to the frequency response (in dB) in step 67, the program also gives the absolute value of the reflection coefficient, $|\Gamma|$, in step 53 and its angle in step 58. If an HP-29C calculator is used, PRx commands (step 53, 58, 61, and 89) should be replaced by R/S commands and step 68 ([g] SPC) should be deleted. When a frequency which causes tangent θ to become zero or infinity is entered, the calculator will show an "error" display. In that case change the frequency slightly and try again.

Note the additional notch in the response at 927.42 MHz when the double stub trap is used. It is caused by series resonance of the Z_2 stub at (90/106.75) 1100 MHz. One big advantage of this configuration is the ease of tuning. If you make the two stubs slightly

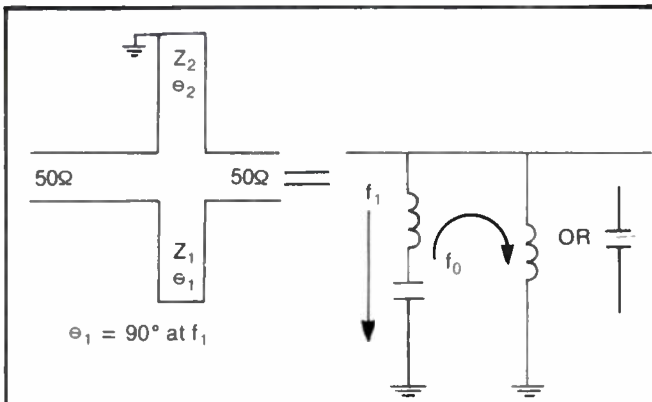


Figure 4. Grounded Microstrip Trap.

longer than required, Z_1 can be trimmed for minimum response at f_1, *then* Z_2 is trimmed for minimum loss at f_0. If this tuning sequence is observed, the two adjustments are independent of each other.

In some cases the trap configuration of Figure 4

Table III

Step	Instructions	Input Data Units	Keys		Output Data Units
1	Key in the program				
2	Store	f_o	STO	1	
		f_1	STO	2	
		Z_1	STO	3	
		Z_2	STO	4	
3	Calculate θ_2		GSB	1	θ_2
4	Calculate response	f	GSB	0	f
					$|\Gamma|$
					<
					dB
5	Repeat step 4 for other frequencies	f	GSB	0	f
					$|\Gamma|$
					<
					dB
6	Recall (if desired)		RCL	5	X_1
			RCL	6	X_2
			RCL	7	$X_1 + X_2$
			RCL	8	R_s
			RCL	9	X_s

Step	Key Entry	Key Code	Step	Key Entry	Key Code
001	(g) LBL 1	25 14 01		RCL 4	55 04
	RCL 3	55 03		÷	61
	RCL 1	55 01		(g) $\tan^{-1}$	25 44
	RCL 2	55 02		(g) X>0	25 41
	÷	61		GTO 2	14 02
	9	09		1	01
	0	00		8	08
	X	51		0	00
	(f) tan	16 44		+	41
010	÷	61	020	(g) LBL 2	25 14 02
	PRx	65		(g) 1/x	25 64
	STO .1	45 .1		(f)→R	16 34

Step	Key Entry	Key Code	Step	Key Entry	Key Code
	(g) RTN	25 13	060	STO 8	45 08
	g) LBL 0	25 14 00		X⇌y	11
	STO 0	45 00		STO 9	45 09
	PRx	65		RCL 8	55 08
	RCL 1	55 01		5	05
	÷	61		0	00
	RCL .1	55.1		—	31
030	X	51		(g)→P	25 34
	(f) tan	16 44		RCL 8	55 08
	RCL4	55 04		5	05
	X	51	070	0.	00
	STO 6	45 06		+	41
	RCL 0	55 00		RCL 9	55 09
	RCL 2	55 02		X⇌y	11
	÷	61		(g)→P	25 34
	9	09		X⇌y	11
	0	00		R↓	12
040	X	51		÷	61
	(f) tan	16 44		PRx	65
	(g) 1/x	25 64		STO .0	45 .0
	CHS	22	080	R↓	12
	RCL 3	55 03		X⇌y	11
	X	51		—	31
	STO 5	45 05		PRx	65
	(g) 1/x	25 64		1	01
	RCL 6	55 06		RCL .0	55 .0
	(g) 1/x	25 64		(g) X^2	25 53
050	+	41		—	31
	(g) 1/x	25 64		(f) log	16 33
	STO 7	45 07		1	01
	(g) 1/x	25 64	090	0	00
	5	05		X	51
	0	00		PRx	65
	(g) 1/x	25 64		(g) SPC	25 65
	(g)→P	25 34		(g) RTN	25 13

may be more desirable. Length θ_2 is 90 degrees different from that of Figure 2 configuration; thus, sometimes, it may be shorter. The entire structure becomes grounded, which may be an advantage at times. In addition, while Figure 2 trap configuration has no attenuation at very low frequency, Figure 4 trap has a zero at zero frequency and thus its attenuation approaches infinity at DC. Table III program calculates θ_2, $|\Gamma|$ and its angle, and the response in dB. These are shown in steps 22, 78, 83, and 92 respectively. All other Table II program notes also apply. For comparison, Figure 5 shows the frequency response for the grounded trap. In this case the series resonance of Z_2 occurs at (180/16.75) 1100 or 11,822.3 MHz. Since the reactance of a stub is a function of tan θ, it is apparent that Z_2 line length can be changed by multiples of 180° without changing the resonant and antiresonant frequencies. This may be desirable in the grounded trap case, if no convenient close ground is available. The overall response does change, however. A response curve for $\theta_2 = 16.75° + 180°$ is shown in Figure 6. The zero caused by Z_2 series resonance is now at (180/196.75) 1100 or 1006.35 MHz. This is close enough to the frequencies of interest to cause appreciable change in frequency response. The length of Z_1 stub can also be increased by 180°. The effect of this increase is shown in Figure 7 for an ungrounded trap. Table II program has to be modified to accommodate this change: 270 is stored in register R.2 and steps 17 and 75 are changed from RCL.4 to RCL.2. Command GSB 1 provides then the right answer for θ_2 of 133.43°

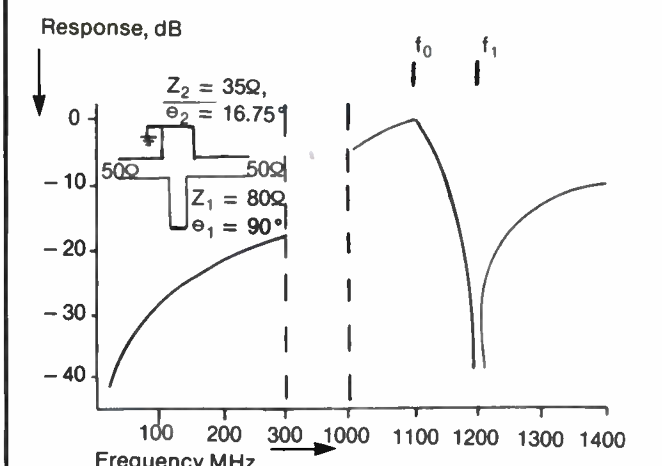


Figure 5. Grounded Double Stub Trap Performance.

instead of the original 106.75°. The Z_2 series resonance becomes (90/133.43) 1100 or 742 MHz. This is further away from the desired pass frequency f_o, than in the original case shown in Figure 3, thus providing more bandwidth, which may be desirable.

Programs

Programs shown in Table II and III perform the calculation in a similar manner. The sequence for calculating Z_2 line length θ_2 (initiated by GSB 1) is:

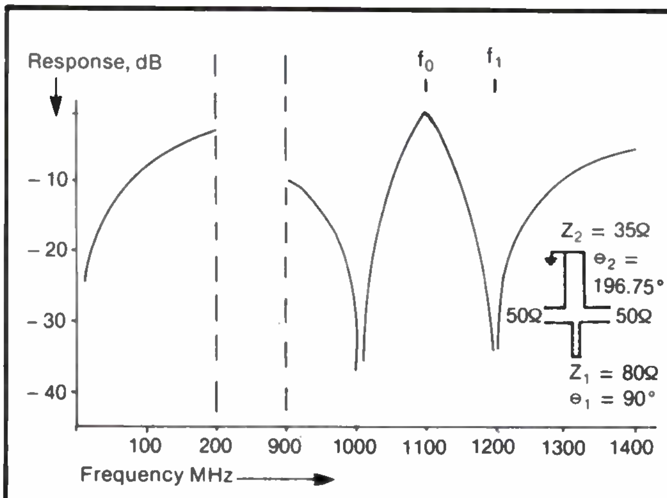


Figure 6. Grounded Double Stub Trap Performance.

- calculate reactance of Z_1 at f_o using equation (1) or (2) and converting θ_1 to length at f_o by multiplying it by f/f_o,
- calculate Z_2 length, θ_2, which would provide the conjugate reactance at f_o,
- if the answer is negative, add 180°,
- print answer, and store in R.1.

The frequency response, in dB, and the reflection coefficient are calculated after the desired frequency is entered and the program is initiated with GSB 0. The operational sequence is:

- the entered frequency is stored in R0 and is also printed for reference.
- the reactances of Z_1 and Z_2 are calculated and stored in R5 and R6,
- Z_1 and Z_2 reactances are added and are stored in R7,
- the parallel reactance and 50 ohm load resistance are changed to the series form, the equivalent series resistance is stored in R8 and the equivalent series reactance in R9,
- reflection coefficient, Γ, in polar form is calculated using equation (3), and the magnitude and angle are printed; the magnitude is stored in R.0,
- loss is calculated using equation (4), converted

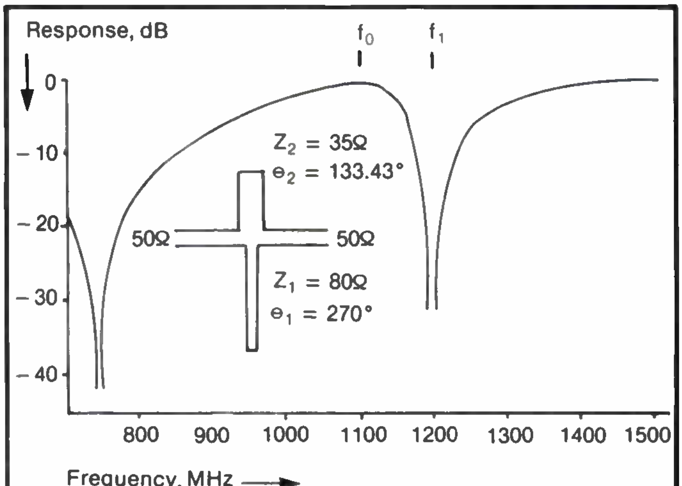


Figure 7. Long Z_1 Line Trap.

Table IV

Step	Instructions	Input Data Units	Keys		Output Data Units
1	Key in the program				
2	Store	f_o	STO	0	
		f_L	STO	1	
		f_H	STO	2	
		50	STO	8	
		90*	STO	9	
3	Calculate Z_1		GSB	0	Z_1
4	Calculate response	f	GSB	1	dB
5	Repeat step 4 for other frequencies	f	GSB	1	dB
6	Recall (if desired)		RCL	5	X_s
			RCL	6	R_s
			RCL	7	$\|\Gamma\|$
	* or 270		RCL	3	$\dot{Z}_1$

Step	Key Entry	Key Code	Step	Key Entry	Key Code
001	(g) LBL 0	25 14 00		+	41
	RCL 0	55 00		RCL 5	55 05
	RCL 1	55 01		X⇌y	11
	÷	61	060	(g)→P	25 34
	RCL 9	55 09		X⇌y	11
	X	51		R↓	12
	(f) tan	16 44		÷	61
	RCL 0	55 00		STO 7	45 07
	RCL 2	55 02		(g) X^2	25 53
010	÷	61		CHS	22
	RCL 9	55 09		1	01
	X	51		+	41
	(f) tan	16 44		(f) log	16 33
	÷	61	070	1	01
	CHS	22		0	00
	RCL 8	55 08		X	51
	X	51		PRx	65
	PRx	65		(g) SPC	25 65
	STO 3	45 03		(g) RTN	25 13
020	(g) RTN	25 13			
	(g) LBL 1	25 14 01			
	PRx	65			
	STO 4	45 04			
	RCL 9	55 09			
	X	51			
	RCL 2	55 02			
	÷	61			
	(f) tan	16 44			
	RCL 8	55 08			
030	÷	61			
	RCL 4	55 04			
	RCL 9	55 09			
	X	51			
	RCL 1	55 01			
	÷	61			
	(f) tan	16 44			
	RCL 3	55 03			
	÷	61			
	+	41			
040	(g) 1/x	25 64			
	CHS	22			
	(g) 1/x	25 64			
	RCL 8	55 08			
	(g) 1/x	25 64			
	(g)→P	25 34			
	(g) 1/x	25 64			
	(f)→R	16 34			
	STO 6	45 06			
	X⇌y	11			
050	STO 5	45 05			

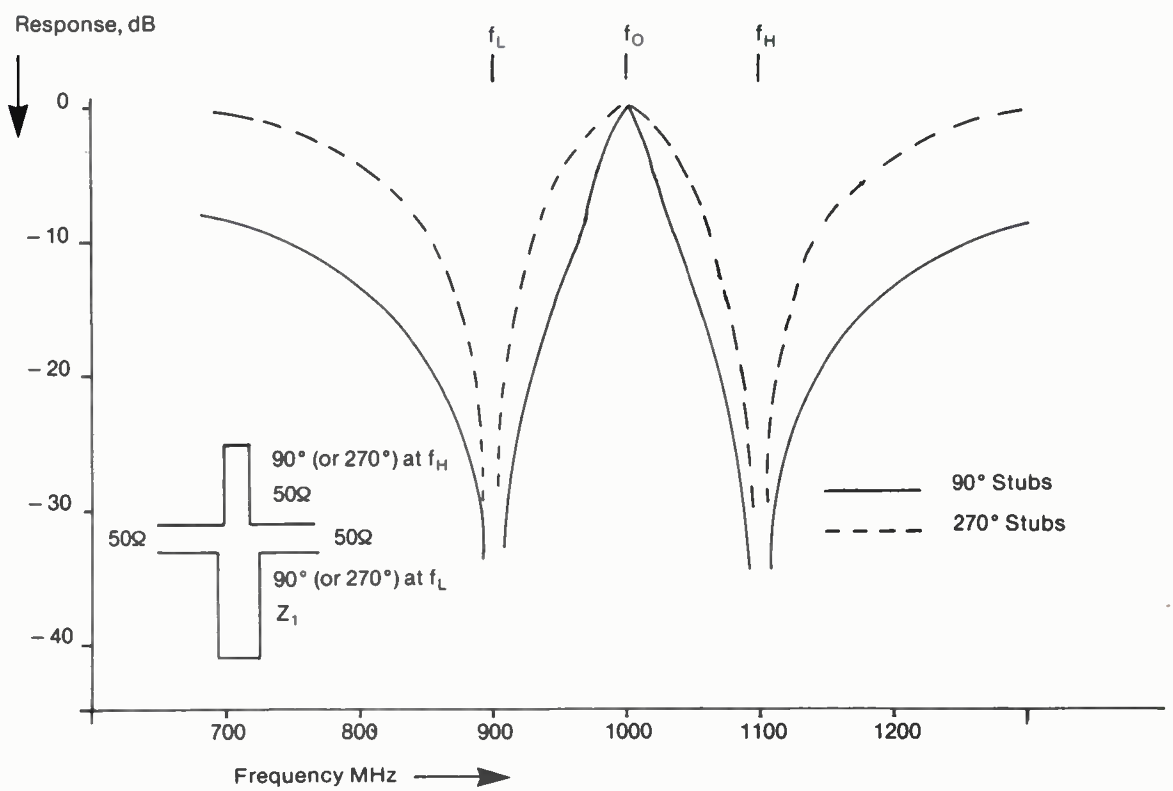


Figure 8. "Bandpass" Circuit.

to dB and printed.

The values stored in R5, R6, R7, R8, and R9 can be recalled after the calculation, if desired.

Bandpass Circuits

Looking at the response of Figures 3 and 7, it becomes apparent that a pseudo bandpass circuit can be constructed using the double stub configuration. Let us assume that a 1000 MHz receiver does not have enough front end selectivity. A low cost, compact filter can be constructed using a simple microstrip configuration of Figure 2 and the following procedures: select two frequencies (one below and one above 1000 MHz) where maximum attenuation is desired (adjacent channels or interfering frequencies) and make the two stubs 90° at these respective frequencies. To provide minimum attenuation at f_o (1000 MHz) the impedance of one of the lines has to be adjusted. The calculator program of Table IV calculates the impedance of that line (the other one is fixed at 50 ohms) and then calculates the frequency response. Selecting for our example, $f_L = 900$ MHz and $f_H = 1100$ MHz, the response is shown in solid lines in Figure 8. Remembering again that tan 90° = tan 270°, we can replace 90 in storage register R9 with 270. The response then becomes as shown in dashed lines in Figure 8. Command GSB 0 calculates the impedance of the low frequency stub: 40.77 ohms for the 90° long stubs and 39.55 ohms for the 270° long stubs. Both figures are reasonable. In the example, the two frequencies of maximum attenuation were selected to provide arithmetic symmetry. This is not necessary; geometric symmetry can be used or any other two frequencies.

PC Materials

Low loss materials should be used in the construction of these circuits, particularly when f_1 (or f_H and f_L) are close to f_o. The preceding analysis does not include material losses; only the 50 ohm loads are considered. For most applications, however, the actual results are very close to the calculated figures.

Conclusions

The microstrip technique provides the means for very versatile low cost frequency response shaping. Accurate design and predicted performance data can be obtained using a low cost programmable calculator. □

New RF Semiconductors

The major manufacturers of RF semiconductors were asked to contribute information on large and small signal devices operating above 3 MHz. The following material is intended to familiarize the designer with the range of products offered by the various manufacturers, as well as to bring him up to date on products introduced within the past year or two. Of special interest are semiconductors recently designed for specific new applications and changing marketplace requirements.

Amperex Electronic Corporation
Providence Pike
Slatersville, R.I. 02876
David R. Pryce (401) 762-3800
INFO/CARD #124

Acrian, Inc.
10131 Bubb Road
Cupertino, Calif. 95014
Michael J. Mallinger (408) 996-8522
INFO/CARD #125

Solid State Microwave —
Division of Thomson CSF Component Corp.
Montgomeryville, Pa. 18936
Robert J. Tyson (215) 362-8500
INFO/CARD #126

Motorola Semiconductor Products Inc.
5005 East McDowell Road
Phoenix, Ariz. 85008
Alan Wagstaffe (602) 244-6394
INFO/CARD #127

Hewlett-Packard
1501 Page Mill Road
Palo, Alto, Calif. 94304
Douglas K. Blackwood (415) 856-4105
INFO/CARD #128

California Eastern Laboratories
3005 Democracy Way
Santa Clara, Calif. 95050
Jerry A. Arden (408) 988-3500
INFO/CARD #129

Avantek, Inc.
3175 Bowers Avenue
Santa Clara, Calif. 95051
Northe K. Osbrink (405) 249-0700
INFO/CARD #130

Siliconix, Inc.
2201 Laurelwood Road
Santa Clara, Calif. 95054
Dick Moss (408) 988-8000
INFO/CARD #131

Available From Amperex

Amperex offers over 50 types of small-signal, high performance "GHz" transistors. Employing shallow diffusion and ion-implantation technologies, these bipolar transistors feature very linear, low distortion operation over wide band widths. All of the types in this line have gain-bandwidth products (f_T) of 1 GHz, or higher. Many are in the 5 GHz range, and one very special type has pushed the state-of-the-art as high as 14 GHz. These high-performance transistors find application in the CATV/MATV, communications, instrumentation, and microwave markets.

A large measure of the Amperex success in these markets is due not only to device performance, but to the variety of packages available. Amperex offers metal cans, plastic T-packs, ceramic strip-line, stud-mounted strip-line, and microminiature types in both ceramic (LID) and plastic (SOT-23) executions. With the increasing emphasis on size reduction, many industry leaders are converting from printed circuit board assembly to hybrid thick-film circuits. Microminiature discrete devices such as the SOT-23 and LID are ideally suited for these re-flow solder applications.

While many factors can influence high frequency transistor performance, the most significant *device* parameter is probably f_T, or transition frequency (commonly called gain-bandwidth product). By definition, f_T is the frequency at which the (short-circuit) common-emitter current gain is equal to unity. Intrinsically, f_T is determined by the equivalent time — constant in the base-emitter circuit. This relationship is: $f_T = 1/2\pi r_e C_e$, where r_e is the dynamic emitter resistance, and C_e is the emitter transition capacitance. The value of r_e is inversely related to emitter current: $r_e = kT/qI_E$, where k = Boltzmann's constant, T = temperature in degrees Kelvin, q = electron charge, and I_E = emitter current. At room temperature, and an emitter current of 1mA, r_e would have a typical value of 26 ohms.

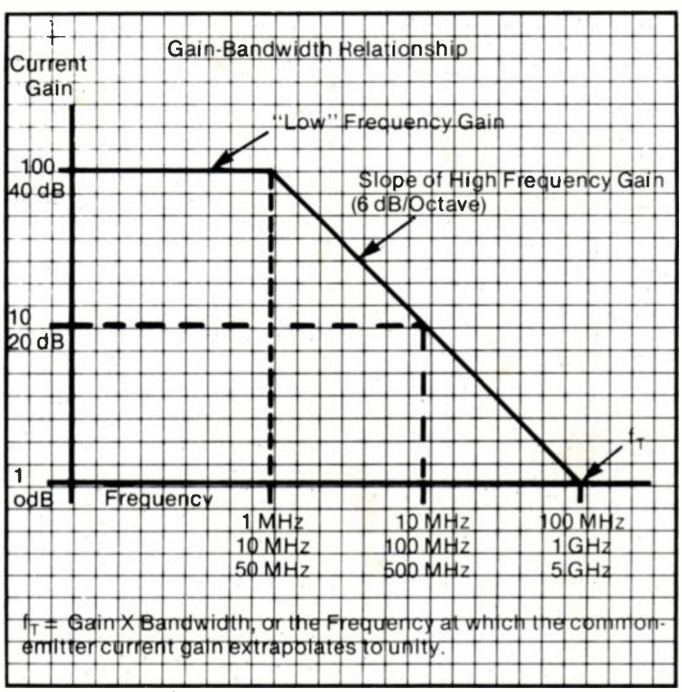


Figure 1.

Figure 1 shows the relationship between f_T and current gain. While a high transition frequency is important for a transistor in a high frequency, narrow-band (tuned) application, it is of even greater significance for wide-band applications where gain must be sacrificed to obtain a wide, flat bandwidth. A transistor with an f_T of 100 MHz (for example) and a low frequency current gain of 100, would have a "flat" bandwidth of only 1 MHz. By means of frequency selective feedback the gain could be reduced from 40 dB to 20 dB, with a resulting improvement in bandwidth to 10 MHz. A transistor with an f_T of 5 GHz would exhibit bandwidths of 50 MHz and 500 MHz under the same conditions.

Figure 2 illustrates the behavior of three different transistors with transition frequencies in the 1 to 2 GHz range. The dependence of f_T on the magnitude of the emitter current is clearly evident. The A490 has a relatively narrow f_T peak in the 10 to 15 mA range, although it is somewhat exaggerated by the non-logarithmic current scale.

The A430 has a useful f_T over a wider range of emitter current. The A490 and A430 employ similar chip geometries with 3 emitter fingers, and 4 base fingers in an interdigitated arrangement. The fingers on the A430, however, are substantially wider, thus providing an increased operating current range. The f_T peak for the A430 extends from about 15mA to 40mA.

The A210 is a larger chip with 12 emitter fingers, and 13 base fingers. There are actually 9 emitters per finger, for a total of 108 separate emitters. As a result, the f_T curve is much flatter, and extends over a very wide range of emitter current. Normally, the A210 would be biased in the 30mA to 100mA range, depending on circuit requirements. Distortion products tend to be lowest in the 70mA to 90mA range. The A210 is particularly well suited for higher level, linear output stages in CATV/MATV or instrumentation amplifiers.

Second generation types have expanded on these basic technologies to provide transistors with gain-bandwidth products in the 3 to 5 GHz range, suitable for operation from as low as 200 μA to over 120mA. A third generation type for use in the 2mA to 20mA range features an f_T of 10 GHz @ 5mA and 14 GHz @ 15mA. While most transistors in the GHz product line are of NPN polarity, there are several PNP types with f_T's in the 5 GHz range.

For maximum *gain* in high frequency circuits, particularly wide-band amplifiers, these transistors are normally biased at, or near their f_T peak. This will also be the approximate point where distortion products such as x-mod and inter-mod will be at their lowest. Where *noise figure* is of prime importance, a compromise in gain is usually necessary, since lowest noise normally occurs considerably lower in current than does the f_T peak.

All of the Amperex high performance transistors are fine geometry, interdigitated types with all gold metallization. Several of the Amperex "GHz" chips are available in as many as 5 or 6 different package choices, providing great versatility for the users specific application or assembly method. Condensed catalogs, data sheets, and application notes are available.

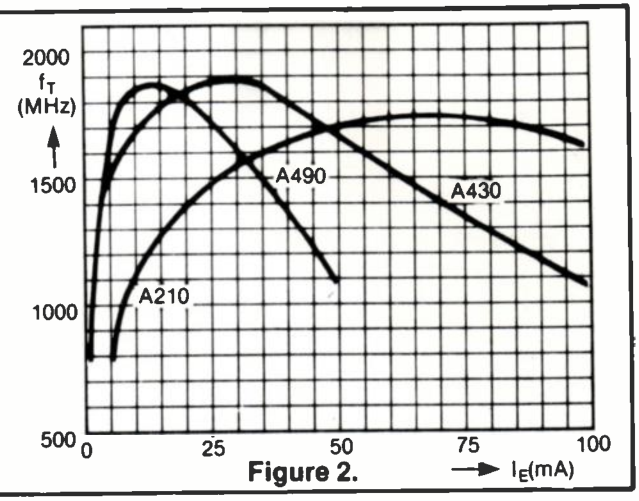


Figure 2.

Available From Acrian

New Avionics Power Transistors perform at wide pulse widths and under high duty bursts.

Acrian, Incorporated has introduced several series of devices specifically geared to handle the more sophisticated waveforms used in advanced versions of avionics and radar equipments.

During the past several years, many avionics and radar systems using power amplifiers have run a very narrow pulse width (<10us) and very low duty cycle (<1 percent). With the requirements to put more information into the signal, for applications such as BCAS or DABS, system users need to move up to using more sophisticated signal processing and transmission, requiring that the transmitter PA be capable of handling both longer pulse widths and "bursts" of pulses which may run at high duty cycles (up to 50 percent) for extended periods (up to several millisec). Transistors designed to function at short pulses and low duty cycles will not live up to the demands of the newer pulse requirements, and still provide the required power output, with minimum pulse droop and low junction temperature, when operating at the extremes of the airborne environment (+70°C air). The new system requirements have created the need for an entirely new set of microwave power transistors geared to operate at higher duty cycles and over longer pulse widths.

Acrian initiated a full scale development activity geared to design and produce products which would provide the power levels required, as well as meeting the full system specs for high duty operation. The Acrian products represent designs optimized for each specific requirement, taking into account RF operating conditions, as well as environmental and reliability goals. In conjunction with the new designs, Acrian has developed the necessary processing and assembly procedures geared to the manufacture and test of these products. These products incorporate gold-thin film topside metalization, gold controlled loop wire bonding and hermetic sealed packages.

The results, confirmed by evaluation of major users, verify that the Acrian Products indeed represent a breakthrough in the state-of-the-art in high power pulsed transistors.

A summary of products and performance:

Product	Power Out	Pg	Pulse Width
Transponders: 1090 MHz			
TPR400A	400W	7 dB	30μs, 1%
DAB200	200W	6 dB	1 μs, 50% for 2 millisec
TACAN: 960-1215 MHz			
TAN250	250W	7 dB	30 μs, 50% for 360 millisec

Pulse droop on these products runs less than 1/4 dB and operating junction temperatures less than 150°C.

All previous products demonstrated very high pulse droop (>1 dB) and junction temperatures (>200°C).

Acrian is now applying the same design, processing and assembly approach to meet the need for products operating at both higher and lower frequencies for Radar and ECM Applications.

Available From Solid State Microwave

Solid State Microwave, has long been a leader in supplying state-of-the-art RF transistors for use in the mobile radio, avionics and CATV markets, offering devices for all of the various frequency bands.

A recent innovation pushes the highband (130-175 MHz) product line to 150W at 12.5 volts V_{cc}, with power gain of 5.5 dB minimum. This device packs nearly two feet of emitter periphery into a silicon chip which measures .094 inch by .250 inch.

For the UHF mobile market (450-512 MHz) a chip has been developed which exhibits higher power gain at the 40 watt level than anything which is presently available elsewhere, and yet has the capability of withstanding all phase angles of an infinite-to-one load VSWR with 50 percent over-driven input power at 16.0 volts V_{cc}. This basic chip type will be used as a building block for a lineup of UHF mobile transistors up to the 75-80 watt power level. These various power levels will be achieved by combining different numbers of the basic active cell that make up the 40 watt device.

The "800 MHz" band is the newest and most challenging of th mobile bands. Solid State Microwave is the only supplier now manufacturing high power (30 watts) 800 MHz transistors (Figure 1) in true production quantities, which is the result of a device development program that significantly extended the state-of-the-art. As can be imagined, many specialized techniques must be applied to the fabrication and testing of high power transistors at this frequency, especially when considering the extreme uniformity of input and output impedances that is required. The transistors in Figure 1 represent one of the assembly techniques (glass rods) used to control the lengths of the bond wires. Solid State Microwave also uses automatic systems which eliminate the need for the rods. Both systems produce the control needed to produce repeatable transistors.

Transistors with power outputs in the 150 watt range are available in the 2 MHz through 50 MHz frequency bands. 100 watts P.E.P. at 12.5V V_{cc} with — 30 dB 3rd order IMD is just one example of a 30 MHz transistor presently being produced.

In anticipation of the expected substantial growth in the market for short and long-pulse power devices for applications such as DME and TACAN, a major development program has been launched. The results have been excellent, and power levels of greater than 400 watts have been achieved with devices which are surprisingly rugged. At the same time a 2 GHz microwave device lineup is being characterized and will include power outputs at least up to the 10 watt level.

Solid State Microwave is constantly initiating programs in an attempt to provide state-of-the-art transistors for our present markets. Solid State Microwave is also involved in development efforts for semiconductors that will be used in markets and applications not presently served by its product lines. Variations in packaging techniques, innovations in device design concepts and methods of realizing higher more useable impedances at the transistor terminals are just some of the areas being investigated in the laboratory. The end results of these efforts are productionable, economical, state-of-the-art semiconductor products.

Just recently Thomson-CSF purchased the RF group of Solid State Scientific. The RF Group has thereby changed its name to Solid State Microwave.

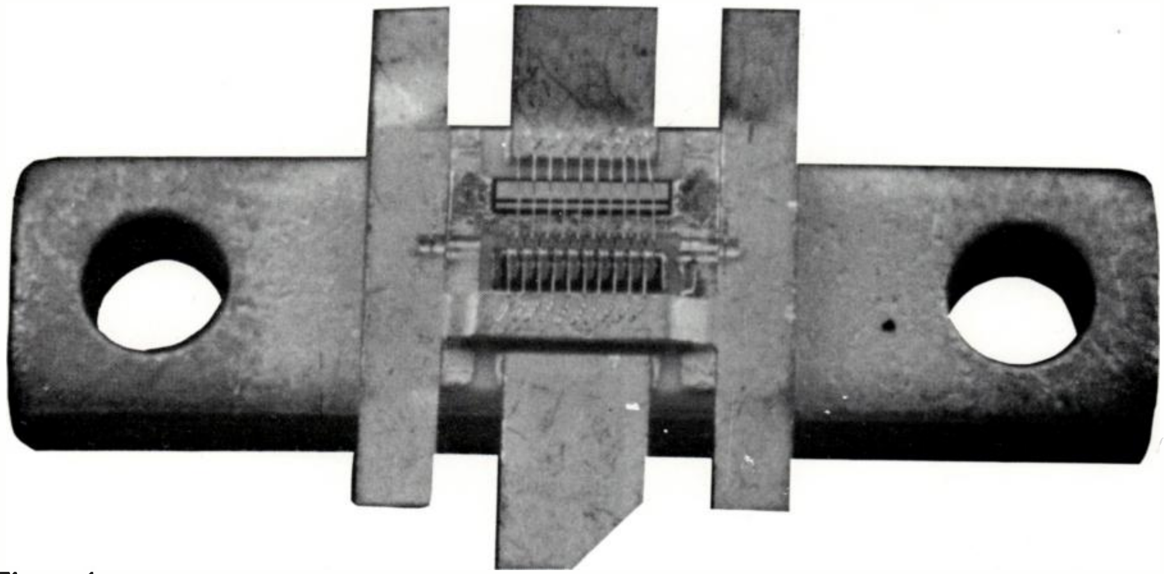


Figure 1.

Available From Motorola

In the past RF bipolar transistor suppliers concentrated on extracting more gain and power output at higher frequencies in transmitting devices and lower noise figures from receiving types. During more recent times design effort has been aimed at transistors which are better suited to the application. RF power transistors are designed with improved thermal performance and emitter site ballasting to improve ruggedness; stability is considered at the initial device design phase producing more realistic and practical stage gains; input impedance Q's are lowered and internal input matching utilized to increase bandwidth. Reliability, once the nemesis of RF power transistors, has been improved to the point where in any well-designed circuit reliability is taken for granted.

Today there are a new set of challenges which the RF transistor manufacturers have to address. The problems to be solved cannot be discussed in general terms as the present and future demands differ depending upon the market and end-use. Space does not allow discussion of all the issues, but it is worthwhile to identify some of the key requirements and present solutions.

Plastic Power

The equipment manufacturer is being subjected to increasing costs in almost all aspects of his operation and is looking, with justification, for component suppliers to provide devices ideally at lower prices, but failing that those which will be subject to minimal price increases over the equipment lifetime.

Today, with few exceptions, RF power transistors are encapsulated in metal/ceramic stripline-opposed-emitter (S.O.E.) packages.

The SOE package has excellent RF performance, but unfortunately contains materials and rare elements which are increasing in price at an astronomical rate. When it is realized that gold, Kovar (cobalt), beryllium oxide and copper are the major constituents, it is easily understood why the SOE package cost is increasing at an unacceptable rate. Assembly of the SOE packaged RF transistor is also labor intensive which further compounds the rate of price increase.

The highest volume users of RF power transistors are manufacturers of mobile, marine, light aircraft, citizens band and amateur radios. These markets are also some of the most price conscious in the communications industry and, consequently, are the first to which Motorola is offering a more "inflation resistant" packaging alternative to the metal/ceramic SOE.

The most obvious choice is to lean on the experience of the consumer industry and adopt the well accepted and understood, from assembly and reliability aspects, TO-220 plastic package. Motorola has developed a series of TO-220 RF power transistor lineups having output power at 40 watts at HF with V_{cc} of 12.5 and 28V; 40 watts at VHF law band, 12.5V; 30 watts at VHF high band, 12.5V; 60 watts peak at 136 MHz, 27V; 12 watt SSB, CB, 12.5V and 7 watts at 470 MHz, 12.5V. Figure 1.

There are a total of fifteen devices all of which are common emitter configuration — flanges and center lead being connected to the emitter for optimum mounting and heatsinking — with the exception of the citizens band devices which are common collector because of historical reasons.

TO-220 packages have parasitic reactive impedance elements which are higher than those of the SOE and, as a result, the available bandwidth is less. The applications for which TO-220 devices are offered do not, however, demand large percentage bandwidths and the performance is more than adequate — and the price is right.

The TO-220 packaged RF power transistor is currently priced below its SOE counterparts and will not be subject to the same rate of inflationary price spiral of the metal/ceramic packages over the foreseeable future.

Cascadable RF Gain Blocks

Many small signal RF applications demand multi-octave bandwidths which cause designers to resort to expensive high f_T transistors, complex impedance matching networks and often cascode stage with combinations of shunt and series feedback. Design cycles may be long and reproduction of the desired performance in quantity production is sometimes problematic due to the accumulated tolerances of a multitude of components and variances in component placement.

Thin film hybrid construction techniques provide for the minimization of parasitic reactive elements and production variables. Not many equipment manufacturers, however, have these facilities and, if they have, do not have the volume demand to make thin film hybrid circuits economically attractive. For many years Motorola has been producing thin film hybrid linear amplifiers for the cable TV (CATV) industry and power amplifier modules for VHF and UHF mobile and handheld radio transmitters. Recognizing the demand for wideband small signal RF gain blocks, Motorola is utilizing its expertise in production of cost effective, high volume thin film hybrid RF circuits and is introducing three families of "MWA" amplifiers in TO-39 packages. Figure 2.

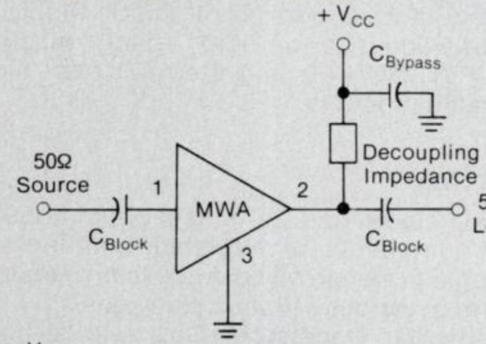
Figure 1. RF Power Transistors in TO-220.

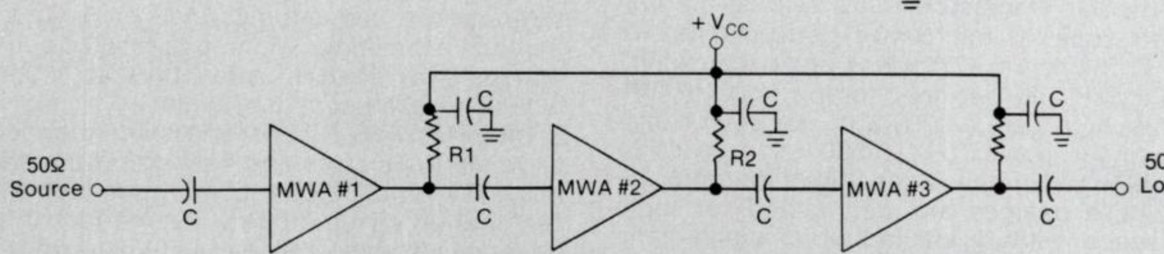
Device Type	Pout Watts	Gp dB Min	V_{cc} Volts	Price 100+
1.5-30 MHz HF/SSB/AM				
MRF 476*	3	15	12.5	1.20
MRF 475*	12	10	13.6	2.50
MRF 485	15	10	28	2.50
MRF 477	40	15	12.5	7.80
MRF 486	40	15	28	9.70
25-50 MHz VHF Lowband				
MRF 479	15	12	12.5	3.15
MRF 497	40	10	12.5	7.80
100-150 MHz VHF/AM				
MRF 340	8	13	27	3.15
MRF 342	24	11	27	6.20
MRF 344	60	6	27	9.70
136-175 MHz VHF Highband				
MRF 260	5	10	12.5	3.15
MRF 261	10	5.2	12.5	4.00
MRF 262	15	6.3	12.5	6.20
MRF 264	30	5.2	12.5	7.80
400-500 MHz UHF				
MRF 660	7	5.4	12.5	5.75

*Common collectors types — all others are common emitter.

Figure 2. MWA Wideband RF Hybrid Amplifiers.

Device Type	Upper Frequency Limit, MHz	Gain dB Typ	1 dB Comp. Output; dBm	NF dB Typ	Price 100+
MWA 110	400	14	−2.5	4.0	5.00
MWA 120	400	14	8.2	5.5	5.40
MWA 130	400	14	18	7.0	6.00
MWA 210	600	10	1.5	6.0	5.50
MWA 220	600	10	10.5	6.5	6.00
MWA 230	600	10	18.5	7.5	6.50
MWA 310	1000	8	3.5	6.5	6.00
MWA 320	1000	8	11.5	6.7	6.50
MWA 330	1000	6.2	15.2	9.0	7.00





All Capacitors (C) are 0.018 μF Chip Capacitors

	Cascade 1	Cascade 2
Frequency Range	0.25 to 400 MHz	0.25 to 1000 MHz
Gain	43.5 dB	20.5 dB
Gain Flatness	+ 1.0 dB	± 0.75 dB
Input VSWR	2.0:1	2.4:1
Output VSWR	1.2:1	2.1:1
V_{cc} Supply	12 Vdc	33 Vdc
I Supply	44 mAdc	150 mAdc
MWA #1	MWA110	MWA320
MWA #2	MWA110	MWA330
MWA #3	MWA120	MWA330
R1	1000Ω	1000Ω
R2	1000Ω	500Ω
R3	300Ω	500Ω

Figure 3. MWA amplifier stage showing external components and typical 400 MHz and 1 GHz three stage cascades.

The MWA series have three frequency ranges, 0.1-400 MHz, 0.1-600 MHz, 0.1-1000 GHz; the lower frequency 3 dB corner being determined by the value of coupling capacitor impedance. Each frequency range of products has three types of single stage class A amplifiers biased at 10, 25 and 60mA with 1 dB compression output levels from −0.25 to +18.5 dBm. Figure 3. The input/output impedance is 50Ω with the amplifiers being unconditionally stable and, therefore, may be cascaded for any desired gain. Only four components are required external to the MWA: two DC blocking capacitors, a resistor or choke through which the DC supply voltage is applied, and a supply bypass capacitor.

Having the blocking capacitors outboard provides flexibility in optimizing frequency response for a particular application and the external DC feed resistor gives the option of using any supply voltage down to the MWA operating voltage which is in the range 1.6V to 5.5V depending upon type.

Construction techniques feature a gold metallized, silicon nitride passivated transistor; alumina substrate with gold conductors and inductor; laser trimmed deposited nichrome resistors; all packaged in a low profile TO-39 hermetic case.

The MWA series of gain blocks eliminate the design pains and ensure consistent performance from unit to unit. The pricing, Figure 2, of the MWA's allows their application in equipment which hitherto could not justify the prices of general purpose hybrid amplifiers offered in TO-8 and TO-12 packages.

MWA amplifiers are available with hi-rel processing similar to MIL-S-883, Method 5004.4, Class B. □

Available From Hewlett-Packard

More than a decade of intensive solid state research has enabled Hewlett-Packard Company to become a leading designer and manufacturer of quality, competitively-priced RF and microwave semiconductor components. HP components, designed to satisfy the needs of researchers and product designers, are used in consumer, industrial, communications, military, and other OEM equipment.

HP's product lines consist of silicon bipolar and gallium arsenide (GaAs) field effect transistors; Schottky, PIN, IMPATT, and step recovery diodes; and integrated products.

Transistors

HP silicon bipolar and GaAs field effect transistors fill most requirements for multistage amplifiers from the VHF region through 18 GHz. Devices are supplied in chip form or various stripline packages.

Silicon Bipolar Transistors: Device-to-device uniformity and superior microwave performance are combined in the new HXTR series of devices which have been individually designed for low noise (HXTR-6000 series), high gain (HXTR-2000 series), or low-distortion linear power (HXTR-5000 series). With guaranteed RF performance specifications from 1.5-4.0 GHz, these devices are well suited for high-reliability space, military, and industrial applications at frequencies up to 6 GHz. Examples of products in this series include the low noise HXTR-6104, which typically offers 1.4 dB NF and 14 dB associated gain at 1.5 GHz, and the HXTR-5102 linear power transistor featuring 27.5 dBm typical P_{1dB} linear power with 7 dB associated gain at 4 GHz.

GaAs Field Effect Transistors: Extensive application support in the form of bulletins and notes helps designers effectively use these rugged new devices. The present family includes such products as the packaged HFET-2201 with 2.4 dB typical NF and 9.2 associated gain at 10 GHz, and the HFET-1001 general-purpose chip which at 12 GHz can produce either 20 mW of linear output power or 4.2 dB NF with 6 dB gain, depending upon bias conditions.

Diodes

Schottky Barrier Diodes: Schottky diodes combine extremely high rectification efficiency with picosecond switching speeds, low series resistance, and low noise characteristics. This combination makes the Schottky an excellent mixer/detector diode. At HF, VHF, and UHF frequencies, HP delivers glass-packaged devices in million-piece quantities at economical prices. These same diodes have many digital circuit applications such as clipping and clamping where switching speed is important. At microwave frequencies their low noise repeatable RF impedance lead to outstanding performance either as mixers or detectors. A new series of zero bias Schottky detector diodes offers improved detection efficiency without the DC bias requirements of conventional detector diodes. Package configurations for mixer/detector diodes include beam-leaded devices as well as conventional microstrip, ceramic, and axial-leaded packages.

PIN Diodes: PIN diodes function as variable resistors at microwave frequencies. By controlling the DC bias, the RF resistance of a PIN diode can be varied from 1Ω to about 10kΩ. This unique property of the PIN diode makes it extremely useful as a switch, attenuator, modulator, phase shifter, limiter, or AGC element at all frequencies from 1 MHz to 18 GHz and above. Several package configurations are available.

IMPATT Diodes: IMPATT diodes are a fundamental source of RF power at frequencies above 4 GHz. CW devices can supply 3.5W at 6 GHz with 10 percent efficiency, while pulse-optimized devices operating at 10 GHz offer 14W at 800 ns pulse width and 25 percent duty cycle.

Step Recovery Diodes: SRDs are intended for use as comb generators and harmonic frequency multipliers. When used as a comb generator, the abrupt termination of the diode's reverse recovery current generates voltage pulses up to tens of volts with pulse widths as narrow as 100 ps giving useful power at frequencies in excess of 20 GHz. By optimizing the circuit around any specific harmonic, high efficiency multiplication can be accomplished.

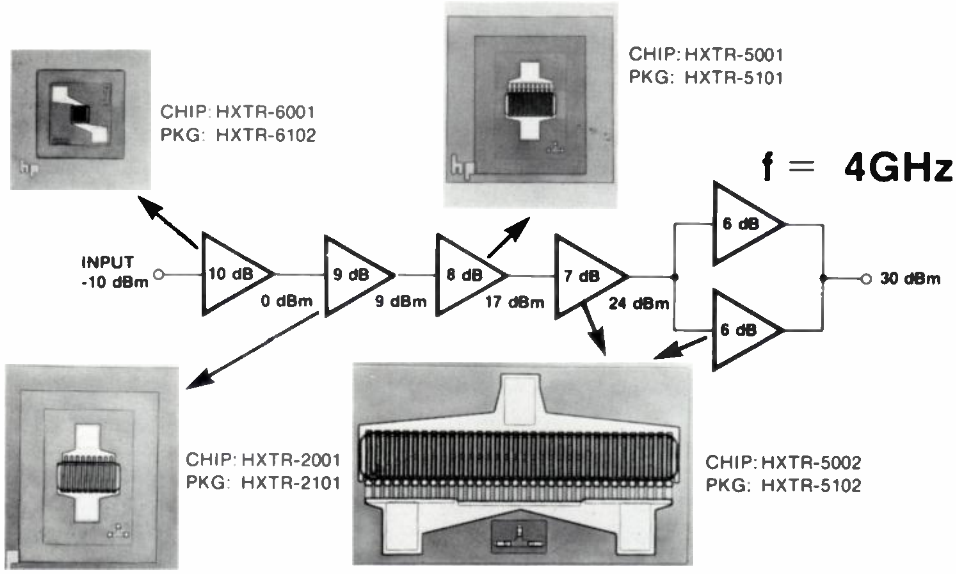
Integrated Products

Hewlett-Packard manufactures a broad line of integrated components for the control, conversion, and generation of RF and microwave signals. This line of products (combination of chip and beam lead diodes with hybrid thin film circuit technology) includes SPST switches, absorption modulators, attenuators, limiters, comb generators, double balanced mixers, and mixer/detectors.

The HXMR-5001 is a double balanced mixer which provides excellent broadband performance and reliability. This rugged mixer has low conversion loss and high isolation across the full 2.0-12.4 GHz RF/LO band, while retaining a wideband IF of 0.01-1.0 GHz. For the HF-UHF range, both double balanced and low cost single balanced mixers are available.

Recently, HP has developed a line of X-band, narrow band GaAs field effect transistor amplifiers. These low noise, frontend amplifiers have excellent state-of-the-art performance. These units, which offer greater reliability and lower costs, compared to devices such as paramps, utilize HP's half micron and one micron GaAs FETS.

HEWLETT-PACKARD BIPOLAR TRANSISTORS
4 GHz AMPLIFIER CHAIN



High Reliability Testing

Hewlett-Packard's high reliability test group maintains military approved JAN and JANTX parts in stock, and can recommend HP standard screening programs, patterned after MIL-S-19500, for any HP component. The reliability of these devices is established by an extensive high reliability testing facility. Those who wish to design their own screening specifications can consult with and obtain quotations from Hewlett-Packard's staff of Hi Rel test engineers.

Available From California Eastern Laboratories

California Eastern Laboratories handles the NEC line of microwave transistors.

The Nippon Electric Co., Ltd. (NEC) is well known for its high quality, low noise, small signal transistors. NEC manufactures over 500 different bipolar transistors of which there are over 30 different microwave (f_T>1 GHz) transistor chips. They are available in over 50 different package styles from low cost TO-92 and Micro-X ceramic stripline to hi-rel multi-chip modules. Though not as well-known, NEC also offers a wide range of RF, VHF-UHF and microwave power transistors. In the VHF-UHF line alone, there are over 40 different transistors for applications from 175 MHz to 900 MHz. Several are available for 7V, 12V and 28V applications.

The NEC VHF-UHF power transistor line includes a rich assortment of models specifically designed for the large volume mobile radio market.

They utilize a new passivated interdigitated structure employing Arsenic-doped-polysilicon (As DOPAS) which provides high power with exceptional reliability. The new structure virtually eliminates emitter to base shorts and electromigration; two areas that constantly plague conventional devices.

Figures 1 through 4 show some typical circuits.

While the procedures to be followed when actually designing amplifiers are commonly known, there are several points that require particular attention. When designing an amplifier, one must consider size, price and workability, and therefore, it is sometimes difficult to put into practice all of the following precautions. However, these precautions should be considered whenever possible.

(1) Preventing transistor breakdown load fluctuations.
(a) A smaller inductance should be used in the output choke coil and ferrite beads should be used on the power source side of the coil. The number of choke coil windings is about 1 or 2.
(b) The series inductance in the output matching circuit should be as small as possible.
(c) Heat radiation is very important and should be as high as possible.
(d) The circuit constants should be set at values where the transistor will have a good collector efficiency.

(2) Improving stability.
(a) In the choke coil on the input side, the resistance is used in parallel or series with the choke to lower the Q. When a series resistance is used, care should be taken in regard to the inverse bias between emitter and base during signal input. It is even more effective if ferrite beads are put on the grounded side of the coil.
(b) When the choke on the input side is composed of a strip line, the electrical length of the line

should be made shorter than λg/4 (a length of about λg/8 is better.)

(c) Two stage matching circuits are recommended between transistor stages. (Figure 1.)

(d) When using a concentrated constant circuit, if possible, use the upper surface of the printed board for the circuit pattern and remove all copper from the rear surface. If it is necessary to use the rear surface of the printed board, the opposite side of the "island" should be removed. For example, if the island is on the bottom surface, the ground on the upper surface should be removed and the length of the island shortened as much as possible. In cases where problems occur, such as a decrease in gain resulting from oscillation and mismatching, a theoretical solution would be difficult if the island itself is considered an inductance because of its length, or if the ground is on the opposite surface and the island is considered a strip line or a capacitance.

(e) In Class C amplification, the transistor might not come on to a sufficient degree if the input power is too small. When this phenomenon occurs, the output level will become unstable with respect to fluctuations of the input level. There will be sudden changes in the output level, disturbances of the band properties, and abnormal oscillations. In such cases, the transistor bias must be changed from Class C to Class B or Class AB. If, for example, the NE020214-7 or NE020214-12 are to be used with a 10 mW input, the bias should be changed to Class B.

(3) Preventing deterioration of h_{FE} caused by inverse bias between emitter and base.

(a) If a V_{EB} voltage is applied repeatedly near or above BV_{EBO}, even for an instant, this might cause deterioration of the h_{FE} of the transistor during prolonged use, resulting in a decrease in gain. The troublesome thing about this phenomenon is that it is difficult to discover until after some time has elapsed. The phenomenon and its prevention are described in detail in NEC's Technical Materials TEA-511. Vehicle-mounted radios are required to have stability during fluctuations of the load and the power source. For this reason, a resistance is sometimes used in series with the choke on the input side, as described above, to improve stability Figure 2.

Since this series resistance will bias the transistor for Class C operation, it will be easier for an inverse bias to occur between the emitter and the base. Therefore, it is safer to make a check of I_B as shown in Figure 3.

If the transistor is biased for Class B, and the breeder resistance is increased, input-output characteristics such as those shown in Figure 4 will result. These characteristics are sometimes used as a sort of level control, but these input-output characteristics are produced because the transistor will be biased for Class C as the input level increases. In other words, there is an ever greater possibility of an inverse bias between the emitter and the base. In this case too, it is necessary to check the I_B to make sure that there is no inverse bias generated between the emitter and the base.

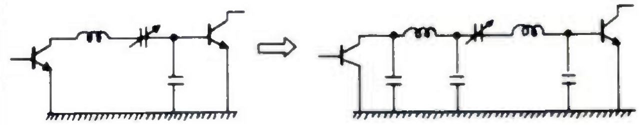


Figure 1. Matching circuit between transistor stages.

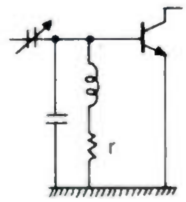


Figure 2. Q-damping of the RFC on the input side is performed for reasons of stability.

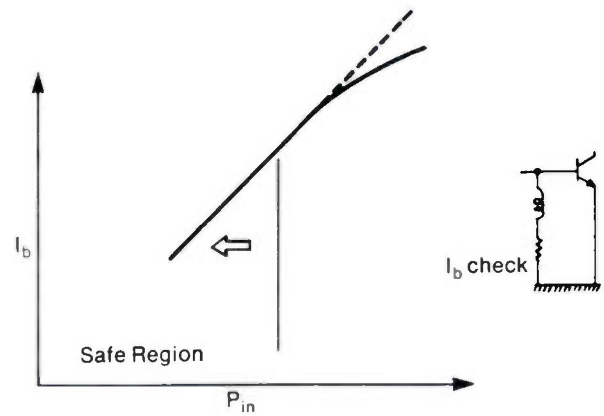


Figure 3. Checking the I_b.

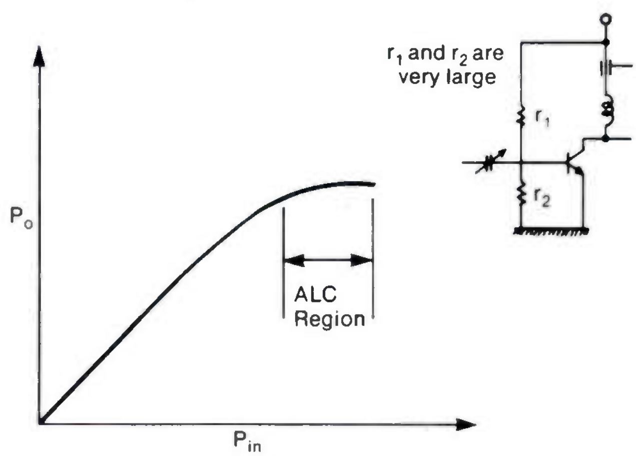


Figure 4.

Available From Avantek

Avantek, Inc., manufactures a wide range of proprietary, high-performance VHF/UHF and microwave small signal and microwave medium power silicon bipolar transistors as well as GaAs FETs for ultra-low noise figure operation. Many of these types are specifically optimized for applications such as satellite earth terminal LNA's and other communications equipment.

Most of the transistors that Avantek offers are the same types used in the Avantek product line which extends from HF through 26 GHz and includes wideband and communications/radar amplifiers, YIG and varactor-tuned oscillators, special purpose amplifiers and assemblies, and transistor packaged cascadable modular amplifiers and accessories.

All Avantek transistors feature gold and refractory metal systems (including all metallization in the GaAs FETs), that assures an extremely thick and uniform conductor for performance and reliability. Every packaged transistor is shipped in a hermetic metal/ceramic package and 100 percent tested for leakage, RF and DC performance before shipment. All types can be qualified under the "R" series high reliability program and many types have been space qualified.

Table 1 lists the Avantek transistor product line.

Table 1. Gallium Arsenide MESFET Typical Specifications @ 25°C

Low Noise, Small Signal

Package	Type	f_{Test} GHz	NF_{opt}[1] dB (max)	G_{NF}[1] dB (typ)	V_{DS} Volts	I_{DS}[1] mA	G_m[7] mmho (typ)	V_p[8] volts (typ)
alumina	AT-8050	4.0	2.0	11	3	15	30	−3
alumina	AT-8110	4.0	1.5	12	3	20	65	−2
stripline	AT-8060	12.0	3.5	8	3	—	30	−2

Silicon Planar, NPN Epitaxial
Guaranteed Specifications @ 25°C (Common Emitter, V_{CB} = 10V)

Low Noise, Small Signal

Package	Type	f_{Test} GHz	NF_{opt}[1] dB (max)	G_{NF}[1] dB (typ)	I_C[1] mA	G_{max}[2] dB (typ)	I_C2 mA	f_T GHz
0.070 in. sq. alumina stripline	AT-4680[3]	4.0	2.8	8.8	3	12	6	8.5
	AT-4690[3]	4.0	3.0	9.5	5	13	15	8.5
	AT4641[3]	4.0	3.5	8.0	5	9.5	15	8.0
	AT-4642[3]	4.0	4.0	7.0	5	9.5	15	8.0
	AT-2645A	2.0	3.0	11	5	15	15	5.5
	AT-2645	2.0	3.5	11	5	15	15	5.5
0.100 in. sq. alumina stripline	AT-4880[3]	4.0	2.8	8.8	3	12	6	8.5
	AT-4890[3]	4.0	3.0	9.5	5	13	15	8.5
	AT-4841[3]	4.0	3.5	7.5	5	9.5	15	8.0
	AT-4842[3]	4.0	4.0	7.0	5	9.5	15	8.0
	AT-1845A	1.0	2.2	14	5	—	—	5.5
	AT-1845	1.0	2.5	14	5	—	—	5.5
	AT-1825	1.0	3.0	13	5	16	15	5.0
TO-72	AT-0045	0.5	1.5	—	3	17	10	3.5
	AT-0025A	0.5	2.0	—	3	17	10	3.5
	AT-0025	0.5	2.5	—	3	17	10	3.5
High Dynamic Range – VHF, TO-72	AT-0017A	60 MHz	1.2	25	5	—	—	3.5
	AT-0017	60 MHz	1.5	25	5	—	—	3.5

Intermediate Power

Package	Type	f_{Test} GHz	G_{max} dB (typ)	P_o dBm (typ)	I_C2 mA	$I_C$max mA	P_T5 mW (max)	f_T GHz (typ)
alumina stripline	AT-3850	3.0	10	+20	35	100	700	4.5
beryllia stripline	AT-2715	2.0	10	+20	40	200	1000	3.5
	AT-7510	4.0	12	+2	110	150	2250	

Note 1: Bias and tuning optimized for noise figure; G_{NF} is gain at optimum noise figure tuning.
Note 2: Bias and tuning optimized for small-signal power gain; G_{max} is conjugate-matched gain.
Note 3: Arsenic emitter device, others are phosphorous emitter.
Note 4: Typical
Note 5: Continuous dissipation, T_a = 25°C.
Note 6: Power output at 1 dB gain compression.
Note 7: Measured at V_{DS} = 3V, V_{GS} = 0V.
Note 8: Pinchoff Voltage at V_{DS} = 3V, I_{DS} = 1 mA.

Available From Siliconix

RF Power VMOS Series with Low Baseband Noise Output

By introducing three new VMOS power FETs, Siliconix makes available the first in a series of devices providing excellent performance at an unusually low price. Operating in the 2 to 200 MHz region, the devices are well suited for broadband RF linear amplifiers. The reason is that baseband noise output is approximately 10 to 15 dB lower than comparable bipolar devices. Each of the new Siliconix RF power FETs delivers high power at a low drain voltage. For example, Siliconix claim that the DV1007 device delivers a true 50 watts output at 28 volts. This is more power than can be provided by any competitive RF VMOS power FET at this supply voltage.

VMOS devices are simpler to configure in RF power circuits than comparable bipolar devices. Because feedback capacitance is approximately half that exhibited by competing devices they are more readily broadbanded. In a typical circuit when the output is coupled to a resistive load, the input impedance remains real and does not become negative, so that operation remains stable.

There is no need for tracking diodes, low-impedance reference sources, separate bias networks or regulators. In fact, when a VMOS power FET is operated in forward bias — Class A or B — it requires only a simple voltage source in series with an isolation resistor. An inherent characteristic of a VMOS device is that the positive thermal resistance tends to shut the device down rather than develop thermal runaway — as in the case with bipolars. VMOS is also more rugged and is more forgiving of changes in VSWR during operation.

When RF VMOS power FETs are operated in parallel, they track better than dipolar devices in regard to both temperature and power. Moreover, in multiple signal applications the higher order intermodulation distortion products are naturally suppressed. VMOS devices are also more predictable in regard to nonlinearity than bipolars.

Siliconix's low prices are due, in part, to the high power density per square mil that has been achieved in this series. The result is higher yield enabling Siliconix to pass along the attendant savings to its customers.

Devices DV1006, DV1007 and DV1008 rated at 25, 50 and 100 watts narrowband output power, respectively. They are priced at $19.95, $35.91 and $71.82 in 100 lot quantities. Developmental quantities are available from stock. □

Microwave Transmission Line Filters

The new text features the most up to date information on microwave filters, including recent advances in exact filter design methods. Dr. Malherbe begins with first principles of filter theory and progresses to treat transverse electromagnetic theory so completely that a reader with a little previous experience will be able to apply these methods to problems outside the scope of this book. Butterworth, Chebyschev, elliptic function bandstop and bandpass filters are discussed in four separate chapters and are applied in turn to numerous design examples. Non-redundant filters synthesis is considered next, while the final two chapters treat the design of multiplexers and linear phase filters. Two valuable appendices deal with computer analyses of filter design and a summary of the design formulas covered in the text. Intended to serve as both textbook and reference manual for the student and practicing engineer, this original treatise contains over 170 figures and tables with detailed references and index.

Available from Artech House, 610 Washington St., Dedham, Mass. 02026, (617) 326-8220. INFO/CARD #95.

Low-Distortion 1.6 to 30 MHz SSB Driver Designs

A general discussion for broadband drivers and their requirements for linear operation. Design examples are given using Motorola plastic transistors and high-gain hybrid modules designed for operation in the 1.0 to 250 MHz range. The amplifiers range in power gain from 25 to 55 dB and are capable of driving power amplifiers to levels up to several hundred watts. AN-779. Contact Motorola Semiconductor Products Inc., 5005 East McDowell Rd., Phoenix, Ariz. 85008. INFO/CARD #42.

Microstrip Lines and Slotlines

A firm grasp of the theory and techniques of microstrip and slotline design allows for increased flexibility in circuit design and improved performance. This comprehensive treatment of the transmission lines used in microwave integrated circuits presents an authoritative and thorough update on the design of microstrip lines, coplanar waveguides and strips, and various coupled lines. Among the techniques explored are quasi-static and fullwave analysis, design considerations, and measurement procedures. This one convenient volume provides the microwave engineer with all the information necessary to maximize circuit design. Graduate students, research workers, and design engineers will find the 225 line drawings and tables especially useful. References and index complete the presentation.

Available from Artech House, 610 Washington St., Dedham, Mass. 02026, (617) 326-8220. INFO/CARD #94.

A 1-Watt, 2.3 GHz Amplifier

Simplicity and repeatability are featured in this 1-watt S-band amplifier design. The design uses an MRF2001 transistor as a common base, Class C amplifier. The amplifier delivers 1-watt output with 8 dB minimum gain at 24V, and is tunable from 2.25 to 2.35 GHz. Applications include microwave communications equipment and other systems requiring medium power, narrow band amplification. A photograph of the amplifier is shown in Figure 1. EB-89. Contact Motorola Semiconductor Products Inc., 5005 East McDowell Road, Phoenix, Ariz. 85008. INFO/CARD #41.

Microwave Prescaler Design

Over the past few years manufacturers of integrated circuits have extended the range of their ECL asynchronous divider counters to operate through the 1000 MHz range. As a result many instrument and modern manufacturers have used these IC's as prescalers to extend the range of their counters.

The purpose of this application note is to present a standard line of thick-film broadband amplifiers to interface with the respective ECL chips to form the basis of a prescaler. Measured performance utilizing Fairchild and Plessey ECL chip is presented mounting instructions for optimum performance is also shown pictorially. Contact Optimax Division of Alpha Industries, Inc., P.O. Box 105, Advance Lane, Colmar, Pa. 18915. (215) 822-1311. INFO/CARD #105.

Semiconductor Census

Just published, D.A.T.A., Inc.'s "1979 Worldwide Census of Semiconductors" measures the growth of semiconductors over the past six years by tracing the number of different commercially available types manufactured during the period. Single copies are available free to electronic engineers and managers from D.A.T.A., Inc., P.O. Box 602-PR, Pine Brook, N.J. 07058. INFO/CARD #104.

Logotype Booklet

To help engineers quickly and accurately translate product identifiers stamped on semiconductors into the device manufacturers' full name, D.A.T.A., Inc. — publishers of D.A.T.A. Books — is making a twelve-page logotype booklet available... free upon request. To claim your copy, either write to D.A.T.A., Inc., P.O. Box 602-PR, Pine Brook, N.J. 07058. INFO/CARD #103.

HP Enhanced Basic

For engineers and scientists with tough problems to solve, a language that's conversational and easy to use, yet powerful and fast is a must.

A new brochure describes 'HP Enhanced BASIC' used on Hewlett-Packard desktop computers for scientific/engineering problem solving, plus data acquisition and instrument-control applications.

HP Enhanced BASIC includes the powerful features associated with FORTRAN and APL, in addition to all the standard ANSI BASIC statements. While at the same time being easy to use, HP Enhanced BASIC offers over 200 functions and statements, more than four times what ANSI BASIC offers. Contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo, California 94304. INFO/CARD #102.

Control Signaling System

The design of the control signaling system for future all-digit communication systems is discussed in a report issued by the National Telecommunications and Information Administration (NTIA). The report, "Control Signaling in a Military Switching Environment," NTIA Report 79-13, reviews the more important advanced signaling concepts available today. It reviews networks in general and the military switching environment, in particular. Network control functions are defined and the ways and means for performing these functions are described. It is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. The accession number is PB 292-377/AS. The price is $9.25.

For further information, contact Russell B. Stoner, (303) 499-1000. INFO/CARD #97.

Microwave Component And Measurement Handbook

This 1979-80 edition of Hewlett-Packard's Coaxial and Waveguide Catalog is available with product information on more than 350 microwave components used in coaxial and waveguide measurements. Product sections include attenuators, detectors, couplers, filters, power sensors, slotted lines and a good selection of 75 ohm items.

Over 25 pages of this 96-page catalog are devoted to a Microwave Measurement Handbook section summarizing common scalar measurement techniques of attenuation, SWR, power, frequency and noise figure.

Hewlett-Packard's Coaxial and Waveguide Catalog, Publication #5952-8207 is available free of charge. Contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, California 94304. INFO/CARD #100.

Newsletter Subscription

Free subscriptions are now being offered to a quarterly publication, the Grayhill Engineer, that provides brief insights into recent developments or established technologies in the electronics industry. Although published by a manufacturer of switches and solid state relays, the far-ranging editorial in the newsletter goes far beyond the company's own products. Topics recently discussed in the Grayhill Engineer have included video displays, keyboard decoding, magnetic bubble memories, software contact conditioning, analog to digital converters, and digital to analog converters. Articles are written in a clear, concise manner and require less than five minutes of reading time. For your subscription to the Grayhill Engineer, contact Tom Menzenberger, Grayhill, Inc., 561 Hillgrove Avenue, La Grange, Ill. 60525, (312) 354-1040. INFO/CARD #99.

EMI Data Guide

A "Data Guide," available from Tecknit, is intended to serve as an initial aid and handy reference guide in the selection of Tecknit products for EMI shielding, grounding, and static discharge applications. The seven groups of materials which comprise Tecknit's product line are described.

Inside is a convenient wall chart which matches a broad range of material characteristics with Tecknit products and lists the applicable data sheets. Also included are charts showing the shielding properties of various metals and how to avoid four common errors in gasket design.

The Data Guide is available free from Tecknit, EMI Shielding Products Divison. Contact Tecknit EMI Shielding Products Division, 320 North Nopal Street, Santa Barbara, Calif. 93103, (805) 963-5811. INFO/CARD #101.

Propagation Path Loss

Radio propagation path loss and local ground conductivity measurements which could be used to determine the suitability of propagation prediction programs are reported in a publication by the National Telecommunications and Information Administration (NTIA), "Measurements of LF and MF Radio Propagation over Irregular, Inhomogeneous Terrain, NTIA Report 78-12.

The report, which should be of value to system designers and engineers, is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. The accession number is PB 291-732/AS. The price is $9.00 a copy. For further information, contact Russell B. Stoner, (303) 499-1000. INFO/CARD #96.

Advances in Solid State Physics

Heyden & Son is pleased to announce the publication of Advances in Solid State Physics Volume XIX, edited by J. Treusch.

Papers included in this volume deal with: the theory of crystal growth; electronic and excitonic properties of semiconductors relating to their bonding properties and optical spectra; photoemission and LEED is relation to surface defects and spin polarization; deep center research, electronic structure and photoconductivity; hopping conduction; nonequilibrium superconductivity; picosecond spectroscopy; tunable lasers; and new means for effectively using solar energy.

420 pages — $50.00 (published by Friedrich Vieweg & Sohn, Wiesbaden, Germany) is available exclusively in North America from Heyden & Son, Inc., 247 South 41st Street, Philadelphia, Pa. 19104, (215) 382-6673. INFO/CARD #98.

Microwave Signals Control

A new catalog of Hewlett-Packard's components for the control, conversion, generation and amplification of RF and microwave signals is now available without charge from the company.

Intended for use by designers of instruments and systems for communications, measurement, EW and radar, the new publication describes in detail some 70 products. These products include switches, attenuators, comb generators, limiters and detectors.

The publication number of the 74-page catalog is 5952-9871. Contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, California 94304. INFO/CARD #61.

Short-Form Product Guide

Intersil, Inc. has published a new 24-page condensed product guide which describes the company's analog, linear, digital and microprocessor integrated circuit line.

Devices in the new catalog are fabricated with CMOS/LSI, MOS/LSI, and bipolar LSI; also included are a new line of VMOS power FETS, numerous discrete devices, and a line of add-in and add-on memory microsystems. Applications include data processing and industrial process control, portable and fixed instrumentation, data acquisition and conversion, and RF and telecommunications. Contact Intersil, Inc., 10710 North Tantau Ave., Cupertino, Calif. 95014. Phone (408) 996-5000 TWX 910-338-0228. Circle INFO/CARD #70.

Module Short Form Catalog

A new short form catalog has been released by E-H International, Inc., to provide engineers a quick reference guide to E-H's broad line of modules, coax switches, and micro matrix switches.

The modules consist of 13 different types with a frequency range from DC to 200 MHz. Single and dual models are available as well as tri-state versions and outputs up to 60 volts peak-to-peak amplitude. Contact E-H International, Inc., 515 Eleventh Street, P.O. Box 1289, Oakland, Calif. 94607. INFO/CARD #85. □

Design of VHF Quadrature Hybrids — Part I

By Chen Y. Ho and Bob Furlow
Motorola, Inc. — Government Electronics Division

The analysis and design of narrow band and broadband quadrature hybrids, which are particularly useful over VHF (3-300 MHz), will be carried out in this two part article. The first part will discuss the design of a narrow band hybrid. The second part will discuss the cascading of two hybrids via two transmission lines to effect a broadband quadrature hybrid.

Since quadrature hybrids are symmetrical, even-mode, and odd-mode ABCD matrices can be written. An analysis of these matrices gives the scattering parameters for the four port device. Constraining the scattering parameters to desired values, then leads to a set of simple design equations for a narrow band quadrature hybrid. Experimental results are in excellent agreement with the theoretical predictions.

Part II of this article will treat the cascading of two hybrids via two transmission lines of appropriate length. An analysis parallel to that of the narrow band hybrid is used to generate the broadband quadrature hybrid scattering matrix. And as in the narrow band case, the appropriate design equations will be developed from constraints placed on this matrix. A Fortran Program for the solution of these design equations will be included in Part II, as well as the experimental data from an actual broadband hybrid.

Narrow Band Quadrature Hybrid

The configuration of the narrow band quadrature hybrid is shown in Figure 1, consisting of two lumped capacitors and a toroid on which two strands of insulated wires tightly twisted together to form a bifilar pair. The self-inductance of the transformer toroid is L and the mutual-inductance is also equal to L. (This is under the assumption of unity magnetic coupling between the inductors.)

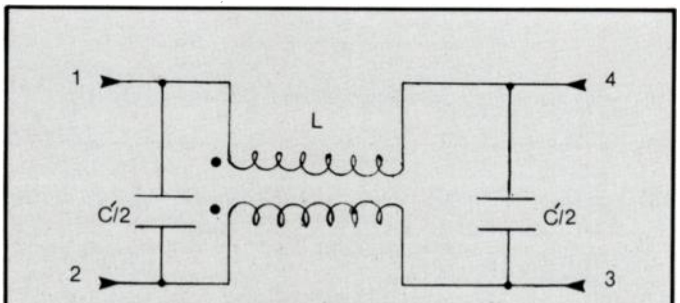


Figure 1. Configuration of a Narrow Band Hybrid.

The analysis of this quadrature follows the even-mode and odd-mode approach of analysis for symmetrical networks[1]. For even-mode excitation, unity voltages are applied at port 1 and port 2 while ports 3 and 4 are terminated with its characteristics impedance, Z_0 in this case. Due to the symmetry of the hybrid, the circuit of Figure 1 can be simplified to the circuit shown in Figure 2. The inductance becomes 2L since the magnetic flux will double for the same polarity excitations. The ABCD matrix for the even mode excitation becomes:

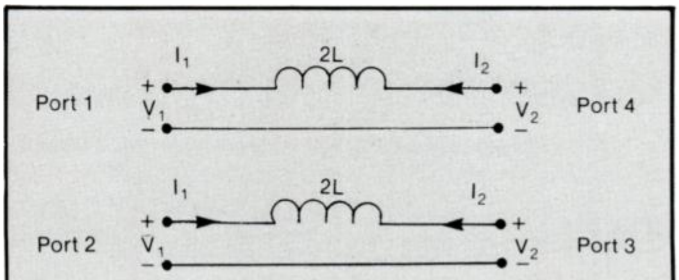


Figure 2. Even-Mode Circuit of the Hybrid.

$$M_+ = \begin{vmatrix} 1 & j2\omega L \\ 0 & 1 \end{vmatrix}, \begin{Bmatrix} V_1 = AV_2 + B(-I_2) \\ I_1 = CV_2 + D(-I_2) \end{Bmatrix} \quad (1)$$

For odd-mode excitation, unity voltages of opposite phase are applied at ports 1 and 2 while ports 3 and 4 are terminated with Z_0. The odd-mode circuit of the hybrid shown in Figure 3 consists of only capacitor 2C. This is due to the fact that the magnetic flux inside the ferrite toroid cancel each other for the odd-mode excitation and the total capacitance is the sum of two capacitors which are half of the capacitance C. The ABCD matrix for the odd-mode excitation is:

$$M_- = \begin{vmatrix} 1 & 0 \\ j\omega 2C' & 1 \end{vmatrix} \quad (2)$$

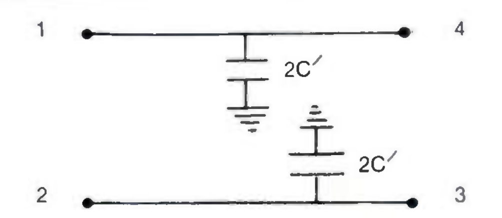


Figure 3. Odd-Mode Circuit of the Hybrid.

In general, the reflection coefficient is defined as $\Gamma = (Z_L - Z_0)/(Z_L + Z_0)$, where $(V_1/I_1) = Z_L$, and $(V_2/-I_2) = Z_0$ (ports 4 and 3 are terminated in Z_0). Substituting for Z_L and then for $(V_2/-I_2)$ the reflection coefficient can be expressed in terms of the ABCD coefficients as:

$$\Gamma = \frac{AZ_o + B - Z_o(CZ_o + D)}{AZ_o + B + Z_o(CZ_o + D)} \quad (2.5)$$

The even-mode coefficient, expressed in terms of elements of ABCD matrix for even-mode excitation becomes:

$$\Gamma_+ = \frac{j\omega L}{Z_o + j\omega L} \quad (3)$$

and the odd-mode reflection coefficient, expressed in terms of the elements of ABCD matrix for odd-mode excitation becomes:

$$\Gamma_- = \frac{-j\omega CZ_o}{1 + j\omega CZ_o} \quad (4)$$

The reflection coefficient at port 1, Γ_T is equal to:

$$\Gamma_T = (\Gamma_+ + \Gamma_-)/2 = S_{11} \quad (5)$$

and the transmission from port 1 into port 2 is equal to:

$$T_{21} = (\Gamma_+ - \Gamma_-)/2 = S_{21} \quad (6)$$

The conditions for a perfect match is obtained by setting Γ_T to zero, which leads to:

$$Z_o^2 = L/C' \quad (7)$$

which is independent of frequency. And equation (6), after substituting (7) yields;

$$T_{21} = \frac{j\omega L}{Z_o + j\omega L} = c \quad (8)$$

The transmission coefficient, T, on the other hand, is defined as the output voltage divided by the incident voltage. In our example the incident voltage a_1 plus the reflected voltage, b_1, equals V_1, and the transmitted voltage is V_2. So. . . $T = V_2/a_1$ where $(a_1 + b_1) = V_1$ and $b_1 = \Gamma$. Hence

$$T = \frac{V_2(1 + \Gamma)}{V_1}$$ which can be

expressed in terms of the ABCD coefficients by recalling equations (2.5), and making use again of $(V_2/-I_2) = Z_o$

$$T = \frac{2Z_o}{AZ_o + B + Z_o(CZ_o + D)} \quad (8.5)$$

The even-mode transmission coefficient T+, expressed in terms of elements of ABCD matrix for even-mode excitation becomes:

$$T+ = \frac{Z_o}{Z_o + j\omega L} \quad (9)$$

and the odd-mode transmission coefficient T−, expressed in terms of elements of ABCD matrix for odd-mode excitation becomes:

$$T- = \frac{2Z_o}{2Z_o + j2\omega Z_o^2 C} = \frac{Z_o}{Z_o + j\omega L} = T+ \quad (10)$$

The transmission from port 1 to port 3 is equal to:

$$T_{31} = (T_+ - T_-)/2 = 0 = S_{31}$$

and the transmission from port 1 to port 4 is equal to:

$$T_{41} = (T_+ + T_-)/2 = Z_o/(Z_o + j\omega L) = S_{41} = t \quad (12)$$

The condition (7) yields both perfect match and perfect isolation for the hybrid.

Because of the symmetry of the hybrid we are now in a position to write its scattering parameter matrix. This matrix will be of use to us when we develop the design equations for the broadband quadrature hybrid in the next article. The matrix is

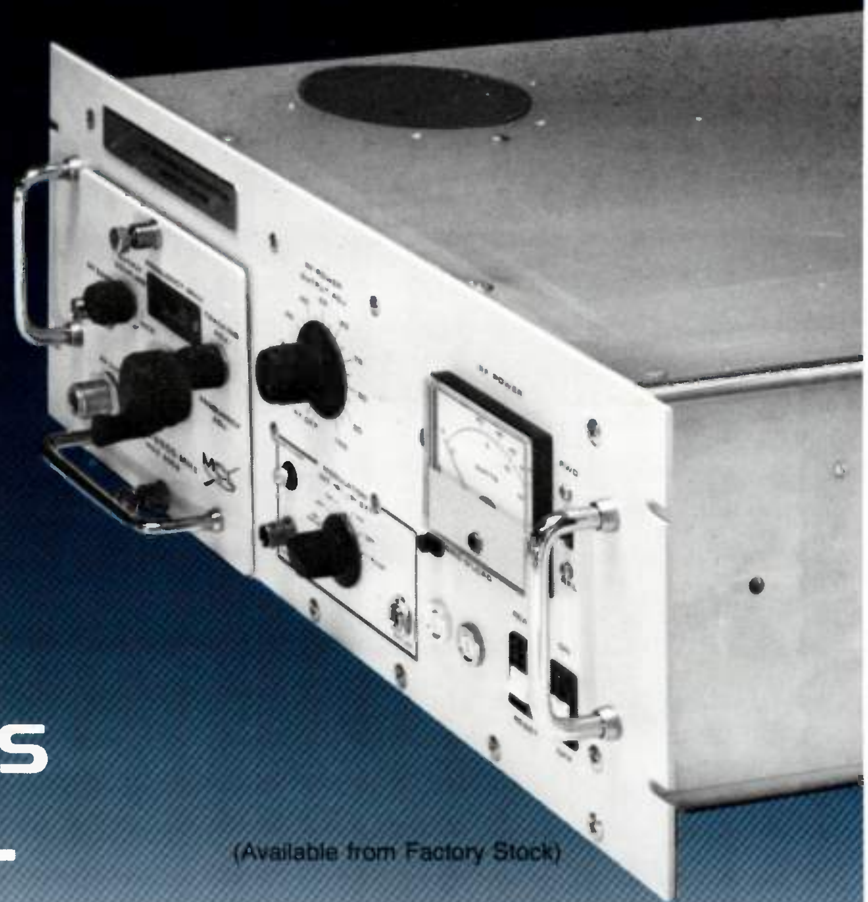
$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{vmatrix} O & c & O & t \\ c & O & t & O \\ O & t & O & c \\ t & O & c & O \end{vmatrix} \begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{vmatrix}$$

where $c = j\omega L/(Z_o + j\omega L)$ and $t = Z_o/(Z_o + j\omega L)$.

The final design parameter to be considered is the output power ratio between port 2 and port 4 for power input at port 1. Let k be defined as:

$$k = \frac{\text{Output Power @ port 2}}{\text{Output Power @ Port 4}} = \frac{(S_{21})^2}{(S_{41})^2}$$

Reliable RF Power Generators From MCL



(Available from Factory Stock)

MCL, a known name in superior microwave electronic components, offers two RF Power Generator models; the 65 W Model 15122 and the 100 W Model 15222. Solid-state main-frame assemblies and panel indicators provide the ultimate in stability and reliability — holding residual AM to 0.1 percent while nearly eliminating AM distortion in the output waveform. A transistor series-pass type anode regulator assures stable oscillator voltage.

MCL 15122 & 15222

Reliability	Meets MIL-STD 461 & MIL-STD 810	✓
Selection	12 Models to choose from	✓
Power	35 W to 100 W	✓
Frequency Range	10 MHz to 2,500 MHz	✓
Size	19" D x 7" H x 18" W	✓

Six different plug-in RF Heads are provided in frequency ranges from 10 MHz to 2,500 MHz. Models can be ordered in 115 VAC or 208/220/240 VAC line voltage types. MCL provides optional rack mounting configuration.

For more information, send for our brochure.

MCL INC
10 North Beach
La Grange, IL 60525
Phone: 312/354-4350

INFO/CARD 13

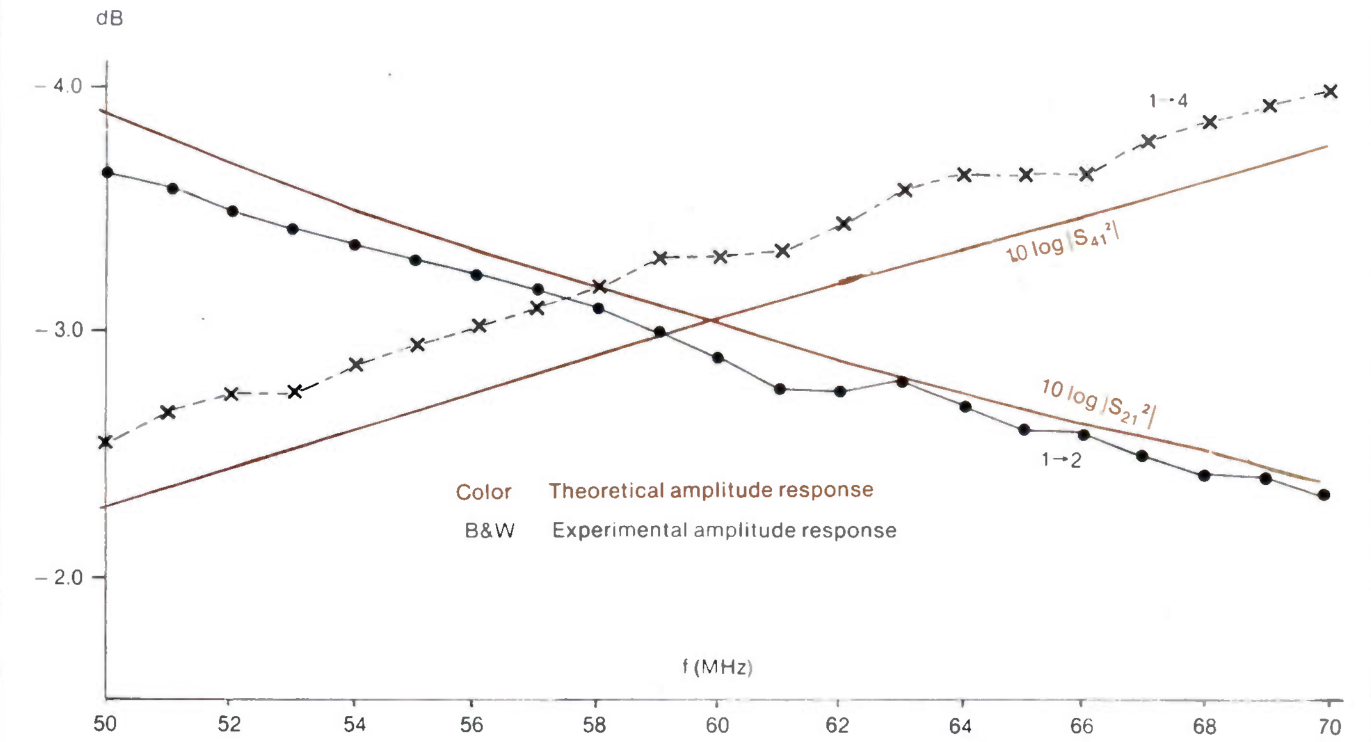


Figure 6. Measured and calculated performance of a 60 MHz quadrature hybrid.

Then by using (8) and (12), we have

$$k = (\omega L / Z_o)^2 \qquad (13)$$

Equations (7) and (13) are the design equations for the design parameters of narrow band quadrature hybrid, Z_o and k. The hybrid thus designed has a quadrature phase relation between output ports 2 and 4 as can be seen from equations (8) and (12). For the same power splitting ratio between output ports 2 and 4, we have $k = 1$ and $Z_o = 50$ ohm, (7) and (12) become

$$\omega L = Z_o, \text{ and } \omega L = 1/(\omega C) \text{ or } Z_o = 1/(\omega C) \qquad (14)$$

Knowing the frequency of operation, the inductance and the capacitance can be easily found from (14). Figure 4 illustrates the calculated amplitude responses as function of ω/ω_o. The 1 dB amplitude imbalance bandwidth is about 20 percent.

Experimental Results of A Narrow Band Quadrature Hybrid

A narrow band quadrature hybrid is to be built centered at 60 MHz. For equal power splitting between output ports, and from (14), we have $L = 132.63$ nH and $C = 53.05$ pF. Capacitors with a value of

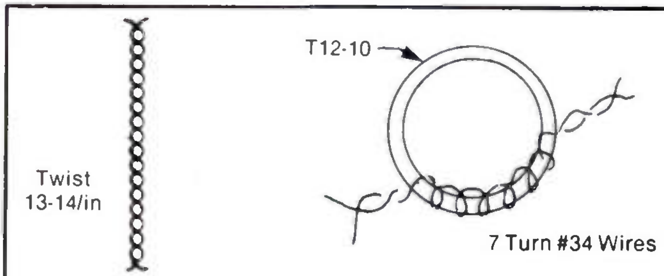


Figure 5. Twisted Wires for Inductors.

$C/2 \cong 27$ pF are used. Inductances are realized by using a T20-10 ferrite core with 7 turns of #36 gauge wire twisted at 13-14 twists/inch as is shown in Figure 5. The measured amplitude responses of the example narrow band quadrature hybrid are shown in Figure 4, which are very close to the theoretical computations also shown, except the frequency is about 4 percent lower than that designed. This may be attributed to the slightly different values of inductor and capacitors used. The measured return loss and isolation (T_{31}) are better than 23 dB over 50-70 MHz and the measured phase imbalance is 90° ± 3° over the same frequency range.

(1) J. Reed and G.J. Wheeler, "A Method of Analysis of Summetrical Four Port Networks IRE Trans. OnMTT Vol. 4 pp. 246-252, Oct. 1965.

Wescon

Technology *plus* Marketing *equals* Information Transfer

The equation tells it all about Wescon, the West's largest high-technology electronics exhibition and convention. Three days of person-to-person contact and hands-on demonstrations of new products and systems, together with examination of the leading-edge technology that will influence electronics in the decade of the 1980's.

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INFO/CARD 15

Power Amplifier Delivers 1000 Watts from 220 to 400 MHz

Amplifier Research, Souderton, Pa., has introduced a high-power amplifier that offers a higher frequency capability than its widely accepted Model 1000L. Whereas the Model 1000L delivers 1000 watts of RF power over the frequency range of 10 kHz to 220 MHz, the new Model 1000HA delivers the same power over the frequency range of 220 to 400 MHz. Moreover, present Model 1000L owners need to purchase only the plug-compatible RF units to obtain the added frequency capability of the Model 1000HA.

A self-contained amplifier, the Model 1000HA is designed for laboratory applications that require instantaneous bandwidth, high gain and high power output. A high-power internal load, specially designed protective circuitry and liquid-cooled tetrodes combine to provide a truly high-power broadband amplifier capable of driving any load impedance without damage, shutdown or reduction of power output. The amplifier will drive inductive or capacitive loads as well as poorly matched antennas.

Model 1000HA offers a minimum power gain of 60 dB over the frequency range of 220 to 400 MHz. Input and output impedances are 50 ohms nominal with a maximum input VSWR of 2.0 : 1. Harmonic distortion is not less than 18 dB below fundamental at 1000 watts output.

Linear operation is used in all stages of the amplifier to permit all types of modulation — AM, FM and pulse — to be reproduced. Low-level stages are solid state to improve reliability and reduce size. A valuable feature is the continuously variable attenuator, which enables the operator to adjust the amplifier gain over an 18-dB range to meet his specific requirements.

Typical applications include general laboratory instrumentation, antenna and component testing, biological research, RFI/EMI susceptibility testing, laser modulation, NMR spectroscopy and broadband communications.

Model 1000HA operates on 208/240 VAC, three phase, 50 Hz primary with 380/415 VAC, three phase, 50 Hz available as an option. The amplifier is available with either forced air or water cooling at no additional cost.

Model 1000HA measures only 22 x 60 x 23 in. and is priced at $35,000. Plug-compatible RF units only are priced at $25,000. Delivery is 120 days.

High Power Amplifier Delivers 2000 Watts From 10 kHz to 220 MHz

A new power amplifier, recently introduced by Amplifier Research, Souderton, Pa., offers 2000 watts of RF power — over the frequency range of 10 kHz to 220 MHz.

Model 2000L features three output modes — 100 watts, 500 watts and 2000 watts — with a top and power gain of 63 dB. Input and output impedances are 50 ohms nominal with a maximum input VSWR of 1.5 : 1.

The amplifier employs Class A operation in all stages to achieve linear operations. Consequently, all types of modulation can be reproduced — AM, FM and pulse. Solid state low-level stages improve reliability and reduce size. A continuusly variable attenuator enables the operator to adjust the amplifier gain over an 18 dB range to meet his specific requirements.

Model 2000L measures 22 x 60 x 23 in. and is priced at $38,000. Delivery is 90 days. Contact Dan Roth (215) 723-8181, 160 School House Road, Souderton, Pa. 18964. INFO/CARD #40.

Measure Capacitor C, R, and Q

The Boonton Model 34A Resonant Coaxial-Line, when coupled to a Model 102D Signal Generator and a Model 92B RF Millivoltmeter, provides an accurate high frequency system for measuring the effective series resistance (esr), effective capacitance, and Q-factor of both leaded and unleaded capacitors.

A resonant, coaxial transmission-line, short-circuited at one end and open-circuited at the other, whose fundamental resonant frequency and Q-factor are known, is perturbed with a test component connected either in series at the short-circuited end of the line, or in shunt at the open-circuited end of the line.

The addition of the component to the line alters the resonant frequency of the system, and the combined Q-factor of the test component and the line is measured using the Δf technique at the newly established resonant frequency. This Q-factor and the parameters of the resonant line, applied in the proper equation, will yield the esr and Q-factor of the test element, as well as the effective capacitance.

Attempts at measuring high Q-factors of capacitors at high frequencies with admittance or impedance bridge techniques have been generally unsuccessful, principally because of imperfect bridge components and the extreme resolution needed to separate the loss from the major parameter

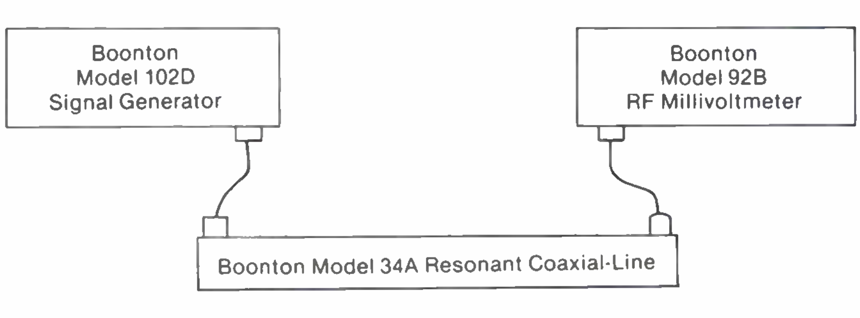

Figure 1.

when the Q-factor is several hundred, or more.

Q-meters have been used with some success to measure the loss of capacitors having modest Q-factors. For high Q-factors, the uncertainty of the indirect measurement is sufficiently great to make the effort questionable. In some instances the measured Q-factor may even be negative.

It has been suggested that S-parameters be used to determine the loss of capacitors at high frequencies. Unfortunately, the resolving power and accuracy of present state network analyzers are inadequate for this purpose, and calculations based upon swept measurements of S_{11} and S_{21} produce random positive and negative numbers which bear no relationship to the actual loss of the test capacitor. Contact Boonton Electronics Corporation, Rte. 287 at Smith Road Parsippany, N.J. 07054. INFO/CARD #39.

Instruments

Universal Counter/Timer

The Model 9648M Militarized Universal Counter/Timer from Ballantine Laboratories, Inc. is the company's latest in its series of Autometronic instruments and makes direct measurements of frequencies from 0.1 Hz to 550 MHz with no pre-scaling. It also has function modes for time intervals and periods from 100 nsec to 10^9 seconds, frequency ratios and totalizing. This automated universal counter/timer is unique in that it conforms to MIL-T-21200 Class II and MIL-T-28800 Type 1 Class II Style A. Contact Ballantine Laboratories, Inc., P.O. Box 97, Boonton, N.J. 07005. INFO/CARD #139.

Universal Counter

The Model RC-5, 5-digit multi-function universal counter is capable of performing any of five functions which include counting events, frequency, time interval, period and frequency ratio.

A 10 MHz crystal controlled time base provides accuracies better than 50 parts per million. Time base settings of .01, 0.1, 1.0 and 10 seconds can be internally selected by jumpering appropriate sockets. Frequency range is DC to greater than 1 MHz. Contact Non Linear Systems Inc., P.. Box N, Del Mar, Calif. 92014. (714) 755-1134/TWX910, 322-1132. Circle INFO/CARD #138.

E-H 1 GHz Waveform Analyzer

A new waveform analyzer for the ATE marketplace has recently been introduced by E-H International, designated the Model 1060. The 1060 is the latest technologically advanced waveform analyzer available.

The Model 1060 waveform analyzer is a dual-channel sampling unit of high accuracy, dynamic range, speed of measurement and convenience in programming.

The Autoscan™ feature allows the operator to automatically search for a signal by changing the sweep and delay values until a signal appears on the CRT. All changes in sweep or delay values are stored in memory and displayed on the CRT screen for the operator. Contact E-H International, Inc., 515 Eleventh Street, P.O. Box 1289, Oakland, Calif. 94607. Circle INFO/CARD #137.

Universal Counter

Eldorado Instruments announces the availability of two new microprocessor controlled microwave counters to its product line.

The Model 990 microwave frequency counter utilizes automatic heterodyning techniques, has a frequency response of 20 Hz to 18 GHz in two ranges, – 25 dBm sensitivity, and + 25 dBm overload specifications. The unit features completely automatic measurements under microprocessor control.

The Model 922 microwave universal counter provides all of the basic features and options of the Model 990 and the capability for time interval, period, width, and rise time measurements. Resolution for the time measurements is two picoseconds (with X 1000 multiplier) and two nanoseconds (one shot). A unique trigger level control provides 10 millivolt increments to ± 9.99 volts in a single range. Contact Eldorado Instruments Company, 2495 Estand Way, Pleasant Hill, Calif. 94523, (415) 682-2100. INFO/CARD #136.

Sweep/Function Generator

The Model 3020 sweep/function generator, which is now available from the B&K-Precision Product Group of Dynascan Corporation, is one of the most versatile signal sources ever offered by the company. The new instrument, designated the Model 3020, can actually replace a function generator, sweep generator, pulse generator and tone-burst generator. The instrument's wide frequency coverage spans from 0.02 Hz to 2 MHz in seven ranges. For additional information, contact B&K-Precision, Dynascan Corporation, 6460 W. Cortland Street, Chicago, Ill. 60635. (312) 889-9087. INFO/CARD #135.

Synthesized Signal Generator

Ailtech introduces its 380 Synthesized Signal Generator utilizing microprocessor control and keyboard entry of all functions.

The new Model 380 retains all the signal generator performance features of the 360, particularly the 20 μ sec switching speed attained through Ailtech's patented direct synthesis, and frequency ranges 10 kHz through 2000 MHz, with options to 4000 MHz. The new model features digital readout of all functions, spin wheel tuning, function incrementing, frequency sweeping and storage of up to ten complete front panel setups. Contact Ailtech, 2070 Fifth Avenue, Ronkonkoma, New York 11779. INFO/CARD #133.

Spectrum Analyzer

The "757" Spectrum Analyzer is a complete instrument with no modules to add and features: Internal Frequency and Amplitude Calibration, Digital Storage, CRT Display of Control Settings, Normalized Display, Uncal Warning Lght and LED Switch Indicators.

The "757" is the newest member of the Ailtech Spectrum analyzer family and is considerably smaller and lighter than earlier models. Designed for ease of operation, the "757" has all of the capabilities of the Ailtech 727 Analyzer: 10 dB On Screen Displays, Built-In Preselection, – 125 dBm/kHz Sensitivity, Highly Selective Filters and Automatic Features. Contact Ailtech, 2070 Fifth Avenue, Ronkonkoma, New York 11779. Circle INFO/CARD #132.

Microprocessor Controlled Pulsed Measurements DC to 26.5 GHz

With a new Automatic Frequency Converter plug-in for Hewlett-Packard's precision 5345A frequency counter, engineers and technicians can now measure pulsed frequencies as well as CW frequencies to 26.5 GHz with greater accuracies than previously possible. Called the Model 5355A, this new instrument not only measures the average frequency in the burst but also uses the time interval capability of the 5345A to measure pulse repetition frequency, pulse width, and pulse-to-pulse timing. Contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, Calif. 94304. INFO/CARD #134.

20 MHz Dual-trace Oscilloscope

A 5" dual-trace 20 MHz triggered-sweep oscilloscope has just been introduced by the B&K-Precision product group of Dynascan Corporation.

A feature offered on the 1520, and rarely found on scopes in this price range, is the x10 magnifier for expanding the displayed waveform, while maintaining relative time base calibration. By varying the horizontal position control, any portion of the displayed waveform may be isolated and expanded by a factor of ten. Contact your local B&K-Precision distributor; or B&K-Precision Sales Department, 6460 West Cortland Street, Chicago, Ill. 60635. Telephone: 312/889-9087. INFO/CARD #123.

Signal Generator

A synthesized signal generator covering the frequency range 10 to 520 MHz and designed mainly for servicing communications equipment — pocketphones, vehicle mobiles, paging systems has been developed by Farnell International.

Known as the SSG520 it offers low

r.f. leakage, thumbwheel frequency selection, simultaneous indication of attenuation in dBs or volts and a SINAD facility which simplifies sensitivity tests. Options include reverse power protection, programmability and IEEE 1B interfacing. Contact Farnell International Instruments Ltd., Wetherby, West Yorkshire LS22 4DH England TELEX 557294 FARIST G. INFO/CARD #121.

Subsystems & Packaging

Modular Primary Frequency Standard

The only modular cesium beam frequency and time standard available in the U.S. — The FTS 4000 is now offered with substantially improved electrical performance. This totally self-contained module directly benefits users of: Satcom and Telecommunications Systems and Precise Navigation Systems. Contact T.J. Parello, Director of Marketing at (617) 777-1255. Frequency and Time Systems, Inc., 182 Conant Street, Danvers, Massachusetts 01923, Telex 9-40518. Circle INFO/CARD #90.

RF Switches

Transco announces its new 92 page RF Switch Catalog. This document covers the entire product line including coaxial, transfer, multiposition, manual and waveguide types. Special sections are devoted to Space Qualified Hi-Rel units and waveguide type switches.

Detailed dimension information including technical specifications with charts, tables and photographs make this a valuable aid for engineering and support activities. Contact Ray E. Williams, 4241 Glencoe Avenue, Venice, California 90291, (213) 822-0800. TELEX 65-2448, TWX (910) 343-6469. Circle INFO/CARD #87.

Boxcar Averager System

EG&G Princeton Applied Research has just published a new and informative 24-page brochure complete with specifications and applications information for the model 162 Boxcar Averager System — the popular signal-to-noise enhancement system for numerous pulsed signal applications. Included are applications of the recently announced 2-ns model 165 sampling plug-in module, showing its novel use as an auto/cross correlation analyzer of noisy inputs and ultra-fast signals. Other applications treated include optical fiber testing, semiconductor testing (DLTS), Raman Spectroscopy and ultrasonics.

Copies of this brochure are available by writing to EG&G Princeton Applied Research, P.O. Box 2565, Princeton, N.J. 08540, (609) 452-2111. INFO/CARD #86.

OCXO

The XTO-02 Series of Oven Controlled Crystal Oscillators can be supplied over the 20 to 125 MHz frequency band. Stability is 0.1 ppm from −25 to +50°C and power output, +7 dBm minimum.

Comb Generator

The model CMB-103926 Comb Generator is designed to operate over the 20-200 MHz input frequency range. The output comb frequencies are at a nominal −30 dBm level, up to 1400 MHz. Input RF level is 0 dBm nominal. Required DC power is +15 volts at 100 mA.

Assembly

The XMI-12 Assembly houses twelve

individually controlled crystal oscillators in the 90 to 125 MHz frequency band. A common output amplifier provides load isolation. Power output is +7 dBm and stability plus/minus 10 ppm from −5 to +55°C. Contact Miteq Inc., 100 Ricefield Land, Hauppauge, New York 11787, (516) 543-8873. INFO/CARD #81.

Thin Film Amplifiers Cover 5-500 MHz

A new series of low noise and general purpose thin film amplifiers is being introduced by Anzac.

The AM-148 low noise amplifier provides 3.5 dB typical midband noise figure, 1.2 typical midband VSWR, and 14 dB gain, nominal. AM-149 and AM-150 general purpose amplifiers provide nominal gains of 15 dB and 11 dB respectively; both offer 30 dBm typical 3rd order intercept, approximately 16 dBm typical midband output power, and 5.0 dB midband noise figure. Contact Adams-Russell Anzac Division, Mark R. Rosenzweig, Marketing Manager, 39 Green St., Waltham, Mass. 02154. (617) 899-1900. INFO/CARD #79.

Detector Covers 10 MHz to 34 GHz

A detector from Wiltron is the first to cover the full 10 MHz to 34 GHz range in a single unit. Designed specifically for wide-band system applications, these low-cost units offer the OEM designer frequency coverage previously unavailable in coax systems. The detectors use a recently-developed Wiltron WSMA connector that has excellent SWR characteristics, improved life expectancy, and compatibility with conventional SMA connectors. They are ideal for applications requiring output voltage tracking over a wide dynamic range. The zero-bias Schottky diode modules used are field-replaceable. Contact Walt Baxter, Wiltron Company, 825 East Middlefield Road, Mountain View, Calif. 94043. TEL: (415) 969-6500. TWX: 910-379-6578. INFO/CARD #38.

Computer Compatible Microwave Synchronizer

The new MS200 Series Microwave Frequency Synchronizers offer full TTL compatible functional control and status monitoring. Several models are available to phase lock two signal sources together in a master-slave configuration where the slave exhibits the short and long-term stability of the master. Frequency coverage is 1 to 40 GHz for RF models with internal mixer, or 20 to 60 MHz for IF models without internal mixer. Contact Niagara Scientific, Inc., 118 Boss Road, Syracuse, N.Y. 13211, (315) 437-0821. Circle INFO/CARD #73.

Computer Compatible Lock Box

The MS100 Series Microwave Frequency Stabilizers offer full TTL compatible functional control and status monitoring Ten standard models cover 1 to 40 GHz with many configuration options offered. Full electronic tuning (includes crystal switching) and advanced oven controller for VCXO improved long-term stability and phase-locked spectrum of microwave signal source. Broadband, optimally damped, second-order phase lock loop maintains locked source stability to eight parts in 10^9 per hour and 6 parts in 10^{10} per millisecond. Contact Niagara Scientific, Inc., 118 Boss Road, Syracuse, N.Y. 13211, (315) 437-0821. INFO/CARD #72.

Wideband RF Hybrid Amplifier Series

Motorola has introduced a series of new wideband RF amplifiers which extends the upper frequency limit from an existing 400 MHz to 1 GHz. The new single-stage devices are designed for broadband linear amplifiers in military, commercial and consumer equipment. Specific applications are in RF, IF and AGC amplifiers, and as line drivers and isolation stages.

The new MWA series of wideband amplifiers have 50 ohm input and output impedances and are fully cascadable for any gain. Contact P.O. Box 20912, Phoenix, Arizona 85036. Phone (602) 244-6900. INFO/CARD #71.

TCXO to 400 MHz Computer Compensated

The new CO-255 Series of VHF TCXOs (temperature compensated crystal oscillators) employ computer compensation techniques to achieve stability to $\pm 2 \times 10^{-7}$ over the 0-50°C temperature range or $\pm 1 \times 10^{-6}$ over −55°C to +85°C. They are available at frequencies to 400 MHz with long term stability (aging) better than 1×10^{-8} per day and 2×10^{-6} per year. This stability is achieved without the use of an oven, resulting in low power drain, small size and instantaneous "on-frequency" operation.

Contact Vectron Laboratories, Inc., 166 Grover Avenue, Norwalk,

Connecticut 06850. Telephone: (203) 853-4433. TWX: (710) 468-3796. Circle INFO/CARD #65.

True Time

A fully illustrated 14-page catalog includes NBS synchronized clocks, WWVB receiver-frequency comparators, receivers, antennas, and portable timing systems.

True Time instruments have found wide use for timing control, such as broadcasting, telemetry, and data acquisition.

The company's time code receivers are specifically designed for the time code transmitted by NBS' WWVB, Fort Collins, Colorado.

For a copy of the new catalog, write True Time Instruments, 3243 Santa Rosa Avenue, Santa, Rosa, Calif. 94501, or call (707) 528-1230. INFO/CARD #62.

Solid-State Oscillators

EMF Systems Inc.'s new catalog is hot off the press — containing application information on our complete line of Solid State Oscillators covering the 10 MHz to 15 GHz frequency range.

Included in the catalog is a section on VCO's, applicator information on three kinds of oscillators. Another section deals with mechanically tuned oscillators. Crystal controlled, and phase locked oscillators are also discussed. For further information contact EMF Systems Inc., P.O. Box 1009, State College, Pa. 16801. (814) 237-5738. INFO/CARD #60.

Microwave Absorbers

A broad range of microwave absorbing products for commercial and military applications is available from Advanced Absorber Products, Inc. of Amesbury, Massachusetts.

AAP Microwave Absorbers are specialty materials that control microwave interference and/or optimize performance in electrical and electronic systems. Constructed from materials including foams, plastics, fiberglass, honeycomb core, rubberized hair, natural and synthetic rubber. Contact Advanced Absorber Products, Inc., Maurice A. Pennisi, Vice President and General Manager, 4 Poplar St., Amesbury, Mass. 01913. (617) 388-1963. INFO/CARD #112.

1-1500 MHz Limiters

New Wiltron 1-1500 MHz Limiters protect detectors and other diode devices against the three most common causes of damage: DC Voltage, AC Voltage, RF Power. The Limiters are ideal for protecting detectors in measurement setups where the low return loss (SWR) and low insertion loss of the limiters enable them to protect without significantly degrading measurement accuracy. Contact Walt Baxter, Wiltron Company, 825 East Middlefield Road, Mountain View, Calif. 94043. Tel: (415) 969-6500. TWX: 910-379-6578. INFO/CARD #63.

Components

Stackpole Components Has Increased Production Capacity for Thick Film Networks

With the addition of new laser trimming equipment, Stackpole Components Company has now substantially increased production capacity for its thick film resistor networks.

The Mini-SIP, with a height above standoff of .175-inch, requires no more PC space than a standard SIP, yet stands no higher than a DIP. Developed as the need for miniaturization increased, the Mini-SIP features Stackpole's unique horizontal geometry, which extends the resistance path beyond that possible with the conventional L-cut configurations, resulting in greater resistor density, fewer hot spots and less current crowding.

Stackpole networks require only about a quarter of an inch on a PC board while holding up to 28 resistors. They are available in both single and dual in-line packages with four to 16 pins.

DIPs may be interchanged with I.C. packages for use in automatic insertion machines. Sixty-four standard resistance values are offered, ranging from 33 ohms to 270 kilo-ohms. Standard tolerance is ±2 percent, but one percent matching is available.

For further information, visit Electro/'79 booth 2134 or contact Charles L. McGill, Stackpole Components Company, P.O. Box 14466, Raleigh, North Carolina 27620. INFO/CARD #43.

Mixers

A new 20 page mixer catalog has just been issued by Lorch Electronics Corp. It describes a total of 87 different types of mixers, ranging in frequency from 10 kHz to 11 GHz. They include low power versions, general

1,000 MHz in one band —with IEEE-488 Bus.

S-D's 1702 Signal Generator.

Since many of today's test requirements go well beyond 520 MHz, Systron-Donner offers you the Model 1702 AM/FM Programmable Signal Generator—with 100 Hz resolution! The Model 1702 not only provides wide coverage but does it with the stability and accuracy of a synthesizer. Furthermore, the 1702's typical level flatness of ±1 dB is significantly better than other signal generators costing much more. The 1702 is one of a growing list of S-D instruments offering the IEEE-488 Bus interface.

New: Model 1618 Frequency Synthesizer. This 18 GHz Frequency Synthesizer is a state-of-the-art frequency source for the most demanding applications requiring high stability and accuracy. Using S-D's unique phase lock techniques, Model 1618 provides wideband coverage without the use of Output multipliers. IEEE-488 Bus interface is standard.

For details, contact Scientific Devices or Systron-Donner in Concord, CA.

S-D: The signal generator people.
And a lot more.

INFO/CARD 23

SYSTRON DONNER

PUT OUR PERFORMANCE TO THE TEST

purpose mixers, low distortion mixers and ultralow distortion mixers. Contct Lorch Electronics Corp., 105 Cedar Lane, Englewood, N.J. 07631. Phone: (201) 569-8282 TWX: 710-991-9718. Circle INFO/CARD #44.

Microwave Components

An extensive catalog of microwave components is being offered by Microwave Development Laboratories, Inc. of Natick, Massachusetts.

The MDL Microwave Component Catalog is a comprehensive reference guide to several thousand standard and special components. Included are waveguide adapters, transformers, bends, twists, shutters, and pressure windows; hybrids; Tees, couplers; rotary joints; filters; mixers; and miscellaneous types.

The MDL Microwave Component Catalog is available free from Microwave Development Laboratories, Inc., 10 Michigan Ave., Natick, Mass. 01760. INFO/CARD #51.

Microwave Pulse Power Transistors

Motorola has introduced eight new microwave pulse power transistors for pre-driver stages in DME, IFF and TACAN avionics equipment and CW systems, operating in the 960-1215 MHz frequency band. Designated the MRF1000/2/4/8 series, the new devices are available in two industry-standard packages — stripline stud and pill mounting. Contact Alan Wagstaffe, P.O. Box 20912, Phoenix, Ariz. 85036. Phone (602) 244-6900. INFO/CARD #59.

RF Fixed Choke

With the introduction of the new Cambion P/N 551-5180 series, Cambridge Thermionic Corporation now offers RF chokes for inductances up to 1000 uH.

It features a high Q and low DCR rating for typical inductance values and is suitable for all RF inductor applications. Contact Cambridge Thermionic Corporation, 445 Concord Avenue, Cambridge, Mass. 02238. Phone: (617) 491-5400. INFO/CARD #50.

GaAs FET

Raytheon has expanded its line of microwave GaAs field-effect transistors with the introduction of a dual-gate device for applications from 2-12 GHz.

The new LND832 typically offers 10 dBm power output at 10 GHz with a 4-volt drain bias. The device can operate at drain biases as high as 10 volts.

Specific applications for the new GaAs FET include mixers, down and up converters, power dividers and fast switches. Contact Raytheon Company, Special Microwave Devices Operation, 130 Second Avenue, Waltham, Massachusetts 02154. INFO/CARD #57.

"Chip" Capacitors

A series of miniature mica "Chip" capacitors has been announced by ARCO Electronics. These mica "UC" series capacitors utilize a unique new method of foilless construction to achieve exceptional performance reliability, especially in high frequency applications.

The entire series is extremely small in size; the type UC12 measures 2 x 1.25mm and is available in capacitance values up to 43pf at 100 working volts, while the type UC55 which is available in values up to 2000pf at 100 working volts and 1200pf at 500 working volts measures only 5.6 x 5.0mm.

Contact Arco Electronics, Inc., 400 Moreland Road, Commack, N.Y. 11725. INFO/CARD #56.

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NEW Model K-7000 [Kit]	7 Digits	550 MHz	$ 79.95
NEW Model 7010	9 Digits	600 MHz	$145.00
NEW Model 8010	9 Digits	1 GHz	$325.00

Note: Model K-7000 is available "KIT FORM" only, other models factory assembled only. Model K-7000 requires #AC-70 Adapter ($4.95) for 115VAC Operation, AC Adapters are included with the other models. See chart below for NI-CAD Battery Pack Option, etc.

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- MADE IN U.S.A.
- COMPACT SIZES: 8010 = 3" H x 7½" W x 6½" D
  K-7000/7010 = 1¾" H x 4¼" W x 5¼" D

7010/7010.1
600 MHz
9 DIGITS

8010/8010.1
1 GHz
9 DIGITS

K-7000 KIT
550 MHz
$79.95

MODEL	$ PRICE	RANGE 10Hz to	LED DIGITS	SENSITIVITY 50 OHM INPUT 25-250 MHz	250-450 MHz	450 MHz-1GHz	HI-Z INPUT 10Hz - 60 MHz	GATE TIMES	RESOLUTION 12 MHz	60 MHz	MAX FREQ	TCXO TIME BASE 20°-40°C	FREQ.	EXT CLOCK INPUT	NI-CAD BATT PACK
K-7000 kit	79.95	550 MHz	7	5-20 mV	10-30 mV	20-50 mV to 550 MHz	1-10 mV	(2) 1.1 SEC	10 Hz	10 Hz	100 Hz 550 MHz	1.6 PPM	5.24288 MHz	NO	YES OPTION $15.
7010 *7010.1	145.00 225.00	600 MHz	9	5-20 mV	10-30 mV	20-40 mV to 600 MHz	1-10 mV	(3) 1.1.10 SEC	.1Hz	1 Hz	10 Hz 600 MHz	1 PPM 0.1 PPM	10 MHz	YES OPTION $25.	YES OPTION $15.
8010 *8010.1	325.00 405.00	1 GHz	9	1-10 mV	5- 20mV	10-35 mV	1-10 mV	(8).01-20 SEC	.1 Hz	1 Hz	10 Hz 1 GHz	1 PPM 0.1 PPM	10 MHz	YES STD	YES OPTION $39.

*Has precision (0.1PPM) TXCO Time Base

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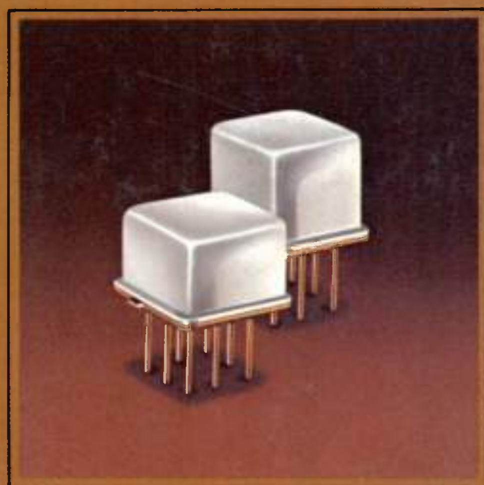
INFO/CARD 26

TO-5 RELAY UPDATE

The Centigrid: You're making it the next industry standard



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