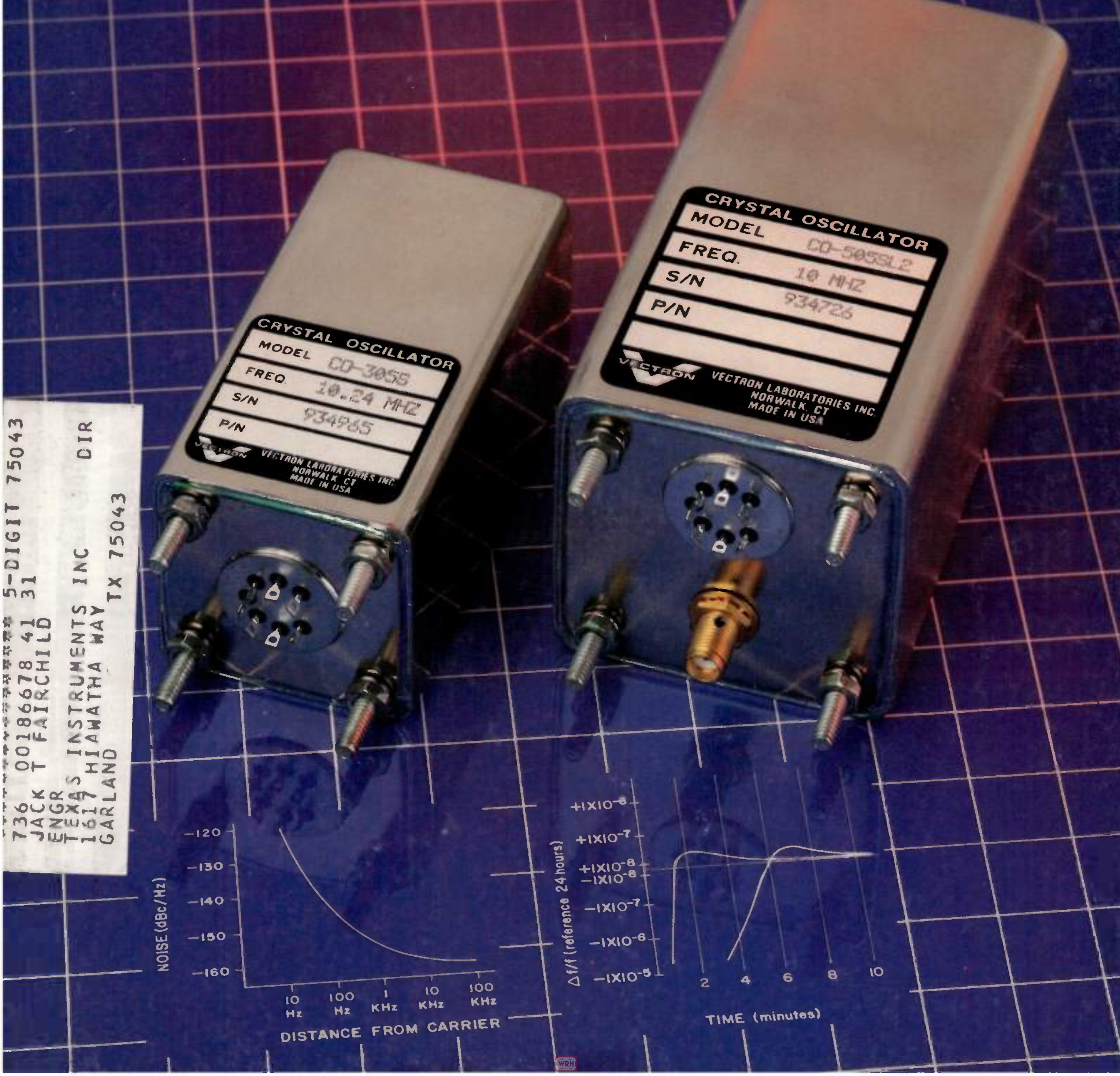
rf design

ideas for engineers

March 1987

Special Report — Oscillators: Heartbeat of RF Circuits



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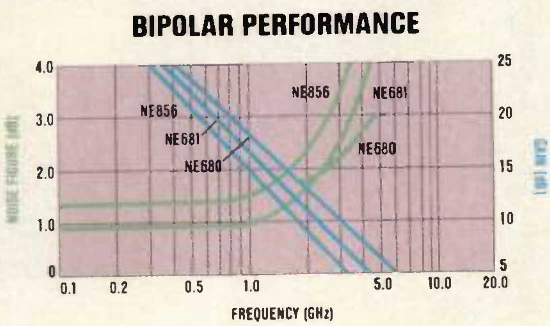

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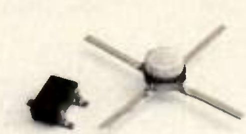

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INFO/CARD 3

rf design

March 1987

Page 28 — Special Report

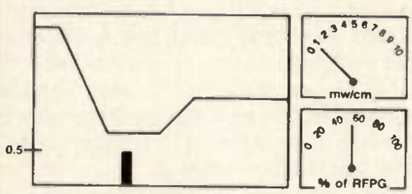
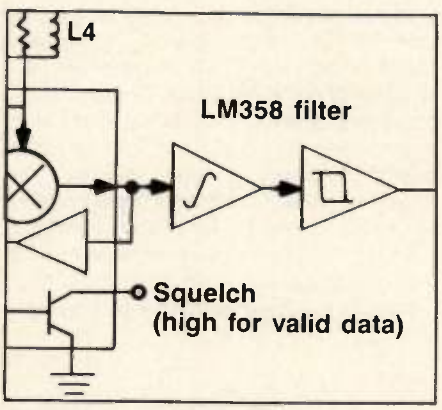


Figure 2. VHF TV.

Page 41 — RF Safety Standards



Page 46 — FSK Data Receiver

Cover Story

Features

Departments

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First, the Bad News . . .

By Gary A. Breed
Editor

It doesn't take a Ph.D. in Economics to see that 1987 will be a ho-hum year for business. Sure, the stock market has been surprisingly enthusiastic, but every serious prognosticator I have read predicts only modest economic growth; some even mention a possible return of inflation (oil prices are going up again).

We have a weak dollar, a lame duck President pitted against the other party's Congress, a terrible balance of trade, and no visible effort to reduce our country's debt. The rest of the world is not much better off: The Third World is as poor as ever, Japan and Europe share our sluggish growth, and political unrest is on the rise.

Now the Good News . . .

Fortunately, most of the bad news in electronics centers around the digital world, with IC manufacturers losing their shirts (or their companies), all the fighting over DRAM dumping by the Japanese, and profits going up and down like yo-yos. Even IBM's massive profits are slowing down. But, it's not quite so scary in the world of RF.

RF has a few things going for it, despite the slow overall economy: Military spending continues strong, and will not likely slow down very much after the next Presidential election. Avionics, electronic warfare, and SDI all are outstanding markets for RF products and services. Communications equipment of all types is a solid part of the economy, and technology-conscious consumers use RF devices for entertainment, convenience, security and information.

The slow economy has its effect, though. There is no easy formula for success when your customers are watching their own slim pocketbooks. When times get tough, any business has to rediscover *the only two roads to success:* A new idea that everyone needs, or a better way of doing an old idea. In the next several months, *RF Design* will examine these avenues in our Special Reports and Featured Technology articles.

April, May and June issues will look at new RF applications, which are integrated with other technologies. Optical, digital and aerospace applications are finding a surprising symbiosis with RF, evidenced by the number of engineers from these disciplines attending the RF Technology Expo and RF Expo East.

In July and August, be ready for a close look at ICs, modules and subsystem "supercomponents," which represent better ways of doing old ideas. Creative engineers are putting their best efforts into high performance building blocks, so a design engineer doesn't have to "reinvent the wheel" with each new project. These components have already changed the way RF products are designed and manufactured.

Maybe this year won't be so ho-hum, after all!

Gary A. Breed

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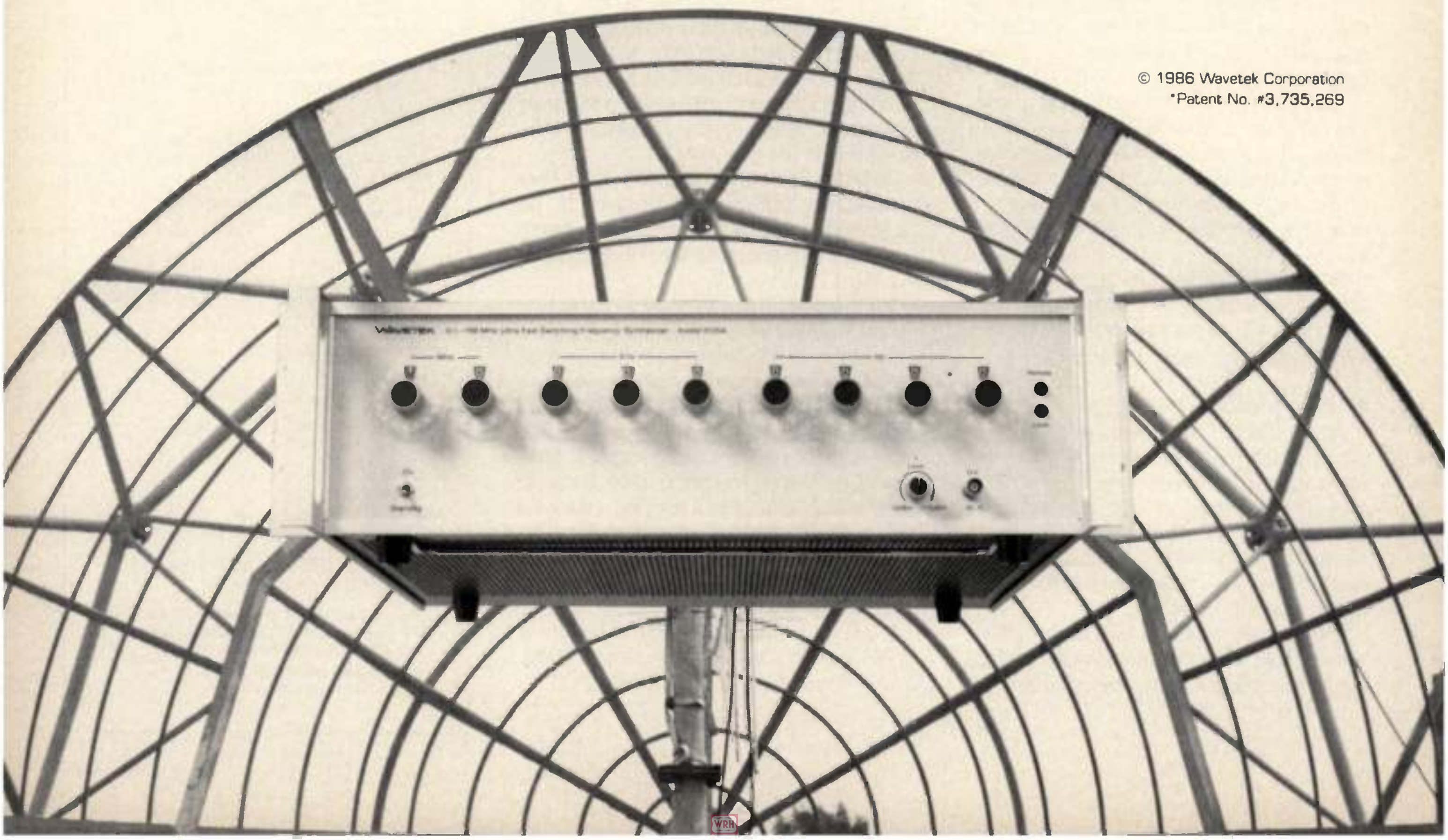

*Patent No. #3,735,269

rf viewpoint

RF Expo Year Three: An Assessment

By Keith Aldrich
Publisher

At this writing we're not sure by exactly how much, but we do know that RF Technology Expo 87, February 11-13 at the Disneyland Hotel in Anaheim, was better attended than either of the RF Expos before it.

That fact by itself, however, fails to convey the spirit of what actually took place there. There was something different, something at once sobering and encouraging. That something is hard to analyze or define, but this column will take a crack at it.

Perhaps the difference is best illustrated by contrasting two events in the 1987 Expo with the same events in the startup 1985 Expo, two years before. . .

1. Registration

At the 1985 Expo, attendees started lining up at the registration area at six in the morning, and hundreds were there by 8:00 a.m. The registration area was mobbed until at least noon before workers there caught up. Until then, it seemed as if attendees were literally storming the gates of the first RF Expo.

By contrast. . .at the 1987 Expo, registration was orderly and evenly paced, even though brisk, from opening day until the closing of the show. While attendees seemed eager to know and to learn, one saw no lineups before convention hours, no "storming of the gates."

2. RF Fundamentals

At RF Expo 85, the long narrow Embassy Room at the Disneyland Hotel's monorail station, set up hopefully for an attendance of 300, was besieged by a crowd of well over 400, pushing into corners, standing in aisles, until a moveable wall was taken out to create a huge "L" of an auditorium, with the hectored speakers at the apex. That was the first day, for a one-day course on "Fundamentals of RF Design." The second day drew almost as many, listening with incredible attentiveness in spite of overcrowding, poor sightlines and a roughly formulated course, to pick up every morsel they could about RF.

At RF Expo 87, a much refined course on the "Fundamentals of RF Circuit Design," taught brilliantly by Les Besser with the benefit of two years' development and held in the same Embassy Room, drew an orderly studious class of about 100 the first day and about 80 the second day. They were well-qualified EEs appropriately chosen, learning RF techniques they needed to know, from a teacher well-qualified to teach them.

The contrasts drawn above will serve to illustrate many more that might be observed, along more or less the same lines, in comparing the first RF Expo and the third.

The development of the RF Expo and its community of engineers is sobering only in the sense that we see a mite less passion, less fervor, in the attitude of attendees. It is encouraging because it indicates not so much of a cooling of the market or of the technology as a maturing of it. We're watching kids become grownups. This means that expectations will be raised, and that standards must be raised to meet them — standards of technical papers, of product offerings, everything.

It all points to a golden age of progress in RF, looming on the immediate horizon. If you doubt that, wait and see.

rf design

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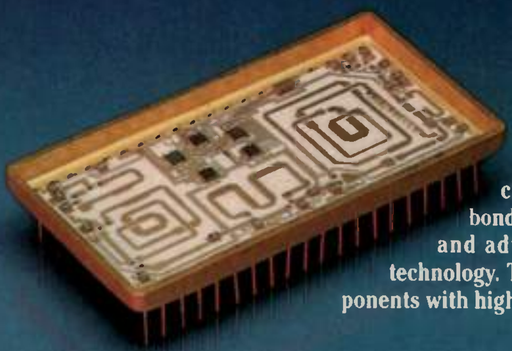

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(Performance @ 1.0 GHz)

Model	Max. Useable Frequency (GHz)	Gain (dB, typ.)	Noise Figure (db,typ.)	P_{1dB} (dBm, typ.)	Package Type	1000 Piece Price $$$
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MSA-0204	4.0	11.0	6.5	4.0	B	1.90
MSA-0370	4.5	12.5	5.5	10.0	C	16.10
MSA-0420	3.5	8.5	7.0	15.0	D	18.45
MSA-0635	4.0	16.5	3.0	1.5	E	4.85
MSA-0835	6.0	23.5	3.0	12.5	E	7.80
MSF-8870	8.0	20.0	NA	9.0	C	29.75

A) 85 mil plastic B) 145 mil plastic C) 70 mil stripline
D) 200 mil BeO E) 1[illegible] mil ceramic

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INFO/CARD 8

rf letters

Letters should be addressed to: Editor, *RF Design,* 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111.

Sprechen Sie Deutsch?

Editor:

I wonder if you can help me.

Sometime in 1980 or 1981, I saw a glossary of electronic terms in German, Russian and possibly another language. I believe it was in your magazine. If this is true, please advise me of the cost of a copy of this glossary or the particular magazine issue. If you can only supply the date of issue of the subject magazine I may be able to find it in a technical library. If you did not in fact, publish such a glossary, maybe you can supply the information from another one of your publications. . .or an outside source.

I am planning to go to Germany for a number of technical discussions and would appreciate any help you can provide.

Michael F. Waters
Digital Consultants Co.
Utica, New York

The glossary mentioned did not appear in RF Design. *Hopefully, one of our readers will recall its source and pass along the information to Mr. Waters and the rest of our readers. — Editor*

Design Article Reactions

Editor:

Your article concerning the "UHF Movement Detector" in the December issue was very interesting. The article appeared to be a little incomplete in dealing with board layout and part placement. I am very interested in this item and would like to construct one to experiment with. Any additional information would be appreciated.

Neil B. Hellewell
Utah Power and Light Co.
Salt Lake City, Utah

Construction details and further information can best be obtained directly from the authors of our articles. Their addresses are always included at the end of their presentations. — Editor

Shielding Addendum

Editor:

Thank you for publishing my letter on the shielding discussions (Jaunary 1987 issue). But, in editing it for publication you left off what I thought were the most important statements, which were:

"Optimum application of shielding to achieve EMC is not a simple matter. The decision to use or not to use shielding should not be made lightly. Once the decision is made to use shielding, a designer not experienced in shielding design will need some expert assistance through consulting or self-study."

Edwin L. Bronaugh
Electro Metrics
Amsterdam, New York

Comment Cards

Editor:

"Low Noise Preamp," page 39 (Jan. 1987) — Excellent article, would like to see more like it with theory and practical example circuits — down to a PCB layout such as for the preamp.

Always enjoy *RF Design.*

T.K. Bierney
IMI
San Clemente, California

Editor:

Excellent RF Cover Story on the Motorola MC3362 single-chip FM receiver in the Jan. 87 (issue). I wish it could have been more in-depth and longer, with the chip's specs added. Thanks for enlightening me about this chip, I was not aware of it at all. I believe it holds much potential in my work.

Michael Kirk
National Public Radio
Washington, D.C.

Editor:

Really enjoy reading the articles from your first RF Design Contest. Looking forward to see more, and then articles from your "second" RF Design Contest.

Wayne Smith
Sencore
Arden, North Carolina

Editor:

Congratulations to Gary Breed on a beautiful editorial. His dissertation on pure vs. applied science was right on the mark.

Al Goldberg
Spectrum Enterprises Inc.
N. Miami Beach, Florida

RF Technology Expo 87 Draws Over 1,700 RF Engineers

Diversity is the best word to describe the crowd of RF designers who attended the third RF Technology Expo in Anaheim, California. Besides the expected groups of engineers from the Los Angeles area aerospace giants, many other facets of the RF industry were represented: broadcasting, government, education, consumer equipment, EMC laboratories, mobile radio, amateur radio, fiber optics, local area networks, instrumentation and many others. The RF industry definitely *does not* have "all its eggs in one basket!"

New Introductions

In addition to those announced in the February issue of *RF Design,* several new products had their first announcement and showing in Anaheim. Digital RF Solutions of Santa Clara, Calif., introduced its Number Controlled Modulated Oscillator, a direct-digital frequency synthesizer with AM, PM, FM modulation capabilities. SMT construction techniques are used in this new product. Doty Scientific of Columbia, S.C., unveiled a line of broadband pulse amplifiers for NMR, MRI and RF testing applications. These class AB amplifiers include a complete range of protection circuits.

Another amplifier product was shown by RF Power Labs of Bothell, Wash., the first in a series of general purpose wideband amplifiers in modular form. The Model 2002 covers 1.0-500 MHz (±1 dB) with 35 dB gain and 2 W output. This also is an SMT design, using MOSFET technology. Texscan Corporation of Indianapolis, Ind., introduced its PSG-1000 Direct Synthesis RF Generator for 10 kHz to 1 GHz applications. The unit is portable, operating from standard AC power or +12 VDC.

A high power amplifier subsystem for the Wind Profiler System being developed by the National Oceanic and Atmospheric Administration (NOAA) was on display in the Microwave Modules and Devices (MMD) booth. MMD is supplying the amplifier to the prime contractor in the NOAA project, Sperry Corp. Installation of the first system will be completed this summer.

Education is High Priority

Most of the engineering attendees indicated they had come to learn. Two hundred attended the RF Fundamentals course, taught by Les Besser of Besser Associates with assistance from Dr. Tim Healy of Santa Clara University. Many of the "students" indicated that the course has become even more applicable to lower-frequency RF engineers with the introduction of new course material and the use of a new textbook. The instructors can be congratulated for their responsiveness to the engineers' educational needs.

The technical sessions represented the same desire for education. The largest audiences were to be found in sessions featuring basic design techniques. Gary Franklin of Hewlett-Packard had a packed house for his "Practical RF Amplifier Design" paper. Standing room only was the situation for three papers on oscillators, "Survey of VHF Crystal Oscillator Circuits" by Robert Matthys of Honeywell, "Noise Prediction in Oscillators" by Dr. Ulrich Rohde of Compact Software, and "A General Procedure for Low Noise Feedback Oscillator Design" by Ed Westenhaver of Quintron Corp. Other popular papers included the subjects of PIN diodes, safety and medical aspects of RF, power amplifier design, phase locked loops, noise figure basics and modulation topics.

Of particular note was the specific nature of comments on the technical sessions. It is clear that engineers are becoming more discriminating in their desire for information. There were many specific requests for topics to be covered at future Expos, and thoughtful evaluation of the papers presented. The nature of the engineers' comments suggested that the gap between an overall engineering education and the needs of RF engineers has not yet been narrowed.

After the expected discussion of facilities, audience and business, several exhibiting companies noted that they had heard of several new applications for their products from visiting customers. Component manufacturers, in particular, were pleased to tell about the gadgets and serious equipment utilizing their products. From remote control "car finders" that beep the horn to locate an auto in a crowded parking lot, to satellite communications systems, engineers continue to find new ideas for RF.

Although the weather represented the Southern California "rainy season," the facilities of the Disneyland Hotel made it possible to stay dry and comfortable. Between sessions and after hours, groups of engineers could be found discussing their latest technical efforts, although the conversations can probably be best described like a fisherman's "one that got away" story, rather than serious intellectual interplay! But that's an important part of RF engineering, too.

Amateur Radio "Novice Enhancement" Adopted by FCC

Amateur Radio's Novice and Technician class operators will receive new operating privileges, including voice and digital modes, beginning 0001 UTC on March 21, 1987. In action announced February 13, the Federal Communications Commission has increased the Novice and Technician privileges in the 10-meter band (28-29.7 MHz), and given Novices limited privileges in the 220-225 MHz and 1240-1300 MHz bands. Technicians already have all privileges above 50 MHz.

Under the new rules, Novices and Technicians may use CW (code) and digital modes (RTTY, AMTOR, Packet) from 28.1 to 28.3 MHz, plus CW and voice modes from 28.3 to 28.5 MHz. Current 10-meter operating frequencies for these classes are 28.1-28.2 MHz, CW only. The 200 watt power limitation has been retained for these licensees, although higher class operators are *not* limited to 200 watts in the Novice/Technician band segments, as had previously been required.

VHF operation for Novices will include all authorized modes in the 222.1-223.91 MHz range, with a 25 watt power limit; plus 1270-1295 MHz, where a 5 watt limit has been set. Although Novices may utilize repeaters with these new provisions, the rules prohibit Novices from acting as Control Operators for repeaters, beacons and other automatic systems.

In addition to establishing new operating privileges, the FCC has modified the examination procedure for Novices and Technicians. Future Novice examinations will require two examiners to be present, and the written test has been expanded to 30 questions. Current Novices and Technicians are "grandfathered" and need not be re-examined. Also, the written examinations for Technician and General Class licenses will no longer be the same. Technicians will take a new Element 3A, Generals the new 3B exam. Morse code requirements are unchanged.

These enhanced operating privileges are intended to increase the number of new Amateur Radio operators by making the entry-level license classes more attractive. By adding these privileges in some of the least-utilized amateur bands, an increased amateur population will have a minimal effect on the most popular (and crowded) bands.

Fixed Cellular Phone Systems Target Homes and Businesses

A series of cellular-based telephone systems designed for fixed-station applications ranging from private homes to large business and industrial complexes has been announced by The Antenna Specialists Co. The new phone systems, marketed under the trade name "CELL-U-PHONE™," are designed to provide high quality telephone service to isolated communities and industrial areas, or on a subscriber basis to fixed locations within existing cellular systems.

The new CELL-U-PHONE systems are particularly applicable to remote areas, where the cost to bring conventional telephone wireline cable may run as high as $10,000 per subscriber, and hostile environments where cable security or theft may be a severe problem.

Optional configurations can provide simple, single line service similar to conventional residential systems, or a more advanced system suitable for small isolated communities, apartment complexes, condominiums and businesses where two or more individual subscribers can share a single line. A third system provides multi-line capability, designed to serve as a trunk connection between the cellular system and a PABX with multiple trunk lines and multiple telephones requiring direct inward and outward dialing.

Keene Corp. Acquires 3M's Microwave Laminate Line

Keene Corporation's Laminates Division and 3M's Electronic Products Division have reached an agreement in principle concerning the sale of 3M's microwave laminate business to Keene. Terms of the pending transaction were not disclosed.

Upon closing of the sale, 3M personnel, production equipment, research laboratories and other assets will begin the transition from 3M locations in Austin, Tex., and Columbia, Mo., to Keene facilities in Bear, Del., where a major expansion is underway.

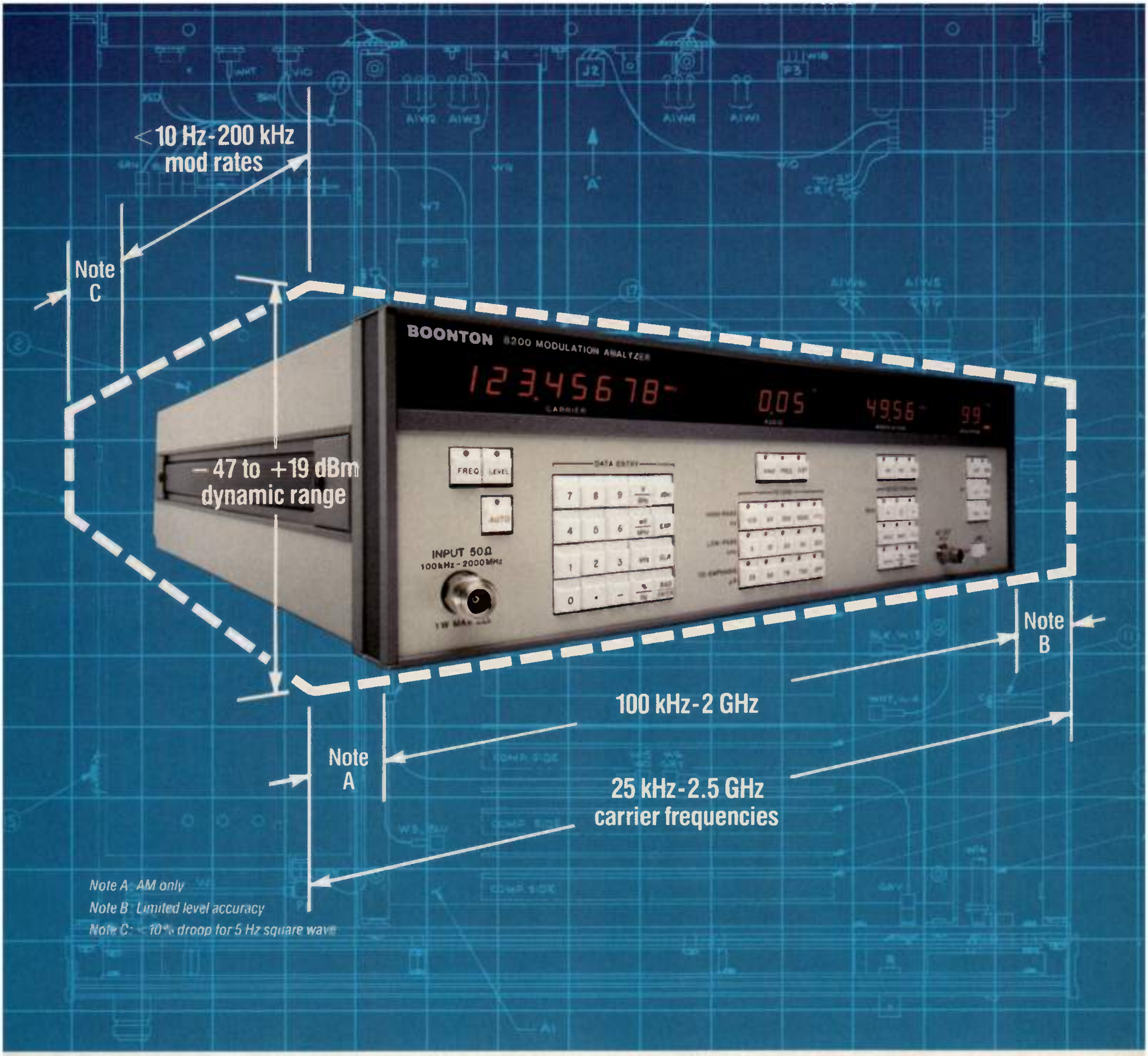
The 3M microwave laminate product line consists of high-performance printed circuit substrate materials used in telecommunications, high frequency radar and satellite transmissions. Included is the CuClad® brand substrate line. The CuClad brand products will complement Keene's existing Di-Clad® electronic substrate line. Both CuClad and Di-Clad products will continue to be marketed under their brand names with Di-Clad products being sold by Keene's existing sales organization and CuClad products being sold by the sales organization acquired from 3M.

Loral Corporation Puts up $640 Million for Goodyear Aerospace

Loral Corporation has agreed to purchase Goodyear Aerospace Corporation, a subsidiary of The Goodyear Tire & Rubber Company, for $640 million in cash. Regulatory approval and transfer arrangements should be completed by the end of March.

Loral's aggressive bidding for Goodyear Aerospace will increase Loral earnings beyond $1.5 billion annually, 90 percent of that in military electronics. Goodyear's products and technologies include tactical weapons systems, anti-submarine warfare systems, guidance systems, infrared imaging systems, and mobile launchers.

Loral expects to maintain Goodyear Aerospace's current plant operations and



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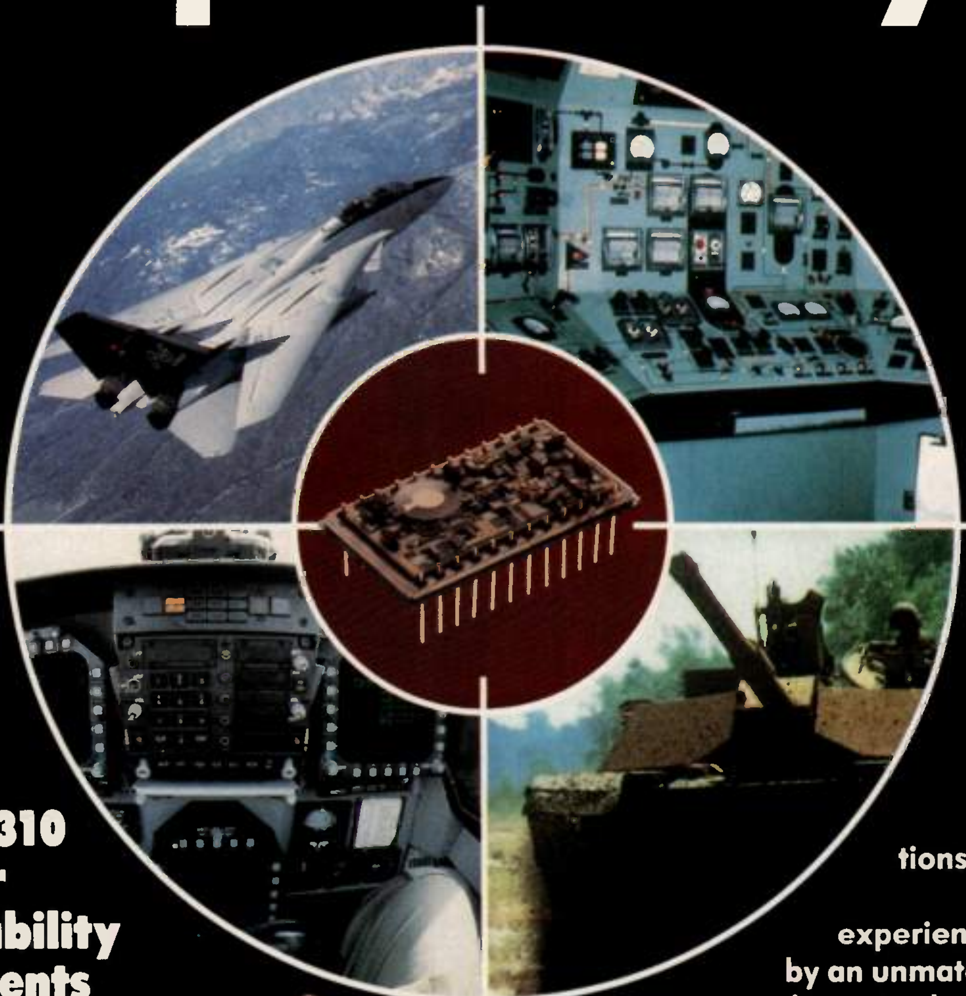

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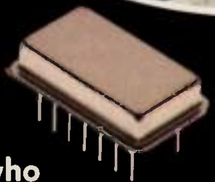

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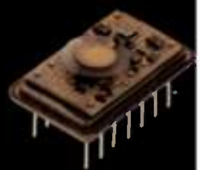

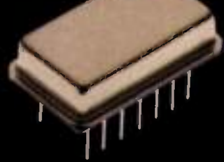

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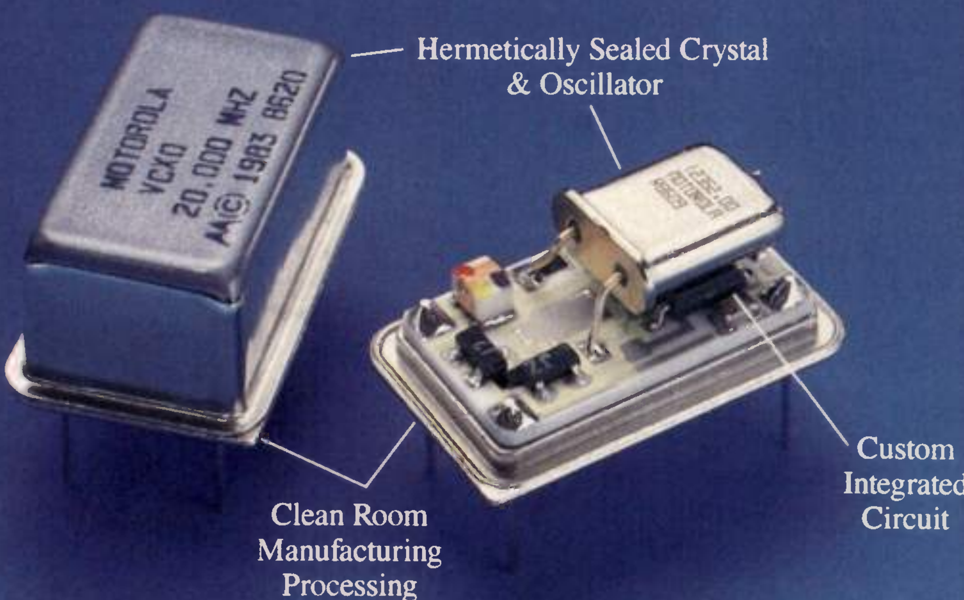
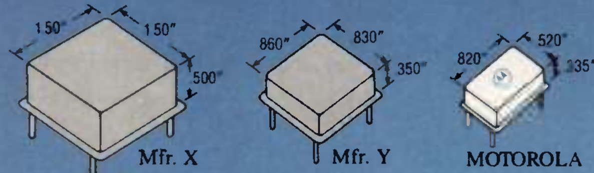


Motorola VCXO's Offer a Space Saving Dimension in System Design

Motorola VCXO's not only deliver the reliability and stability your applications demand...they also provide space saving dimensions for greater design flexibility! Hybrid and I.C. component technologies give the Motorola VCXO a space saving size of just .820″ x .520″ with a .355″ seated height. Motorola's new VCXO occupies only .426 in.² of board space compared with some competitive offerings of 2.25 in.² or .714 in.².



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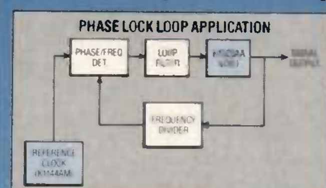
Inherent Reliability

Motorola's custom integrated circuit minimizes the number of components, resulting in a VCXO that offers outstanding reliability and consistency from unit to unit. The double hermetic seal with class 100 clean room processing enhances reliability.

Phase-Lock Loop Applications

VCXO's are predominantly used in all phase lock loop applications for communications equipment and analog/digital interface as well as in LAN's and other forms of computer-shared management systems. For phase lock loop applications, Motorola offers a wide variety of reference oscillators to fill your system needs.



Contact us for complete information and samples at the following address: Motorola Inc.—Components Division, 2553 North Edgington Street, Franklin Park, IL 60131. Phone: (312) 451-1000 EXT. 4835. TWX: (910) 255-4619, FAX: (312) 451-7585, TELEX 499-0104.

MOTOROLA INC.
Components Division

Motorola Components Division is a broad-based supplier of quality components for the electronics OEM. For more information about specific product lines, contact:
Quartz Bars / Carlisle, PA (717) 249-1456 • **Data Clocks, TCXOs, Crystals, Filters, Memory Backup Batteries** / Franklin Park, IL (312) 451-1000, Ext. 4835
Piezo-Ceramic Speakers, Annunciators, Filters, Transducers, Displays / Albuquerque, NM (505) 822-8801 • **Hybrid Circuits** / Ft. Lauderdale, FL (305) 475-5000
NiCd Batteries / Ft. Lauderdale, FL (305) 475-5000 • **Printed Circuit Boards** / Schaumburg, IL (312) 576-8468

INFO/CARD 15

management personnel. Plants are located at Akron, Ohio; Phoenix, Ariz.; and Rockmont, Ga.

Bliley Electric Company Acquires Sunburst Electronics

Bliley Electric Company has announced its acquisition of Sunburst Electronics as a wholly-owned subsidiary. Richard D. Bliley, president of Bliley Electric, described Sunburst as a very high quality subcontract electronics assembler, specializing in research and development, as well as the design and manufacture of industrial electronic controls. These include printed circuit board and cable assemblies, wire harnesses and control panel wiring.

Robert W. Heiges, Sunburst's founder, will be retained under long term contract as president to supervise an accelerated growth program projected by the new association with Bliley. Bliley Electric Company designs and manufactures custom, high precision quartz crystals and crystal oscillators for aerospace guidance systems, computers, telecommunications and a number of other military, commercial and industrial applications.

Honeywell ICA Contract Goes to Racal-Dana

Racal-Dana Instruments Inc. has been awarded a contract for interface connector assemblies (ICAs) from Honeywell Inc., Military Avionics Division. The contract is for Racal-Dana's MATE-compatible Model 1276 universal ICA. The units will be used in prototype and preproduction test systems for the TISS (Tews Intermediate Support System) and GATE (Generic Automatic Test Equipment) electronic warfare test systems.

The first phase of the contract is estimated to be worth approximately $1.8 million, with the anticipated worth over the life of the contract over $10 million. The ICA is capable of switching a range of signals, including DC and AC power, precision measurement, matrix and RF measurement, and stimulus. The order represents the first major contract for Racal-Dana of MATE-compatible ICAs.

North Hills Electronics Completes Expansion

North Hills Electronics, Inc. announced the completion of the company's first major facilities expansion. A two-story addition has been added to the original manufacturing and administrative office complex. The expansion significantly increases production floor space and has also provided new engineering labs and office space for the company's growing microwave operations. Additionally, the company's power conversion subsidiary, Displex, Inc., has consolidated its engineering and sales departments to an adjoining building.

Alpha Industries Announces Restructuring

Alpha Industries recently announced the formation of its Advanced Products Division located in Methuen, Mass. This restructured operating group combines Alpha's Microwave Components Division, formerly located in Lawrence, Mass., and its Methuen-based millimeter wave and multifunction assemblies operations. Alpha's Advanced Products Division will manufacture millimeter wave components and subsystems, antennas, microwave PIN diode switches, limiters, attenuators, multifunction assemblies, and GaAs FET amplifiers.

rf calendar

March 24-26, 1987
Southcon/87
Georgia World Center, Atlanta, Georgia
Information: (800) 421-6816 (outside California); (800) 262-4208 inside California; or (213) 772-2965

March 27, 1987
IEEE Princeton Section Sarnoff Symposium
RCA Laboratories, Princeton, New Jersey
Information: Dr. David K. Sharma, RCA/David Sarnoff Research Center, Princeton, NJ 08540; Tel: (609) 734-2387

April 1-8, 1987
Electronics and Electrical Engineering '87
Hannover Fairgrounds, Hannover, West Germany
Information: Hannover Fairs USA, Inc., 103 Carnegie Center, P.O. Box 7066, Princeton, NJ 08540; Tel: (609) 987-1202

April 21-23, 1987
Electrical Overstress Exposition
San Jose Convention Center, San Jose, California
Information: Jim Russell, EOE, 2504 N. Tamiami Trail, Nokomis, FL 33555; Tel: (813) 966-9521

April 27-29, 1987
IEEE Instrumentation and Measurement Technology Conference
Sheraton-Boston Hotel, Boston, Massachusetts
Information: Robert Myers, Myers/Smith, Inc., 1700 Westwood Blvd., Los Angeles, CA 90024; Tel: (213) 475-4571.

May 11-13, 1987
37th Electronics Components Conference
Boston Park Plaza Hotel and Towers, Boston, Massachusetts
Information: Tom Pilcher, Electronic Industries Association 2001 Eye St. N.W., Washington, DC 20006; Tel: (317) 261-1306

May 18-22, 1987
National Aerospace and Electronics Conference (NAECON) Set
Dayton Convention Center, Dayton, Ohio
Information: Cathy Joyce, SAE Headquarters, Dept. 935, 400 Commonwealth Drive, Warrendale PA 15096; Tel: (412) 776-4841

May 27-29, 1987
41st Annual Frequency Control Symposium
Dunfey City Line Hotel, Philadelphia, Pennsylvania
Information: Dr. R.L. Filler, U.S. Army Electronics Technology and Devices Laboratory, SLCET-EQ, Fort Monmouth, N.J. 07703-5000; Tel: (201) 544-2467.

June 9-11, 1987
IEEE MTT-S International Microwave Symposium
Bally's Grand Hotel, Las Vegas, Nevada
Information: Steve March, Maury Microwave Corporation, 8610 Helms Ave., Cucamonga, CA 91730; Tel: (714) 987-4715

June 9-11, 1987
NEPCON East '87
Bayside Exposition Center, Boston, Massachusetts
Information: Show Manager, Nepcon East, Cahners Exposition Group, 1350 East Touhy Ave., P.O. Box 5060, Des Plaines, IL 60017-5060; Tel: (312) 299-9311

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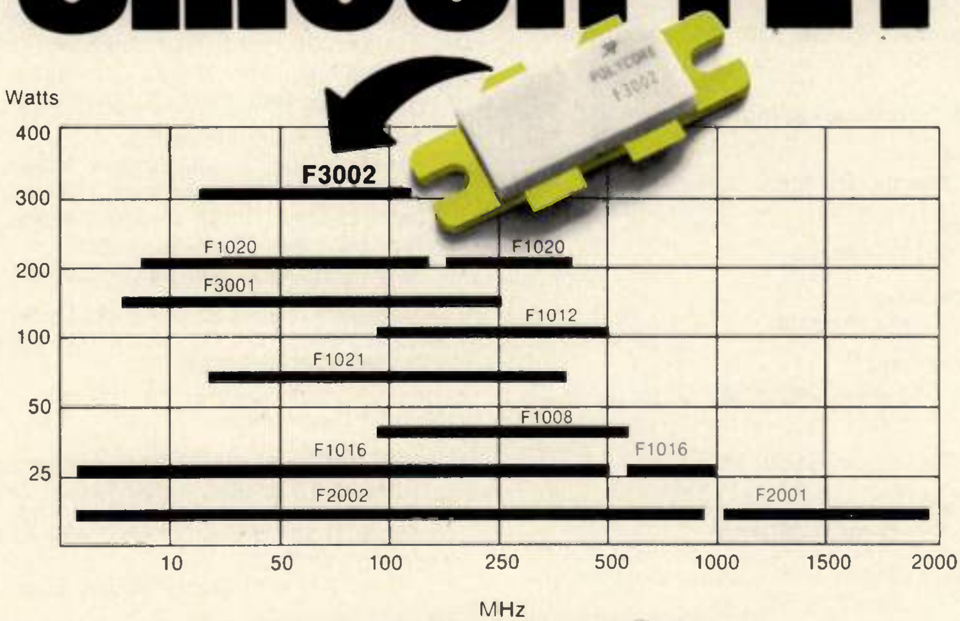

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INFO/CARD 19

Georgia Institute of Technology

Digital Signal Processing Fundamentals
March 23-25, 1987, Atlanta, Georgia

Multidimensional Digital Signal Processing
March 25-27, 1987, Atlanta, Georgia

Power Spectrum Estimation
March 25-27, Atlanta, Georgia

Millimeter Wave Systems and Technology
April 6-9, 1987, Atlanta, Georgia

Information: Deidre Mercer, Department of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332; Tel: (404) 894-2547.

The George Washington University

Principles of Air Defense and Air Penetration
April 6-9, 1987, Washington, DC

Synchronization in Spread Spectrum Systems
April 6-10, 1987, Washington, DC

Wind Shear Radar
April 20-22, 1987, Washington, DC

Information: Shirley Forlanzo, Off Campus Programs, Continuing Engineering Education Program, George Washington University, Washington, DC 20052

Southeastern Center for Electrical Engineering Education

Antennas: Principles, Design, and Measurements
March 24-27, 1987, St. Cloud, Florida

Information: Ann Beekman, SCEEE, 1101, Massachusetts Ave., St. Cloud, FL 32769; Tel: (305) 892-6146

Interference Control Technologies, Inc.

Practical EMI Fixes
April 14-16, 1987, Atlanta, Georgia

TEMPEST Facilities
April 7-10, 1987, Atlanta, Georgia

Grounding and Shielding
April 7-10, 1987, Phoenix, Arizona

Design and Measurement
April 20-24, 1987, San Jose, California

ESD Control
May 18-19, 1987, San Diego, California

Intro to EMI/RFI/EMC
May 18-20, 1987, San Diego, California

Information: Interference Control Technologies, Inc., P.O. Box D, Gainesville, VA 22065; Tel: (703) 347-0300

Continuing Education Institute

Signal and Network Analysis Microwave Products and Systems Characterization
April 6-9, 1987, Danvers, Massachusetts

Information: Continuing Education Institute, 21250 Califa St., Suite 102, Woodland Hills, CA 91367

UCLA Extension

High Speed Si and GaAs IC Design
April 6-10, 1987, Westwood, California

Modern Microwave Measurements and Applications
April 21-24, 1987, Westwood, California

Modern Telecommunications Networking: Local/Metropolitan Area and Satellite Communication Networks
May 11-14, 1987, Westwood, California

The Techniques and Technology of the Application of Kalman Filters and Nonlinear Filters
May 18-22, 1987, Westwood, California

Microwave Circuit Design I
June 1-5, 1987, Westwood, California

Navstar Global Positioning System (GPS)
June 15-19, 1987, El Segundo, California

Information: UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024; Tel: (213) 825-1901

Besser Associates, Inc.

Principles of RF and Microwave Circuit Design
March 23-25, 1987, Santa Clara, California

Information: Les Besser, Besser Associates, Inc., 3975 East Bayshore Road, Palo Alto, CA 94303; Tel: (415) 969-3400

Integrated Computer Systems

Digital Signal Processing
March 24-27, 1987, Boston, Massachusetts
March 31-April 3, 1987, Anaheim, California
April 7-10, 1987, Toronto, Canada
May 5-8, 1987, Palo Alto, California

Fiber Optic Communication
March 31-April 3, 1987, Boston, Massachusetts
April 7-10, 1987, Los Angeles, California
April 28-May 1, 1987, Toronto, Canada
May 5-8, 1987, Washington, DC
May 19-22, 1987, San Diego, California

Information: Integrated Computer Systems, 5800 Hannum Ave., P.O. Box 3614, Culver City, CA 90321-3614; Tel: (800) 421-8166; (213) 417-8888

Norand Corporation

FCC, VDE and CISPR Regulations and Design Criteria
March 17-18, 1987, Cedar Rapids, Iowa

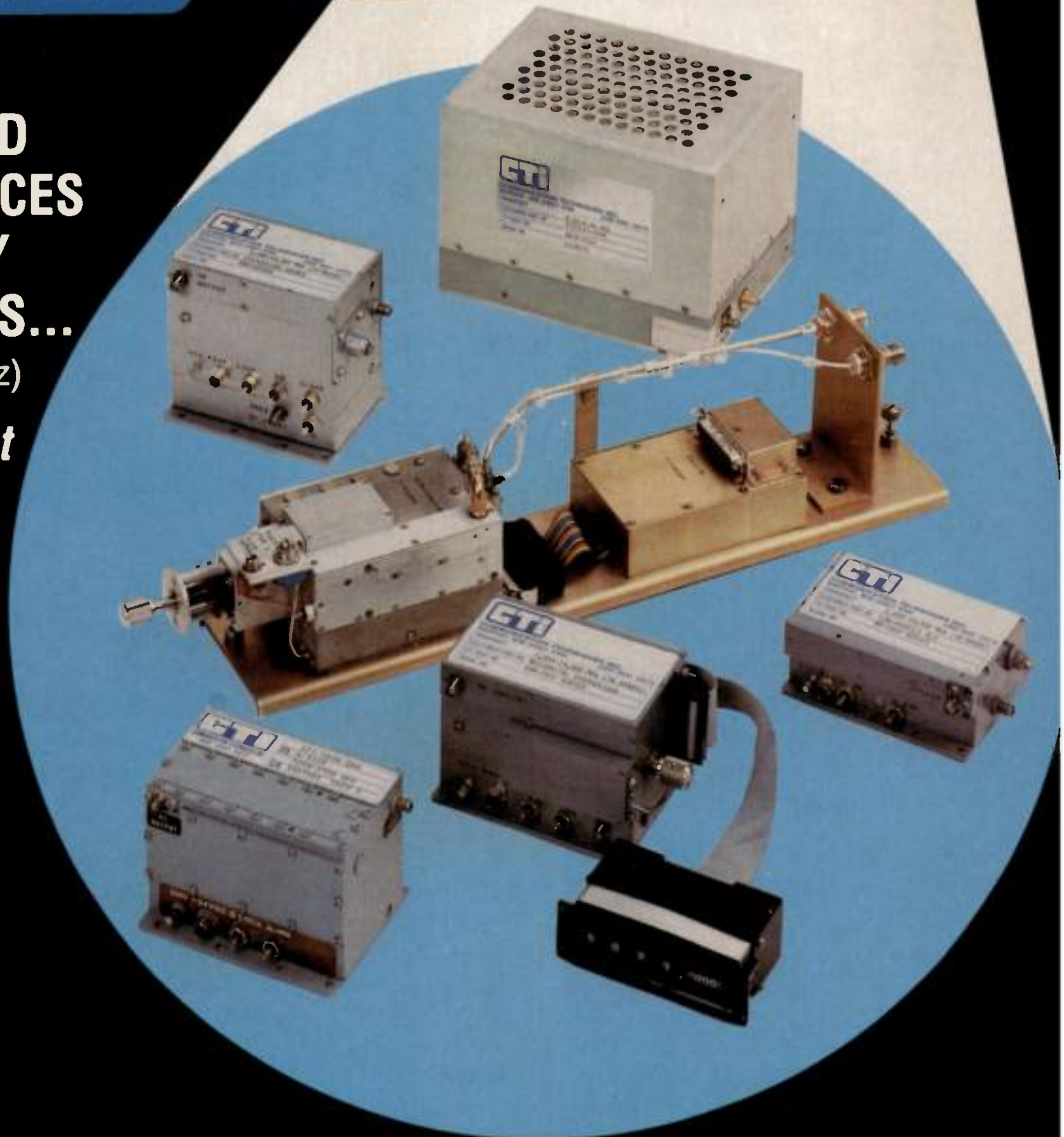
MIL-STD 461 B/C & MIL-STD 462 Regulations and Design Criteria
April 7-8, 1987, Cedar Rapids, Iowa

Grounding, Bonding, Shielding & PCB Design for EMI/EMC
April 28-29, 1987, Cedar Rapids, Iowa

RF Susceptibility and ESD Testing
May 19-20, 1987, Cedar Rapids, Iowa

Information: Bev Reynoldson, 550 2nd St. S.E., Cedar Rapids, IA 52401; Tel: (319) 369-3782

CTI PRESENTS



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XSM & XSMP	Ultra-Low Noise Sources, Locked to 5 or 10 MHz
FMPL	Modulatable Phase-Locked Transmitters; Modulatable 10 Hz to 12 MHz
MX	Frequency Multipliers; High Efficiency-Low Noise to 21 GHz
MFSR	Microwave Synthesizer; Ultra-Low Noise & <1 kHz Steps
SLSR	Microwave Synthesizer; Moderate-Low Noise & 1 to 10 MHz Steps
DSR & MDSR	Microwave Synthesizer; Low Noise, Small Size & Low Cost–10 kHz Step
PXS & PXSM	Crystal Oscillators; Free Running or Locked to 5 or 10 MHz
C & VCO	Cavity Oscillators; Low-Noise Mechanically or Voltage Tuned
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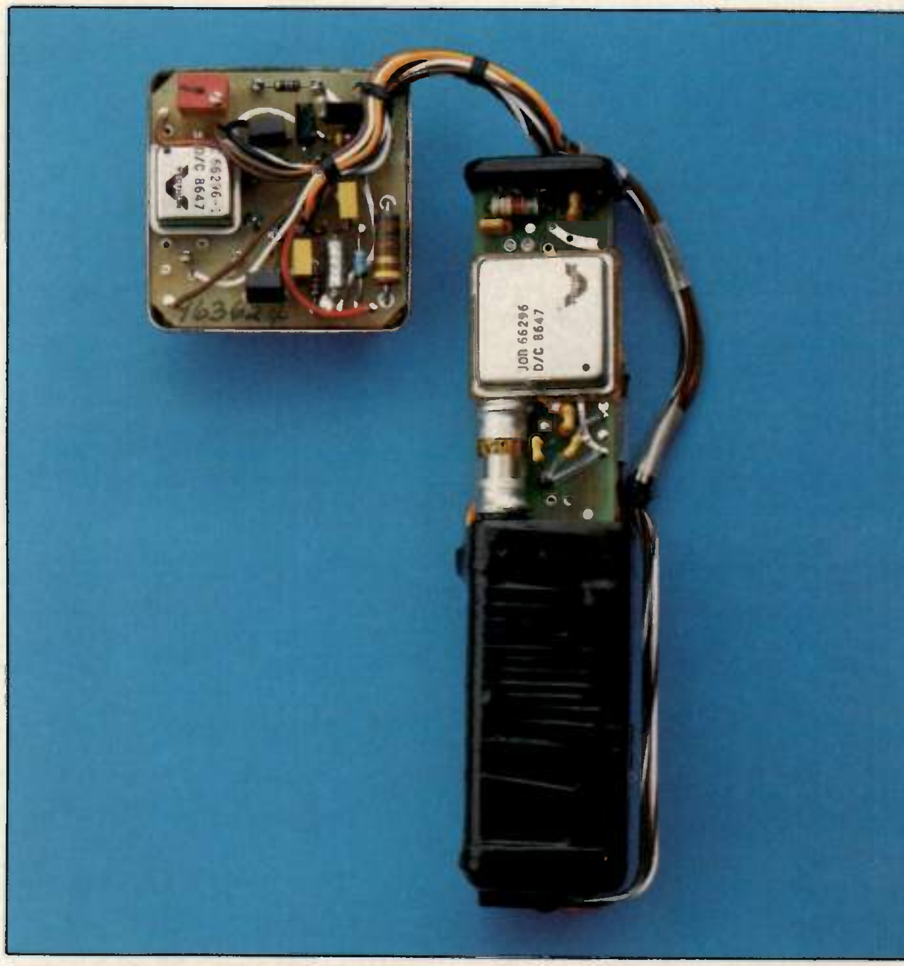
New Oscillator Takes Advantage of SC/IT Cut Crystals

By Gary A. Breed
Editor

An example of the kind of performance demanded by system designers, the Vectron Series CO-505SL2 Oven Controlled Crystal Oscillators provides low noise, fast warm-up, minimum aging rate, and gain-controlled crystal drive level. The key component in achieving this performance is a doubly rotated (SC and IT) cut crystal. The use of these crystal cuts by Vectron is significant, since the company is not a crystal manufacturer. Choice of the crystal was made entirely for its performance capabilities.



Hybrid circuitry simplifies construction of Vectron's CO-305S, smaller companion to the CO-505SL2.

Performance features of the CO-505SL2 include a noise floor lower than −163 dBc/Hz, with phase noise 10 Hz from the carrier guaranteed to be lower than −120 dBc/Hz (typically −125 to −130 dBc/Hz). Aging is less than 5×10^{-10} per day and 1×10^{-7} per year. Short term stability (Allan Variance) is less than 5×10^{-12} per second. The unit operates from a 24 VDC supply, with any voltage from 12-28 VDC optional. Standard output level is +7 dBm into 50 ohms, with +13 dBm, TTL and HCMOS outputs also available.

The crystal, its oscillator circuit and buffer amplifiers are housed in a proportionately controlled oven which maintains crystal temperature virtually constant over large changes in ambient temperature. The oven is set to the turn-over point of the crystal, where SC and IT cut crystals have a low frequency vs. temperature slope characteristic. Operating temperature range options include: $\pm 1 \times 10^{-9}$ over 0°C to 50°C, and $\pm 1 \times 10^{-8}$ over −55°C to +85°C.

Fast restabilization is one of the highlights of the CO-505SL2 performance. The crystal itself is housed in a small second proportionally controlled oven, within the primary oven. It is a phased-in booster heater which allows the crystal to reach its final operating temperature quickly, but without the overshoot common to fast warm-up oscillators with single ovens. In two minutes after turn-on, the frequency is within 1×10^{-7} of the 24-hour stabilized frequency; 1×10^{-8} is achieved within seven minutes. At −55°C ambient temperature these times are five minutes and 12 minutes, respectively. The fast warm-up characteristics are valuable in airborne communications and navigation equipment in which the oscillator may not be continuously energized, but which requires an accurate reference frequency.

The oscillator has a screwdriver adjustment available to reset the frequency. Also, voltage control is provided for fine adjustment or for locking to an atomic standard. Power consumption at turn-on is 15 watts, which may be reduced if the fast warm-up features in not needed. At 25°C ambient, the stabilized power drain is less than three watts.

The CO-505SL2 is packaged in a 2 × 2 × 4 inch enclosure. If a smaller package is required, a companion oscillator, the CO-305S, is available. The CO-305S uses two hybrids, one incorporating the oscillator/AGC/Buffer amplifier, and the other including the oven control. This achieves a 58 percent volume reduction to 1.5 × 1.5 × 3 inches. Also, hybridization has resulted in a mechanically simplified design. Vectron produces the hybrids in-house, and can test them per MIL-STD-883.

This product represents one of the first standard products in the oscillator industry to use a doubly rotated cut crystal. SC and other cuts have been available, but only on an optional basis. More information on the relative merits of the doubly-rotated SC cut and related crystals is contained in this month's Special Report on page 28.

Vectron Laboratories, Inc., Norwalk, Conn. For more information, please circle INFO/CARD #177.

Oscillators: Heartbeat of RF Circuits

By Gary A. Breed
Editor

As the title of this Special Report implies, oscillators provide the reference impulses for RF circuitry, no matter what the application. Every RF device has different requirements for the performance of its oscillator, from just an approximation of a frequency to the maximum available precision and stability. In response to the needs of their customers,the oscillator manufacturers have created a variety of new packaging and performance features to allow engineers to design-in the optimum level of performance at the minimum cost.

Reviewing all the new oscillator products would take an encyclopedia-sized report, but there are a number of recent developments that are significant. These can be summarized into three categories: greater precision, lower cost and smaller packages.

Precision Oscillators

Applications requiring a precision frequency reference are growing at a furious pace. The Global Positioning System, spread spectrum communications, navigation equipment and test instruments all need accurate time base oscillators. To meet these needs, manufacturers have developed some interesting techniques.

Advanced frequency compensation schemes include double ovens, with the crystal controlled separately from the remaining circuitry. Vectron Laboratories uses this technique in the product featured on this month's cover to achieve fast warm-up times. Integrated circuit RF and control circuitry is also becoming common, enhancing the ability to manufacture oscillator products with repeatable precision and a minimum of "tweaking" after assembly. Of course, the cost of production drops significantly when fewer manual adjustments are required. Motorola Components Division products uses their "Flip-Chip" custom IC in their MDO-4 oscillator, achieving ±2 ppm stability over -30 to +85 deg. C.

Sometimes the precision is best achieved by an external reference. This is where the Voltage Controlled Crystal Oscillator (VCXO) has its place. Fine adjustment of frequency is accomplished via an external voltage, whether from a manual control or through a phase locked feedback system. In many applications, a single precision reference can be used with several slave VCXOs locked to it. An example of a currently available VCXO product is a 70 MHz sinewave oscillator from Reeves-Hoffman, packaged in a 0.4 inch high, double-wide DIP. This VCXO's hybrid construction has allowed Reeves-Hoffman to reduce size by 50 percent and power consumption by 25 percent, com-

The AM Microtransmitter from RF Monolithics puts a SAW oscillator buffers and AM modulator in a TO-5 package.

This high performance oscillator from CTS represents the precision that many RF applications require.

pared to previous products.

One more method of temperature compensation is digital, storing the inverse of the frequency vs. temperature response in a PROM or EPROM, as part of the compensation control circuitry. Hughes Solid State Products offers digitally compensated oscillators with replacable EPROM data storage, allowing later recalibration for changes due to aging or replacement of oscillator components.

SC-Cut Crystals

In the area of performance, the growing use of doubly rotated crystal cuts deserves special mention. This family includes SC, IT and FC cuts, with the SC cut the most common, representing the optimum stress compensation, hence the name "SC." Oscillators using SC cut crystals offer the following advantages when compared to the more well known AT cut crystals:

Improved aging. For a given frequency and overtone, SC crystals exhibit two to three times aging improvement.

Warm-up. For the same oven design and power consumption, the SC crystal reaches its final frequency faster.

Phase noise. With a higher Q, SC crystals have better phase noise characteristics, but only very close to carrier since the ultimate noise floor is a function of oscillator design.

High operating temperature. The lower turn-over point (minimum slope of frequency vs. temperature curve) of the doubly rotated crystals is approximately the same as the upper, or higher temperature turn-over of AT crystals. This allows SC, and particularly the IT cut, to be operated at higher oven temperatures required for high ambient temperature applications.

Orientation and vibration. Theoretically, the SC crystal is less sensitive to mechanical influences than AT crystals. However, this apparent advantage is so small that it is not a factor in crystal choice. The design of the remainder of the circuit and packaging has the greatest effect on mechanical stability.

There also are some significant disadvantages that an engineer should know before specifying an SC crystal in an oscillator:

Cost. Fabrication of SC crystals requires tight control of the angle rotations around two axes, compared to one axis for AT crystals. This added complexity increases the cost twofold or more over AT crystals.

Pullability. The motional capacitance of an SC crystal is less than the AT, reducing the available range of frequency shift. Many current VCXO and TCXO designs cannot use SC crystals for this reason.

Operating temperature. The high temperature of the turn-over point is accompanied by a fairly large variation in frequency vs. temperature at lower temperatures. In short, many of the advantages of the SC crystal are lost at room temperature.

Companies making high performance oscillators using SC cut crystals include Vectron, CTS Knights, Hughes and Piezo Crystal Co. Engineers will find an increasing number of SC cut crystals in future high performance oscillator products.

SAW Oscillators

VHF and UHF oscillators using surface acoustic wave (SAW) resonators or delay lines have found increasing RF applications. Although SAW oscillators do not have the phase noise and accuracy specifications of crystal oscillators, there are many applications where the low cost (in quantity), small size and lack of subharmonic energy make SAW devices attractive.

Size is a big advantage for SAW oscillators, which do not require a number of intermediate multiplier stages to reach a high operating frequency. The accompanying power consumption savings is another advantage. Even the disadvantages of lesser stability and accuracy can be minimized through compensation circuitry or by locking the oscillator to an external reference, since SAW resonator oscillators tune easily over a modest deviation from the center frequency. Published performance data from Sawtek Inc. indicates that temperature compensated SAW oscillators can have accuracies of ±20 ppm over a 0 to 70 deg. C range. In an oven-controlled environment, this specification improves to ±5 ppm.

Another product of interest is the SAW delay line oscillator, which exhibits a large tuning range in exchange for reduced performance. This type oscillator has great value in applications up to 1-2 GHz where a broad frequency range must be tuned. The SAW delay line products fill a gap between varactor-tuned oscillators and expensive YIG-tuned designs.

Low cost applications are another area pursued actively by SAW manufacturers. Although RF Monolithics makes high performance SAW devices and modules, they have achieved greater recognition for their low cost receivers and transmitters for FCC Part 15 short-range control and telemetry applications — from garage door openers to industrial monitoring. Their latest entry into this area is the new AM Microtransmitter (see photo). In a low-profile TO-5 case, RFM has included a SAW resonator and a custom IC providing maximum Part 15 output signal strength and 30 dB modulation depth for up to 50 kb/s data rate. This little device can operate from 290 to 420 MHz, with 318 MHz offered as a standard product.

Packaging

What size, shape and pin configuration do you want? Although standard hybrid packages are most common, an engineer can get his desired product in a variety of other packages. Flat packs and gull-wing leaded devices are available for surface mounting, and all sorts of low-profile packages can be had for through-hole construction.

High performance oscillators usually take the form required by their design, with enough room to accomodate ovens, insulating material, control circuitry and connectors. Size is also determined by the necessary thermal mass designed into the product.

Applications, however, are the driving force behind oscillator packaging. Most standard products started out as an answer to specific design needs of a customer. Design engineers are reminded to ask for the availability of custom packaging if a standard product doesn't quite fit the design requirements.

Oscillator development is a evolutionary, not revolutionary, industry. Progress in performance and other aspects of product suitability comes surely and steadily. This year it's SC cut crystals and advanced compensation circuits. Next year will find a different aspect of oscillator development in the news. rf

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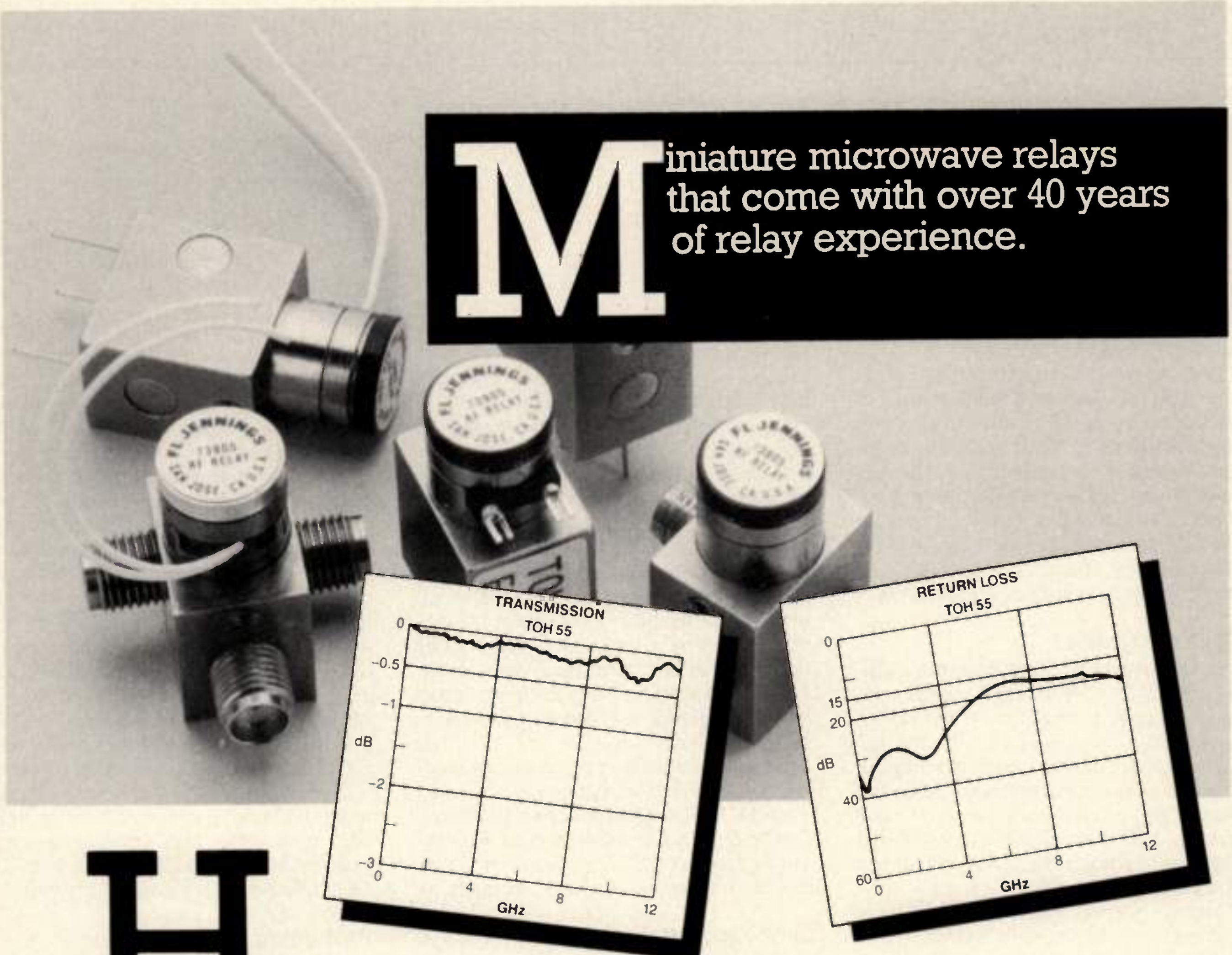

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A High Performance VHF Crystal Oscillator Circuit

By Robert Matthys
Honeywell Systems and Research Center

Do you need a VHF crystal oscillator with good short term frequency stability? A new version of the harmonic emitter coupled crystal oscillator circuit is available with very good short term frequency stability. Originally described by Driscoll (1), the circuit has been simplified and improved by eliminating a transistor stage and a transformer, and adding an RC phase lag network.

The basic schematic of the new harmonic emitter coupled oscillator is shown in Figure 1. It uses only one transistor and operates at frequencies up to 100 MHz. The crystal is connected as the transistor's emitter load impedance and controls the oscillation frequency by controlling the transistor's gain and phase shift. The circuit's short term frequency stability comes from the low impedance load shunted across the crystal by the transistor's low output impedance, which keeps the crystal's in-circuit Q high. The crystal is located at the lowest power point in the circuit (minimum crystal heating) and the output signal is taken at the highest amplitude point in the circuit (maximum signal/noise ratio and minimum external amplification). In addition, the crystal has direct emitter control of the transistor's gain.

The circuit in Figure 1 has positive feedback and will oscillate at the frequency of 0° (or 360°) phase shift, presuming the loop gain is greater than one. The L_1C_1 network normally operates just above resonance, and provides about 120° of phase lag. The R_2C_2 network provides an additional phase lag of about 60°. And the transistor provides 180° of phase reversal giving a total of 0° (or 360°) around the circuit's feedback loop. In practice the crystal's internal impedance (a high Q series LCR network) controls the transistor gain, but it also can vary the normal 180° phase shift through the transistor stage by ±50°. The crystal uses this phase shift mechanism to control the oscillation frequency.

Some typical circuits

A typical circuit at 20 MHz is shown in Figure 2. The crystal, which has an internal series resistance R_s of 14 Ω, oscillates at its third harmonic. The diode clamp D_1-D_2 provides a constant amplitude control. The transistor operates continuously in a linear mode over a complete cycle of oscillation, and reflects a reasonably constant load across the crystal at all times. Figure 3 shows the oscillation waveforms at various points in the oscilla-

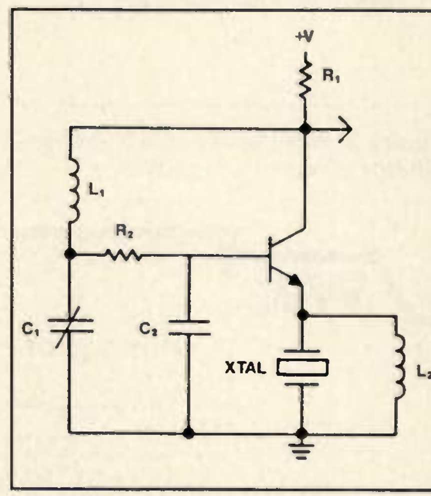

Figure 1. Basic circuit of the harmonic emitter coupled oscillator.

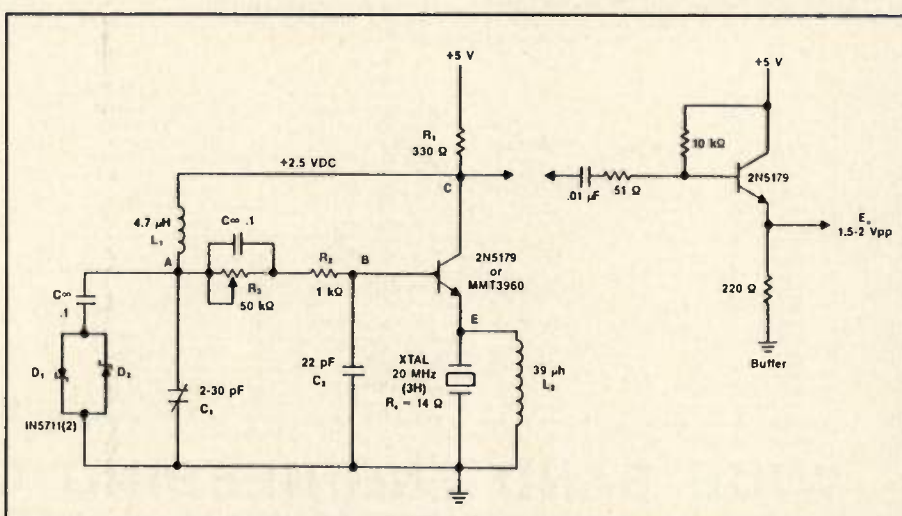

Figure 2. Harmonic emitter coupled oscillator at 20 MHz.

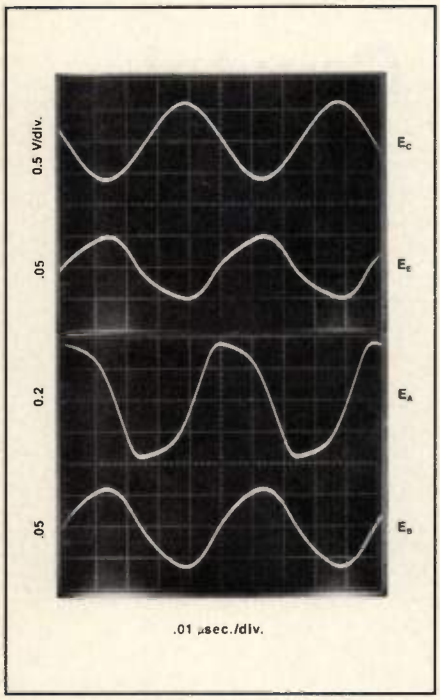

Figure 3. Waveforms for 20 MHz oscillator circuit in Figure 2.

tor circuit. The calculated gain and phase characteristics for the oscillator's entire closed loop are shown in Figure 4. The steep phase change with frequency is an indication of good frequency stability.

A crystal's internal Q is degraded in any oscillator circuit by the external series load resistance R_L added to the crystal's internal series resistance R_S. Figure 5a shows the actual external load impedance seen by the crystal, and Figure 5b shows the equivalent series R_L and C_L values of that load.

The crystal's terminal-to-terminal capacitance C_o is included as part of the load in Figure 5a. The transistor's emitter resistance r_e (4 Ω) is calculated in the traditional way: 30 mV divided by the emitter current (7.6 mA). The 22 pF shunt capacitance from the transistor's base to ground is reflected to the transistor's emitter terminal multiplied by the transistor's (minimum) current gain h_{FE} of 30. From Figure 5b the crystal's internal Q is degraded in-circuit by the ratio of R_L/R_s = 4/14 or 29 percent, a low value that points to good short term frequency stability.

The circuit values in Figure 2 are derived as follows. The transistor's gain is proportional to the ratio of the collector's load impedance to the emitter's load impedance. At the crystal's series resonant frequency, this is approximately the ratio R_1/R_s, where R_1 is the collector's load resistance and R_s is the crystal's internal series resistance. R_s is fixed by the crystal and the operating frequency. R_1 is selected as a ratio to R_s giving enough gain for the circuit to oscillate. L_1 is selected to have a high shunt impedance with respect to R_1 and still resonate at or just above the oscillation frequency with a reasonable-sized variable capacitor C_1. R_2 is selected to provide a relatively high load resistance to C_1.

The impedance of C_2 is reflected across the crystal by the transistor. To provide a low impedance load and high Q for the crystal, C_2 should be as large as possible consistent with R_2C_2 providing a large phase lag without too much gain loss. R_3 controls the transistor's DC current, which is adjusted to set the transistor's collector voltage at half the power supply voltage. L_2 can be any value larger than what will resonate with the crystal's terminal-to-terminal capacitance C_o. The circuit will not oscillate if L_2 is less than or equal

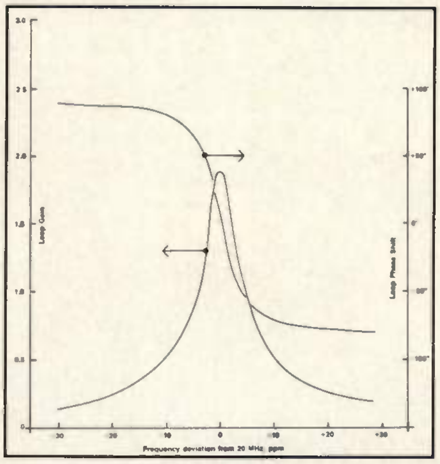

Figure 4. Calculated gain and phase characteristics for Figure 2.

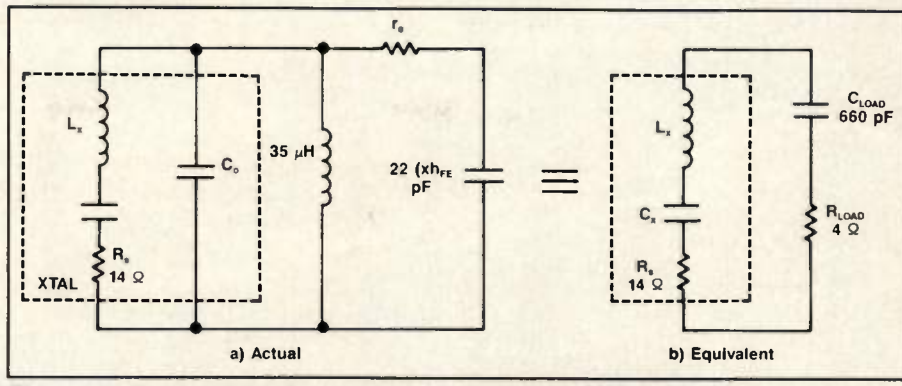

Figure 5. External load seen by crystal in 20 MHz circuit.

to this resonance value. At low frequencies, the 2N5179 transistor in Figure 2 is a good selection. But at 50 MHz and above, the higher gain of the MMT3960 is needed.

Figure 6 shows a 50 MHz oscillator, operating on the third harmonic. Note that the collector's load resistor R_1 has been increased because the quartz crystal's internal series resistance R_s increases with frequency in the VHF range. The crystal's internal series resistance R_s is 30 Ω, and the transistor's (minimum) current gain h_{FE} is 100. Using the same technique shown in Figure 5a,b for the 20 MHz oscillator, the external series R_LC_L equivalent load seen by the 50 MHz crystal in Figure 6 is 5.6 Ω (R_L) and 1000 pF (C_L). The crystal's internal Q is thus degraded in-circuit by the ratio of R_L/R_s = 5.6/30 or only 19 percent.

Figure 7 shows a 100 MHz oscillator operating on the fifth harmonic. Again to maintain the transistor's gain, note the increase in the collector's load resistance R_1 because of the increase in the quartz crystal's internal series resistance R_s. This increase in R_1 with frequency is a design drawback to the harmonic emitter coupled oscillator circuit. From shunt capacitance considerations, it would be better to reduce R_1 as the frequency increased.

An extra capacitor C_3 has been added to the circuit in Figure 7 from collector to ground. C_3 is needed at frequencies above 50 MHz to tune out the shunting

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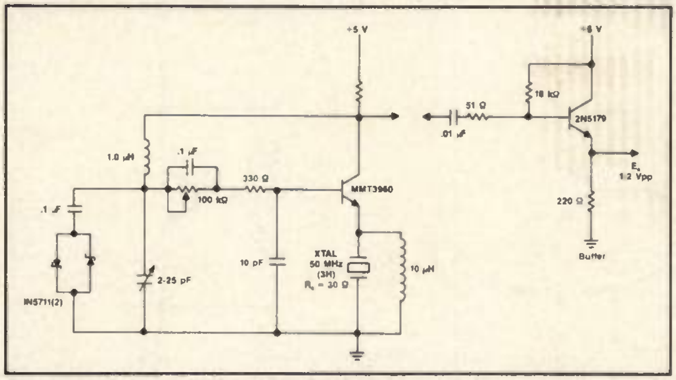


Figure 6. Harmonic emitter coupled oscillator at 50 MHz.

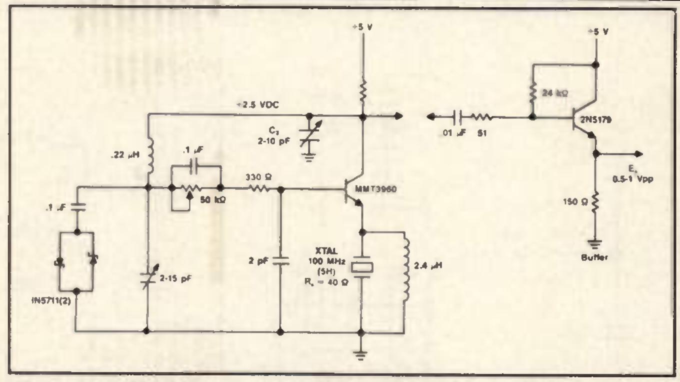


Figure 7. Harmonic emitter coupled oscillator at 100 MHz.

effect of L_1 on R_1, to maintain a high load resistance for the transistor and get enough gain for oscillation. The equivalent series R_LC_L load across the crystal is 8.2 Ω (R_L) and 200 pF (C_L). With the crystal's internal series resistance (R_s) of 40 Ω, the in-circuit Q is $R_L/R_s = 8.2/40$ or only 20 percent less than the crystal's internal Q and the power dissipated is less than 300 uW.

If a desired oscillator frequency is between the oscillator frequencies given in Figures 2, 6 and 7, the circuit values at the desired frequency can be interpolated between the values given in the three figures.

Trimming the frequency

In general, harmonic oscillator circuits do not have a wide frequency tuning range. The frequency can be adjusted by changing any of the phase lags in the oscillator circuit. The frequency trimming shown in Figures 2, 6 and 7 by adjusting C_1 is limited to 5-15 ppm. This can be increased to 25-60 ppm by putting a 35 pF variable capacitor in series with the crystal and using it to vary the frequency. If this

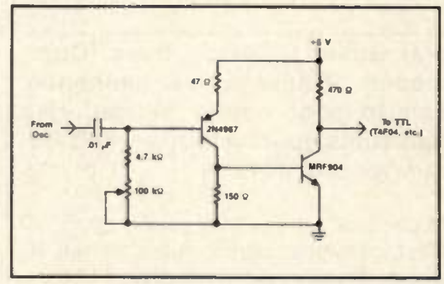
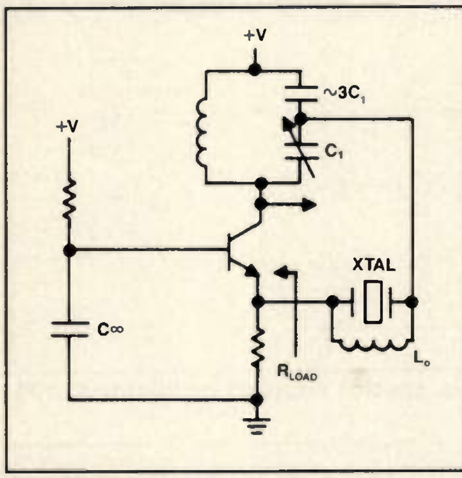
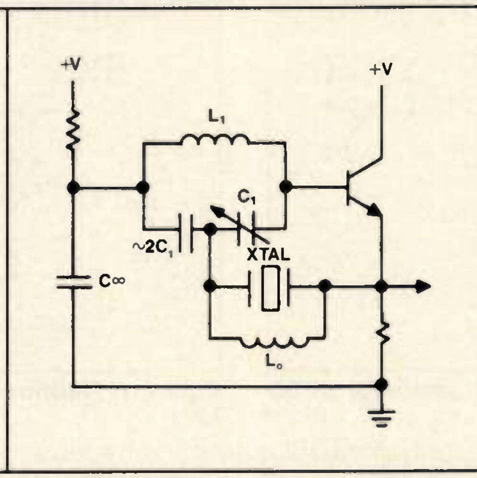


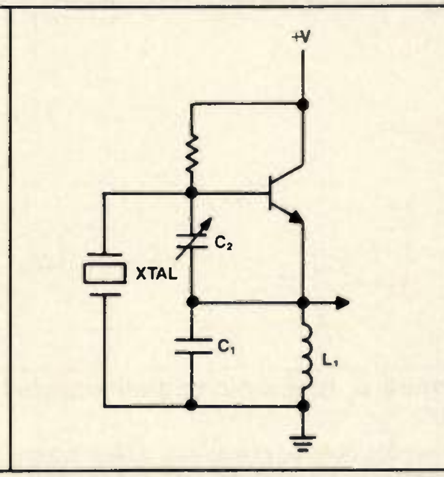
Figure 8. Alternate digital buffer amplifier for driving TTL.



9(a) Butler Common Base. Operates at or near series resonance. Fair to poor circuit design. Has parasitics, touchy to tune. Fair frequency stability.



9(b) Butler Emitter Follower. Operates at or near series resonance. Good circuit design. No parasitics, easy to tune. Good frequency stability.

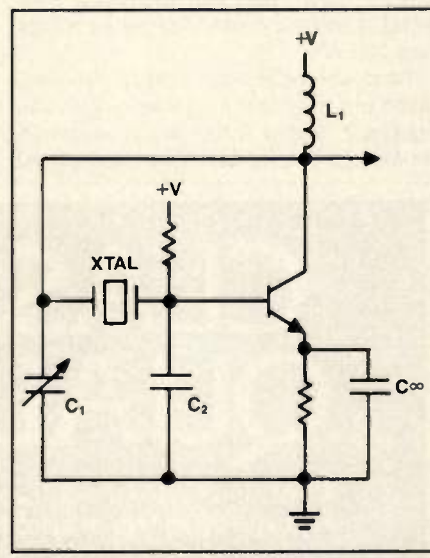


9(c) Harmonic Colpitts. Operates 30-200 ppm above series resonance. Physically simple, but analytically complex. Low cost. Fair frequency stability.

is done at a frequency above about 70 MHz, one must also then put a small inductor directly across the crystal to resonate with the crystal's terminal-to-terminal capacitance C_o and tune C_o out of the circuit.

Performance

The short term stability of all three oscillators described here at 20, 50 and 100 MHz is better than the author's 0.1 ppm measurement capability. Experimental measurements show their short term sta-



9(d) Harmonic Pierce. Operates 10-40 ppm above series resonance. Good circuit design. Good to very good frequency stability.

Figures 9a-d. Basic circuits for four VHF crystal oscillators.

bility to be better than any of four other VHF harmonic oscillator circuits available, all of which have been tested under identical conditions. All three oscillator circuits are relatively independent of changes in the 5V power supply, changing 2 ppm or less for a 2 volt (±1V) supply change. And the circuits have no parasitic effects when a good circuit layout is used. The low phase noise of the original harmonic emitter coupled circuit should remain low in the improved circuit since the primary reason for the low phase noise, the direct

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crystal-emitter control of the transistor's gain (as shown in Figure 1), is present in both versions.

Alternate buffer amplifier

The isolation buffer amplifiers shown with the oscillators in Figure 2, 6 and 7 are intended for sine wave output. An alternate digital buffer amplifier for driving TTL circuitry at frequencies up to 100 MHz is shown in Figure 8. At frequencies below 50 MHz a 2N5179 transistor can be substituted for the MRF904 in Figure 8.

Circuit comparisons

Four other VHF harmonic oscillator circuits are shown in Figure 9(a-d). The design and detailed schematics of these oscillators are given in (2) and (3). The basic schematics of the oscillators in Figure 9 should be compared to the basic schematic of the harmonic emitter coupled oscillator in Figure 1.

The Butler Common Base (Figure 9a) is the poorest circuit and is not recommended because it suffers badly from parasitics, and because its collector current must be held within relatively narrow limits or it won't oscillate. The Butler Emitter Follower (Figure 9b) is a good circuit with good frequency stability, and is particularly useful at the higher frequencies of 100 MHz and above because of its simple wideband amplifier.

The Harmonic Colpitts and Harmonic Pierce are variants of the Colpitts and Pierce circuits used for fundamental oscillation at lower frequencies. The Harmonic Colpitts (Figure 9c) is useful in low cost medium performance applications. It is also used frequently in VCO applications, because of the ease of putting a DC operated varactor diode in series with the crystal. The Harmonic Pierce (Figure 9d) is a simple and excellent circuit whose short term frequency stability is almost as good as the emitter coupled circuit. The Harmonic Emitter Coupled circuit (Figure 1) is a little more complex than the others and can have more parts, but it has the best short term frequency stability.

Applications

As to applications, the harmonic emitter coupled oscillator circuit with its very good short term frequency stability should be a good candidate for the reference oscillator in UHF multipliers, and for signal generators using a phase lock loop to multiply a lower frequency standard up to UHF. And since a varactor can easily be put in series with the crystal in this circuit, it has potential as a stable VCO. Its clean sine wave output should also make it useful as a local oscillator in VHF receivers. rf

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2. R. Matthys, *Crystal Oscillator Circuits*, Wiley Interscience, 1983.
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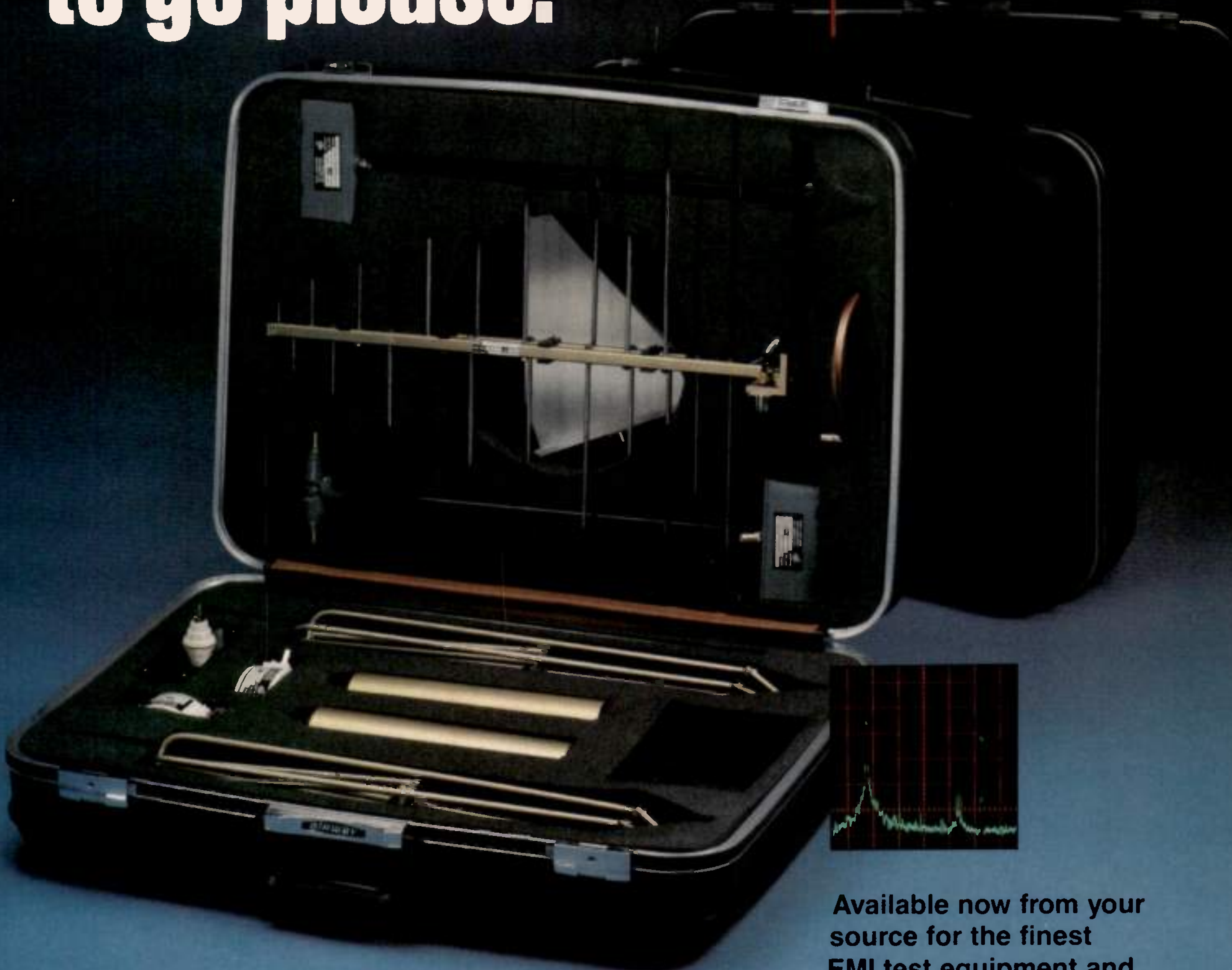

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SAS-200/541	20 - 300 MHz	Bicon'l Collapsible
SAS 200/542	20 - 300 MHz	Biconical, Folding
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Environmental Monitoring for Human Safety Part I: Compliance with ANSI Standards

By John Coppola and David Krautheimer
Narda Microwave Corporation

In the last 35 years there has been a steady increase in the use of microwave energy for commercial, industrial, and consumer as well as military applications. The growth in military satellite communications, navigational and fire control systems is paralleled in commercial satellite and point to point communication systems, navigation aids for aircraft and ocean vessels, and airport and harbor surveillance systems.

Industrial applications of microwave energy for heating, drying, and detection have become widespread in the food processing, wood processing, steel, chemical, baking and cooking industries. The increased use of microwave energy for consumer and industrial ovens and the passage of the Radiation Control for Health and Safety Act have provided a need to measure near field radiation from these devices.

The awareness of potential radiation hazards coupled with the increased use of microwave energy in military and commercial communications, navigation and surveillance systems has prompted action on the part of many organizations and government agencies. The American National Standards Institute (ANSI) has created a new standard (C95.1-1982) which recommends safety levels to prevent harmful effects from human exposure to radio frequency electromagnetic fields. The new standard covers the frequency range from 300 kHz to 100 GHz, and explicitly provides exposure guidelines for both near and far field radiation in terms of both electric and magnetic field strengths. Compliance with the new standard creates the need to measure far and near field radiation over broad frequency ranges. From a practical standpoint, it is necessary to obtain a true measurement of electromagnetic energy of any polarization, emanating from any direction.

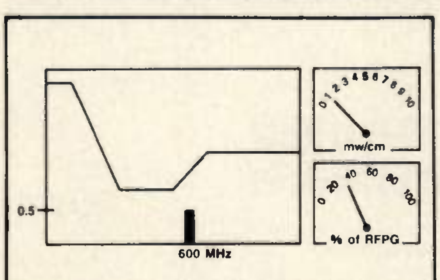

Figure 1. UHF TV

While the new ANSI standard was evolving, many agencies accepted the premise of a frequency dependent exposure limit based on the concept that the rate of energy absorption in humans varies widely with frequency. Various state and local governments have pending or adopted legislation based upon the recommendations contained in ANSI C95.1-1982. In several instances, the maximum exposure limits set forth in this legislation for general public or occupational exposure have been orders of magnitude lower than those contained in the new ANSI standard.

The Federal Communications Commission (FCC) has moved to enforce exposure guidelines which apply to emitters under its jurisdiction. In February 1985, the FCC approved an amendment to the rules implementing the National Environmental Act of 1969. All applicants for new facilities and renewals must inform the commission if the station would result in human exposure to RF radiation in excess of the ANSI guidelines. Indications are that agencies such as the Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) will establish occupational exposure limits similar to the new ANSI standards, and the Environmental Protection Agency (EPA) will also address a frequency dependent limit on general public exposure.

The military is also responding to the new ANSI standard. The Navy's Combat Readiness Electromagnetic Analysis and Measurement (CREAM) Program includes a radiation hazard test set (RADHAZ) keyed to the new standard. The AN/PSM-46 test set will be used for the measurement and control of RF and microwave radiation aboard ship, where multiple signals over a broad frequency range are expected. This instrument reads the weighted signal levels compared to the maximum allowable intermittent exposure. The key to the performance of this system is a unique isotropic electric field probe with a frequency response which mirrors the ANSI standard from 2 MHz to 40 GHz, normalizes all incident signals to a percent-of-standard, and displays the summary contribution directly as a percent of standard. This system represents the state-of-the-art in radiation monitoring technology.

For ANSI C95.1-1982 monitoring applications over the range from 300 kHz to 1500 MHz, where the radio frequency protection guide (RFPG) varies with frequency, the ANSI RFPG Conformal Probe reads exposure level directly as a percentage of the RFPG. Square law response and isotropic design permit the meter to read the net percentage of recommended maximum exposure level even in multiple signal situations, regardless of the num-

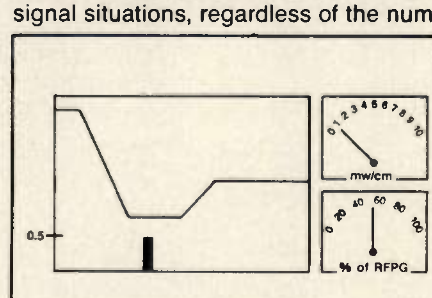

Figure 2. VHF TV

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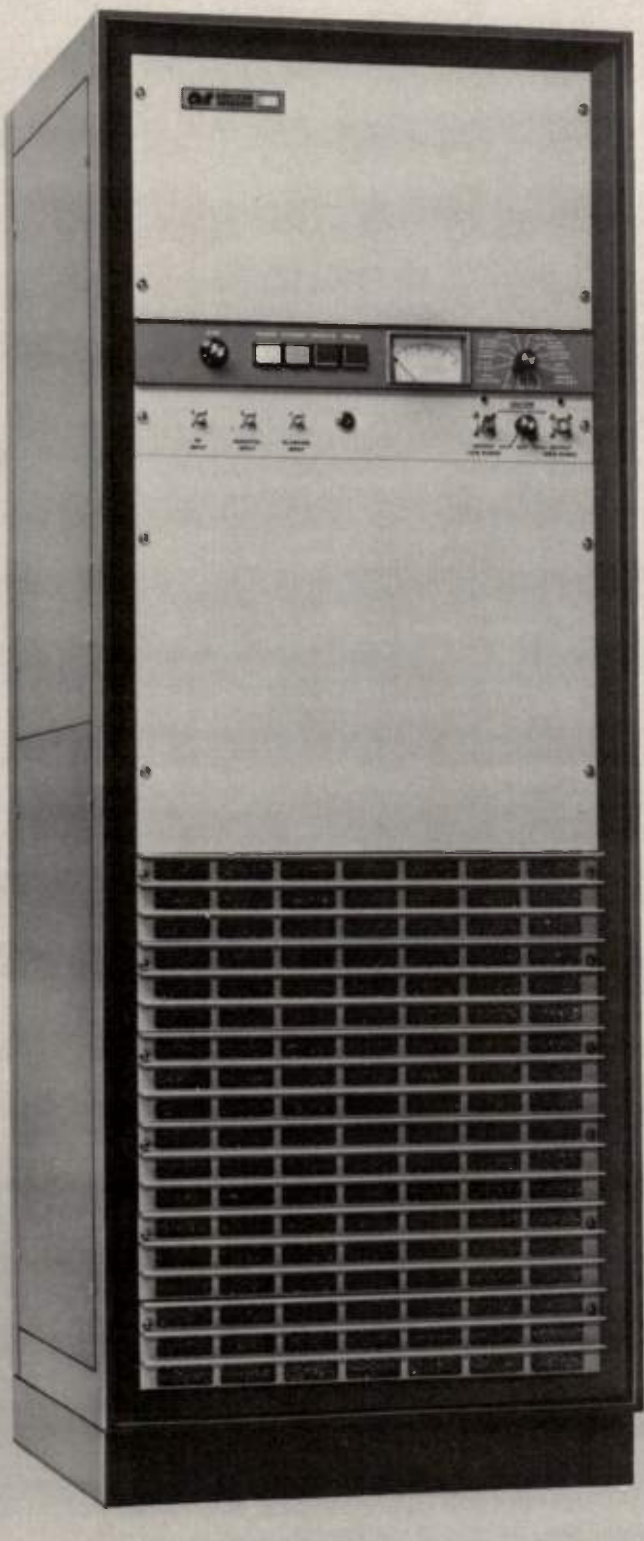

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ber, frequency, modulation, polarization or direction of incident signals in the 300 kHz to 1500 MHz range.

Multiple Signal ANSI Measurement

The RFPG for television broadcast varies depending on the band. VHF TV is within the 30-300 MHz region (1 mW) while the RFPG for UHF TV varies from 1.57 mW at 470 MHz to 2.97 mW at 890 MHz. For a UHF transmitter creating a field of 0.5 mW/cm² at 600 MHz, a "flat" RMS reading probe would measure the true equivalent power density level, corresponding to 25 percent of the RFPG; and a shaped probe would read 25 percent of the RFPG directly (See Figure 1). Likewise, for a VHF TV transmitter creating a 0.5 mW/cm² field, the readings would be 0.5 mW/cm² and 50 percent of the RFPG for the three sensor types respectively (Figure 2).

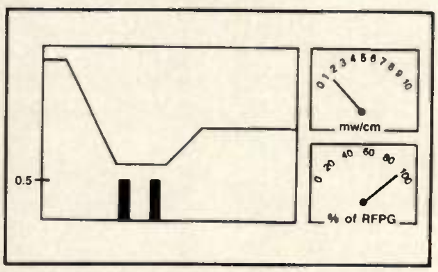

Figure 3. Two VHF TV

Two VHF transmitters with the same output power and field strength (0.5 mW/cm² each) would cause the square law (RMS) sensor to indicate the sum of the two power levels, or 1.0 mW/cm². The shaped probe would also indicate twice the exposure level, or 100 percent (Figure 3).

If VHF and UHF transmitters share the same tower, with each generating a 0.5 mW/cm² field at the point of measurement, the flat RMS reading probe will respond to the true net equivalent power density and read 0.5+0.5=1.0 mW/cm². How should this reading be interpreted? According to the C95.1 Standard, for multiple signals "the fraction of the protection guide incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity." In fact, the shaped sensor would "normalize" each signal as a percent-of-standard independently before adding their contributions, and would indicate 75 percent of the RFPG, the correct value (Figure 4).

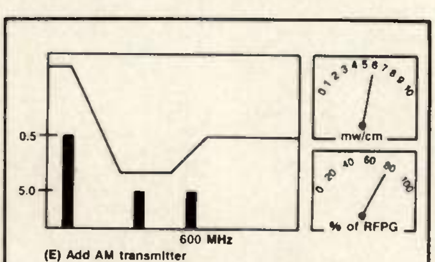

Figure 4. VHF and one UHF

To complicate the situation further, now add an AM broadcast transmitter which contributes a field of 5 mW/cm². The square law "flat" probe would indicate 5+0.5+0.5=6 mW/cm², essentially obscuring the VHF and UHF signals. The shaped probe, however, will add the contribution of a signal which is only 5 percent of the RFPG at that frequency and show the correct value of 80 percent of the RFPG (Figure 5).

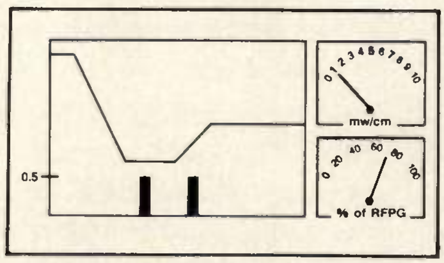

Figure 5. Add AM transmitter

Equivalent Power Density

The conventional description of RF energy propagating in free space consists of an electric and magnetic field, in phase, each perpendicular to the direction of propagation (Figure 6). At long distances (many wavelengths from the source), the RF energy may be viewed as a plane wavefront moving outward from the source (Figure 7).

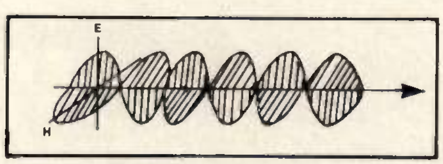

Figure 6. Electromagnetic field.

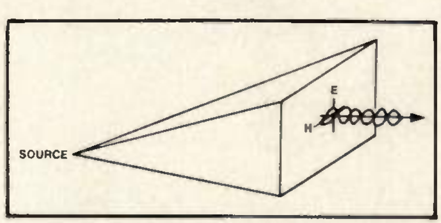

Figure 7. Plane wavefront moving outward from the source.

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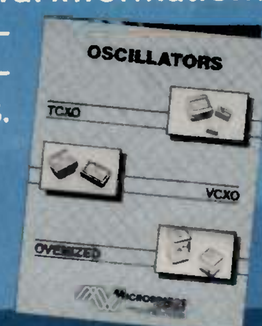

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It is useful to consider the power P which would be intercepted by an object with area A exposed to this plane wave in terms of a normalized plane wave power density P/A in w/m² or, more conveniently, mW/cm². The electric and magnetic fields and the equivalent power density are all related by the characteristic impedance of free space. That is:

$$\frac{E}{H} = 377\ \Omega$$

and $P = E \times H$

so $P = E^2/377$ and $P = H^2 \times 377$

If these measurements are made in the far field, the E/H ratio will be 377. Because the far field relationship between the electric and magnetic field is well defined, the measurement of any one of the quantities E^2, H^2 units are inconvenient to work with, as compared to power density units. Consider, however, that an object exposed to a reactive field of

$$H^2\left(\frac{A^2}{m^2}\right) \text{ or } E^2\left(\frac{V^2}{m^2}\right)$$

receives the same energy as an object exposed to a plane wave with power density $377 \times H^2$ or $E^2/377$, respectively. Thus, near fields are sometimes described in terms of an equivalent plane wave power density, the plane wave power density level which would result in an equivalent exposure level. For example, an equivalent power density of 1 mW/cm² corresponds to an electric field strength of 3763 V²/m² or a magnetic field strength of .02657 A²/m².

Note that in the near field the electric and magnetic fields, even in expressed in the same equivalent plane wave power density units, must still be measured separately, and their levels compared with the ANSI C95.1-1982 RFPG, regardless of the units employed in the measurement. If these measurements are made in the far field, the E/H ratio will be 377. Part II: Radiation Monitors, will feature isotropic radiation monitor systems for measurement of power densities. rf

About the Authors

John Coppola is the vice president of marketing and sales and Dave Krautheimer is a regional sales manager. Both authors have 20 years RF experience. They can be contacted at Narda Microwave Corporation, 435 Moreland Rd., Hauppauge, N.Y. 11788. Tel: (516) 231-1700.

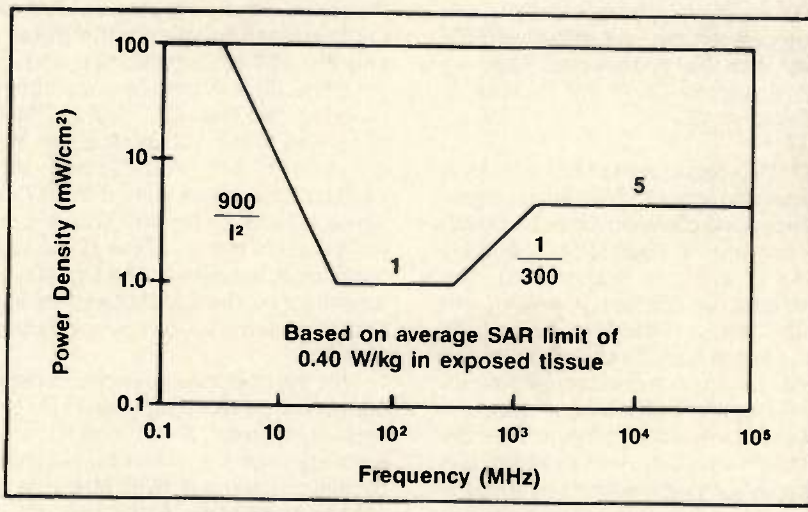
ANSI Standard C95.1-1982

American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields (300 kHz-100 GHz)

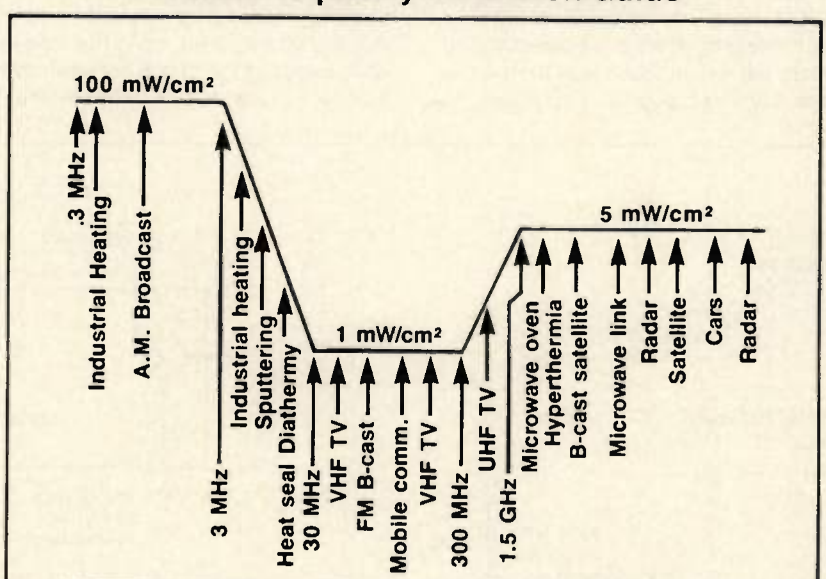
Whole body exposure averaged over 0.1 hours. Both electric and magnetic fields must be measured separately below 300 MHz (near field exposure). For mixed or broadband fields consisting of a number of frequencies for which there are different values of the RFPG, the fractions of the RFPG incurred within each frequency interval shall be determined, and the sum of all fractions shall not exceed unity.

Radio Frequency Protection Guide (RFPG)

Frequency Range (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3-3	400,000	2.5	100
3-30	4,000 ($900/f^2$)	0.025 ($900/f^2$)	$900/f^2$
30-300	4,000	0.025	1.0
300-1500	4,000 (f/300)	0.025 (f/300)	f/300
1500-100,000	20,000	0.125	5.0



Radio Frequency Protection Guide



Typical Emitters within RFPG Spectrum

A Simple FSK Data Receiver

By Mitchell Lee
National Semiconductor Corporation

Provision is made under Part 15.117 of the FCC rules for low-power communication devices operating in the 49.82 to 49.90 MHz band. Under these rules, which limit emitted field strength, useful ranges of well over 100 feet can be achieved in various applications. A popular use of this allocation is digital communications and telemetry. A simple, yet effective, FSK receiver can be constructed from an LM3361A Narrow Band FM (NBFM) IF Amp/Detector IC.

A block diagram of the FSK receiver is shown in Figure 1. The various signal frequencies are obtained for an incoming carrier centered at 49.86 MHz (see 15.117 for a list of available frequencies). The receiver employs double conversion, with IFs at 10.7 MHz and 455 kHz. Ceramic filters are used in both IFs for selectivity and reduced coil count. A quadrature detector is used to recover the baseband data, and an integrator and schmitt trigger filter the demodulated output. Also included is a squelch circuit that functions as a status line; the open-collector output switches high when a signal is received. The LM3361A functions as the 2nd LO, 2nd mixer, limiting IF, quadrature detector, and squelch, yet it consumes less than 4 mA from a 5 V logic supply. The entire receiver requires approximately 10 mA.

Figure 2 shows the complete circuit diagram. A relatively short whip (18" to 24") is used as an antenna. An "L" network matches the whip impedance (4 to 6 pF and 50 to 100Ω in series) to the RF amplifier Q1. Q2 is a Pierce oscillator operating with a 3rd overtone crystal at 39.16 MHz. Q2 is emitter coupled to the mixer, Q3, and the 10.7 MHz difference frequency (49.86-39.16) is filtered by a common FM radio ceramic filter, CF1. The 10.7 MHz IF is applied to the LM3361A at pin 16. An on-board 10.245 MHz Colpitts crystal oscillator is mixed with the 10.7 MHz signal to produce the 455 kHz second IF. An AM radio ceramic filter (CF2) further band limits the signal. The signal is then amplified by the LM3361A's limiting IF amp and demodulated by a quadrature detector.

With the components shown, a detector conversion gain of 0.15 V per 1 kHz of carrie shift is typical. A common transmitter topology uses a crystal-controlled master oscillator running at 16.62 MHz that is tripled to 49.86 MHz. A 16.62 MHz fundamental crystal is easily pulled 1 kHz or more for modulating purposes and when this signal is tripled, so is the frequency shift. Because the Q of a crystal increases as the square of the order of the harmonic, a 49.86 MHz third overtone crystal can only be pulled a few hundred hertz by comparison. A 3.3 kHz frequency shift results in a detected output of 0.5 Vp-p at pin 9 of the LM3361A. Proportionately higher conversion gains are achieved by increasing the 20 kΩ Q-setting resistor at pin 8 of the LM3361A.

The receiver circuit performs significant baseband filtering, as illustrated in Figure 3. An input signal of 100 uV at 1 kbaud data rate was applied. The top trace (a) is the output from pin 9 of the LM3361. Riding on the baseband data is the twice IF product of the quadrature detector. This 910 kHz component is eliminated by the 1 nF/7.5 kΩ/10 nF filter at pin 9 (see Figure 2), resulting in a clean waveform (Figure 3(b)). A LM358 dual op-amp is used as an integrator and a schmitt trigger to filter the data. Trace (c) is the output of the integrator, and trace (d) shows the output of the schmitt trigger.

Figure 4 shows the same set of oscilloscope traces photographed under weak signal conditions. A very noisy detected waveform (a) is effectively filtered and squared, leaving a data stream with approximately 10 percent pulse width jitter at 1 kbaud data rate (d). An input signal of slightly less than 570 nV was used in Figure 4.

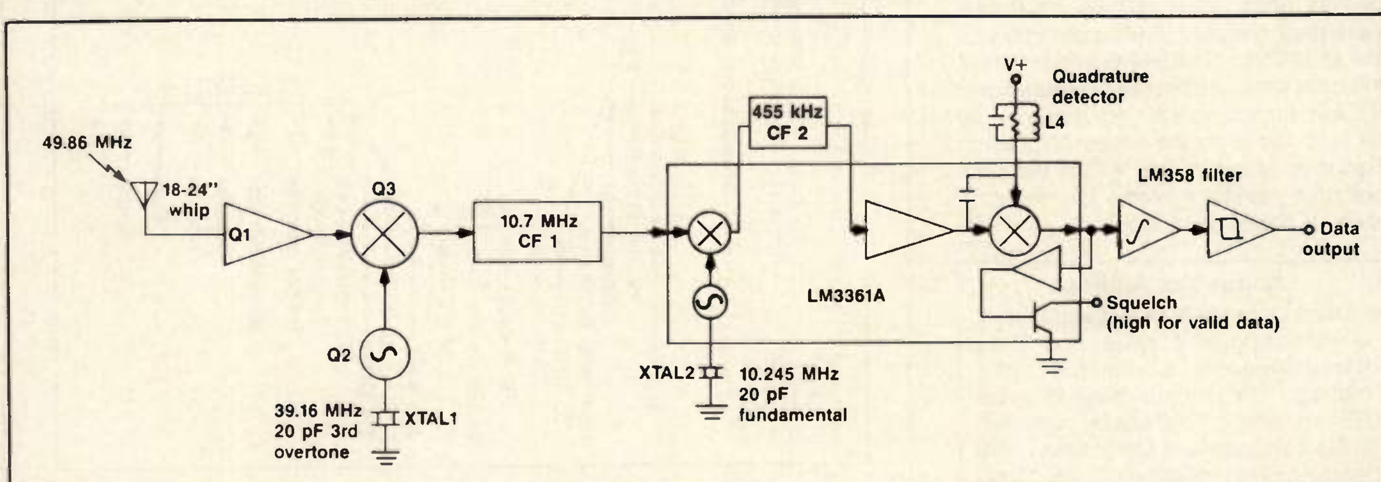


Figure 1. FSK receiver block diagram.

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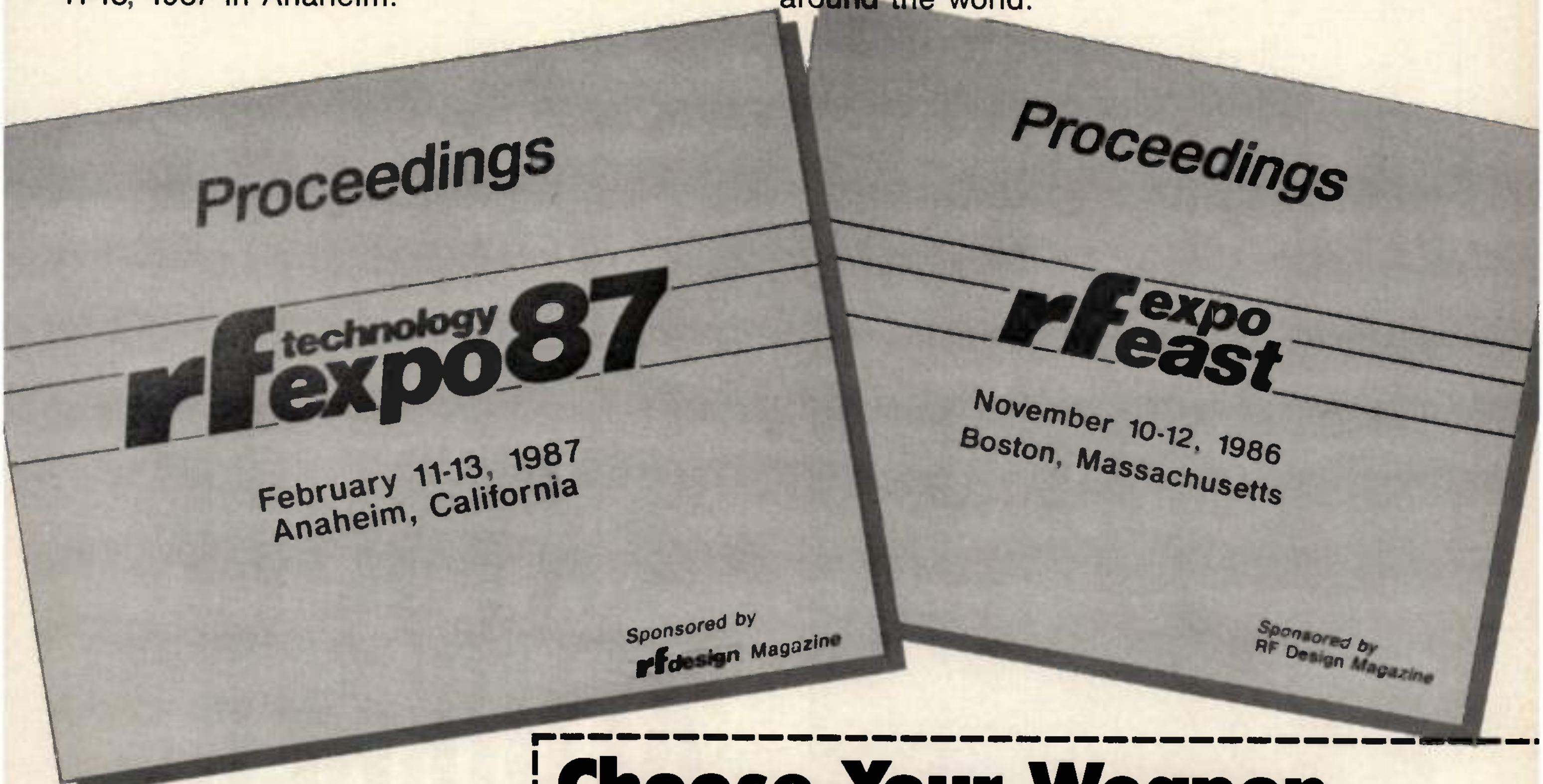

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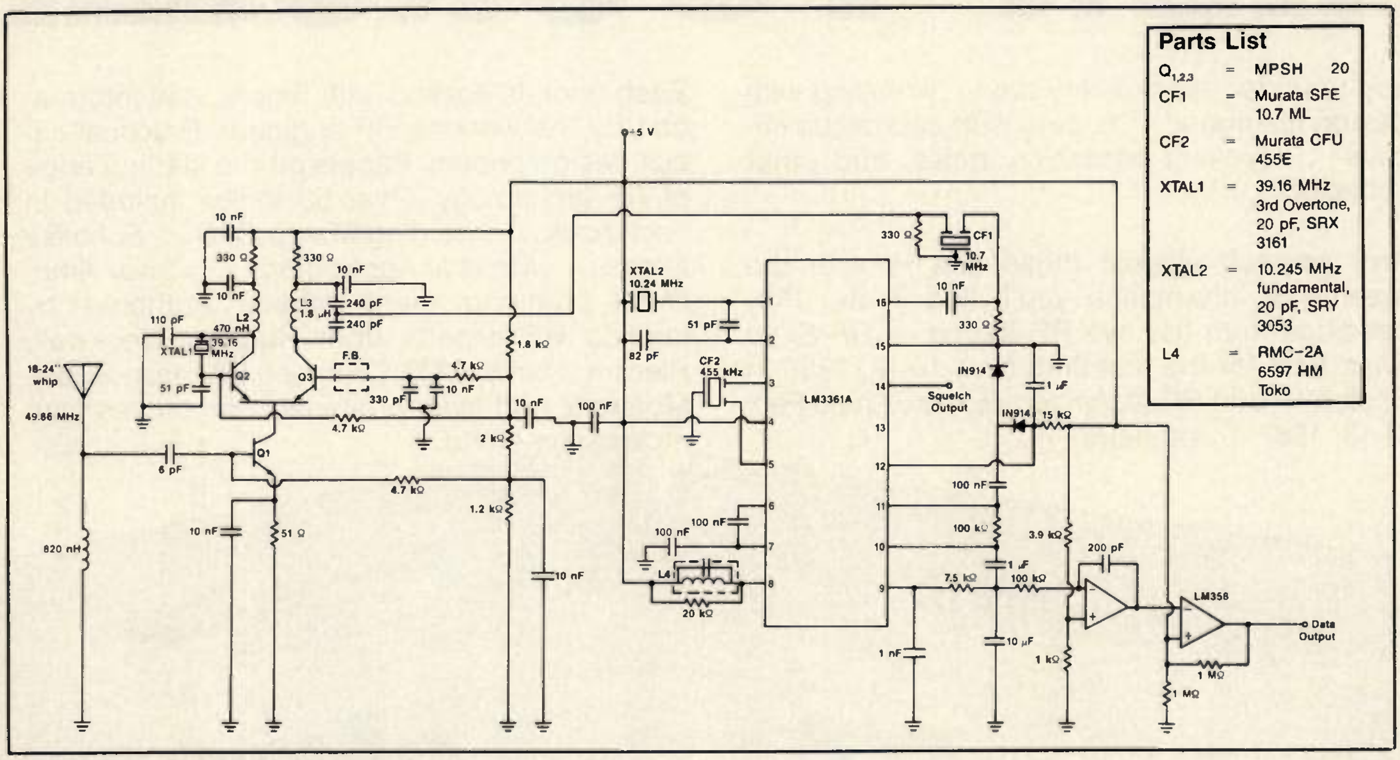

Figure 2. FSK data receiver.

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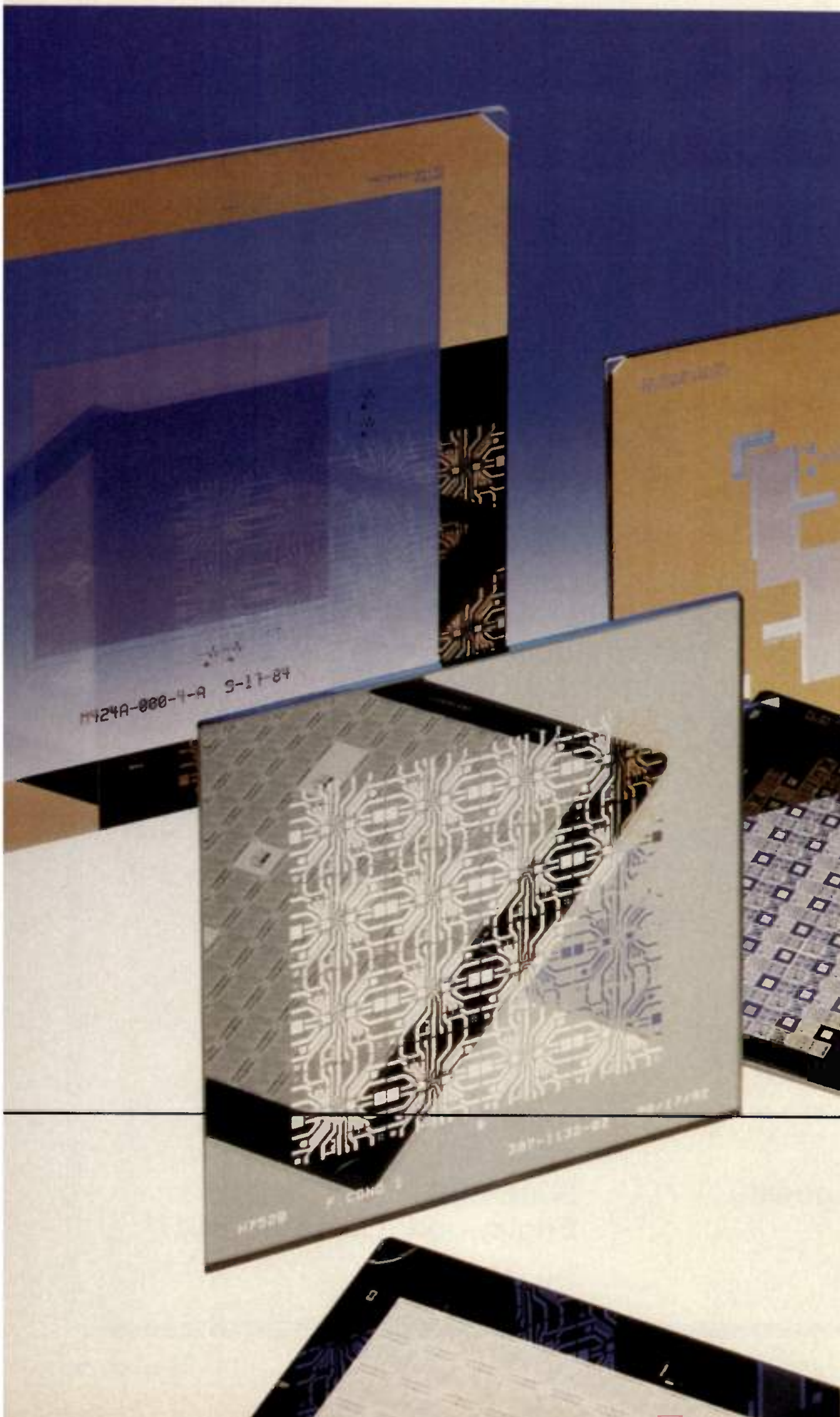

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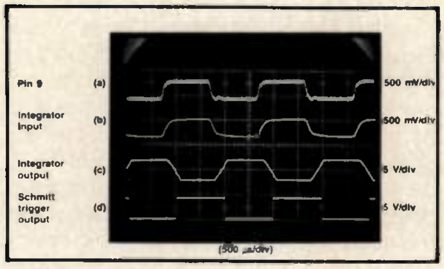


Figure 3. 100 μV input, 1 kbaud data rate.

Given limitations in the bandwidth of CF2, L4, the integrator, and the transmitted signal itself, a data rate of 1.2 kbaud (600 Hz square wave) is a practical limit for this circuit. Since the data is DC coupled throughout, long strings of zeros or ones are handled without complication.

A note of caution: many RF test generators that feature FM capability cannot generate FSK owing to an AC coupled external FM source input. The Boonton 103 and 1020 are examples of generators that can be used for squarewave testing only. Clean output was observed with 500 nV RF input. At this point the baseband signal could be characterized by 10 percent pulse width jitter and occasional loss of a bit. At 600 nV input the squelch line (pin 14) was solidly high with very clean output data. The squelch line goes solidly low for inputs of 300 nV and less, although the data is still visible at the output. The generator was coupled through 6 pF in lieu of the whip antenna for the sensitivity tests. The input impedance of Q1 is approximately 75 Ω. With a 6 pF coupling capacitor approximately 50 to 75 Ω is reflected back to the test generator to provide proper termination.

As an aside, it is a common misconception that a short 49 MHz whip exhibits just a few ohms of resistance. While this may be true, the impedance as measured from the base of the whip to ground is 50 to 200 Ω in series with the capacitive reac-

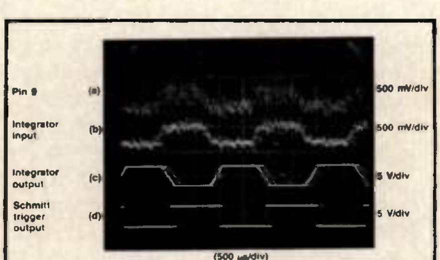


Figure 4. 570 nV input, 1 kbaud data rate.

tance (about 4 to 6 pF). The high driving point resistance is the result of a lossy ground, not the whip itself. The whip reactance varies widely depending on its orientation, and depending on what constitutes "ground." A vector impedance bridge, such as a Hewlett-Packard HP4815, can quickly characterize individual cases for optimum matching.

The squelch circuit detects a carrier in approximately 3 ms, and it detects loss of carrier in 1 ms. Figure 5 shows an oscilloscope photograph of the receiver reacting to a pulsed signal. The top trace (a) shows the squelch output. The oscilloscope is triggered by the start of the signal, and in this picture the squelch opened 3 ms after a carrier appeared. The actual demodulated data (b) that appears at pin 9 begins almost immediately. The DC shift in output is corrected within 1 or 2 ms by the integrator (c) — note that the first bit may be lost. Valid data (d) is available even before the squelch line has switched. The squelch line switches low again within 1 ms of loss of carrier. Data is lost immediately, but be prepared for noise to appear at the data output. Tuning is accomplished by receiving a weak (<2 uV) carrier modulated by a bit stream of alternating ones and zeros, and then adjusting the quadrature coil while observing the integrator output. Tune L4 for a symmetrical trapezoidal waveform at the integrator output. With crystal tolerances of 0.005 percent, no other adjustments are necessary. L1 can be adjusted to peak the receiver's sensitivity.

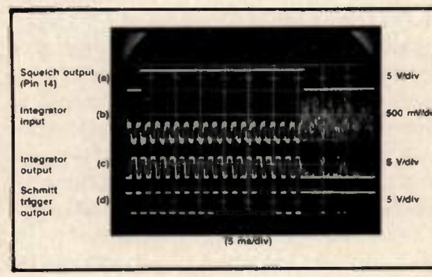


Figure 5. 1 μV input, 1 kbaud data rate.

Circuit performance is affected by component selection and layout. Lead lengths should be trimmed to a minimum, and bypass capacitors — especially in the RF 1st mixer and 1st LO stages — should exhibit low reactance at high frequencies. Disc ceramics are usually excellent in this regard. When in doubt, measure the reactance of a prospective bypass capacitor with an impedance bridge at the intended operating frequency. The recommended transistors are suited for use through 250 MHz, and they will oscillate at those frequencies if adequate layout and bypassing precautions are not observed. A spectrum analyzer is useful for finding spurious oscillations.

About the Author

Mitchell Lee is a linear applications engineer with National Semiconductor Corporation, working with consumer, industrial, and RF integrated circuits. He attended Openshaw Technical College in Manchester, England, and received a BSEE degree in 1980 from California Polytechnic State University, San Luis Obispo. The author can be contacted at NSC, 2900 Semiconductor Drive, MS/C2500, P.O. Box 58090, Santa Clara, CA 95052-8090, telephone (408) 721-5609.

Stable LC Oscillators

Considerations for Electrical, Mechanical and Thermal Stability.

By Fred Brown
Palomar Mtn., Calif.

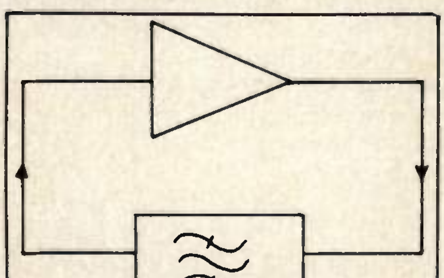
The designer of an LC oscillator must work with frequency-determining components with Q values about 1 percent those of quartz crystals. In comparison to quartz, these components usually have higher temperature coefficients. Copper has a thermal expansion coefficient of about 28 times quartz. In spite of these handicaps, it is possible to design an LC oscillator that rivals the frequency stability of ordinary production-run crystal oscillators.

An LC oscillator consists of an amplifier with a frequency-selective positive feedback loop, as shown in Figure 1. It is unusual for the feedback path to employ a filter more elaborate than a single pole or single zero, although there are stability advantages to doing so. Similarly, the amplifier seldom utilizes more than one stage, although cascaded stages yield certain advantages.

Mechanical and Thermal Considerations

Frequency stability requires mechanical stability of the frequency-determining components. Where the oscillator is subject to vibration, potting or shock mounting of the oscillator compartment may be called for. To prevent the influence of external electromagnetic fields, a totally shielded enclosure is required. If air-dielectric variable capacitors are used, the oscillator compartment should be airtight since humidity changes can affect the dielectric constant (permitivity) of air. Consideration should be given to the temperature coefficient (TC) of the box as well as the components inside; steel is better in this respect than aluminum, although there exist low TC alloys such as invar that are superior to steel.

Even though it is theoretically possible to temperature compensate any combination of components, it is wise to choose them with low TCs. One reason is that the thermal response of a compensating capacitor will not always perfectly track the components that are being compensated. In addition, each component will not necessarily change temperature at the same rate.



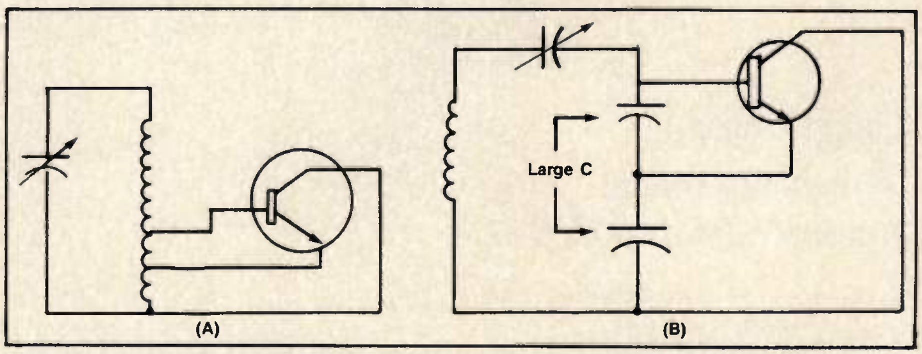


Figure 2. Tapping down of the circuit by active device parameters.

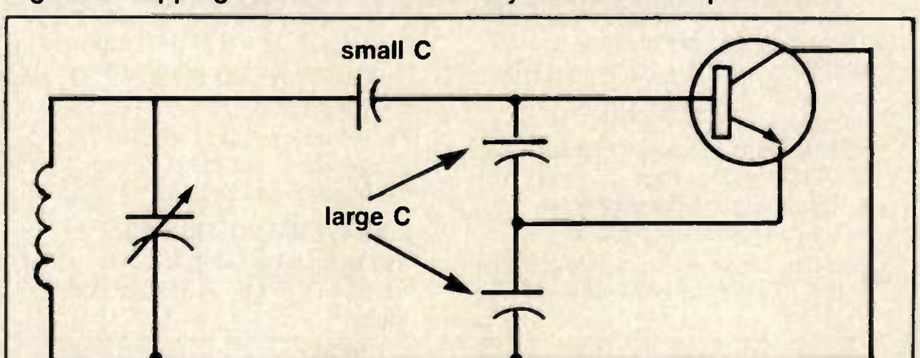


Figure 3. Seiler Oscillator. Capacitive voltage divider decouples parallel tuned circuit from active device.

Inductors are usually wound with copper wire, although silver-plated wire of low TC alloy is preferable. The TC of copper wire can be improved if the wire is wound under tension onto a low TC ceramic form. Where a toroidal core is used the expansion of the wire is of secondary importance, but the TC of the magnetic material must be taken into account.

Heat inside the oscillator compartment should be avoided. During the vacuum tube era, oscillator tubes were often placed outside the oscillator compartment to minimize warm-up drift. This is seldom necessary with transistors, but it is advisable to operate the oscillator at a minimum power level. Thermostatically controlled ovens are often used for crystal oscillators, but the simple on-off type thermostat will usually result in a periodic frequency change when used with an LC oscillator. Almost complete immunity from ambient temperature changes is possible if a non-cyclical type of thermostatic control system is used for oscillator compartment temperature control.

Circuit Design

An oscillator's frequency is not entirely determined by the reactances in the feedback network: amplifier hybrid parameters (input, output, and transfer impedances) also influence the frequency. A good design calls for a circuit that will minimize these influences.

The earliest attempts, which date back to the 1920s, employed parallel tuned circuits of very high C to L ratio in an effort to "swamp out" the influence of the oscillator tube on the frequency. This technique is still used, but high-C tuned circuits suffer from two drawbacks: large circulating currents and lower Q. For a given voltage across a parallel resonant circuit, the circulating current is proportional to the shunt capacitance. The large circulating currents of high-Q designs give rise to component heating and resulting frequency drift. In addition, high-C tuned circuits are usually of lower Q. For a given wire size, low inductance coils generally have a lower Q because the wire resistance is proportional to the number of turns, n, whereas inductance is proportional to n^2. The wire size can be increased for coils of fewer turns, but there are practical limitations to Q improvements with heavy wire. For one, the series resistance of capacitor rotor contacts can become a substantial fraction of the total tuned circuit resistance.

A better way to decouple the active device from the tuned circuit is to "tap down." Examples are shown in Figure 2. Tapping the inductance as shown at A will invite VHF parasitics; it's better if the

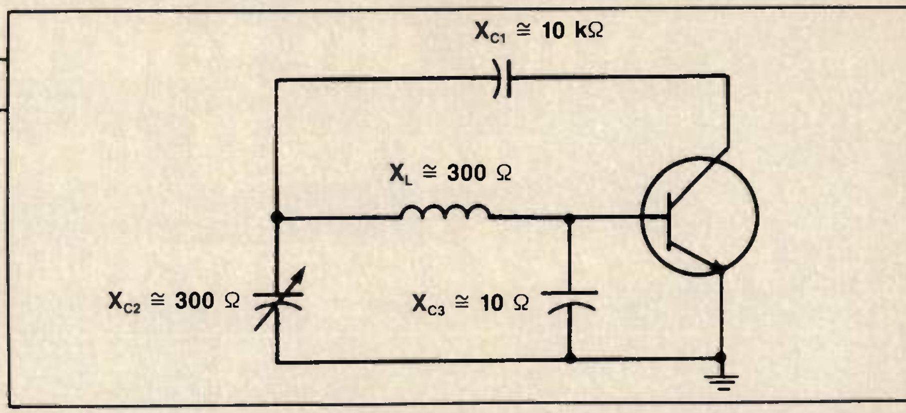


Figure 4. The Inversion Oscillator. Large shunt and small coupling capacitor isolate tuned circuit from active device.

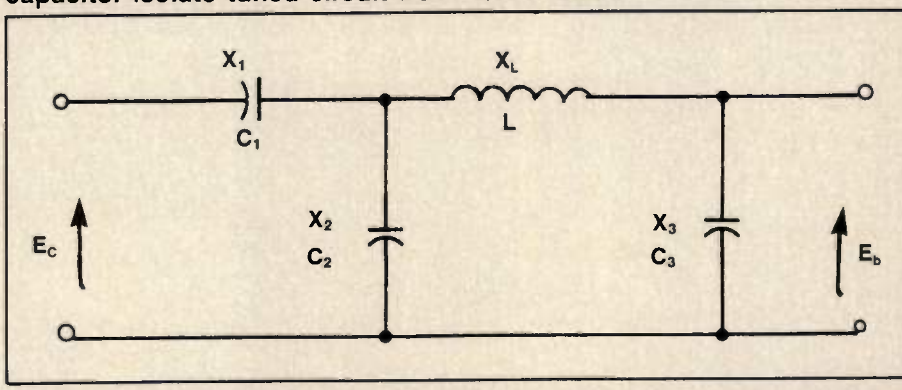


Figure 5. The network between collector and base of the inversion oscillator.

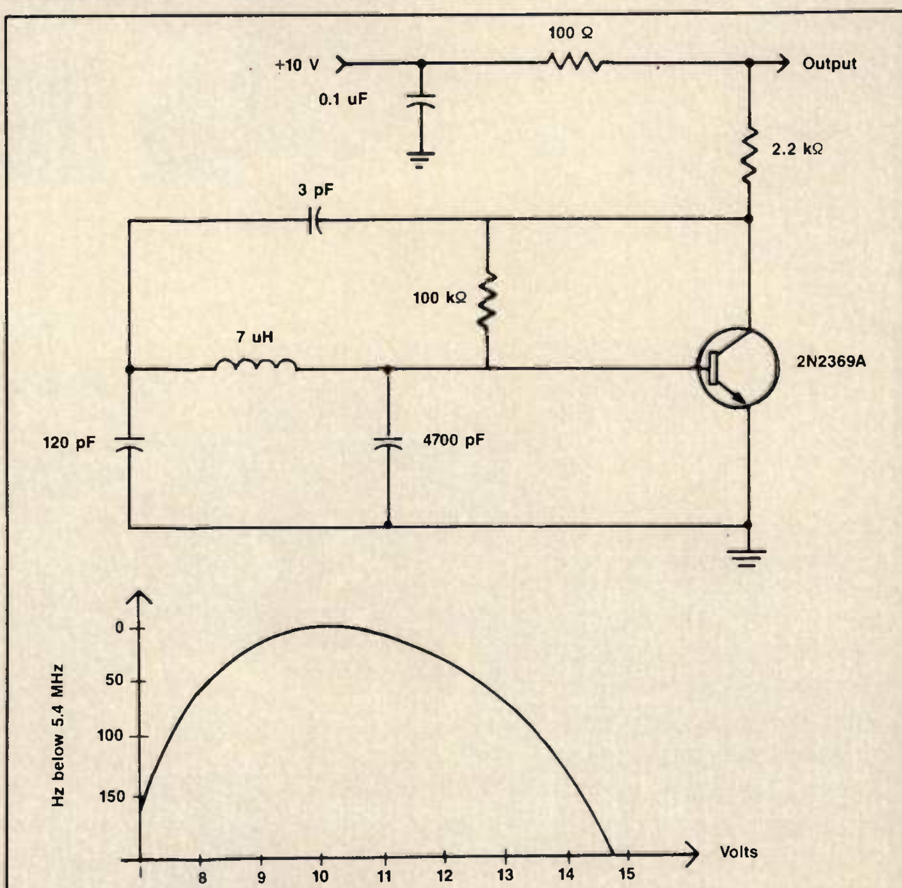


Figure 6. A practical form of the inversion oscillator. The curve is the frequency vs. supply voltage characteristics.

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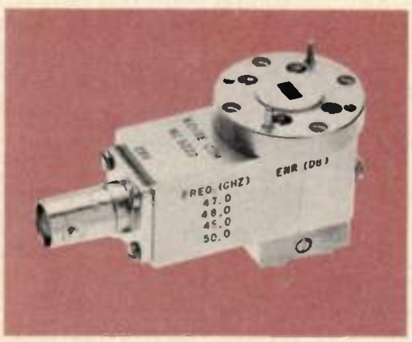

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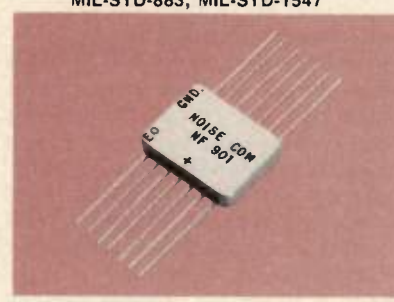

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device is tapped down across the capacitor, as shown at B. The latter circuit was first described by J.K. Clapp in 1948 and is known as the Clapp or series-tuned Colpitts (1), (2). The Clapp can exhibit excellent frequency stability, but has a limited tuning range if the series capacitor is used for tuning. A wider tuning range is possible if the oscillator is tuned by means of inductance variation (permeability tuning).

Another method of decoupling the active device from the resonant circuit is shown in Figure 3. This oscillator was first described by E.O. Seiler in 1941 (3). The Seiler does not suffer the tuning range limitations of the Clapp, and in fact will work with a wide variety of LC ratios over a wide frequency range. Therefore, it is suitable for applications such as bandswitching signal generators and receivers.

The Inversion Oscillator

The arrangement shown in Figure 4 is sometimes called an *inversion oscillator* because the tuned circuit also provides a phase inversion between collector and base. Isolation of the active device is accomplished through use of a large shunt capacitor between base and emitter, and a very small coupling capacitor from the collector to the tuned circuit.

Figure 5 shows the reactive network between the collector and base of the inversion oscillator. The voltage transfer function for this network is:

$$\frac{E_b}{E_c} = \frac{X_3 X_2}{(X_1+X_2)(X_2+X_3+X_L)-X_2^2} \quad (1)$$

At resonance

$$X_L = -X_2-X_3, \quad (2)$$

which simplifies (1) to

$$\frac{E_b}{E_c} = -\frac{X_3}{X_2} = -\frac{C_2}{C_3} \quad (3)$$

The minus signs in (3) shows that the network performs the 180°phase inversion necessary to sustain oscillation. Equation (3) also indicates that the magnitude of the transfer function depends on the ratio of C_2 to C_3 and is independent of the reactance of C_1. This is because the above analysis assumes infinite Q for the reactances and does not take into account the finite input resistance of the transistor. In practice, C_1 can be small, but not zero.

A practical form of the inversion oscillator and its supply-voltage/frequency relationship is shown in Figure 6. Frequency sensitivity to supply voltage is

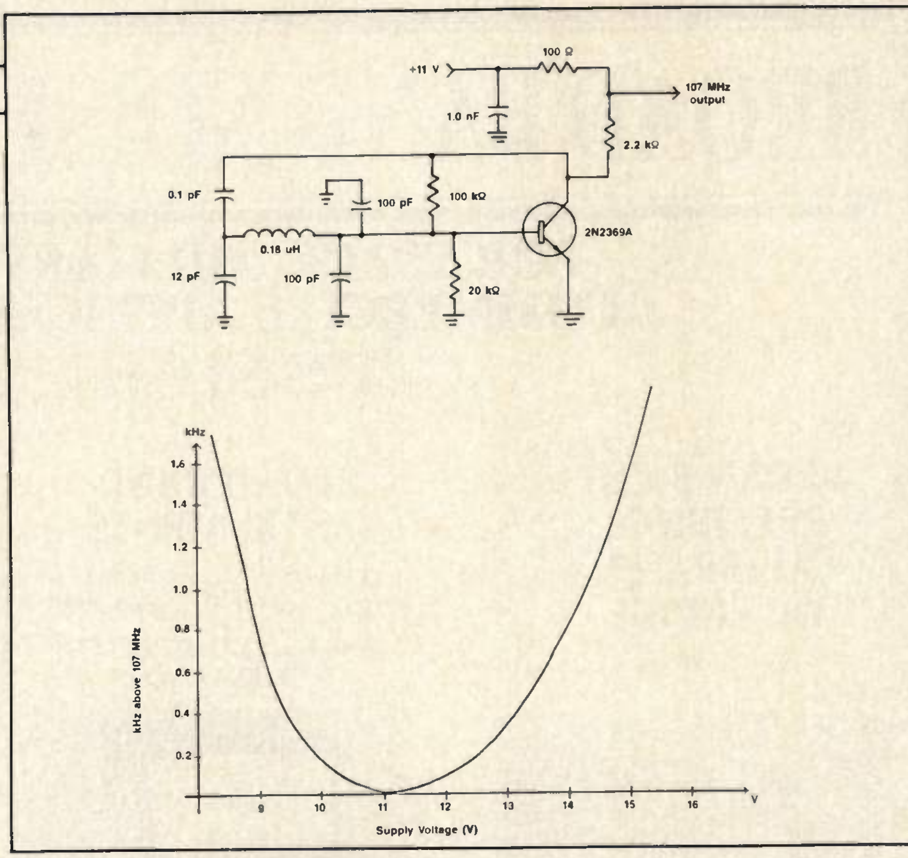


Figure 7. VHF version of Figure 5.

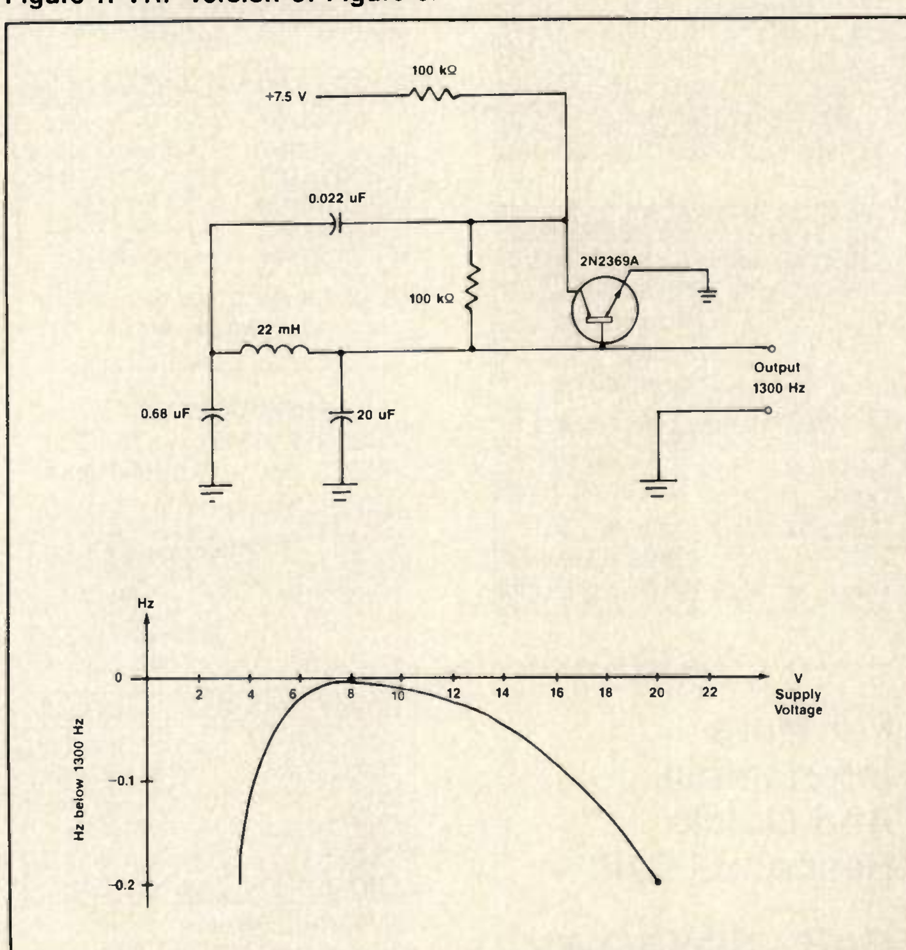
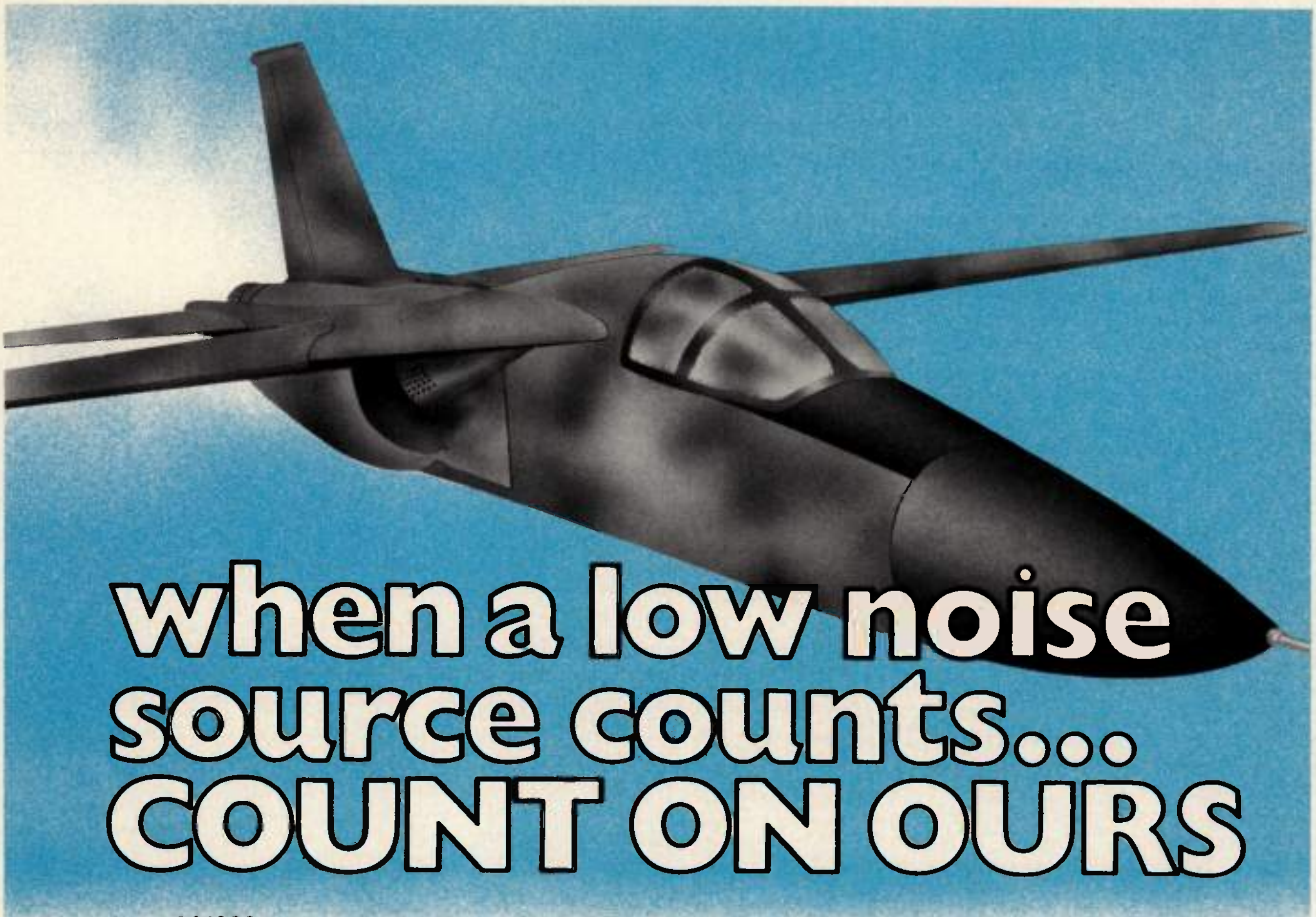
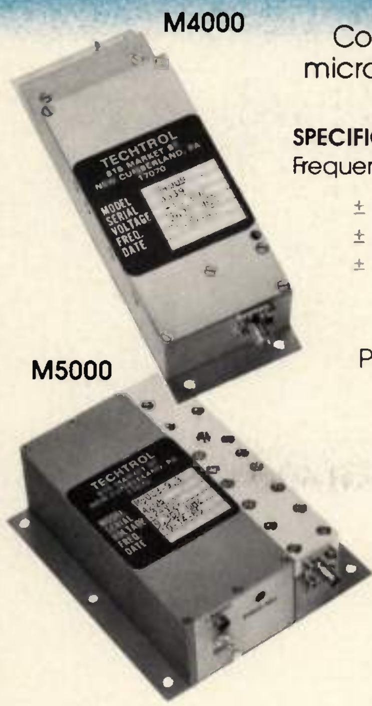


Figure 8. An audio form of the inversion oscillator.





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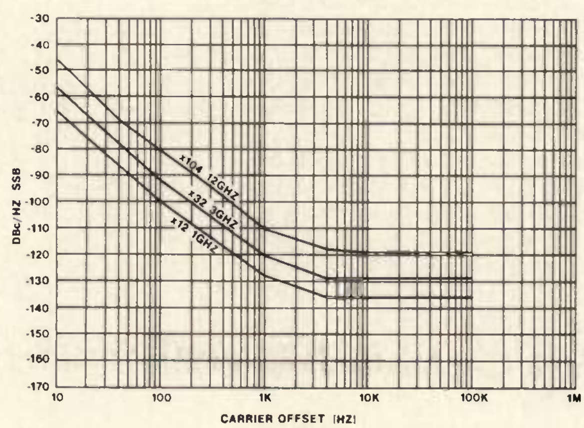

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generally a fairly good indicator of the degree to which amplifier parameters can affect oscillator frequency. Figure 7 shows a VHF version and Figure 8 an audio version.

An interesting characteristic of the inversion oscillator is that if component values are properly chosen it is possible to achieve a U-shaped supply-voltage vs. frequency relationship such as is shown in Figures 6, 7 and 8. On such a curve there will be a region of zero slope, where frequency will be nearly independent of supply voltage.

The Franklin Oscillator

The Franklin oscillator (Figure 9) uses two stages, greater gain and consequently better isolation from the tuned circuit is possible than is the case with only one stage. The Franklin enjoyed some popularity during the tube era although the tube version usually exhibited poor frequency stability with respect to supply voltage changes.

A series-tuned version of the Franklin oscillator is shown in Figure 10. In this case the tuned circuit is isolated from the amplifier by means of small shunt reactances, L2 and C1, at the output and input of the two stage amplifier. As a general rule, these reactances should not exceed 20 ohms or 3 percent of the tuned circuit reactances. Small values will enhance stability, however, too small values will prevent oscillation. TR4 in Figure 10 is a buffer amplifier. If output is taken from the base of TR5, a waveform of low harmonic content will be obtained.

By proper choice of emitter resistors the series-tuned Franklin, like the inversion oscillator, can be made to exhibit a U-shaped frequency vs. supply voltage relationship, as shown in Figure 11. When adjusted, stability with respect to supply voltage is comparable to many crystal oscillators.

Conclusions

Factors that influence LC oscillator stability can generally be separated into two categories: the LC tuned circuit, and the amplifier or active device(s). Several circuits have been presented which minimize the influence of the active device on oscillator frequency. The relationship between supply voltage and frequency is often a good measure of the degree to which changes in transistor hybrid parameters affect oscillator frequency. All four hybrid parameters are affected by supply voltage.

A simple linear analysis using hybrid parameters can easily lead to erroneous conclusions. Unless some kind of ampli-

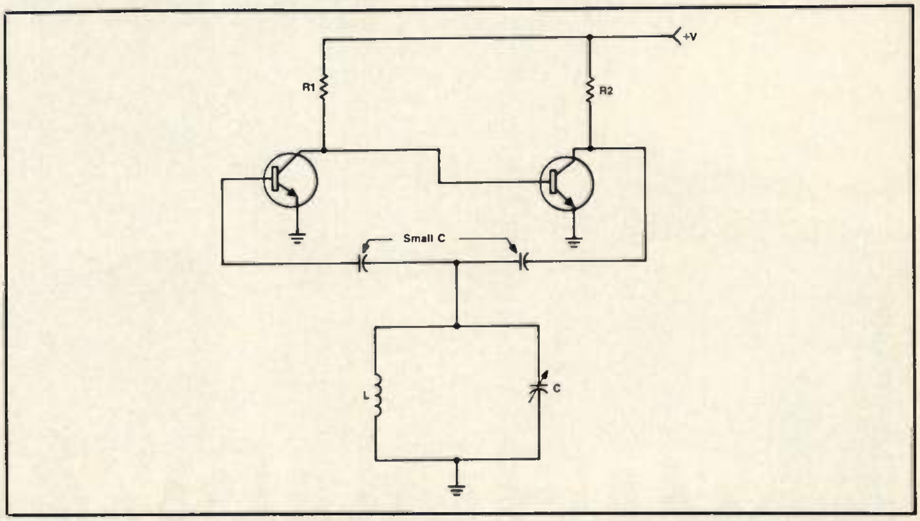
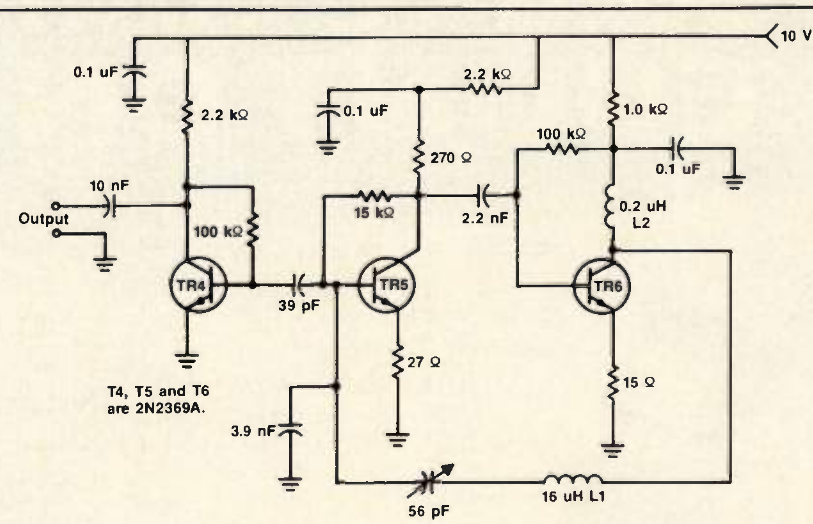


Figure 9. The Franklin Oscillator. The tuned circuit is isolated from the two-stage amplifier by means of exceedingly small capacitors.



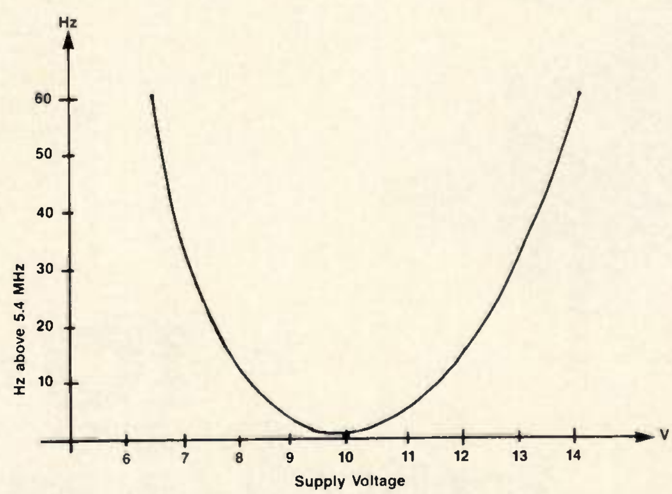


Figure 10. The series tuned Franklin oscillator. Frequency can be changed through C2 or L1.

tude control is used, oscillation amplitude will nearly always stabilize at a point where the transistor is driven into saturation and consequently will function more as a switch than as a linear amplifier. rf

References

(1) J.K. Clapp, "An inductance-capacitance oscillator of unusual frequency stability," *Proc. I.R.E.*, March 1948.

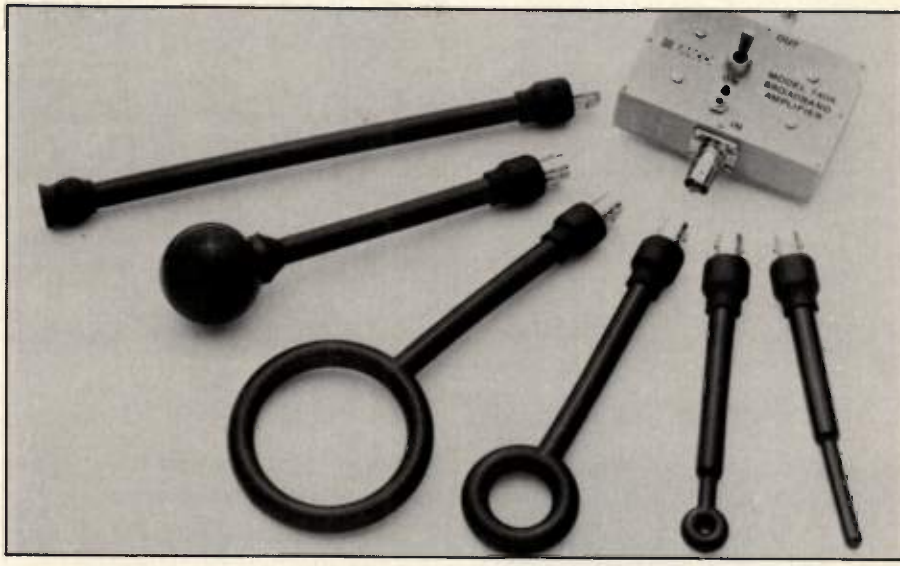
(2) J.K. Clapp, "Frequency Stable LC Oscillators," *Proc. I.R.E.*, August 1954.

(3) E.O. Seiler, "A Variable Frequency Oscillator," *QST*, November 1941.

About the Author

Fred Brown is a self-employed RF consulting engineer. he has worked with RF for 30 years and holds a MSEE from the University of Illinois. He can be contacted at Box 73, Palomar Mtn., Calif. 92060. Tel: (619) 742-1328.

EMCO Offers Low Cost Hand Held Probe



The Electro-Mechanics Company unveils a hand held diagnostic probe set for detection of electric and magnetic signal sources. It is a passive near field probe set designed for use as a diagnostic aid in compliance testing with FCC, VDE, TEMPEST and MIL-STD. The set includes three loop probes, one ball probe, an extension handle and optional preamplifier.

Model 7405 loop probes are selective of magnetic (H) fields and are directional. For each loop probe, H-field sensitivity is relative to loop diameter. At 6 cm, the 901 loop probe is the largest and most sensitive in the set. The 901 can be used to detect the weakest signals in applications where probe size does not affect accessibility. The 3 cm 902 loop probe is designed for maximum sensitivity in applications where access is more restricted. At 1 cm, the 903 loop is the smallest and is recommended for locating the exact source of strong H field signals. The ball and stud probes are optimized to receive electric (E) fields and are omnidirectional. The 905 stud probe is desensitized for precise E-field signal source location.

The optional 910 broadband preamplifier provides amplifications of weak signal sources before input to signal analyzing device. The unit covers a frequency range of 300 Hz to 600 MHz. With 18 dB of flat voltage gain, a noise ratio of 6 dB and a 1 dB compression point of 4 dBm output. Internal battery power eliminates erroneous readings due to ground loops or power line noise.

The Model 7405 covers a frequency range from 100 kHz to 2.3 GHz. It is designed for near field relative readings and is not intended for use as an absolute measurement device. The Model 7405 probe set is priced at $495 while the preamplifier is $225. **The Electro Mechanics Company, Austin, Tx. INFO/CARD #220.**

Rhode & Schwarz-Polarad Introduces the FSAP Specnet

The FSAP Spectrum/Network analyzer covers the 100 kHz to 1.8 GHz (usable to 1 kHz with reduced specifications) frequency range. The Specnet is a combination Spectrum and Scalar Network analyzer. It is compact and incorporates a softkey/hardkey concept with a multicolor high resolution display. All the functions, except power and brightness, are programmable via IEEE-488 Bus. Internal firmware provides hard copy screen dumps on a digital plotter via 488 Bus without an external controller. The unit provides −120 dBm sensitivity, harmonics to −70 dBc and intermodulation to −65 dBc. Frequency span range of 500 Hz to 200 MHz per division plus the zero span receiver mode enables both full span overview measurements and detailed modulation analysis.

Narrow spans are automatically phase-locked and displayed with low close-in phase noise. In the CFCAL mode the center frequency is microprocessor-controlled to ±100 kHz. Resolution bandwidths, video bandwidths and scan rates are automatically correlated with frequency spans in the coupled auto mode and status indication is provided in the uncoupled mode. In the scalar mode, the FSAP uses an internal tracking generator (50 kHz to 1800 MHz) which enables frequency response measurements of filters, amplifiers and transmission circuits. Normalization is a feature that eliminates measurement system errors enabling the use of 0.5 dB/div. range with 0.01 dB resolution bringing low level effects, such as ripple into clear view.

The FSAP is suited for communication signal analysis, CATV, CB, wide range distortion and low noise measurements, test equipment calibration, EMC testing and other frequency domain applications up to 1.8 GHz. **Rhode & Schwarz-Polarad, Inc., Lake Success, N.Y. Please circle INFO/CARD #219.**

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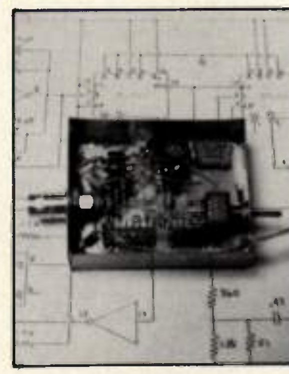

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RULES AND JUDGING CRITERIA

Judging Criteria

Each entry will be evaluated in three categories, each having equal weight:

1. Originality: The purpose of the contest is to reward engineers for their unique design contributions. Each design will be evaluated according to its similarity to work by others, unusual application of a device or technique, and other judgments of its contribution to the advancement of the engineering craft.

2. Engineering: Engineering is the application of technology to solve a problem or meet a design goal. Entrants should clearly identify how their circuit was created in response to such a need. Judges will evaluate performance, practicality, reproducibility and economy.

3. Documentation: Communicating ideas to others is the business of *RF Design* and a necessary part of good engineering. Each entry will be judged on its description, analysis and graphical material. Each circuit should have a complete list of components, explanation of functions, and a summary of performance and test data.

Entry Rules

1. Entries shall be RF circuits containing no more than 6 single active devices (tubes or transistors), or 4 integrated circuits, or be passive circuits of comparable complexity.

2. The circuit must have an obvious RF function and operate in the below-2 GHz frequency range.

3. Circuits must be the original work of the entrant.

4. If developed as part of the entrant's employment, entries must have the employer's approval for submission.

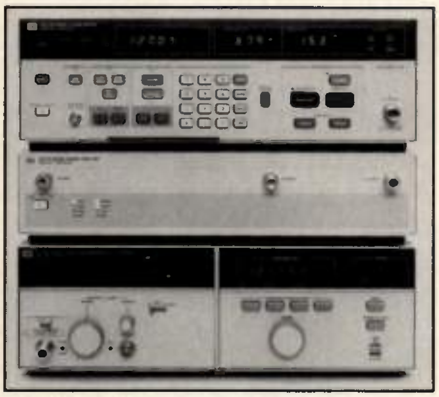
5. Components used must be generally available, not obsolete or proprietary.

6. Submission of an entry implies permission for *RF Design* to publish the material. If published, the entrant will receive the normal per-page author's honorarium.

7. Deadline for entries: **March 31, 1987.**

System for Noise Figure Measurement

The HP 8970T microwave noise figure measurement system provides a measuring solution covering 10 MHz to 18 GHz. This assembly of instruments measures noise figure and gain across the entire frequency range with a single connection and calibration sequence. The system consists of three instruments. The HP 8791B noise figure test set is the central instrument of the measuring system. It is a single sideband down converter with all the necessary tracking pre-selection, mixing and switching built in. The HP 8671B synthesized CW generator serves as the local oscillator and provides the sweeping signal for the microwave portion of the measurement range. The third instrument is the HP 8970B noise figure meter, which automatically measures, corrects and processes the noise figure/gain data for the entire system. **Hewlett-Packard Company, Palo Alto, Calif. INFO/CARD #215.**



Design Kits for SMT Prototypes

Surface mount component design kits for circuit board prototypes are available from Kyocera. The kits come with either 43 standard capacitor values or 129 standard five percent resistor values. It features ceramic chip capacitors in NPO, X7R and Z5U dielectrics, while the resistor kit has size 1206 chip resistors with a ¼ W power rating and a ±300 ppm temperature coefficient. All components have nickel barrier terminations. **Kyocera Northwest, Inc., San Diego, Calif. INFO/CARD #214.**

VHF/UHF Intercept Amplifier

Interad introduces the Model 2719 High Intercept amplifier. The features include a frequency range of 30-500 MHz with a gain of 32 dB and a noise figure of 5.0 dB max. The maximum VSWR is 2:1. Output intercept point for 2nd order IM products is +72 dB, while for the 3rd order it is +39 dB. **Interad Ltd., Gaithersbury, Md. INFO/CARD #213.**

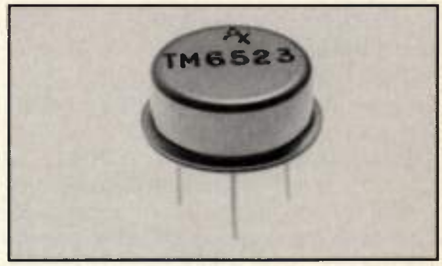
Sweep Generator is Low Cost

New from Anghel Laboratories is the Select-A-Sweep Model 87 sweep generator series. It covers selected bands in the 0.5 to 18.5 GHz frequency range utilizing a series of VCO modules that attach directly to the unit under test allowing an electromechanical interface. Power output into a 50 ohm load is +10 dBm typical. The power variation over the specified frequency range is 2 dBm max. Couple port

mower is −20 dBc ±2.5 dBm. Spurious and harmonics up to 18.5 GHz is 60 dBc max. Output VSWR is 1.5:1. The Select-A-Sweep is priced at $1,995. **Anghel Laboratories, Inc., Fairfield, N.J. Please circle INFO/CARD #212.**

RF Hybrid Amplifier

Amplifonix announces a new RF hybrid amplifier, model TM 6523 in a TO-8 hermetic package. The device provides a gain of 25.5 dB over a frequency range of 5 to 500 MHz. Other specifications include a noise figure of 4.5 dB, 2:1 VSWR



and a 75 mA current at 15 V. The amplifier is priced at $95 in quantities of 1 to 9. **Amplifonix, Inc., West Langhorne, Pa. INFO/CARD #211.**

Field Repair Kit for Conductive Coatings

Carrol Coatings Co. has introduced a field repair kit for products that have been coated against electromagnetic and radio frequency (RFI/EMI) interference. The kit provides a convenient and cost effective means of retouching conductively coated materials without the use of spray equip-

ment. It consists of an aerosol spray unit and a 1, 2 or 4 oz. quantity of pre-thinned two-part epoxy, two-part polyurethane or air-dry acrylic conductive material. **Carroll Coatings Co., Inc., Providence, R.I. INFO/CARD #210.**

General Purpose Amplifier

The model 330 amplifier manufactured by Sonoma Instrument Co. is a general purpose instrument having a 3 dB bandwidth of 10 kHz to 2.5 GHz. Typical gain flatness is ±0.5 dB from 20 kHz to 2 GHz with a gain of 20 dB. This amplifier can

be used to improve the sensitivity of a spectrum analyzer or counter, as well as for increasing the power level of a signal source. The noise figure is typically less than 7 dB at 100 MHz. Isolation from the output to the input is 50 dB to 1.3 GHz and 45 dB to 2.5 GHz. **Sonoma Instrument Company, Santa Rosa, Calif. Please circle INFO/CARD #209.**

Variable Delay Line

Sage Laboratories announces the availability of a new variable delay line or phase shifter with in line SMA or type N connectors. Features of the model 6801 include a variable line from 4.3 to 6.8 ns

and a typical VSWR of 1.2:1 maximum and insertion loss of 0.6 dB maximum to 750 MHz. **Sage Laboratories, Inc., Newton Highland, Mass. Please circle INFO/CARD #208.**

Custom DC to Microwave Amplifiers

Custom transistor amplifiers with a frequency range from DC to microwave that can incorporate hybrid, discrete or integrated technologies to maximize performance and flexibility are introduced by Trontech, Inc. Operating parameters include

a low noise figure (<1 dB), power to 5 W with multi-octave bandwidth to 5 decades and higher. **Trontech, Inc., Neptune, N.J. INFO/CARD #207.**

GaAs Varactors

M/A-Com Semiconductor Products, Inc. announces two GaAs hyperabrupt tuning varactors with constant gamma values of 1.0 to 1.25. The varactors feature high Q values of up to 4000, and are designed from L through Ka bands. They provide linear frequency tuning with bias voltage. **M/A-Com Semiconductor Products, Inc., Burlington, Mass. Please circle INFO/CARD #206.**

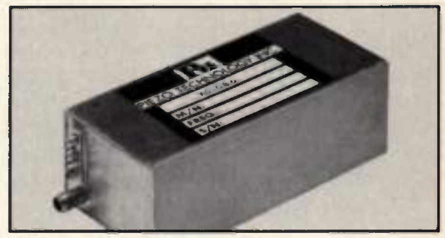
Pulse Amplifiers are Broadband

Picosecond Pulse Labs unveils two broadband pulse amplifiers. The model 5808 has a gain of 6.5 dB and a risetime of 130 ps, while the model 5812 has a gain of 11 dB and a rise time of 150 ps. These amplifiers cover from 10 kHz to 2 GHz. The 5808 is a power amplifier with a maximum linear output of 1.5 Vp-p (7.5 dBm). The amplifiers are packaged in a module with SMA connectors and bias regulator.

Picosecond Pulse Labs, Boulder, Colo. INFO/CARD #205.

Oscillator for GPS Applications

Piezo Technology introduces an oscillator designed for GPS applications. The model X01086 offers $5X10^{-9}$ stability at standard frequencies of 10 to 10.23 MHz. It features fast warm up, low power consumption and low SSB phase noise. The unit operates over a range from −55° to +95°C and is designed for a 100 g/6 in-sec (sawtooth) shock. Acceleration sensi-



tivity is $1X10^{-9}$/G max. **Piezo Technology, Inc., Orlando, Fla. INFO/CARD #204.**

Noise Sources Improve Testing

The NC 3300 series low noise coaxial noise sources are designed to improve measurements of low noise circuits. They have ENRs of 6 dB ±0.5 dB, and are available in either full coverage models (100 MHz to 18 GHz) or various segments from 10 MHz to 18 GHz. Maximum output

power is 28 V at 15 mA. Noise output varies by 0.01 dB with temperature (−55 to 85°C). Rise and fall times are less than 1 us. On/off VSWR is less than 1.2:1. **Noise Com, Inc., Hackensack, N.J. INFO/CARD #203.**

Dielectrics Allow Ag/Au Conductor Combinations

ESL #4905-C and #4905-CH are porous blue multilayer REGAL (Reinforced Glass Alumina) dielectrics with CTE match to 96 percent alumina. Multiple layers and refires are posssible. The via definition for #4905-C is 400 microns X 400 microns compared to 250 microns X 250 microns for #4905-CH. The firing profile for each product is 45 minutes in an air atmosphere with a peak temperature of 850°C for 10 minutes. Minimum dielectric thickness is 37.5 microns for Au conductors and 50 microns for Pd/Ag conductors. Both are compatible with most air fired ESL cermet conductors. **Electro-Science Laboratories, Inc., King of Prussia, Pa. INFO/CARD #202.**

Thin Film Limiting Amplifier

Avantek introduces a thin film limiting amplifier in a DIP package with a gain of 30 dB over the full 5-500 MHz frequency

range. Model UDL-503 has a maximum noise figure of 10 dB. Minimum saturated output power is −2 dBm. The device features ±0.5 dB output power flatness over a 40 dB input power range, low phase shift and high even harmonic suppression (15 dBc to 20 dBc). **Avantek, Inc., Santa Clara, Calif. Please circle INFO/CARD #201.**

Standard Cell GaAs IC Line Expands

TriQuint expands their Q-Logic family of GHz GaAs IC components. The added components are TQ1111 3 GHz counter series, TQ1112 synchronous counter, TQ1121 divide 4/5 counter, TQ1131/32 4:1 Mux/Demux series and TQ1133/34 8/16:1 Mux/Demux series. **TriQuint Semiconductor, Beaverton, Ore. Please circle INFO/CARD #200.**

Oscillator Features Fast Warm-Up

Frequency and Time Systems, Inc., introduces the ultra stable FTS 1000B crystal oscillator, which features high precision and fast warm-up. Phase noise is −116 dBc at 1 Hz and −160 dBc at 10,000 Hz. Maximum frequency change as a function

of temperature is 4×10^{-10} over the temperature range of 0°C to 60°C. **Frequency and Time Systems Inc., Beverly, Mass. INFO/CARD #199.**

Frequency Synthesizer is Low Noise

Model MFSR-5302 Frequency Synthesizer covers from 4512.5 to 5312.5 MHz in 1 kHz steps. This device has low phase noise, low microphonics and no phase hits for applications such as low data rate digital communication, radar, telemetry and instrumentation systems. Power output is +13 dBm, harmonics are >60 dBc, in band spurious >80 dBc. **Communication Techniques, Inc., Whippany, N.J. INFO/CARD #198.**

New Microwave Repeater and Multiplier

Channel Master introduces the model 6651 and 6656 microwave repeater and the model 6650 and 6655 microwave multiplier. The repeater, available in 1 to 5 W, is a low noise amplifier designed to consolidate transmitter and receiver functions, allowing microwave links to be cascaded or hopped without downconverting or upconverting a signal. The multiplier allows the addition of microwave paths to a single transmitter. **Channel Master, Avnet, Inc., Smithfield, N.C. Please circle INFO/CARD #197.**

rf software

Filter Synthesis Program (SYN)

SYN can synthesize RF Chebyshev filters, high or low pass, up to the 29th order. The user specifies: impedance, cutoff frequency, ripple (in dB), number of sections (up to 29), coil diameter and wire gauge. SYN will synthesize the filter, then calculate the exact number of turns for each inductor (single layer solenoid), and the Q of each inductor. SYN can then run a complete analysis of the filter's performance, with its built-in circuit analysis program. Analysis includes: attenuation (S21), phase, return loss, group delay and input impedance, for any frequencies. It comes with both standard and 8087 versions and is priced at $29.00. **RF Engineering, Norwich, N.Y. INFO/CARD #180.**

Software Package for Printed Circuit Boards

Bishop Graphics, Inc. and Douglas Electronics have printed circuit board layout and manufacturing systems for the Macintosh. The ability to have circuit boards manufactured directly from the design file is a feature of the system. The basic layout system sells for $95; $395 with the print option, and $525 with both print and plot option. Free upgrades are available to customers with the 3.0 version of Quik Circuit. **Bishop Graphics, Inc. and Douglas Electronics, Westlake Village, Calif. INFO/CARD #179.**

Circuit Stimulation and Analysis Program

EI Software has developed ProSpice, a package for the IBM PC or compatible. ProSpice is based on "SPICE" 2G.6. This new PC software offers all of the advantages of SPICE without the cumbersome mainframe card image interface. ProSpice includes a preprocessor, a library feature and on-line HELP messages. ProSpice is $495. **Energy Incorporated, Idaho Falls, Id. INFO/CARD #178.**

RF Filter CAD Programs

8th Dimension Enterprises introduces a set of four programs for filter design. They are low pass filter DC to 1200 MHz, high pass filter 1 kHz to 1100 MHz, band pass filter 10 kHz to 1000 MHz, and band reject filter 10 kHz to 1200 MHz. The program begins with basic requirements and calculates component values. However, if you change a component value, the program recalculates the new values for the other components and shows the frequency response during the actual calculation. The price ranges from $49.95 to $99.95. **8th Dimension Enterprises, Sunnyvale, Calif. INFO/CARD #146.**

Technical Brief on GaAs Amplifier

Information on the use of GaAs monolithic amplifiers is contained in an Application Technical Brief from Anadigics, Inc. The ATB101 describes the use on the ADA25001 DC to 2.5 GHz amplifier. The application discussed is the layout of a single stage amplifier using the ADA25001 to provide flat gain response from 100 kHz to 2.5 GHz over a temperature range from −55° to 125°C. The layout includes a temperature compensation loop. **Anadigics, Inc., Warren, N.J. INFO/CARD #194.**

Instrument Rental Guide

Leasametric has released its 1987 rental product guide. This document lists more than a thousand models of electronic test, industrial and telecommunications equipment. It incorporates an overview, product descriptions, specifications and selection guides. Features such as manufacturers, product indexes and cross reference charts are included. **Leasametric, Foster City, Calif. INFO/CARD #193.**

The Everest System Brochure

A brochure titled "The Everest™ System: The Peak in Hybrid Materials Compatibility" is available from Engelhard Corporation. It consists of 10 matched electronic materials used in the manufacture of complex multilayer hybrid circuits. Included are data sheets, information on combining the different Everest materials and instructions on obtaining extensive test results and application advice from Engelhard. **Engelhard Corp., Iselin, N.J. INFO/CARD #191.**

High Frequency Power Ceramic Capacitor Catalog

A new 20-page High Frequency Power Ceramic Capacitor catalog, #61-11, is available from Murata. It includes data on series DCC, DCC and DAU, DCT and DAT, DCF and DAF and DE. The capacitors are rated to 40 kV and 250 A RMS. Also included is specification information on the line of monolithic ceramic capacitors for RF power applications. **Murata Erie North America, Inc., Smyrna, Ga. INFO/CARD #190.**

Electroactive Polymer Review

Electroactive Polymer Materials is a 1986 review of worldwide developments in the field of electrically conductive polymers. The report covers filled polymers in which the electrical properties come from materials like carbon or aluminum. Other polymers that are discussed include inherently or molecularly conductive, piezoelectric and pyroelectric polymers. Among the present and future applications considered are radar, hydrophones and EMI shielding. The review is priced at $18. **National Technical Information Service, Springfield, Ill. INFO/CARD #188.**

Pure PTFE Brochure

Polyflon's brochure covering its CuFlon® pure PTFE ultra low loss microwave substrates has been updated. The brochure covers typical applications, performance data and specifications. CuFlon substrates feature a pure PTFE dielectric with a dielectric constant of 2.1, and a dissipation factor 0.00045 at 1.0 to 30 GHz. **Polyflon Company, New Rochelle, N.Y. Please circle INFO/CARD #182.**

New Cable Assemblies Buyers Guide

Anixter Bros. has published a buyers guide featuring the various cable assemblies for voice/data, networking systems and applications. The wide range of assembly products include coax cable assemblies, combination connector cable assemblies, D subminiature cable assemblies and telephone type cable assemblies. **Anixter Bros., Skokie, Ill. INFO/CARD #187.**

Current Probes Brochure

Fischer Custom Communications has four new brochures. They are titled "Current Probes," "Linear Impedance Stabilization Networks," "Spikeguard Suppressors (nanosecond transient protection)" and "Power Line Impedance Stabilization Networks." **Fischer Custom Communications, Inc., Hawthorne, Calif. INFO/CARD #186.**

EMC Products and Services Report

Frost & Sullivan has completed a 194-page analysis of the Electromagnetic Compatibility Products and Services market in the U.S. It defines, categorizes and analyzes the principal types of EMC products and services. The features include operating characteristics and applications, end use application for EMC products, current products and expected advances, impact of EMC imports and EMC suppliers by product category with their market shares. The report is priced at $1,775. **Frost & Sullivan, Inc., New York, N.Y. INFO/CARD #185.**

Direct Methods of Calculation and Analysis

Howard W. Sams & Co. has recently released "Feedback Amplifier Principles" by Dr. Sol Rosenstark. The circuit analysis required for the calculations in this text consists of the voltage divider, current divider, Thevenin's and Norton's theorem. Topics include feedback amplifier circuit analysis, calculation of loop gain frequency response and common oscillator configuration. "Feedback Amplifier Principles," No. 22545, retails for $32.95. **Howard W. Sams & Company, Indianapolis, Ind. Please circle INFO/CARD #184.**

Application Note 106

KeyTek Instrument Corporation announces the availability of an application note describing techniques for conductive surge testing of powered electronic equipment. The AN106 describes surge test requirements, test waves, method of coupling to the equipment under test (EUT) and isolation of the EUT. Techniques for monitoring the surge wave within the EUT is also discussed. **KeyTek Instrument Corp., Wilmington, Mass. Please circle INFO/CARD #183.**

SMD Catalog

Bliley Electric Company has published a 12-page color catalog, which updates the specifications for its line of quartz crystals and crystal oscillators. Bliley's SMT crystals, OCXO and TCVCXO oscillators are covered in detail. The C/D5 catalog is available on request. **Bliley Electric Company, Lewiston, N.Y. Please circle INFO/CARD #189.**

Signal Processing Filters Catalog

Wavetek has released a short form catalog of dual and multichannel signal processing filters. Following a brief overview of filter types and methodology, applications for band limiting, digital signal processing, acoustic studies and distortion measurements are highlighted. **Wavetek, Inc., San Diego, Calif. Please circle INFO/CARD #181.**

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Advertiser's Index

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INFO/CARD 54

SAW Questions and Andersens.

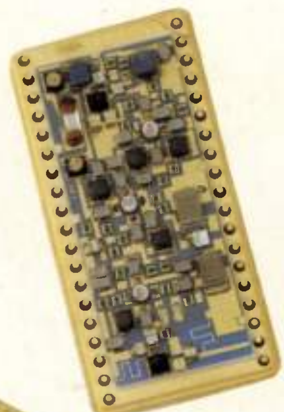
Oscillators:

QUESTION: I've heard a lot about SAW hybrid oscillators. When should I consider using one?

ANDERSEN: Any time you need a compact, rugged low noise source in the 100 MHz to 1 GHz range.

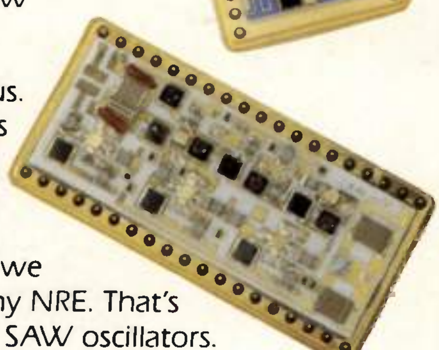
QUESTION: What do you mean by low noise?

ANDERSEN: We build SAW hybrid oscillators to phase noise specs of −95dBc/Hz at 100 Hz offset from the carrier to less than −160dBc/Hz at 100KHz.



QUESTION: Are there high NRE costs associated with SAW oscillators?

ANDERSEN: Not with us. We've developed designs for fixed frequency and VCO applications which can cover the entire 100 MHz to 1 GHz range. So we normally don't charge any NRE. That's why we're the leaders in SAW oscillators.



QUESTION: Where are SAW oscillators being used?

ANDERSEN: Our fixed-frequency SAW oscillators are being used in IFF and air traffic control systems, as local oscillators for frequency up/down converters in radar and communications systems, as master clocks for digital communications systems, just to name a few of the applications.

Our SAW VCO's are used in a wide range of Phase Locked Loops including timing recovery circuits for fiber optic data transmission systems where the oscillator reestablishes the timing of the data stream at the end of the fiber optic lines.

QUESTION: How do I get started?

ANDERSEN: Just give us a call. We'll do everything we can to meet your needs. If you simply want more information, send for our handbook on SAW Hybrid Oscillators. Write to Andersen Laboratories, 1280 Blue Hills Avenue, Bloomfield, CT 06002, Phone (203) 242-0761/ TWX 710-4253 2390

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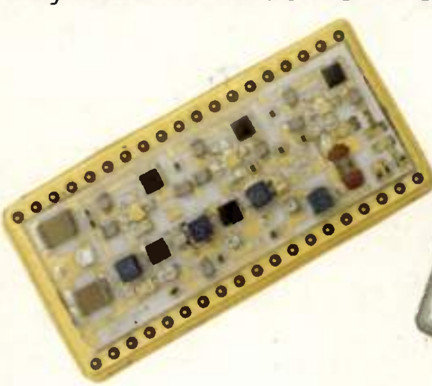

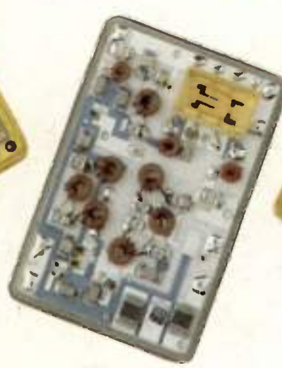

When it's a question of SAW, Andersen is the answer.

(actual size)

INFO/CARD 55