GREEN MOUNTAIN
RADIO RESEARCH LLC

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Organization and Capabilities

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Frederick H. Raab is well-known and respected for his expertise in the development of high-efficiency power amplifiers and transmitters. He has also been professionally involved with general RF design, antennas, matching networks, communication systems, and signal processing. Graduating from Iowa State University, he received his B.S.(1968), M.S.(1970), and Ph.D. (1972) degrees in electrical engineering. He received the I.S.U. Professional Achievement Citation in Engineering in 1995. was named an IEEE fellow in 2006, and received the Pioneer award from the IEEE MTT Society in 2019. The classic textbook *Solid State Radio Engineering*, coauthored by Dr. Raab, is widely used by both academics and practicing engineers. Other professional achievements include publication of over 100 technical papers and award of twelve patents. Professional leadership includes serving as technical program chairman for RF Expo East '90 and founding technical committee MTT-17 that expands the IEEE MTT Society to include HF/VHF/UHF engineers.

Green Mountain Radio Research (GMRR) is owned by Dr. Raab. Since 1980, GMRR has provided his technical expertise to numerous clients in both government and business.

Technical Expertise

- RF power amplifiers
- Radio transmitters
- Radio communication
- Radio navigation and position finding

Technical Scope

- Theoretical investigations
- System concepts and designs
- Simulation and modeling
- Prototype-hardware design
- Testing and evaluation
- Licensing of proven amplifier designs and IP

Technical Activities

- Research-and-development contracts
- Prototype-design projects
- Consulting
- Seminars and tutorials
- Production arranged through third parties

Technical Capabilities

- 40+ years of experience
- Novel and optimum solutions
- Merging theory with practice
- Background in both RF hardware and communication theory
- RF laboratory, fully equipped and computerized
- Clear and concise technical writing

RESUMÉ

Education

- Iowa State University, B.S.E.E. 1968
- Iowa State University, M.S.E.E. 1970
- Iowa State University, Ph.D.E.E. 1972

Employment

- 1980 - present: GMRR
- 1975 - 1980: Polhemus Navigation Sciences
- 1971 - 1975: Cincinnati Electronics
- 1970 - NASA Marshall Space Flight Center (summer)
- 1966 - 1969: Collins Radio (Rockwell) (summers)

Awards

- IEEE senior member, 1980
- Professional Achievement Citation in Engineering, Iowa State University, 1995
- Service Recognition, IEEE MTT Society, 2005
- IEEE fellow, 2006
- DeForest Audion Gold Medal, VWOA, 2008
- RCA fellow, 2009
- Pioneer, IEEE Microwave Theory and Techniques Society, 2019

Memberships

- IEEE (BC, CAS, MTT, and SSC Societies)
- AFCEA
- Association of Old Crows
- Radio Club of America (RCA)
- American Radio Relay League

Professional Activities

- Extra-class amateur-radio operator W1FR, licensed in 1961
- Session Chairman: RFTE'85, RFXE'92, ISCTA'95, IMS, RWW/PAWR
- Program Chairman: RF Expo East, Orlando, 1990
- Secretary, Vermont Section IEEE 1995 - 1997
- Editorial Advisory Board, *Applied Microwave and Wireless*
- Founder and Chairman, IEEE MTT committee #17 on HF/VHF/UHF technology

- MTT-S Technical Program Committee 1998 - present
- MTT Workshop Organizer, IEEE MTT-S
- Coordinator of ARRL 500-kHz experiment
- Member of committee for Ph.D. candidate working on power amplifiers at CICESE

SELECTED PUBLICATIONS

Dr. Raab's ability to translate theory into practice is illustrated by over 100 publications in both IEEE and trade journals. These publications also illustrate the ability to work in a variety of different disciplines, including power amplifiers, transmitters, receivers, signal processing, antennas, and propagation.

- F. H. Raab, "Radio frequency pulsewidth modulation," *IEEE Trans. Commun.*, vol. COM-21, no. 8, pp. 958 - 966, Aug. 1973. [TP72-1]

- F. H. Raab, "Idealized operation of the class E tuned power amplifier," *IEEE Trans. Circuits and Syst.*, vol. CAS-24, no. 12, pp. 725 - 735, Dec. 1977. [TP75-3]

- F. H. Raab, "Effects of circuit variations on the class E tuned power amplifier," *IEEE J. Solid State Circuits*, vol. SC-13, no. 2, pp. 239 - 247, April 1978. [TP75-4]

- H. L. Krauss, C. W. Bostian, and F. H. Raab, *Solid State Radio Engineering*. New York: Wiley, 1980. [TP76-4] [30,989 copies sold]

- F. H. Raab, "Efficiency of outphasing power-amplifier systems," *IEEE Trans. Commun.*, vol. COM-33, no. 10, pp. 1094 - 1099, Oct. 1985. [TP84-2]

- F. H. Raab, "Average efficiency of power amplifiers," *Proc. RF Technology Expo '86*, Anaheim, CA, pp. 474 - 486, Jan. 30 - Feb. 1, 1986. [TP85-1]

- F. H. Raab, "Efficiency of Doherty RF-power amplifier systems," *IEEE Trans. Broadcasting*, vol. BC-33, no. 3, pp. 77 - 83, Sept. 1987. [TP85-4]

- F. H. Raab, "Suboptimum operation of class-E RF power amplifiers," *Proc. RF Technology Expo '89*, Santa Clara, CA, pp. 85 - 98, Feb. 14 - 16, 1989. [TP88-5]

- F. H. Raab and I. R. Joughin, "Signal processing for through-the-earth radio communication," *IEEE Trans. Commun.*, vol. 43, no. 12, pp. 2995 - 3003, Dec. 1995. [TP95-2]

- F. H. Raab, "Simple and inexpensive high-efficiency power amplifier for 160 - 40 meters," *Communications Quarterly*, vol. 6, no. 1, pp. 57 - 63, Winter 1996. [TP96-1]

- F. H. Raab, "Intermodulation distortion in Kahn-technique transmitters," *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 12, part 1, pp. 2273 - 2278, Dec. 1996. [TP96-3]

- F. H. Raab, "Low-cost high-efficiency HF power amplifiers," *Proc. Nordic Shortwave Conf. (HF 98)*, Fårö, Sweden, pp. 2.2.1 - 2.2.10, Aug. 11 - 13, 1998. [TP98-2]

- F. H. Raab, "Electronically tunable class-E power amplifier," *Int. Microwave Symp. Digest*, vol. 3, pp. 1513 - 1516, May 20 - 25, 2001. [TP01-1]

- F. H. Raab, "Maximum efficiency and output of class-F power amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. 49, no. 6, pp. 1162 - 1166, June 2001. [TP01-2]

- F. H. Raab, "Class-E, -C, and -F power amplifiers based upon a finite number of harmonics," *IEEE Trans. Microwave Theory Tech.*, vol. 49, no. 8, pp. 1462 - 1468, Aug. 2001. [TP01-4]

- F. H. Raab, P. Asbeck, S. Cripps, P. B. Kenington, Z. B. Popovic, N. Pothecary, J. F. Sevic, and N. O. Sokal, "Power amplifiers and transmitters for RF and microwave," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 3, pp. 814 - 826, March 2002. [TP02-1]

- F. H. Raab, R. Caverly, R. Campbell, M. Eron, J. B. Hecht, A. Mediano, D. P. Myer, and J. L. B. Walker, "HF, VHF, and UHF systems and technology," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 3, pp. 888 - 899, March 2002. [TP02-2]

- F. H. Raab, "High-efficiency linear amplification by dynamic load modulation," *Int. Microwave Symp. Digest*, vol. 3, pp. 1717 - 1720, Philadelphia, PA, June 8 - 13, 2003. [TP03-1]

- F. H. Raab and D. Ruppe, "Frequency-agile class-D power amplifier," *Ninth Int. Conf. on HF Radio Systems and Techniques*, pp. 81 - 85, University of Bath, UK, June 23 - 26, 2003. [TP03-2]

- F. H. Raab, "Transmitter architectures for high-efficiency amplification," *Power Amplifier Workshop Digest, Radio and Wireless Systems Conf. 2006 (RWS'06)*, San Diego, CA, Jan. 16 - 17, 2006. [TP06-1]

- J. L. B. Walker, D. P. Myer, F. H. Raab, and C. Trask, *Classic Works in RF Engineering: Combiners, Couplers, Transformers, and Magnetic Materials*. Boston, MA: Artech House, 2006. [TP06-2]

- F. H. Raab, M. F. Gladu, and D. J. Rupp, "Complementary class-D power amplifier for LF and MF," *QEX*, no. 235, pp. 9 - 13, March/April 2006. [TP06-3]

- F. H. Raab, "Broadband class-E power amplifier for HF and VHF," *IEEE MTT-S Int. Microwave Symp. Digest*, paper WE4C-1, pp. 902 - 905, San Francisco, CA, June 11 - 16, 2006. [TP06-4]

- F. H. Raab, "Model for the low-frequency performance of ferrite-loaded balun transformers," *2007 Int. Microwave Symp. Digest*, Session TU3A, Honolulu, HI, June 3 - 8, 2007. [TP07-1]

- F. H. Raab, M. C. Poppe III, and D. P. Myer, "High-efficiency transmitter for magnetic-resonance imaging," *Technical Digest, 2009 IEEE Topical Symp. on Power Amplifiers for Wireless Commun.*, paper 1.4, San Diego, CA, Jan. 19 - 20, 2009. [TP09-1]

- R. Beltran, F. H. Raab, and A. Velazquez, "HF outphasing transmitter using class-E power amplifiers," *IEEE MTT-S Int. Microwave Symp. Digest*, paper WE4A-1, pp. 757 - 760, Boston, MA, June 7 - 12, 2009. [TP09-2]

- F. H. Raab and M. C. Poppe III, "Kahn-technique transmitter for L-band communication/radar," *Digest, 2010 IEEE Radio & Wireless Symp. (RWW 2010)*, paper MO3A-1, pp. 100 - 103, New Orleans, LA, Jan. 10 - 14, 2010. [TP10-1]

MAJOR RESEARCH AND DEVELOPMENT CONTRACTS

High-Efficiency Amplifiers for Linear Accelerators

GMRR is developing a series of high-efficiency RF-power-amplifier systems for U.S. Department of energy particle accelerators and other applications. These PAs are based upon GaN FETs and class-F operation. Prototypes have been developed for frequencies ranging from 160 to 952 MHz and the power levels from 10 to 150 W. The overall efficiencies range from 80 to 86 percent. The gain is typically about 18 dB. Manufacturable prototypes have been developed for several specific frequencies and exhibit excellent repeatability.

Low-loss splitters and combiners were designed and used to implement modules based upon five power amplifiers. These modules deliver 500-700 W peak with overall efficiencies from 76 to 83 percent. A class-S modulator has been developed for amplitude control in Envelope-Elimination-and-Restoration (EER) and the system demonstrates excellent linearity and efficiency over a wide range of outputs. Amplitude control through outphasing has also been demonstrated. These systems operate under the control of a digital signal processor which ensures both maximum efficiency and linearity.

High-Efficiency HF/VHF ISM Power Amplifiers

GMRR has developed high-efficiency power amplifiers for several ISM applications. Typical frequencies are 6.78, 13.56, 27.12, and 40.68 MHz. Individual PAs are quite simple and typically are configured for peak outputs between 200 W and 400 W, with combining used to obtain higher power outputs. The overall efficiency ranges from 86 percent at the lower frequencies to 80 percent at the upper frequencies. The overall efficiency includes the drive power of about 2 W.

High-Efficiency Transmitter for L-Band Radar

Under this SBIR Phase-II contract, GMRR developed a prototype high-efficiency transmitter for L-band radar. This application requires generation of FM-CW pulses at 1.2 GHz and delivery of a variable-amplitude signal into an antenna element with a variable impedance. The transmitter is based upon a combination of a high-efficiency RF-power amplifier, power combiners, high-efficiency class-S modulators, electronic tuning, and digital signal processing. The PA is a class-F design that uses a GaN HEMT. It produces up to 55 W with an overall efficiency of 74 percent, and maintains an overall efficiency of 60 percent or better at power levels of 5 W or more. Drive is provided by 15-W GaN HEMT PA operating in class B. Gysel combiners in a corporate configuration produce an output of 175 W with an efficiency of 60 percent. The PA can also generate a wide variety of amplitude-modulated signals with efficiencies two or more times those for conventional linear amplifiers. Signals originate in the digital signal processor and are predistorted to correct for amplitude nonlinearity and amplitude-to-phase conversion. Two-tone signals are produced with third-order IM products at about -26 dBc. Adaptation to load impedances with SWR up to 3:1 is accomplished by a three-stub tuner with stub lengths controlled by pin diodes.

Electronically Tuned VHF Power Amplifier

At VHF, class-E provides the highest efficiency with an output network of minimum complexity. The electronically tunable VHF PA is therefore based upon an LDMOS FET operated in class E. A double-T output network allows adjustment of both drain resistance and reactance. Band segments are selected by switching the inductors, after which tuning is accomplished by highvoltage varactor capacitors. The PA operates from 20 to 90 MHz and produces 50 W with an efficiency of about 60 percent. With a different tuner, the PA is capable of operating to frequencies of 300 MHz with good performance and 500 MHz with useable performance.

Electronically Tuned UHF Power Amplifier

The electronically tunable UHF power amplifier uses a GaN HEMT operated in class C. The input tuning is accomplished by two arrays of varactors. The output tuning is accomplished by a three-stub tuner. Ten pin diodes on each stub control its electrical length. This PA produces 40 - 45 W from 325 to 800 MHz (2.5:1 tuning ratio) with an overall efficiency of 50 to 55 percent.

High-Efficiency Power Amplifier for UHF Radar

GMRR developed a prototype GaN-HEMT class-F power amplifier for use in UHF radar. This project began with an experimental comparison of operation in classes B, E, and F. The prototype PA operates at 500 MHz and produces an output of up to 54 W. An overall efficiency of 70 percent or better is maintained for outputs from 8 to 54 W, and the overall efficiency is 60 percent or better for outputs as low as 2 W. A version of this PA adapted to operation at the 915-MHz ISM frequency has similar performance.

High-Efficiency Transmitter for Magnetic Resonance Imaging

GMRR has developed a high-efficiency transmitter for MRI applications and other applications from 1.8 to 128 MHz. The transmitter is based upon the Kahn EER technique and includes class-E RF power amplifiers, 2-MHz class-S modulators, and a digital signal processor. The RF PA module produces up to 200 W with an efficiency from 70 to 90 percent. The DSP produces the input signals to the RF chain and modulators, and includes correction for amplitude and phase nonlinearities. The system can generate a downloaded signal on command or digitize and amplify a low-level input RF signal. The linearity is excellent, with two-tone IMD products at -35 dBc or lower. [NSF1/NSF2]

Broadband VHF/UHF Class-D Power Amplifier

The broadband VHF class-D PA uses ferrite-loaded transformers at its input and output. The design was evaluated with a wide variety of transistors, including LDMOS FET, SiC MESFET, and GaN HEMT. The best performance is achieved when using a pair of GaN HEMTs. Thus configured, the PA produces over 100 W from 50 to 300 MHz, with useable power to 500 MHz. The efficiency varies from 55 to 67 percent. No tuning is required.

Components for High-Power Electronic Tuning

GMRR has developed electronically variable capacitors and inductors for use in power amplifiers. The electronically variable capacitor is based upon a novel semiconductor structure and provides a 3:1 range of variation. The electronically variable inductor is based upon a novel ferrite configuration and provides a 3:1 variation. A class-D power amplifier was designed that can be tuned electronically from 5 to 20 MHz; it produces 100 W with an efficiency of 70 percent. [SWL7]

Low-Frequency Spread-Spectrum Navigation System

Determined power, antenna, receiver, and signal-processing requirements for a low-frequency spread-spectrum navigation system. Prepared plan for development and field-testing. [DOT1]

Electronically Tuned Class-E Power Amplifier

Designed class-E power amplifier capable of being tuned electronically continuously from 19 to 31 MHz. The amplifier produces a 20-W output with an efficiency 61 to 71 percent across the band. When tuned conventionally, it produces 25 W with an efficiency of 71 to 74 percent, but has a bandwidth of only about 1 MHz. It also has excellent amplitude-modulation linearity, and demonstrated the capability to produce amplitude-modulated signals with efficiency roughly double that of linear amplifiers. [VTE1]

Low-Cost Class-D and -E Power Amplifiers

Designed and tested experimental broadband class-D and -E power amplifiers using APT ARF449 MOSFETs. The class-D push-pull PA deliver 500-W with 80-percent efficiency from 2 to 4 MHz and 300 W at 21 MHz with 60-percent efficiency. The single-ended class-E PA delivers 250 W from 1.8 to 14 MHz with an efficiency of 80 percent and 125 W at 30 MHz with a 60-percent efficiency. Amplitude-modulation linearity is excellent, allowing the production of AM, SSB, and multitone-data signals through the Kahn EER technique. [IR&D]

VLF Link Predictions

Predicted the SNR for various VLF-communication links for an improved TACAMO system. [RAY1]

Integrated Antenna/Amplifier System

The objective of this project was to integrate the power amplifier, matching network, and antenna to achieve the maximum radiated HF/VHF signal for a given dc-input power. Various whip and loop antennas were compared with the Numerical Electromagnetics Code (NEC). Simulation was also used to evaluate techniques for improving the gain of the whip antenna by both fixed and switched in-antenna inductors. Selected approaches were confirmed by field testing. At most frequencies, the low-angle gain was improved by 3 to 6 dB. Broadband-matching techniques were used to devise a set of filters that provide approximate matching over their respective subbands. Filter and matching networks tuned by pin-diode switches were also evaluated. [SWL3/5]

RF Transmitter/Locator

Instrumentation canisters used in explosives testing can be scattered over distances of several kilometers and buried at depths as great as 30 m. The RF TL concept developed in this Phase-I feasibility study provides a means of locating the instrumentation canisters and recovering their data. The surface equipment interrogates the RF TLs with a directional UHF signal. Upon interrogation, an RF TL responds on either VHF or VLF. The VHF signal allows location at depths of 3 m and distances of 4 km, while the VLF allows location at depths of 30 m and distances of 90 m. The subsurface transmitter is an ASIC that operates in class D and delivers an output of about 1.4 W. [WES1]

Adaptive-Jammer Power-Amplifier System

Under this set of contracts from the U. S. Army Intelligence Electronics Warfare Directorate, GMRR developed a prototype adaptive-jammer transmitter for the production of CW, AM, FM, SSB, and noise signals at HF and VHF. The Phase-I feasibility study investigated the use of a number of techniques for improving performance, including techniques include class-D operation of the RF PAs, envelope elimination and restoration, amplitude modulation by a class-S modulator, wideband AM by outphasing, harmonic cancellation, feedforward error cancellation, and multicoupler combining.

In Phase II, 100- and 250-W transmitters were developed. The RF PAs can operate in untuned class-D (high efficiency and maximum noise-power output), tuned class D (for clean communication signals with high efficiency), or class B (for wide bandwidth). Other system components include RF signal generators, a programmable waveform generator, AM/SSB modulator, FM modulator, frequency converters, and a class-S modulator. The transmitter uses the Kahn envelope-elimination-and-restoration (EER) technique. Test results show both superior average efficiency (60 percent vs. 20 percent for conventional transmitters) and superior linearity (third-order IMDs at -42 dBc vs. the usual -30 dBc). Multiple PAs can be combined to produce up to nearly 1 kW. [SWL2]

A power-combined version of the Adaptive Jammer power amplifier was designed and tested under a quick-reaction contract. [HAC2]

Moveable-Scatterer Model

The fields scattered by helmet-mounted CRTs can significantly degrade the performance of a magnetic-field helmet-mounted sight. Under contract to U.S. Air Force Aerospace Medical Research Laboratory, GMRR developed a multipole model of this phenomenon and software for extraction of its parameters. Laboratory measurements showed that the dipole terms of the model predict the scattered fields with no more than a 16-percent error. The residual field-prediction error was shown to be due to noise and multipole components. [LTS3], [LTS4]

Noise-Canceling Receiver for VLF Communication

This two-phase project for the U. S. Air Force Ballistic Missile Office developed advanced signal-processing concepts for through-the-earth communication and tested them in an experimental VLF receiver. In Phase I, a multicomponent noise model was developed and various signal-processing techniques were analyzed and simulated. In Phase-II, an experimental receiver that can receive all six electromagnetic-field components was developed and tested. The analog portion of the receiver a superhet design with a high-side IF. Remote preamplifiers allow the antennas to be located at some distance. Noise cancellation and detection were done in C-language software. The receiver and auxiliary equipment are operated by the computer through an IEEE-488 interface bus. Field tests at three sites produced SNR improvements from 10 to 24 dB. [BMO1/BMO2]

Signal-Processing Algorithms for Magnetic Helmet-Mounted Sight

Previous HMS systems estimate position and orientation as if they were in free space and then attempt to compensate the estimates for the effects of nearby metal (such as an aircraft cockpit). Consequently, they can be highly sensitive to noise and sometimes erratic. Under contract from the U.S. Air Force Aerospace Medical Research Laboratory, GMRR has developed a new signal-processing algorithm. This algorithm is based upon a minimum-variance linear estimator and converts magnetic-field measurements directly into the correct position and orientation estimates. Simulations and tests in the GMRR lab have shown it to be stable and its estimates to be almost as accurate as those made in a free-space environment. An auxiliary nonlinear estimator and supervisory algorithm ensure absolute stability. GMRR work on these algorithms includes formulation, simulation, optimization of computations, and development of automatic-mapping software. [SRL8 - SRL13]

VLF Radio-Navigation Analysis and Simulation

As part of a Transport Canada program, GMRR predicted navigation-system performance derived from new VLF-navigation transmitters. Included were field-strength predictions for OMEGA and candidate VLF-NAV stations, conversion of SNRs into rms accuracies, determination of system availability at a specified accuracy, and estimation of the required radiated power. [KW1]

TYPICAL CONSULTING ASSIGNMENTS

- 137-MHz class-E power amp for satellite communication
- High-efficiency LF/MF transmitter for nondirectional beacon
- High-efficiency VHF power amplifier for expendable jammer
- High-efficiency UHF HBT power amplifier
- 1-kW RF-power module
- Techniques for measurement of position and orientation
- Power amplifier for RF heating
- Direct-conversion HF-SSB receiver
- MOSFET power amplifier (TACJAM)
- Simulation model for RF-power MOSFET
- RF power amplifier for fluorescent lamp ("E-lamp")
- 400-W VHF power amplifier (Piranha)
- L-band tracking system
- VLF link analysis
- Design review, 500-kHz RF PA for medical heating

SEMINARS

GMRR provides two continuing-education seminars:

- *Fundamentals of Power Amplifiers and Transmitters*
- *High-Efficiency Power Amplifiers*

"Fundamentals" follows the *SSRE* textbook, covering linear power amplifiers, tuned power amplifiers, high-efficiency power amplifiers, CW/FM/AM transmitters, and SSB transmitters. "High-Efficiency Power Amplifiers" uses a 500-page seminar notebook and covers power-amplifier fundamentals; classes C, D, E, F, S, and G; and technique such as Kahn envelope elimination and restoration, Doherty, and outphasing.

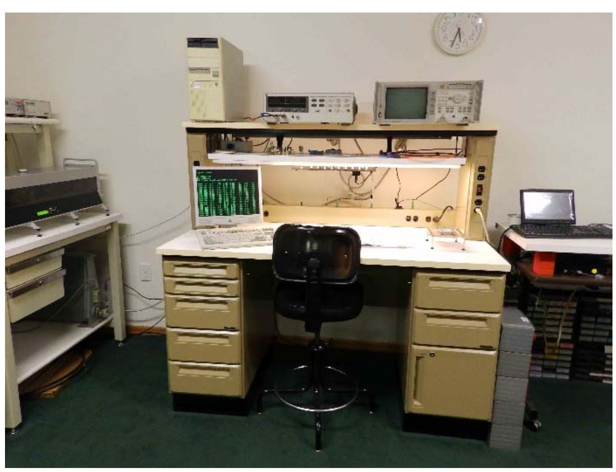
FACILITIES

Office

GMRR owns its office building, which provides 2000 ft^2 (200 m^2) of floor space as well as additional storage space. Land behind the building provides room for testing antennas.

Electronics Laboratory

The GMRR electronics laboratory provides instrumentation for R&D work at frequencies up to 40 GHz and power levels up to 5 kW. Instrumentation include a 500-MHz digital oscilloscope, spectrum analyzers for 1 GHz (IFR A-7550) and 40 GHz (R&S FSP-38), network analyzers for 300 kHz - 3 GHz (HP 8714B) and 40 MHz - 40 GHz (Anritsu 37269), RF signal generators for 9 kHz - 1 GHz (Fluke 6061A), 9 kHz - 3 GHz with I/Q modulation (R&S SM-300), and 40 MHz - 40 GHz (Anritsu 67369A). The lab also includes a 1-GHz vector voltmeter (HP 8508A), programmable-waveform generators (WT-195 and WT-275), driver amplifiers, RF-power meters, multimeters, and power supplies. The entire lab is computer-controllable via the IEEE-488 bus, allowing data collection to be accomplished with speed and accuracy. Waveforms and spectra can be captured and transferred to text/graphics software for inclusion in reports. GMRR also has a small shop for basic mechanical work.



Micro-Computer Facility

GMRR makes use of an assortment of Intel-based computers. Both FORTRAN and C are available. An extensive set of libraries provides mathematical, matrix, random, and other functions. Circuit simulation is accomplished via PSpice. Numerical Electromagnetics Codes (NEC2 and NEC3) are available for simulation of antennas. A large number of in-house programs and subroutines are also available for power-amplifier and communication-link analysis. GMRR has both Windows and Linux microcomputers.

Library

GMRR has one of the most extensive collections of literature on RF power amplifiers and transmitters. On hand is a variety of engineering journals (IEEE as well as trade). Over 12,000 papers and reports are indexed for rapid access by author or subject. Searches can also be run via IEEE Xplore.

Technicians and Programmers

Electrical-engineering students from nearby Iowa State University serve as technicians, assemblers, and programmers.

Production

GMRR has contracted with various assembly houses such as Eastman Benz and Imagineering for production of tens to hundreds of boards.

CLIENTS

GMRR has worked with a wide variety of clients in the public and private sectors. Most of our work is repeat business from satisfied customers. Most new business originates in response to a query initiated by the customer.

- Advanced Power Technology
- Advanced Technology Systems, A Subsidiary of The Austin Company
- Aethercomm
- American Electronics Laboratories (AEL)
- Ameritherm
- Apple Computer
- AT&T Bell Telephone Laboratories
- Basic Telecommunications Corporation
- Bendix Aviation Electric
- Continental Electronics
- Critical Response Systems
- Design Automation
- Diablo Lighting, Inc. (Litek International)
- EPL
- Fujant
- Honeywell Marine
- Hughes Aircraft Corporation
- Hypres
- Kershner, Wright, and Hagaman, P. C.
- Lockheed Electronics

- Loral Control Systems
- Metcal
- Motorola Personal Products / Pagers (Florida)
- Motorola Satellite Communications (Scottsdale, AZ)
- Motorola Semiconductor Products (Phoenix)
- Motorola University (Phoenix)
- NASA George C. Marshall Space Flight Center
- National Science Foundation
- Navigation Sciences Corporation
- OAO Corporation
- Qualcomm
- Questech
- Raytheon Electronic Systems
- Remec Microwave
- RF Micro Devices (RFMD)
- Rockwell International (Collins Telecommunications Division)
- Seminar Development Corporation
- Simmonds Precision Products
- Spar Aerospace Limited
- Spectrian
- Sperry Research
- Tadiran Israel Electronics Industries
- Teleco Oil Field Services
- Townsend Associates
- Transport Canada
- U.S. Air Force - Aerospace Medical Research Laboratory
- U.S. Air Force - Ballistic Missile Organization
- U.S. Air Force - Air Force Research Laboratory (Albuquerque,Bedford)
- U.S. Army - Intelligence and Electronic Warfare Directorate
- U.S. Army - Waterways Experiment Station
- U.S. Bureau of Mines - Pittsburgh Mining Safety Research Center
- U.S. Department of Transportation - Volpe TSC
- U.S. Department of Energy - Brookhaven
- U.S. Department of Energy - Argonne
- U.S. Department of Energy - Fermi Lab
- U.S. Department of Energy - Oak Ridge
- U.S. Navy - Office of Naval Research
- U.S. Navy - NAVEODTECHDIV
- U.S. Navy - NAVAIR