MILITARY APPLICATIONS OF MMICs

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ABSTRACT

This paper will serve as a progress report on the Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMIC) program by describing some of its current and planned insertions into Department of Defense (DoD) systems.

Some of the products of the MIMIC program have already found application in DoD systems that are currently deployed. Many others are slated for increasingly wide scale use in future DoD systems. In addition, most of the new hardware and software products will be readily adaptable for commercial applications by the microwave/millimeter wave community.

INTRODUCTION

At the 1988 Microwave and Millimeter-Wave Monolithic Circuits Symposium, I was honored by being invited to present a paper on the then (almost) new program called Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMIC) [1]. The program is under the management of the Defense Advanced Research Projects Agency (DARPA) with participation by the Army, Navy, Air Force, and several other U. S. Government agencies.

At that time, I described the program structure and funding, its objectives, accomplishments made by industrial participants during the time period of the program definition phase (Phase 0) and plans for both technology development and insertion of that technology into systems over the next several years. It is a singular honor to be invited once again to address this distinguished group of engineers and scientists and to provide a progress report on the program's accomplishments. I believe that, although much remains to be accomplished, many of the program objectives have indeed been fulfilled.

During the first three year phase of hardware development, which began in May, 1988, very substantial progress has been realized in all of the areas of MIMIC development. Improved gallium arsenide substrates are available. Computer aided design, fabrication, and test capabilities have been extended. Integrated, high throughput manufacturing facilities have been installed. The fabrication recipes have been refined and demonstrated to result in a high yield of MIMIC chips. New techniques have been developed that can drastically reduce the cost of packaging and testing these chips. All of these advances are contributing to the successful achievement of the primary MIMIC program goal of making advanced microwave and millimeter wave circuits affordable for wide usage in military systems.

Some of the products of the MIMIC program have already found application in Department of Defense (DoD) systems that are currently deployed. Many others are slated for increasingly wide scale use in future DoD systems. In addition, most of the new hardware and software products will be readily adaptable for commercial applications by the microwave/millimeter wave community. The goal of the next three year hardware development portion of the program will be to establish fully integrated design, manufacturing, and testing capabilities that can produce, inexpensively and rapidly, the full range of advanced microwave/millimeter wave circuits required for systems.

The early system applications of MIMIC have largely involved the retrofit of MIMIC hardware into existing modules and subsystems. The primary purpose of these applications has been to reduce cost although the benefits of increased unit-to-unit reproducibility, higher reliability, and improved component performance have also been gained. However, a retrofit does not generally result in space savings or significant improvements in system performance since it is a direct one-for-one substitution of MIMICs for older hybrid microwave integrated circuits (MICs). In contrast, the current MIMIC applications and those planned for the future fall into two categories that are not only more technically challenging but also are certain to have a greater overall impact on system design and on manufacturing approaches. The first category is the use of MIMICs specifically to increase system functionality within reduced space requirements, while, at the same time, retaining the benefits of reduced cost and improved reliability. The second and most important category is the use of MIMIC as an "enabling" technology, *i. e.* to design and produce systems (at an affordable cost) that would not otherwise be feasible.

During the past three years, over 80 MIMIC chip types have been fabricated for use in sixteen MIMIC demonstration brassboards. However, even more exciting is the fact that the MIMIC program has promoted the early use of MMICs in fielded DoD systems. In some cases, these MMICs are chips designed

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under the program; in others, particularly in the early applications, the chips were designed outside the program but are being fabricated on production lines developed as part of the program effort.

In the balance of this paper, I will describe how MMICs are already being used in several fielded DoD systems and are being evaluated for use in numerous other systems currently in various stages of development. The paper will focus on the use of MIMIC technology in four categories of systems: smart weapons, electronic warfare, radar, and communications.

SMART WEAPONS

One of the earliest applications of MIMIC to DoD systems is in the Navy/Air Force High Speed Anti-Radiation Missile (HARM) which is being produced by Texas Instruments and Raytheon. Both TI and Raytheon are producing 0.5 GHz to 4.0 GHz IF amplifiers for this missile on their MIMIC production lines to replace older MICs. Both companies report achieving immediate cost savings of 50% for the amplifiers by using MMICs in place of the MICs. Additional savings are expected in the future. Approximately 1200 MMIC chips per month are being produced for this application with expectations that this rate of production will continue for the next several years.

Two other promising smart weapon applications of MIMIC are in the Army's MOFA (multi-option fuze for artillery) and SADARM (sense and destroy armor), systems that are currently under development.

MOFA is expected to provide the most important advance in fuze technology since World War II. The use of a MIMIC chip has greatly increased the accuracy of setting the height at which the projectile bursts. Furthermore, MIMIC technology has made it possible to increase the operating frequency of the fuze so that the antenna as well as the RF circuitry can be further miniaturized. The packaged MIMIC chip, consisting of a complete FM/CW radar, must cost less than $10 in order to meet the budget constraints for large quantity procurement of the system. The required chip has already been successfully designed by Hittite and TRW, fabricated by Triquint and TRW, and integrated into MOFA by Motorola. Packages being used cost between 25 cents and $1.40, the less expensive being non-hermetic and the most expensive being hermetically sealed. MOFAs containing MIMIC chips have been successfully field tested by the Army at their Blossom Point, Maryland test facility. Two MOFAs were dropped from helicopters at different heights. Each functioned exactly as expected, making the tests a complete success. MOFA is expected to enter the production phase in the mid-1990s and replace approximately ten fuze types that have been in use by the U. S. Army since World War II. A second version of the FM/CW radar on a chip for MOFA uses heterojunction bipolar transistor (HBT) technology. The HBT version of this circuit is expected to provide even lower noise levels and higher output power than the MESFET one, allowing longer range and the ability to operate against smaller targets.

SADARM uses millimeter wave and infrared sensor technologies to detect stationary targets. It is designed to primarily be a counterbattery weapon although it is capable of defeating any armor in its scan area. Two versions of SADARM are under development, one by Alliant Techsystems, Inc. and the other by Aerojet. Alliant is working with the TRW MIMIC team and Aerojet with the Raytheon/TI MIMIC team. Successful MIMIC transmitter and receiver chips have already been produced by both teams. Rail gun tests of MIMIC hardware conducted at Army and contractor facilities indicate that the chips are capable of withstanding 12,000 g's. High electron mobility transistor (HEMT) MIMICs are under consideration for use in the receiver to substantially lower its noise figure and to increase overall system performance. The MIMIC hardware proposed for SADARM is designed to be a part-for-part replacement to reduce cost, increase reliability, improve producibility, and, in one case, reduce the space requirement. Future MIMIC technology developments will enhance SADARM's system performance through follow-on P^3I efforts.

Another smart weapon committed to the use of MMICs is the Navy/Air Force AMRAAM (Advanced Medium Range Air-To-Air Missile). Seventeen MMIC chips of twelve types will be used in each missile. MMIC use leads to lower overall costs because fewer parts and modules will be required and the overall electronic assembly will be simplified. MMICs will be phased into AMRAAM production by Hughes Aircraft Company between 1991 and 1992.

The program managers for several other smart weapons currently under development have strongly endorsed the use of MIMICs in their systems. These include the Army's Longbow (formerly Airborne Adverse Weather Weapon System), the Navy's AAAM (Advanced Air-to-Air Missile) and X-Rod, a joint U. S. Army/DARPA initiative.

Longbow, under development by Martin-Marietta and Westinghouse Electric Corporation, consists of a helicopter mast-mounted millimeter wave fire control radar and a missile using a millimeter wave seeker. It is being developed to enhance the all-weather capabilities of the AH-64 Army combat helicopter. During 1989, a Longbow missile was successfully test fired at Eglin Air Force Base with a direct hit scored on a tank by the missile. Savings of several thousand dollars per seeker are expected by substituting MIMIC technology for MIC technology.

AAAM is a long range air-to-air missile, under development by General Dynamics and TRW, which contains a dual-band, four channel, monopulse receiver. The use of MIMIC results in substantial space and weight savings, by reducing the electronics from four boards to a single board. Cost savings of up to $10,000 per unit are projected. In addition, the MIMIC low noise amplifier chip developed for AAAM reduces noise figure by 3 dB and thereby provides substantial performance improvement.

The X-Rod projectile, under development by Hercules Defense Electronics Systems, is a "smart" kinetic energy weapon that will penetrate advanced armor at extended ranges. At present, X-Rod uses a W-band millimeter wave transceiver that is produced using hybrid, planar waveguide technology. Although this approach will satisfy the program requirements, lower costs can be realized through the use of MIMICs. In addition, MIMICs require less space for guidance which, in turn, provides more space for propulsion and advanced guidance. The development of W-band amplifier chips under the MIMIC program sparked the interest of this program manager in using MIMICs.

Another application of W-band amplifier chips is in the MLRS-TGW (Multi Launch Rocket System - Terminally Guided Weapon). TRW and Martin-Marietta are participating in the development of this multi-national weapon system and both are also MIMIC program participants. Martin-Marietta has developed one of the first W-band MIMIC amplifiers for potential use in this system. Co-planar waveguide is used on one side of the chip to contact the active device and microstrip on the other for bias and matching networks. Martin-Marietta has also developed a downconverter chip for MLRS-TGW. TRW is developing several chips for MLRS/TGW, all using heterojunction bipolar technology. These include synthesizer chips, an in-phase/quadrature detector, and a 5-bit attenuator.

ELECTRONIC WARFARE

The Raytheon/Texas Instruments MIMIC Phase 1 team has concentrated upon electronic warfare applications for their MIMIC chips and modules. Several impressive technological advances have been made by this team including the development of wideband MIMIC power amplifiers with efficiencies approximately twice those achieved previously and packages made from metal-matrix composites that show promise for lowering module packaging costs to as little as $5.00. A system selected by this team as a MIMIC Phase 1 demonstration, the GEN-X (Generic decoy), is already in use as part of Operation Desert Shield. GEN-X is a Navy decoy against the terminal guidance phase of approaching missiles. It is deployed from a standard chaff/flare dispenser. Initial testing of the GEN-X was so successful that the next scheduled phase of testing was bypassed in order to get the weapon into the field as quickly as possible. MIMIC is an enabling technology for this application because size and cost constraints could not be met without its use. The decoy is manufactured by Texas Instruments with MIMICs supplied by the Raytheon/Texas Instruments MIMIC team. To date, more than 9,200 MIMICs of twelve different circuit types have been supplied for this application. Full decoy production could involve several hundred thousand units.

The Raytheon/Texas Instruments team is also building a MIMIC brassboard for other electronic warfare applications. Several of the chips being used in GEN-X as well as others will be incorporated into a stackable phased array module for evaluation. The modules can be stacked into a two-dimensional array. The size of a 1x8 subarray of these EW modules has been dramatically reduced through MIMIC use from a pre-program volume of 106 in^3 to 12 in^3. In addition, the improvement in module power added efficiency will greatly reduce the problems associated with conducting away the heat generated by large, transmitting phased arrays. Potential system applications for this MIMIC array include AN/ALQ-131, AN/ALQ-99(A) and (E), AN/ALQ-135 and AN/ALQ-165.

The ITT/Martin-Marietta MIMIC Phase 1 team has developed improved hardware for the Army's AN/ALQ-136 helicopter mounted jammer and the Navy's AN/ALQ-165 tactical fighter jammer. Over 23 MIMIC chip types including amplifiers, oscillators, attenuators, downconverters, modulators and a discriminator are used in 12 modules to upgrade the capabilities of these systems while saving substantially on module cost and improving reliability. Each system will have shop replaceable units retrofitted with MIMIC chips to achieve the cost and performance objectives. Brassboards of several retrofits have already been successfully developed and demonstrated.

TRW is also pursuing EW applications of MIMIC. In particular, TRW has developed a heterojunction bipolar transistor (HBT) MIMIC log amplifier that provides greater than 60 dB dynamic range, -68 dBm tangential sensitivity and + or - 1 dB logging accuracy over a frequency band from 300 MHz to 1.5 GHz. The size reduction of individual modules achieved from MIMIC use will allow 24 channels of an EW channelized receiver to occupy the same space that 4 channels do now using conventional technology, a 6 to 1 volume reduction.

RADAR

The first ground based phased array radar system to make use of MIMICs is the COBRA (Counter Battery Radar).[2] The primary chip type to be used is a power amplifier being produced by General Electric, Hughes Aircraft Co., Harris Microwave, AT&T and M/A COM. A similar chip served, in the MIMIC Program, as a successful example of the ability to transfer design technology between MIMIC team members. The technology transfer process has been described previously.[3] Currently, it is planned to build 50 of these radars, each of which will use several thousand MIMICs. These MIMIC chips will replace the tubes used in conventional radars. COBRA is being produced by an international team with GE Aerospace, Thomson-CSF, Siemens and Thorn EMI as members.

The Hughes/GE team is also developing chips, modules and a brassboard demonstrator for airborne phased array radars. Potential platforms for MIMIC airborne radars include the Air Force's Advanced Tactical Fighter (ATF), the F-15 and F-16 aircraft. As is the case with EW phased arrays, the elimination of thermal problems is critical for achieving successful, reliable array operation. Hughes Aircraft Company has successfully produced power amplifiers with greater than 30% power added efficiency, operating over the 7 GHz to 11 GHz frequency range. The amplifiers produce power outputs of over 2 watts. Amplifiers of this type will be combined into 4-unit modules to form the building blocks of the overall phased arrays. Achieving a power added efficiency of over 30% for the MIMICs was a critical step toward assuring the viability of the overall array.

The ITT/Martin-Marietta team is developing a complete transceiver on a chip for C-band phased array radar/communications use. This impressive chip operates in the 5.25 GHz to 5.85 GHz frequency range, contains 66 FETs and provides complete transmitting and receiving functions. Early results included a transmitting gain of almost 40 dB, output power of over 3 watts and a power added efficiency of approximately 35%. Receiver gain was approximately 22 dB with a noise figure of 4.0 dB.

Finally, the Raytheon/TI team has developed Ku-band power and low noise amplifiers, and a variable attenuator for radar use.

COMMUNICATIONS

Several communication systems are expected to use MIMICs during the next several years. Perhaps the highest volume communication application for MIMICs will be the Global Positioning System (GPS). Hughes Aircraft Company, with team member E-Systems, is developing the next generation of antenna electronics for this system. Three MIMIC chip types and three silicon chip types will be used to provide the first MIMIC brassboard demonstration for this system. Use of MIMICs in the active weight module of this system will reduce parts count by 50%, package size by 79% and weight by 65%.

Other communication applications are being pursued by the ITT/Martin-Marietta team with team member Harris playing a major role. This team is producing MIMICs for use in the defense satellite communication system (DSCS) which operates in the X-band frequency range. Seven chip types have been developed for upconverter and downconverter functions. In particular, the MIMIC brassboard under development will demonstrate 30% savings in weight, size and cost over previously designed communication terminals that employ MIC hybrid technology. MIMIC is an enabling technology for the SHF manpack portable communication terminal.

Millimeter wave (Q-band) chips for communications have been developed by the Raytheon/TI team with team member Magnavox actively involved. These chips include a VCO, low noise amplifier, power amplifier and mixer.

CONCLUSION

In summary, MIMIC technology has already found its way into numerous military applications. Fielded systems such as HARM and GEN-X are currently using chips from MIMIC production lines. Other systems such as AMRAAM and COBRA are close behind. Eventually, more than 50 DoD systems will make use of MIMICs. The primary keys to acceptance of MIMIC products are the dramatic reduction of cost, and the ability to meet system specifications for performance, reliability, and environmental conditions. An example of the dramatic cost reductions that have been achieved in the program has been furnished by the Raytheon/TI team. This team uses as a figure of merit the cost per mm^2 of gallium arsenide chip area. At the start of MIMIC Phase 1 this cost was \$20 mm^2; eighteen months later, it had decreased to just over \$3 mm^2 for power amplifier chips and just under \$3 mm^2 for low noise amplifier chips. Every team has shortened testing time by more than an order of magnitude and every team makes extensive use of on-wafer testing to eliminate unacceptable products early in the fabrication cycle. Both of these steps were needed to meet the cost reduction objective.

The continuing and expanding acceptance of MIMIC technology for DoD and commercial systems use provides assurance that the production and design capabilities will be independently sustained by industry after the conclusion of the program. These capabilities constitute a national asset that represents an excellent return on the investment made by the DoD in the MIMIC Program.

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