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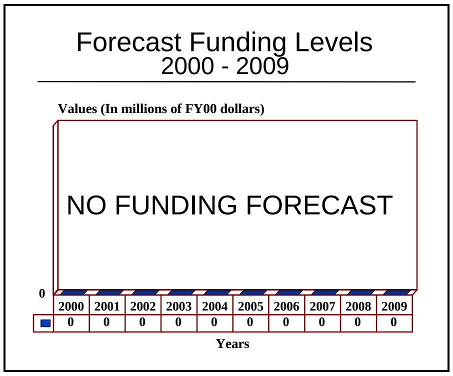
MAFET - Archived 01/2001

Outlook

- MAFET program completed in FY99
- No funding expected for MAFET in future US DoD budgets
- Barring any unexpected activity, this report will be archived next year (2000)



Orientation

Description. The Microwave and Analog Front End Technology (MAFET) program is a follow-on to the Millimeter Wave Monolithic Integrated Circuits (MIMIC) program. The goal of MAFET is to reduce non-recurring costs for military microwave/millimeter wave sensor systems.

Sponsor

Defense Advanced Research Projects Agency (DARPA)
Washington, DC
USA

Contractors

The MAFET program has not been identified as being under any particular contractor. However, as MAFET is a direct descendent of the MIMIC program it is possible that one or more of the former MIMIC team leaders is currently working on MAFET. Team leaders for MIMIC were as follows:

General Electric Co
1 River Road
Schenectady, New York (NY) 12301-0008
USA
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ITT Corp
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E-mail: tglover@hq.ittind.com

Lockheed Martin Corp
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Raytheon E-Systems Richardson
(formerly Texas Instruments)
PO Box 831359
Richardson, Texas (TX) 75083
USA
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Web: www.electrospace.com
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TRW Inc
Space & Defense Group
One Space Park #5076
Redondo Beach, California (CA) 90278
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Tel: +1 310 813 7685
Web: www.trw.com

(Hughes Electronics Corp was also an original MIMIC contractor; however, Raytheon acquired Hughes and is thus not included in the above list).

Status. MAFET is in the RDT&E phase.

Total Produced. No equipment is expected to be produced since MAFET's goal is to reduce non-recurring costs.

Application. While MAFET is addressing a number of areas from the MIMIC program, the main thrust is to significantly reduce non-recurring costs for military microwave/millimeter wave sensor systems.

Price Range. Per unit costs for MIMIC-derived boards remain highly variable. While costs had markedly decreased during MIMIC, from a US$20-$50 level at the beginning of the program down to the present US$3-$6 range, the level was still too high to be economically feasible.

MAFET's goal is to bring down the cost to approximately US$0.80 per square millimeter of GaAs (the usual measure for determining MIMIC costs).

Variants/Upgrades

Increased functionality, enhanced reliability, enhanced environmental capability, further size miniaturization, and continued cost reduction are unending objectives of microcircuit development programs within the electronics industry. Begun in 1995, MIMIC's successor, the MAFET program, continues to address these objectives.

Program Review

To better understand the goals of the MAFET program, the Program Review begins with a synopsis of the original MIMIC program.

MIMIC Program. In 1985, a study was conducted on ways to reduce the cost of microelectronic components needed for the new generation of precision-guided munitions. This survey, jointly conducted by OSD, DARPA, and the three US Military Services, resulted in the initiation of the Millimeter Wave Monolithic Integrated Circuits (MIMIC) program. The successful developmental program was an eight-year effort completed in 1995 at a cost of approximately US$500 million. With DARPA currently heading the effort, a MIMIC office was formed at the same level as its strategic technology office to manage the program.

Phase 0. Completed in February 1988, the concept definition phase identified 50 systems that could benefit from MIMIC technology. Twelve companies, including seven of the Phase 1 participants (Lockheed Martin/ITT, Raytheon/TI, Hughes/GE, and TRW), working under contracts worth from US$750,000 to US$1 million, participated in this phase. ***Please Note:*** *Hughes is now Raytheon Co. and TI is Raytheon E-Systems*.

Phase 1. Contracts for initial hardware development were awarded in May 1988. Each of the four Phase 1 teams developed experimental brassboard versions of MIMIC chips. All four teams worked under three-year contracts. Phase 1 involved 29 of the 48 companies that participated in the competition. The US Navy Naval Air Command was in charge of the Phase 1 effort. The first MIMIC chips to be finished in the Phase 1 effort were completed and demonstrated by the TRW-led team in early 1989. In Phase 1, Raytheon and Texas Instruments set up process lines. Phase 1 was completed in the late spring of 1991.

Phase 2. Started in the late spring of 1991, the main thrust of this phase was a continuation of Phase 1 technology and product development with the goal of demonstrating the readiness and sustained availability of MIMIC design/fabrication capabilities. Pilot production lines were expanded to include sophisticated system capabilities. During this phase, the possibility of using less familiar materials with enhanced properties was explored. Phase 2 was scheduled to be completed by the end of FY95. Contracts were awarded to the Hughes (US$79 million), Raytheon/TI (US$83.5 million), and TRW (US$65.7 million) teams.

Phase 3. This phase was conducted at the same time as the consecutive Phase 1 and Phase 2 efforts. It provided the innovative, additional capabilities or tools needed to meet the overall goal of affordable MIMIC technology for DoD systems in the 1990s and beyond. The focus was on providing reliable and inexpensive methods of producing MIMIC chips and modules. Areas of interest included: MIMIC computer-aided design; GaAs material/device process analysis, modeling, and screening; MIMIC wafer, chip, and module automated testing; and additional technological areas encompassed by the MIMIC program. This phase was designed to address areas of greatest need.

Phase 3 was supported by annual funding of approximately US$25 million through FY93. The first contracts were issued in mid-1989, with areas of emphasis being computer-aided design, development of improved material growth techniques, automated testing techniques, multi-chip packages, and novel processing techniques. In early 1991, Avantek received a 24-month contract totaling nearly US$3 million for research into foundry fabrication techniques. TriQuint, with GE's Electronics Laboratory acting as a subcontractor (chip design), fabricated and tested MIMIC chips under a US$2.65 million contract.

In May 1992, DARPA announced that the following 10 contractor teams would receive 1992 contract awards under the technology support phase (Phase 3) of the MIMIC program. An approximate total of US$6.1 million was awarded. The winning team leaders by technology area were:

<u>Materials</u>
- Bandgap Technology Corp, Broomfield, CO

<u>Computer Aided Design and Modeling</u>
- Compact Software Inc, Paterson, NJ
- Motorola Inc, Scottsdale, AZ
- Sonnet Software Inc, Liverpool, NY

<u>Processing and Fabrication</u>
- University of California San Diego, La Jolla, CA
- University of Illinois, Urbana, IL

<u>Testing</u>
- Casade Microtech, Beaverton, OR
- Scientific Atlanta, Atlanta, GA

<u>Packaging</u>
- Ceramic Process Systems, Milford, MA
- Lockheed Martin, Orlando, FL

Phase 1 Teams. The following is a listing of Phase 1 teams, highlighting each team's area of responsibility.

<u>Hughes Aircraft/General Electric</u>. Hughes and GE were the team leaders for Phase 1. The team worked under a US$50 million contract with the US Air Force acting as the lead agency. The Aeronautical Systems Division, Wright-Patterson AFB, OH, issued the contract. This team was specifically concerned with developing brassboards for the Airborne Active Phase Array, (ACPA), the Active Tactical Surveillance Radar (ATSR), the Global Positioning System (GPS), and the Advanced Millimeter-Wave Seeker (AMMWS).

The brassboard for the ACPA is an adaptable, active X-band radar array block that incorporates four transmit/receive modules and control circuitry enclosed in a hermetically sealed single housing. Potential platforms include the Advanced Tactical Fighter, F-14, F-15, F-16, and F/A-18 aircraft. The ATSR radar array block is similar to the ACPA but includes added specifications for efficiency, noise figure, output power, phase error, and spurious/harmonious output parameters.

GPS work involved replacement of the existing hybrid technology in the antenna with MIMIC components that resulted in equivalent performance but with lower costs and weight, and smaller size. E-Systems ECI Division was awarded a three-year US$1.2 million contract by Hughes in August 1988 for this effort. The AMMWS technology has application across the whole range of US smart munitions systems, with particular emphasis on the Maverick missile.

This team has apparently been quite successful in sharing technology, with know-how transfers in such areas as automated test algorithms, epitaxial high-power amplifier processes, gate-recess spray-etching, ion-implanted low-noise amplifier processes, and 0.5-µm fine-line lithography being accomplished. In the Phase 2 contract, GE was no longer referred to as a team leader; just a team member.

(Hughes Aircraft is now Raytheon Co.)

<u>ITT/Lockheed Martin</u>. ITT Defense Technology Corp and Lockheed Martin Electronics and Lockheed Martin Space and Missiles Group were the team leaders. ITT focused on microwave applications and Lockheed Martin was concerned with millimeter-wave technology

suitable for smart munitions. This team worked under a US$49.3 million contract. The US Army was the lead agency. The Electronics Technology and Devices Laboratory, Fort Monmouth, New Jersey, issued the contract.

Contract work included brassboards for EW systems, including the ALQ-165 Advanced Self-Protection Jammer, the ALQ-136, Sense and Destroy Armor (SADARM), Multiple-Launch Rocket System Terminal Guidance Warhead (MLRS/TGW), SHF SATCOM, Airborne Adverse Weather Weapons System (AAWWS), and other missile seekers and communications systems. In the ALQ-165, MIMIC technology replaced existing WRAs (weapons replaceable assemblies) and provided the capacity to add future functional capabilities.

The ALQ-136 brassboard provides five SRUs (shop replaceable units) that include four MIMIC modules in the transmitter, receiver and log video units, with the result that functional capacity was increased while reliability improved and costs and maintenance were reduced.

The Army has indicated that it may be able to save as much as US$120 million in the SADARM program alone through the replacement of present hybrid technology with MIMIC components that increase transmitter power, reduce transceiver size, and lower the noise figure. Enhanced performance, lower costs and smaller size also result from MIMIC insertion in the MLRS/TGW.

The SHF SATCOM manpack uses MIMIC to meet requirements for reliability, cost, weight, and size. As much as US$150 million may be saved in the AAWWS program with replacement of hybrid technology by MIMIC. The space savings in the HELLFIRE missile allows the inclusion of enhanced Built-In Test (BIT) and calibration capabilities. Interestingly, this team did not receive a Phase 2 contract.

<u>Raytheon/Texas Instruments</u>. Raytheon and Texas Instruments (TI) were the leaders of the third joint venture team. The companies worked under a US$68.6 million contract. The US Navy was the lead agency while the Naval Air Systems Command issued the contract. Efforts focused on an EW application called a transmit/receive module that combines both elements into a single subsystem. This team had hoped to reduce the cost of MIMIC chips from US$20 per square millimeter to US$0.80 per square millimeter by 1994.

The primary focus of the work was on developing a wideband, medium-power, EW Linear Transmitter Array brassboard using a 1 x 8 linear phased configuration. Eight MIMIC amplifier/phase shifter modules were to be driven by two power dividers. A module would then be assigned to drive each polarization of a dual-polarized antenna element. Stacking the interleaving flange design blocks of the brassboard in different configurations enabled it to meet the requirements of a self-protection and stand-off jammer. The self-protection jammer application of MIMIC was predicted to result in a substantial cost savings, as well as lower weight and smaller size.

(*Texas Instruments is now Raytheon E-Systems).*

<u>TRW</u>. This last team worked under a US$57 million contract. The US Army was the lead agency, with the team supplying chips to the Army's Electronic Technology and Devices Laboratory, which issued the contract. This team developed five brassboards for smart munitions, including SADARM, MLRS/TGW, Multi-Optional Fuzed Armament (MOFA), Advanced Air-to-Air Missile (AAAM), and the Integrated EW System (INEWS).

MIMIC work for SADARM focused on the insertion of MIMIC macrocells in the transceiver interconnected by a planar antenna in a Ka-band radar front-end module. Enhanced transmitter efficiency and receiver sensitivity was expected, along with a 50 percent cost reduction. MIMIC work for MLRS/TGW involved inserting MIMIC modules into the receiver and synthesizer subassemblies. The result was better phase tracking and amplitude, improved frequency accuracy, and reduced cost, weight, and size. The MOFA work saw a reduction in the size of the RF section through the installation of a single-chip MIMIC module containing a mixer and duplexer, a power amplifier, and a VCO.

The MOFA was a particularly challenging task, since this smart artillery shell project called for chip costs of less than US$10 each, with a complete fuze to cost less than US$100. TRW was reported to have built a C-band transceiver chip (frequency-modulated, continuous wave radar-on-a-chip) that makes the fuze capable of true ranging (determining where the target is and estimating range to target).

The AAAM brassboard contained five modules: one synthesizer/LO module and four monopulse receiver modules. The use of MIMIC technology resulted in substantial weight and volume reductions, with lower costs and higher reliability. Increased acquisition was expected to result. The EW brassboard saw the installation of MIMIC technology in a tuner, synthesizer, and channeled receiver, resulting in faster threat processing, greater system availability, and significant size and weight reductions.

In February 1989, this team delivered the first chips to be completed and demonstrated in the MIMIC program.

One was an attenuator chip designed to lower signal strength. The other two were signal amplifiers. According to TRW, these chips were to be used on at least one of the brassboards that the team was working on.

The USAF AAAPT Program. The US Air Force Advanced Aircraft Avionics Packaging Technology (AAAPT) program also uses MIMIC. The objective of this program was to expand and enhance the use of modular avionics across the range of virtually all airborne electronic systems, in an effort to achieve a 30-day war-fighting capability for system avionics. MIMIC is used along with VHSIC, wafer-scale integration, phased arrays, opto-electronics, and high- density power supplies. The Aeronautical Systems Division is the sponsoring agency.

The program is envisioned as having three phases. Phase 1 is a trade-off design study. Phase 2 uses the PAVE PILLAR modular avionics design concept for integrating racks and single/double wide module form and fit, and core avionics functions. Phase 3 is concerned with the application of the technologies that were expected to be in an advanced state of development by 1995. Objectives include improving thermal management, reducing vibration failure effects, lowering the number of connectors, lessening power requirements, and reducing the electronics packaging weight.

Additional Involved Contractors

Perkin-Elmer. Located in Hayward, California, Perkin-Elmer was reportedly developing an enhanced version of its Aeble-150 direct-write electron beam system for the MIMIC program. This version was to be capable of generating feature sizes of 0.25 micron and below.

A contract awarded in May 1988 was to result in the company receiving approximately US$13 million over the following 30-month period to develop the enhanced Aeble-150, with the Army's Electronic Technology and Device Laboratory awarding the first increment. Most of the enhancements to the system were concerned with the electronics and computer portions of the system. The original version of the Aeble-150, of which Perkin-Elmer supplied one to Raytheon for the MIMIC program, reportedly cost about US$3 million.

The machine was to be used to not only write the gate level with an E-beam, but also to use the E-beam to develop the drain and source levels of the MIMIC device, whereas previously only the gate level could be written with an E-beam. Contact printers had filled the other roles prior to that time.

Lockheed Corp. In mid-1988, Lockheed Corp announced that it was making a major commitment to MIMIC, with the main focus on making sure that its own systems stayed current with those of the competition. Apparently, the sufficiency of Lockheed's investment in the MIMIC area had been questioned internally, especially after Lockheed Sanders lost in the MIMIC competition. In 1989, Lockheed Sanders launched its own MIMIC Initiative Program (MIP).

The MIP included four tasks scheduled to be completed by early 1991. These included developing the key MIMIC chips needed to support the company's own EW programs; using advanced packaging and automation to increase fabrication yield and improving module assembly techniques; and developing accurate cost and yield models for those chips and modules that are used in DoD programs. In conjunction with the US Navy, Lockheed Sanders embarked on a Navy Potential Contractor Program under which the company's Microelectronics Center would qualify as a producer of Phase I chips.

Lockheed Sanders received two additional MIMIC contracts in 1992. The first contract, awarded in February by the Raytheon/Texas Instrument team for US$8.9 million, was for the development of four key MIMIC technology areas. These were: develop a brassboard electronic combat array for the F-22; improve MIMIC processing and develop advanced fabrication methods; establish a high-volume, low-cost automated production line for MIMIC modules; and demonstrate the selected manufacturing process. DARPA awarded the second contract in September to demonstrate the feasibility of fabricating and manufacturing MIMICS using X-ray lithography, in place of conventional light optics, to illuminate the printing of the circuits.

The major accomplishment achieved under the Phase 2 program throughout 1992 was the transfer of advanced materials, devices, design software, packaging and testing technologies into MIMIC fabrication lines. FY93 saw the delivery of the first multifunction MIMIC meeting required system specifications.

During this time period, assembly of advanced MIMIC modules and system brassboards was started, with development of advanced materials, devices, design software, packaging, and testing technologies continuing. Hughes Aircraft selected ITT as a second source for X-Band power computer chips on DARPA's MIMIC Phase II project in May 1993. The award consisted of chip design and processing 200 wafers and data analysis. Options included processing and analyzing up to 400 additional wafers.

As the program progressed throughout 1994, work continued on MIMIC Phase 2 contracts, including delivery of process demonstration wafers and the completion of MIMIC Phase 2 chip fabrication.

Assembly of MIMIC modules and brassboards also continued.

The MIMIC program was successfully completed by the end of FY95. This included final delivery of MIMIC chips, modules, brass-boards, and demonstrations of advanced technology and hardware.

MAFET. In 1995, DARPA initiated a follow-on to the MIMIC program aimed at significantly reducing non-recurring costs for military microwave/millimeter wave sensor systems. The program was designated as Project Element PE#0603739E - Project MT-06 - *Microwave and Analog Front End Technology (MAFET).*

Specifically, the MAFET program was intended to provide the DoD with state-of-the-art electronic systems needed to maintain its force multiplying capabilities. Program objectives include:

1. reducing design time and cost for every radio frequency (RF) system being developed or upgraded through an improved microwave/millimeter wave design environment;
2. breaking the very expensive cycle and time-consuming current practice of design-build-test/redesign-rebuild-retest;
3. putting in place repeatable, robust processes to produce high frequency components;
4. making strategic investments in critical passive, packaging, and integrated circuits devices needed for millimeter wave systems; and
5. investigating revolutionary solutions to the long-standing problem of insufficient power in solid-state radar and communications transmitters.

MAFET has a continuous time line which extends through 1999 and an approximate budget of US$121.4 million between 1995 and 1999.

The tasks initiated in 1995 focused on beginning implementation of a microwave/millimeter wave computer-aided design environment that would reduce non-recurring chip/module/system costs by providing improved design, simulation, synthesis, and cost analysis capabilities. This task included enhancement of CAD tools specifically needed for microwave and millimeter wave circuit use (i.e., not digital circuit design tools which are different), tool set integration, effective use of performance and cost databases, needed circuit and module development, and work on the Microwave Hardware Description Language (MHDL).

In 1995 and 1996, computer-aided drafting (CAD) tools were devised to improve the design and simulation of the chips, modules, and system capabilities required in the MAFET program as well as to aid in the advancement of sensor technology development programs and associated tests.

In FY1997, quantitative demonstrations were conducted of the performance improvements and cost savings achieved through use of the program’s selected critical system applications. In addition, the development of an all-solid-state X-band source with high power output and low manufacturing cost was initiated during 1997.

FY98 activity included the completion of the CAD environment and continued implementation of MHDL. Demonstrations were conducted of advanced manufacturing techniques, fabrication, and packaging. In addition, use of the following equipment was demonstrated: a novel high-power transistor; high-power amplifier; quasi-optical Ka-Band sources; a MEMS-switch area four-bit true-time-delay phase shifter in X- and Ka-Bands; and thermal management circuits.

The last year of the MAFET program, FY99, included the demonstration of a set of quasioptical grid-, array-, card-, and slab-combined power amplifiers; the demonstration of an MEMS-tunable Chebyshev filter and MEMS-array transmitting beam steerer; the demonstration of a micromachined SSPA (W-Band Power Cube); and the fabrication of the power cube with InP Power MMICs.

This program ended in FY99. No funding is expected to be provided for this program in the future.

Funding

US FUNDING

	FY98		FY99		FY00		FY01	
	QTY	AMT	QTY	AMT	QTY	AMT	QTY	AMT
RDT&E (DARPA)								
PE#0603739E Advanced Technology Development Project MT-06								
MAFET	-	17.5	-	4.0	-	0	-	0

Source: US DoD FY1999/2000 Biennial RDT&E Descriptive Summary

All US$ are in millions.

Note: Project MT-06 was completed in FY99. No further funds have been requested for this project, nor are they expected to be in the future.

Recent Contracts

No known contracts have been let for the MAFET program.

Timetable

Month	Year	Major Development
	1985	Initial study conducted
Feb	1988	Phase 0 completed
Mid	1989	First Phase 3 contracts issued
Nov	1989	Chip architecture defined
May	1990	Pilot lines in place
Sep	1990	Phase 2 RFP issued
Feb	1991	Fabricated prototype modules
May	1991	Phase 1 effort completed
Aug	1991	Phase 2 contracts issued
Mar	1992	Transfer of Phase 2 technology to member companies completed
Jun	1992	First Phase 3 silicon wafers produced
Oct	1992	Installation of Phase 3 fabrication tools and equipment completed
Sep	1993	Integrated Phase 3 manufacturing process demonstrated fully and transferred to member companies
Jun	1994	Fabrication of MIMIC chips completed
Aug	1994	Scheduled completion date for Phase 2 contracts
	1995	MIMIC program ends; technology to form basis for efforts in the Microwave and Analog Front End Technology (MAFET) program
	FY1995	MIMIC Phase 2 chips, modules, and brassboards delivered. Integrated design/ fabrication/test capabilities at MIMIC Phase 2 contractors completed
	FY1997	Integrated digital, analog, and optical function modules in system brassboards demonstrated
Mar	1998	20-W X-band all-solid-state sources demonstrated
Jun	1998	Embedded transmissions line MMICs demonstrated
Sep	1998	Ultra-low-cost SiGe T/R modules
Dec	1998	10-W millimeter wave power amplifier array demonstrated

Month	**Year**	**Major Development**
Jan	1999	Millimeter wave micromachined solid-state power amplifier demonstrated
Mar	1999	Millimeter wave beam steering module demonstrated
Jun	1999	> 100-W low cost X-band electronically steerable source demonstrated
Sep	1999	Full interoperability of CAD vendors demonstrated
Late	1999	MAFET program completed

Worldwide Distribution

Although MAFET and MIMIC are **US DoD** programs, overseas interest is obvious in MAFET/MIMIC technology. Defense Technology Security Administration officials have stated that MAFET/MIMIC design and manufacturing technology should not be transferred to foreign countries due to national security and competitiveness concerns. However, they also indicated that sales of US-produced MAFET/MIMIC hardware are acceptable to certain allies. It is significant that the first ground-based radar to incorporate MIMIC chips, prior to the MAFET program, is the multinational COBRA counter-battery radar, produced by the Euro-ART consortium (GE Aerospace, Siemens, Thomson-CSF). In 1991, GE Electronics Laboratory built the first two COBRA solid-state active-array antennas, each incorporating several thousand of GE's MIMIC chips.

Forecast Rationale

The Microwave and Analog Front End Technology (MAFET) program, a follow-on to the Millimeter Wave Monolithic Integrated Circuits (MIMIC) program, was completed in FY99. The MAFET program was directed at significantly reducing non-recurring costs for military microwave/millimeter wave sensor systems through improved computer-aided design capabilities.

Activities during FY99 focused on the demonstration of a set of quasioptical grid-, array-, card-, and slab-combined power amplifiers; the demonstration of a MEMS-tunable Chebyshev filter and an MEMS-array transmitting beam steerer; the demonstration of a micromachined SSPA (W-Band Power Cube); and the fabrication of the power cube with InP Power MMICs.

The MAFET program was wrapped up by the end of FY99. No future funding is anticipated, and, barring any unexpected activity, this report will be archived next year (2000).

Ten-Year Outlook

ESTIMATED CALENDAR YEAR FUNDING ($ in millions)

			High Confidence Level			Good Confidence Level			Speculative				
Designation	**Application**	**Thru 99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**Total 00-09**
MAFET	Prior Prod'n:	120.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Project MAFET was completed in FY99.

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