# RECENT MMW TECHNOLOGY DEVELOPMENT AND ITS MILITARY AND COMMERCIAL APPLICATIONS

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## ABSTRACT

This paper highlights key recent advances in the infrastructure of Milli-Meter Wave (MMW) technology. They include improved MMIC design methodologies, enhanced HEMT and HBT wafer processes, new on-wafer testing capabilities, automated assembly of MMW Multi-Chip Assemblies (MCAs) and new packaging techniques. It also addresses the implications of these advances in terms of their impact on a wide range of military and commercial systems. The paper concludes with comments on future trends and directions of the MMW technology.

## INTRODUCTION

MMW components are becoming more available and affordable due to recent advances in the design, processing, testing and packaging technology for MMW GaAs and InP MMICs and MCAs. Significant impetus has been provided by the DARPA sponsored MAFET program. As a result more and more MMW systems, both military and commercial, are being developed and deployed which provide new and unique capabilities such as more information transfer (wider bandwidth), enhanced precision (higher resolution) and all weather operation (through fog, dust and smoke).

## TECHNOLOGY ADVANCES

MMW MMIC Design Technology: The advancement in design techniques and enhancement in design tools have been key factors for many successful MMW MMICs in recent years:

**Enhanced model accuracy** - Without accurate active device and passive component models, designers cannot simulate and optimized the MMIC designs. In the past few years, new test techniques including on-wafer probing and calibration standards were developed. We were able to extend accurate testing to 94 and 120 Hz. With many MMICs fabricated at MMW frequencies, we were also able to further validate the models from measured data of LNA, power amplifier and mixers. These accurate and verified models modes were the cornerstones of MMIC design in MMW frequencies.

**EM simulation** - In MMW frequencies, discontinuities, transmission line coupling and packaging effect will greatly impact the performance of MMICs. With a good EM simulation tool, we were able to accurately calculate the coupling and parasitic of certain structures and incorporate these effects in the final design. With these tools, we were able to reduce the number of iteration on chip design. In the MAFET Thrust 1 program, the speed, memory usage and area of simulation will be further improved to have a major impact on MMIC chip design.

**Design maturity** - With many more MMW MMIC developed, the industry as a whole gain a great deal of knowledge in designing

MMIC in MMW frequencies. Techniques in biasing the circuitry, layout of complex functional blocks on the same chip, using the optimum devices and processing technologies were developed and distributed among designers. These knowledge not only eliminated many design errors but also improved the design efficiency substantially.

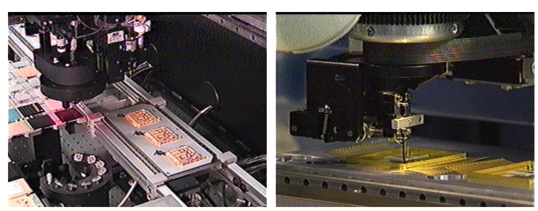
<u>MMW MMIC Processes</u>: Wafer fabrication processes that support MMW MMICs include GaAs HEMT, InP HEMT and InP HBT processes. Process improvement tasks performed under MAFET Thrust 2 established the GaAs HEMT process on 2 mil thick wafers as a process of choice for high power MMW MMICs. InP power HEMT process promises to produce MMICs with higher Power Added Efficiency but the process maturity is low. The yield of 3 inch InP HEMT and InP HBT process has improved significantly to qualified them as a production process[1]. Table 1 shows the frequency range of each of the MMW processes and its circuit functions. The dimension in the process description refers to the gate length for the HEMT process and emitter size of the transistor in the HBT process.

| Process | Freq. Range | Circuit Functions |
|---|---|---|
| GaAs HEMT 0.15 µm | 1-65 GHz | Power MMICs |
| GaAs HEMT, 0.1 µm | 44 -100 GHz | Power MMICs |
| 1 µm InP HBT | DC to 65 GHz | VCO and high linearity amplifier |
| 0.1 µm InP HEMT | 44 - 160 GHz | Low noise amplifiers and downconverters |

Table 1. MMW wafer processes

<u>MMW On Wafer Testing:</u> The ability to select known good die is crucial for producing affordable MMW components. On wafer measurements capability is the most cost effective means for implementing the known good die strategy. The frequency range for on-wafer measurements has been extended beyond W-band with the development of improved on wafer probes. These measurements include small signal, noise figure, and pulse power measurements. Good correlation between on-wafer and fixture measurement of MMICs has been obtained.

<u>Automated Assembly of MMW MCAs:</u> Automated assembly reduces the cost of MCAs for moderate and large production quantities. The application of automated assembly to the production of MMW MCAs requires tight control of dimension tolerances and interconnect designs that compensates for the many discontinuities in the MCA. EM simulation techniques provide designs with no more than .25 dB of loss in a W-band interconnect with >5% bandwidth. With these techniques MMW MCAs can now be assembled in an automated assembly line shown in Figure 1 at a cost no more than their microwave counterparts.



Die attachment Ribbon bond

Figure 1. Automated assembly of MMW MCAs through W-band.

<u>Recent MMIC and MCA accomplishments:</u> As the technology infrastructure matures, record performances are being demonstrated. For improved power, a 6 W 24% PAE power module at Ka-band was reported[2]. Figure 2 is the picture of this module. It consists of a driver amplifier and

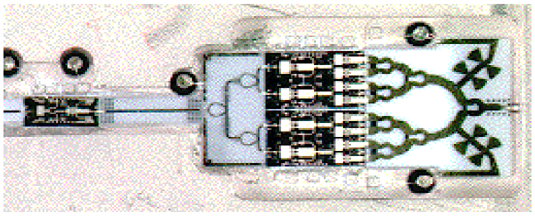


Figure 2  Six (6) Watt Ka-band MCA

The power level that is achieved at W-band is demonstrated by the module shown in Figure 3. Here a combination of 4 MMIC chips produced 26 dB gain and a output power in excess of 350 mW.

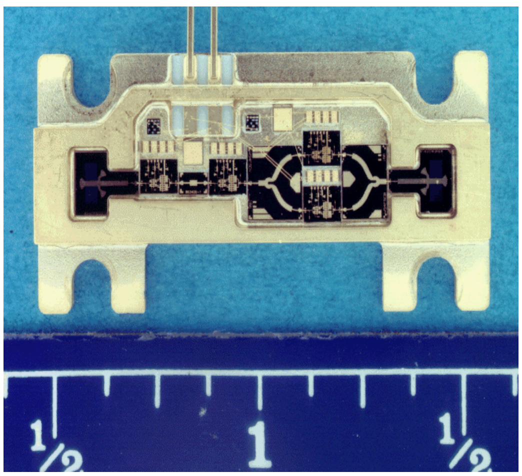


Figure 3. 350 mW W-band MCA

In the low noise arena, excellent noise figure (NF) are achieved by InP HEMT MMICs. 5 dB NF at 155 GHz was demonstrated in a InP HEMT LNA.  Figure 4. Compares the measured NF of InP and GaAs LNA at various MMW frequencies.

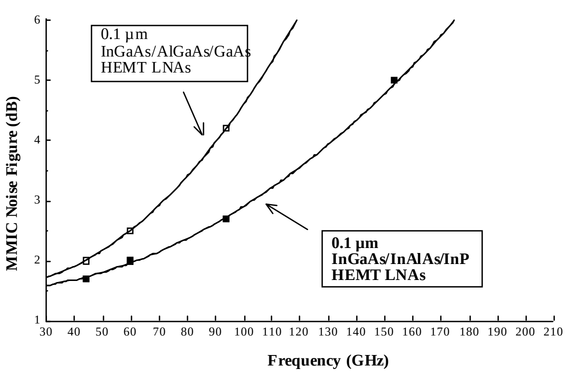



Figure 4.  NF of InP and GaAs HEMT LNA

## MILITARY APPLICATIONS

Military MMW systems have advantages in size, directionality and sensitivity. They provide enhanced capabilities in precision strike, covert communication, portability and all weather operation. Technology advances reduce system cost and increase system performance. Examples of MMW military systems include smart weapon (Longbow, SADARM, BAT), Anti-fratricide (BCIS), communication (SCAMP) and space systems (MILSTAR, SBIRS Low). The smart weapon system shown in Figure 5 employs MMW transceivers as active seekers. Space based system such as SBIRS Low in Figure 6 uses MMW components in its V-band crosslink.

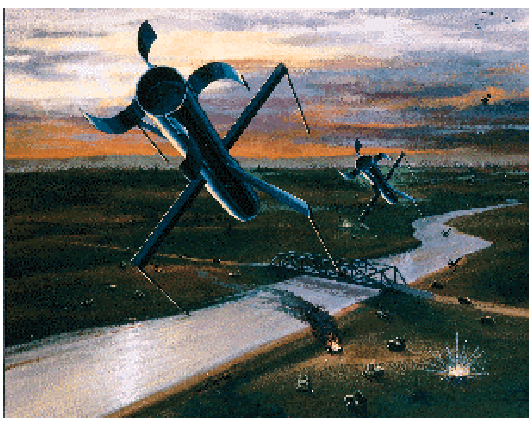


Figure 5. Smart Weapons

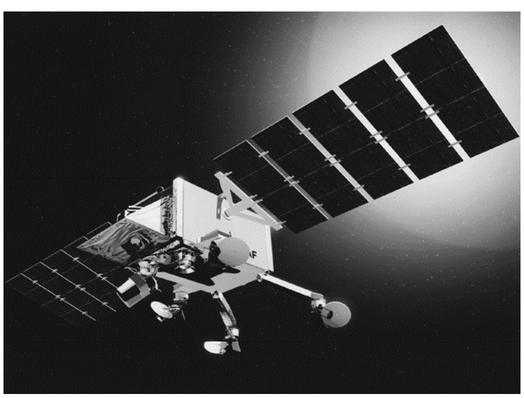


Figure 6. SBIRS Low Satellite

## COMMERCIAL APPLICATIONS

Two major areas for millimeter-wave commercial applications are telecommunication and transportation. Table 2 and 3 summarizes some of the applications.

Telecommunication:

| Application | Frequency (GHz) | MMW Insertion |
|---|---|---|
| Short-Haul Radio Link | 17.7 - 19.7<br>21.2 - 23.6<br>24.5 - 26.5<br>37.0 - 39.5 | Transceiver |
| VSAT | 27.5 - 30.5 (Uplink)<br>17.7 - 20.2 (Downlink) | Modulator, HPA, Receiver |
| LMDS | 27.5 - 29.5 | Transceiver |
| In-Door Wireless LANs | 60 | Transceiver |

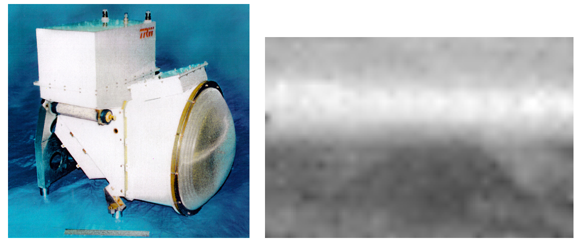
Table 2 MMW Telecommunication applications

Transportation:

| Application | Frequency (GHz) | MMW Insertion |
|---|---|---|
| Automotive Radar | 76 - 77 | FM-CW Transceiver |
| Enhanced Vision System | W-band | MMW FPA |

Table 3 MMW Transportation applications

Figure 7 shows a W-band real time passive millimeter-wave camera that has successfully flight tested recently. The camera consists of 1040 pixels W-band focal plane array (FPA).



(a) Camera (b) View of a runway
Figure 7. W-band real-time passive millimeter-wave camera
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## TECHNOLOGY TRENDS

The need to lower system cost will demand development in the InP HBT and InP HEMT technologies, providing further advantages in lower DC power consumption and higher power efficiencies. This is all the more significant for space system applications. The ability to further miniaturize the MMW components by selective epitaxy, 3-D MMIC and higher level of integration will revolutionize future MMW systems.

## CONCLUSION

Significant advances are being made in all aspects of the MMW technology. Record performances are being demonstrated. The technology is enabling a wide range of military and commercial systems. The revolution in the MMW technology is continuing.

References:

1. D. Streit *et.al*., “An InP-Based HEMT and HBT MMIC Production Line”, 5th European GaAs Application Symposium
2. D.L. Ingram *et. al*.,“A 6 Watt Ka-band Power Module Using MMIC Power Amplifiers” IEEE Transactions on Microwave Theory and Techniques, Vol. 45, No. 12, December, 1997