APPLICATION SPECIFIC MMIC: A UNIQUE AND AFFORDABLE APPROACH TO MMIC DEVELOPMENT

E. Turner(1), Z. Lemnios(2), S. Moghe(3), A. Podell(3),
C. Korgell(3), R. Genin(3), H-C Huang(4)

(1)Ford Aero., Palo Alto, CA, (2) Ford Micro., Colorado Springs, CO,
(3)Pac. Mono., Sunnyvale, CA, (4)COMSAT, Clarksburg, MD

ABSTRACT

The high levels of integration possible with GaAs Microwave Monolithics Integrated Circuits has the potential of tremendous benefits of reduced cost, size, and weight and increased reliability of microwave systems. These benefits have only been realized for systems that can justify the high costs and risk of MMIC development.

Application Specific MMIC (ASMMIC) promises to simplify the development process and hence reduce the development cost and risk. Furthermore, ASMMIC can realize volume production savings through a shared production process and through increased production demand. The foundation of the innovative ASMMIC concept is a predesigned footprint building block. This footprint comprises the layers containing FETs, resistors and diodes in an array compatible with a wide range of circuit functions. The chip is completed by applying personalized metalization to the footprint.

Wafers of footprints can be produced in volume, fully characterized, and placed in inventory. The characterized data will be used as accurate parameters of the models contained in the ASMMIC CAD library. The ASMMIC CAD will facilitate the design of the metalization layers which establish the circuit functionality (amplifier, mixer, oscillator, limiter, switch, isolator, attenuator, etc.) and the operating frequency and power range. The design and application of the metalization layers can be accomplished with high confidence and within a time span of a few weeks. This contrasts with a complex ''from the ground up'' custom design and production process requiring many months and one that inherently has the potential for many design and process errors.

ASMMIC offers the possibility of making MMICs accessible, affordable and available for a broad range of systems applications. To ensure accessibility, the ASMMIC technology will be readily transferable to a wide range of users through computer aided engineering tools which are being developed.

ASMMIC CONCEPT

The research described in this paper presents the results of seven footprints and twenty two personalizations as summarized in Table 1-1. These components were designed by the Ford Aerospace MIMIC Team* as company sponsored demonstration projects to provide initial proof of concept validation of ASMMIC. It can be seen that ASMMIC is applicable to a wide range of functions and to a wide range of frequencies. We have extended the ASMMIC concept to millimeter wave frequencies. Figure 1-1 shows 27 GHz and 30 GHz amplifiers that were designed using the same footprint. Our analysis indicates that ASMMIC can be extended up to 60 GHz with little or no performance degradation.

Table 1-2 is a comparison of the projected performance of ASMMIC and custom chips and provides a commentary of critical design methodology used to maintain ASMMIC performance. A graphic representation of two footprints and eight personalizations are clearly shown in Figure 1-2. These ASMMIC circuits were designed for operation in a dual channel direction finding receiver used in an antiradiation missile seeker.

Figure 1-3 shows the block diagram of a QPSK demodulator, an image rejection down converter, and a dual channel down converter. These block diagrams are functionally quite different but they are comprised of similar functional elements. The genesis of the ASMMIC concept was the Ford QPSK design project where lower level similarities (minor FET resizing was necessary) were observed and most of the circuit design was centered around the upper level metalization elements. This same observation carried over to the other converter circuits and the concept of ASMMIC was established. The lower level mask layers for the Ford 3 GHz and 4 GHz QPSK demodulators are shown in Figure 1-4a. As can be seen, there is virtually no difference. With interdigitated FETs, active element sizing can easily be accommodated.

Figure 1-4b shows the combined layout of the footprint and the metalization for QPSK demodulators that operate at 3 GHz and at 4 GHz along with operational data in Figure 1-5a & b. It can be seen that these two circuits are very similar except for the size of the spiral inductors and transformers which establish the operating center frequency. The lumped element design approach using spiral inductors and capacitors rather than a distributed transmission line approach is a key factor in making ASMMIC feasible. If a transmission line approach were used in the QPSK example, the chip sizes would probably be scaled according to operating frequency and therefore could not use a common footprint.

Figure 1-6 shows that the performance penalty of ASMMIC vs. a custom design is negligible. With accurate ASMMIC models these penalties can be reduced even further.

The lumped element approach also results in small chip sizes. A typical ASMMIC chip is less than 100 mils square. Figure 1-7 shows that for chips of this size that very little cost penalty is incurred due to excess area taken by unused components or due to a somewhat less than optimized layout.

Figure 1-8 shows that ASMMIC is more cost effective than a custom design for systems requiring less than approximately ten thousand units.

In the rare occasions when a custom design is justified over ASMMIC (very high performance or very high volume), ASMMIC still can serve a valuable role as a quick turn proof of concept or prototype prior to the initialization of a costly custom design.

CONCLUSION

ASMMIC has been shown to be a more cost effective approach for implementing MMIC chips in most systems. This is achieved with little or no performance penalty and with the completion of an ASMMIC library and CAD tools promises to yield the benefits of MMIC to a broad range of system applications.

*The Ford MIMIC Team consists of Ford Aerospace Western Development Laboratories and Aeronutronic Division and Ford Microelectronics, Inc., the team includes Singer Dalmo Victor and Electronic Systems Divisions, IBM Federal Systems Division, Pacific Monolithics, Interstate Electronics, and COMSAT Laboratories. TriQuint Semiconductor and Harris Microwave Semiconductor, Inc., round out the present team.

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Table 1-1. Company Sponsored Demonstration Project Validates ASMMIC Approach Covering 0.2 to 30 GHz.

Footprint	Function	Personalization	Frequency	Measured Performance
1	Converters Amplifiers	6	1 - 18 GHz	2 - 8 GHz converter 5 dB conversion gain
2	Oscillators Amplifiers	2	2 - 14 GHz	10 dB ± 0.75 dB Amplifier
3	Power Amplifiers	3	2 - 8 GHz	11 dB ± 0.25 dB Amplifier
4	Converters	2	8 - 16 GHz	8 - 16 GHz converter 12 dB Conversion
5	IF Components	5	0.2 - 5.0 GHz	0.8 - 50 dB Attenuator
6	MM-Wave Power	2	26.5 - 30 GHz	480 mw 4.4 dB gain
7	MM-Wave Power	2	15 - 22 GHz	500 mw 4 dB gain

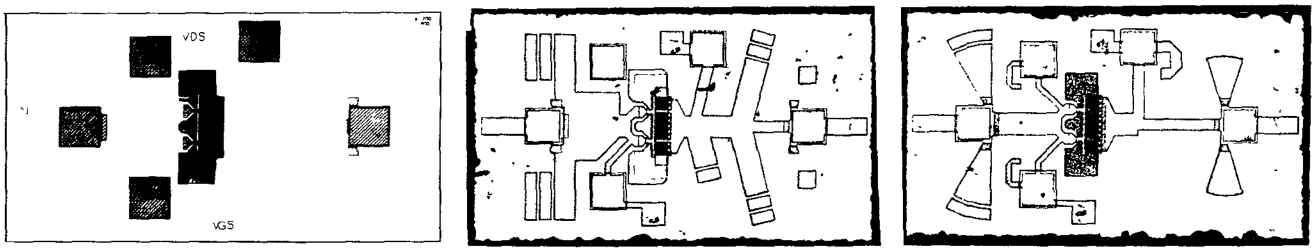


Figure 1-1. A Millimeter Wave ASMMIC Footprint has been Personalized Resulting in a 27 GHz Narrowband and a 30 GHz Wideband Amplifier.

Table 1-2. Comparison of Custom MMIC vs. ASMMIC Chips for High Performance Parameters (0.5 - 18 GHz).

Parameter	Performance Delta Compared to Full Custom	Comments
Noise Figure	No Difference to 0.3 dB worse	The footprint and the personalization can be done carefully to realize the lowest loss inductors and other elements.
Bandwidth	No Difference to 5% bandwidth reduction	Bandwidth reduction due to parasitics of the spare parts can be minimized by careful modeling and layout of the footprint.
Power Output	No Difference	Power degradation in ASMMICs can be reduced by using footprint designs which allow lowest loss output matching elements on devices.
Power Efficiency	No Difference	Requires highest efficiency design at footprint layout and careful modeling of parasitics.
Dynamic Range	No Difference	Requires highest dynamic range design at footprint layout by adding 8 or 12 diode mixers and higher power FETs to the footprint.
Phase Noise	No Difference	Requires negative R device to be in close proximity to I/O pads.
Mixer Conversion Loss	No Difference	Requires a footprint that allows realization of low loss transmission lines, coils and diodes.

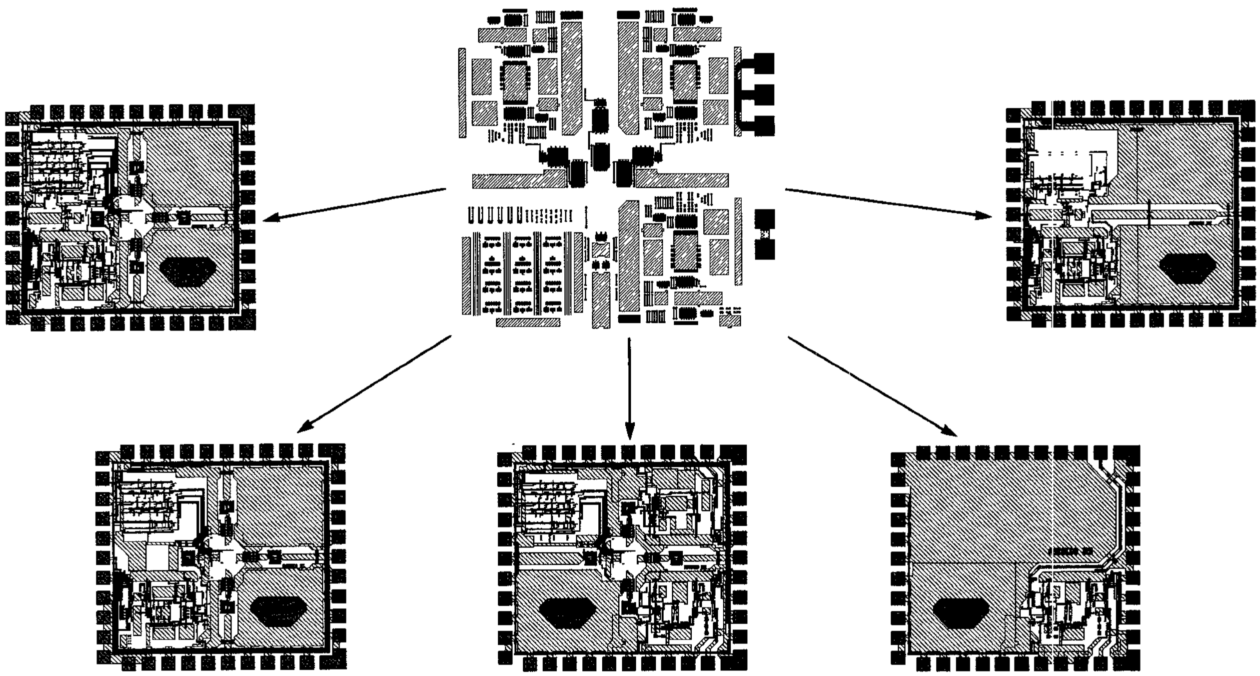


Figure 1-2(a). Low Frequency ASMMIC Footprint and Five Personalizations (Ford Microelectronics Inc., 1987).

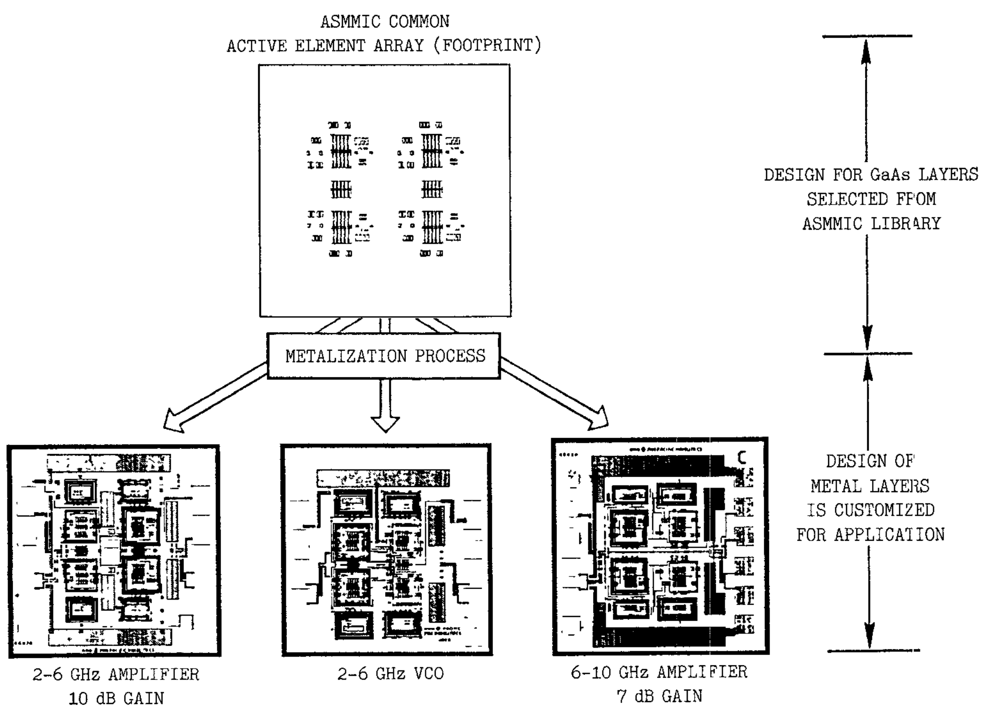


Figure 1-2(b). Three Different Chip Designs are Realized From One Footprint (Pacific Monolithics Inc., 1986).

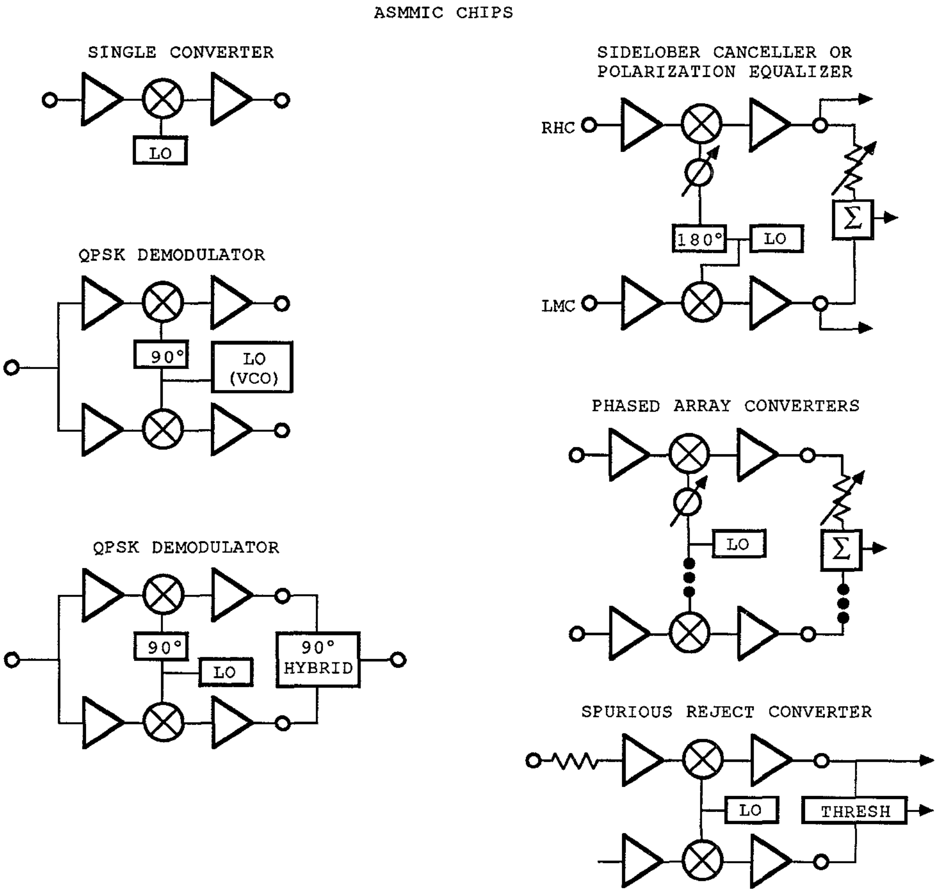
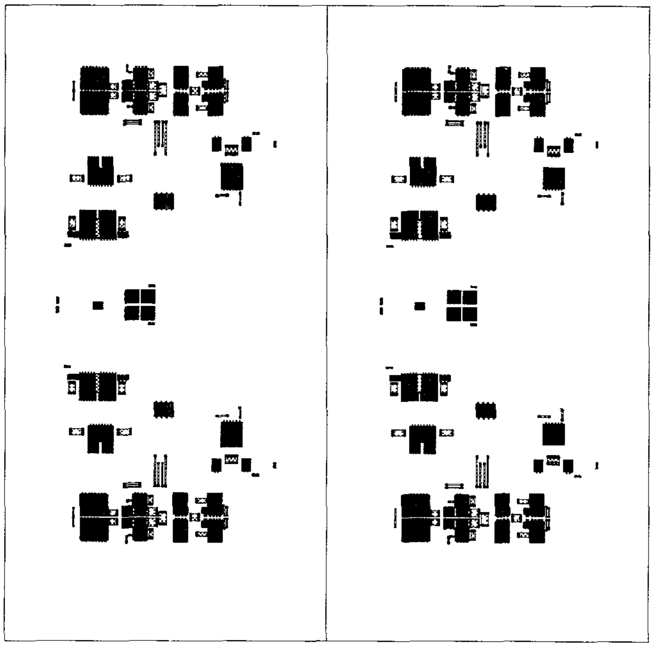
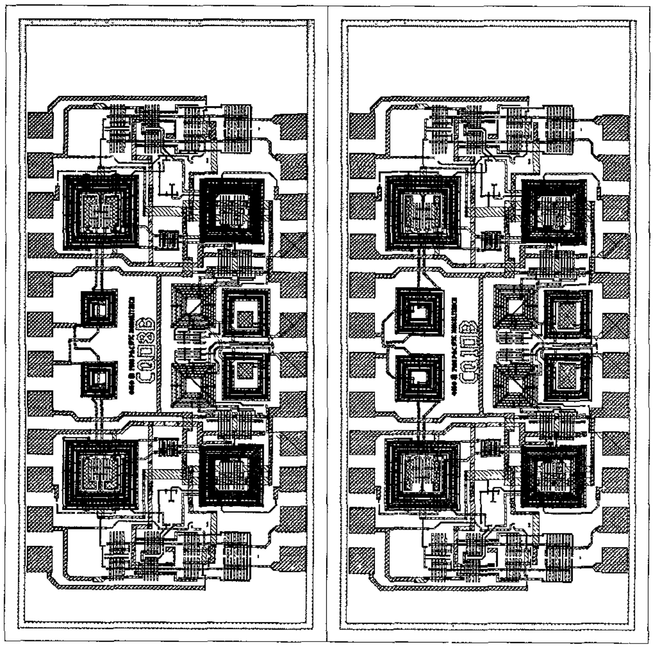


Figure 1-3. Variations of Converter Footprint.



CQ08 – 3 GHz QPSK (1-7)   CQ10 – 4 GHz QPSK (1-7)

Figure 1-4(a). Lower (Footprint) Layers.



CQ08 – 3 GHz QPSK (8-11)   CQ10 – 4 GHz QPSK (8-11)

Figure 1-4(b). Metal (Personalization) Layers.

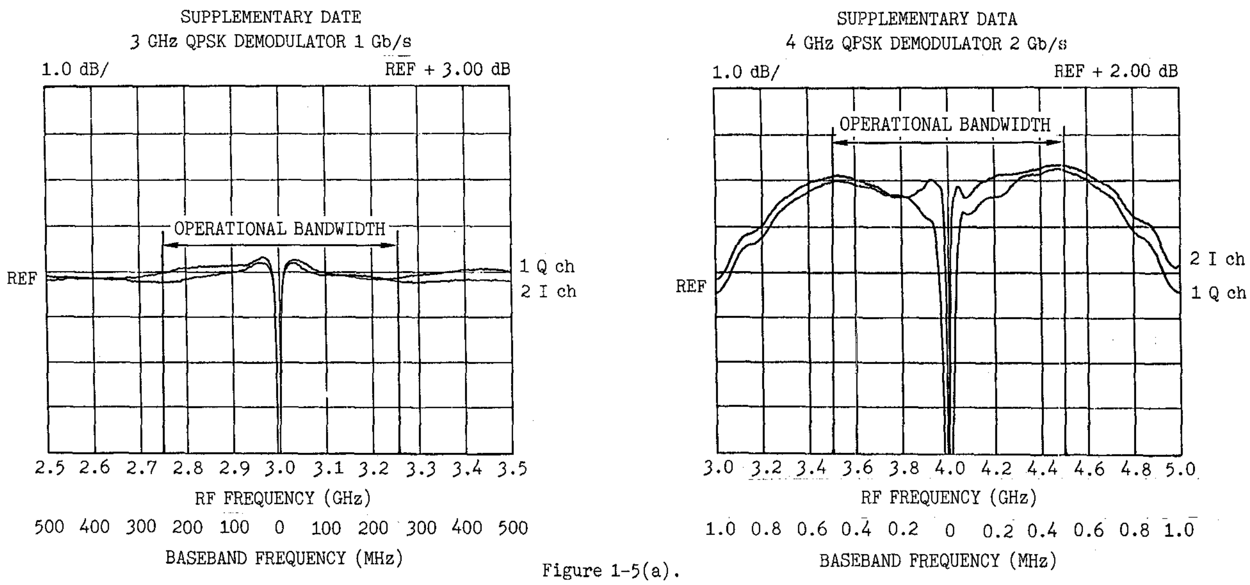
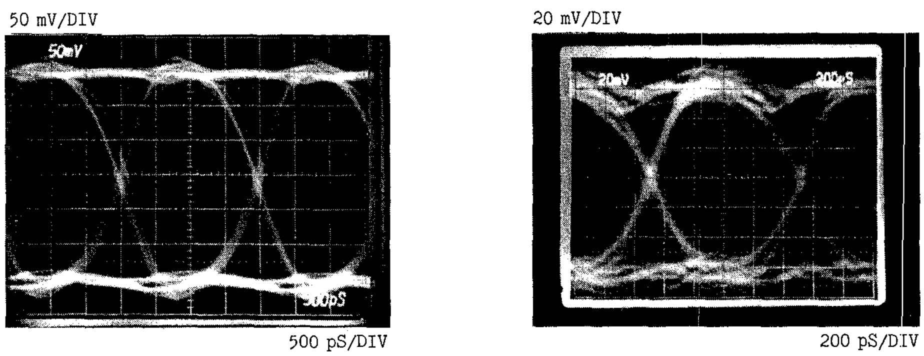


Figure 1-5(a).



3.0 GHz DEMODULATOR - 500 Mb/s PER SIDE

4.0 GHz DEMODULATOR - 1 Gb/s PER SIDE

Figure 1-5(b). EYE PATTERN - 3 AND 4 GHz DEMODULATOR

Figure 1-5. Ford QPSK Circuits With Frequency and Time Domain Performance.

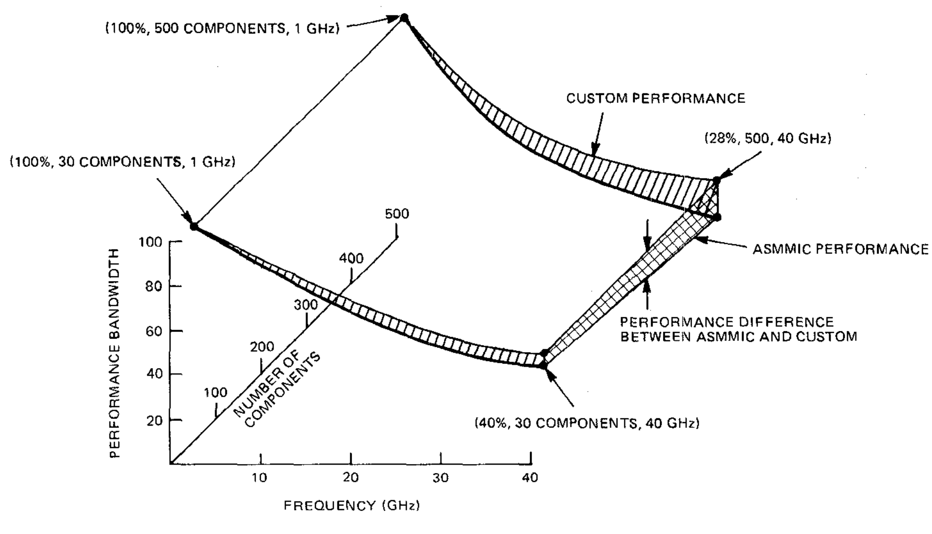


Figure 1-6. Performance Penalty of ASMMIC is Insignificant.

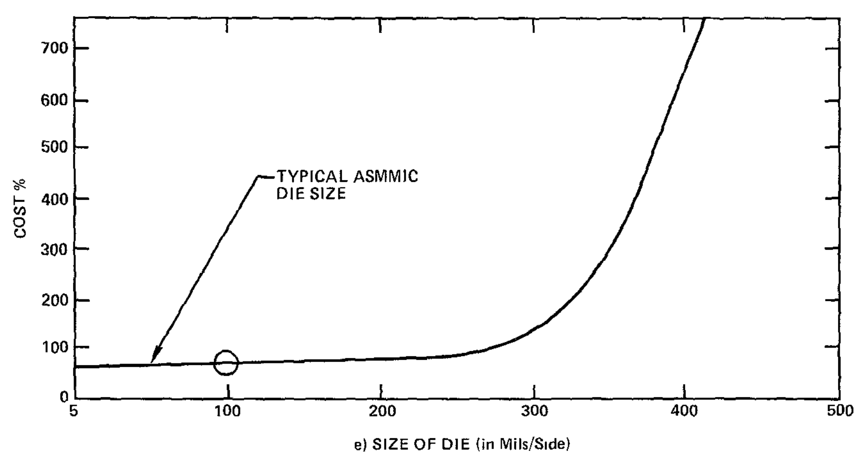


Figure 1-7. Real Estate Penalty of ASMMIC Real Estate is Insignificant.

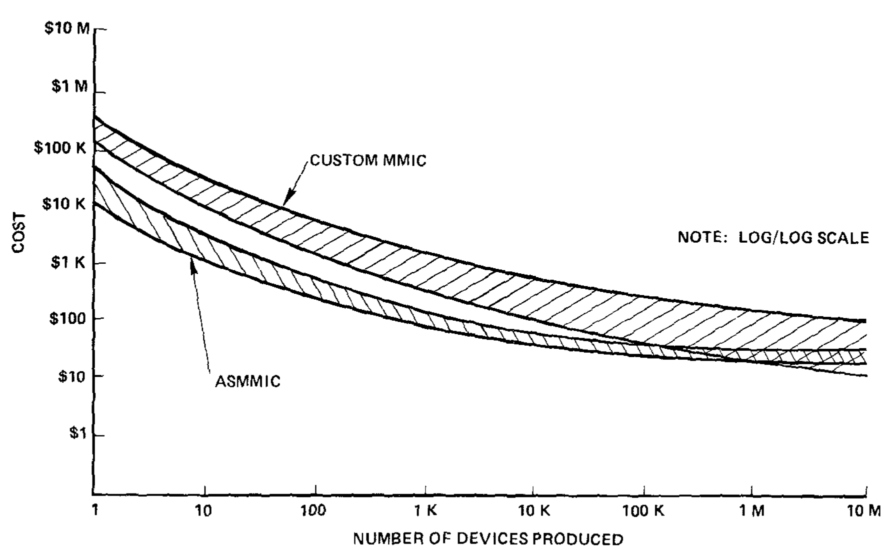


Figure 1-8. Performance Penalty of ASMMIC is Insignificant.
ASMMIC is More Cost Effective for Most Applications.