1988 IEEE MTT-S International Microwave Symposium Keynote Address

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Good morning, friends. I am both pleased and honored to be here with you today and to have an opportunity to share some of my thoughts, opinions, and prejudices about our industry as we look ahead to the future.

Before starting, I want to express my appreciation to several colleagues who were kind enough to lend me some visual aids and to discuss ideas and concepts. These are Harlan Howe of Adams Russell; Alex Chu, Gerry DiPiazza, Joe Saloom, all of M/A-COM; Bob Bierig of Raytheon; Gene Gregory of Hughes; Dave McQuiddy of TI; and Glenn Patton of GE.

I suppose that when Chuck Buntschuh and his colleagues were in the process of searching for a keynote speaker they reasoned that I had been around for a good part of our past and that would be adequate qualification to prognosticate on the future.

Well that's at least partly true, I have been around the microwave business for virtually all of my working life. As a matter of fact, my first job, right out of school in 1950, was concerned with fabrication techniques for magnetrons, and within a couple of years I began my involvement with semiconductors. At that time, the only available microwave semiconductor device was a silicon point contact diode and that did not even receive honorable mention in vintage 1950 market studies of microwave components.

Now, of course, semiconductors tend to dominate our industry, so let me make the first of several assertions: *Semiconductor technology is the principal driver of the microwave industry.*

Shortly after the invention of the transistor, Bell Labs briefed the defense agencies because of the obvious implications of this new technology and a tri-service-sponsored contract was set up with Murray Hill to explore ways in which transistors could be exploited in defense applications. That was almost 40 years ago.

Although Shockley had predicted the junction transistor, the only proof of its existence lay in germanium point contact transistors. Remember germanium? It's a semiconductor, not a flower.

In the early 1950's we managed to persuade Bell Labs to accept an R&D task called Improved Crystal Rectifiers, the first significant R&D contract on microwave semiconductors since Radiation Lab days. At the time, conventional wisdom suggested that transistors would not be useful at microwave frequencies because of the high values of junction capacitance. Unconventional thinking asked the question, Is there some other way we can utilize a semiconductor junction at microwave frequencies? From that question came varactors, p-i-n diodes, and the like. This leads me to my second assertion: *Unconventional wisdom has been an important ingredient in the development of our technology and growth of our industry. It will continue to be so.*

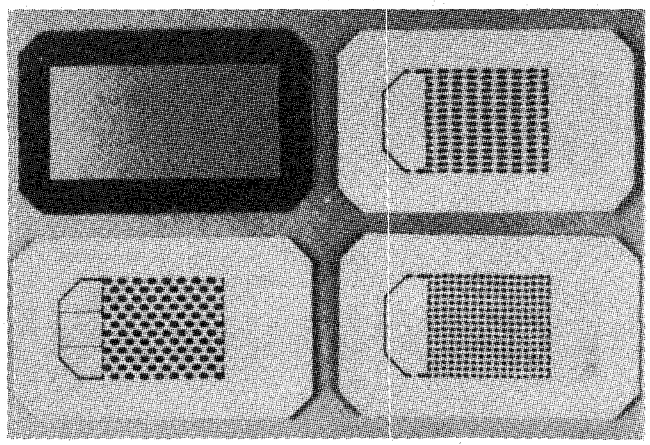


Fig. 1. 35 GHz bulk window (courtesy of M/A-COM).

Another example of unconventional wisdom is the so-called bulk window, shown in Fig. 1. This device can be used as a receiver protector, and it has particular merit at millimeter frequencies. Conventionally this function is served by shunt-mounted p-i-n diodes. In this case, the injecting junctions serve to flood the semiconductor material with carriers so that the window becomes opaque. Joe White's Ph.D. dissertation was one of the forerunners of this device, which has lain dormant for many years but has recently been resurrected and refined. These devices can switch peak powers in excess of 500 W and CW power of 30 W at 35 GHz, which I believe represents a record for semiconductors at this frequency. Isolation is 40 dB and insertion loss 0.78 dB. Switching speeds are hundreds of ns. Interestingly, this device uses a monolithic diode array as the active element.

Numerous papers on FET- or HEMT-based MMIC's are being presented at this Symposium. Fig. 2 shows a complete 35 GHz "receiver on a chip" using GaAs diode technology. The interesting feature here relates to the fact that this monolithic circuit was fabricated using M/A-COM's existing diode production facilities and process technology. Similar work is being done at Alpha and Minneapolis-Honeywell. Earlier work (1981) at Lincoln Lab did not include the local oscillator.

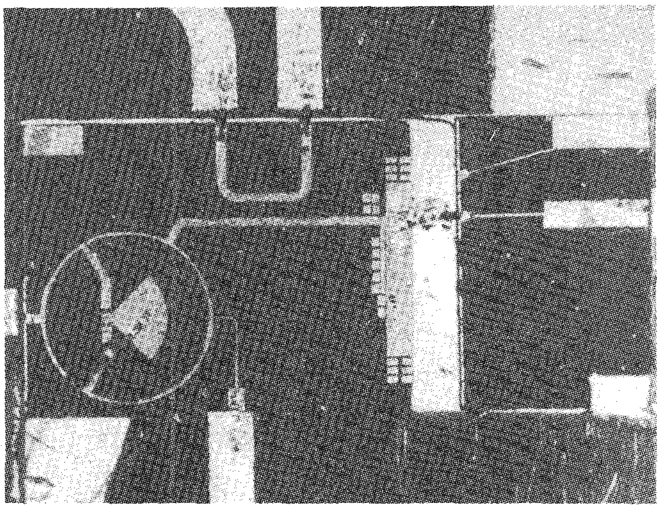


Fig. 2. 35 GHz receiver on a chip (courtesy of M/A-COM).

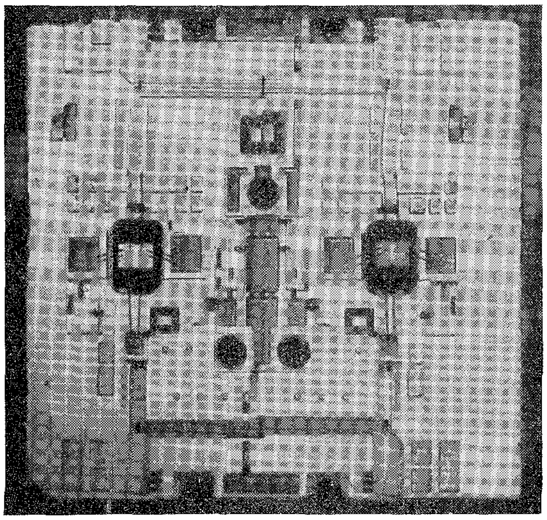


Fig. 3. 7–18 GHz FET amplifier using glass substrate (courtesy of M/A-COM).

Integration technology will be of key importance to TR modules. Fig. 3 shows one approach, using glass substrate for all of the passive elements needed in an amplifier. The active elements are shown in the dark rectangles. This amplifier operates over the 7–18 GHz band. The substrate is 8 mils thick and 1/4 in on a side. This work is fairly new, but we believe it has a great deal of promise.

Talk about unconventional wisdom—how many of us would have given any credence to high-temperature superconductors?

When Chuck approached me about today's meeting he admonished me to focus on technical developments. However, we do not live in an ivory tower and do not enjoy the luxury of doing our technological developments in a vacuum. There are external factors which affect us and influence the rate at which we progress and sometimes the direction.

What I propose to do this morning is to discuss both the "rapid" technological evolution in which we find ourselves and the dynamics of our industry from a business point of

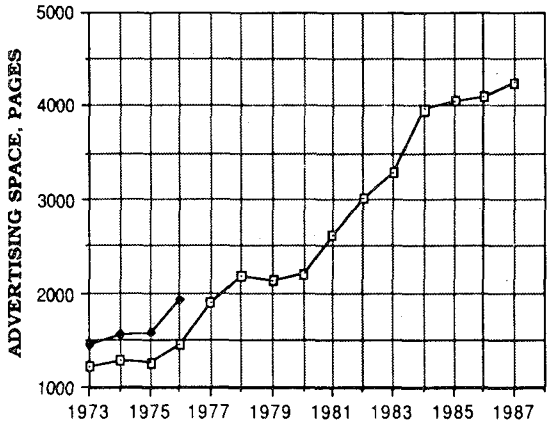


Fig. 4. Advertising space in *MSN*, *Microwave Journal*, and *Microwaves & RF*.

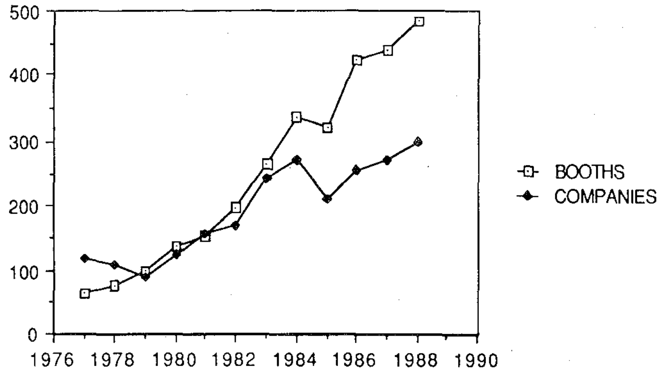


Fig. 5. MTT-S Exhibition: number of companies and number of booths.

view, pointing out some connections between the two. While our Symposium deals with technology, the microwave exhibition which accompanies our technical sessions is ample evidence that we do recognize we live in a real world, and a fairly exciting one at that.

Earlier, Barry Spielman reflected on the development and growth of our Symposium and the fact that a sizable percentage of our participants join us here in the U.S. from all over the world. We are indeed, a global *and* world-class Society.

Merely as a crude way of measuring our industry's level of activity and growth, Figs. 4 and 5 show as a function of time, respectively, the total number of advertising pages in the three trade journals serving our industry and the total number of companies participating in the exhibition together with the total number of booths at the exhibition. It is interesting to note that the growth rate of booth space exceeds the rate of increase of particpating companies. One would conclude that this implies a more aggressive marketing effort on the part of the corporate participants. This can be viewed in different ways:

- business is good and opportunities are better,
- business is not so good and we better try harder.

Finally, in Fig. 6, we show the total number of participants in the exhibition and Symposium combined. Barry has already given us a measure of Symposium participants.

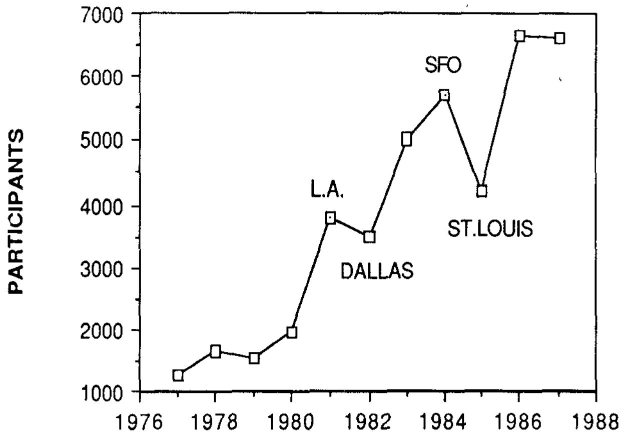


Fig. 6. MTT-S Symposium and exhibition participants.

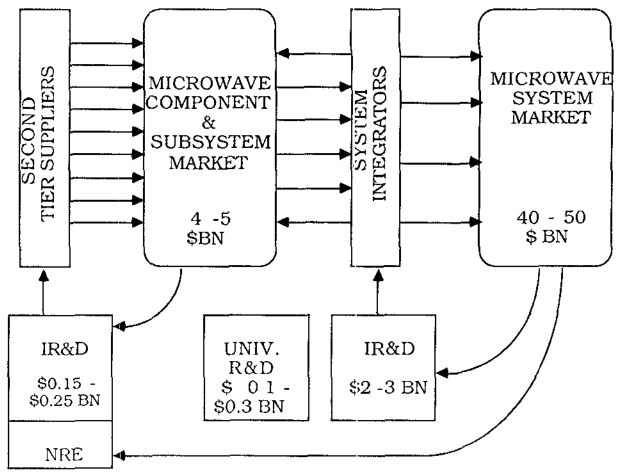


Fig. 7. Microwave industry flow diagram.

The dips we see in the curves relate more to the choice of location for the Symposium and do not necessarily reflect anything meaningful about the industry. It remains to be seen how attendance at this year's meeting stacks up. The exhibition is "sold out" and it is probably safe to assume that attendance probably will not be lower than last year.

So what conclusions should we draw? On the surface, one must conclude that our industry is in fairly robust shape but slowing somewhat while the level of technological innovation is high. However, the facts are that technical activity and the rate of progress are high, but the industry is facing a difficult period for a variety of reasons.

One of the problems facing the U.S. segment of our industry derives from regulations imposed by the government with respect to procurement and export policies. Clearly these policies, which, in the long run, will increase the cost of defense procurements, will change. In fact, we are already seeing some signs of a more enlightened approach to the issue of procurement, an approach that rewards past performance and reliability of supply.

For example, Major General Billy M. Thomas at Fort Monmouth, NJ, recently has instituted a policy that clearly favors contractors who do a good job of supporting Army requirements. This new program, called the Blue Ribbon Contractor Program, provides an opportunity for contractors who have performed well in the past to receive awards even if they are not the low bidder. The program is geared towards spares procurements, which traditionally have been awarded solely on the basis of price. Obviously, this is a step in the right direction.

Our biggest dilemma, however, lies in the fact that, as an industry, our global capacity exceeds demand. Our appetite has grown while the pie may be decreasing or at best is not getting any bigger.

Now before everyone gets up and heads for their career counselors I want to clarify my comment. Ironically, our production capacity is larger than the market requirements, but, at the same time, we have a shortfall in available engineering talent worldwide, especially in the newer technologies. So there is no need to panic.

As a frame of reference in Fig. 7 I have attempted to depict our industry in a kind of flowchart or value-added chain. The data shown are my guesstimate of relative market sizes on a worldwide basis, including commercial as well as defense segments. The components portion includes captive business where OEM's opt to "make" rather than "buy." As one moves from left to right, the number of participants decreases and the stakes are larger. For example, there are several hundred competitors in the components market but many fewer in the equipment area. Clearly the defense segment dominates our industry. This is both good and bad. Good, because it is relatively large, yet bad because it tends to be cyclical. Obviously this rendition is greatly simplified. There are many additional tiers on both the components side and the systems side. We have not included the ultimate customers, who may be aircraft manufacturers, communications network installers, or even our various government agencies.

We also attempt here to illustrate the R&D refueling process as the industry, with considerable direct government support, reinvests in new technology for future growth. It is the profits derived from prior technological investments that pay for today's R&D. The boxes listed as IR&D include government supported IR&D as well as company investments. We will come back to this a little later to discuss some business trends.

Earlier we said that semiconductors make the world go round. The pervasiveness of semiconductor technology in this week's meetings is very impressive, particularly since we are focusing on new capabilities. Yet semiconductors operating at microwave frequencies are just one aspect of technology that impinges on our industry. While great progress is being made on the microwave semiconductor front, equally impressive results are evolving in the digital world and these developments impact us as well.

The digital developments actually impact the industry in a twofold manner. First, they afford the possibility of smart components with microprocessor chips an integral part of the RF packages and perhaps some day integral to the MMIC chips. In this kind of scenario the digital segment may provide a control function, giving beam steering instructions to an active array module, for example. Alternatively, a microprocessor chip may provide pro-

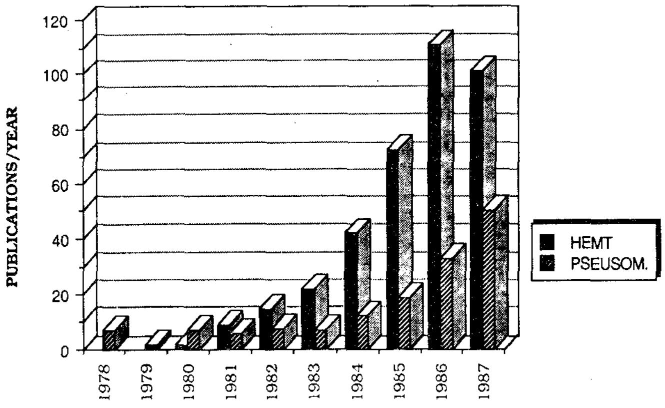


Fig. 8. Microwave semiconductor R&D.

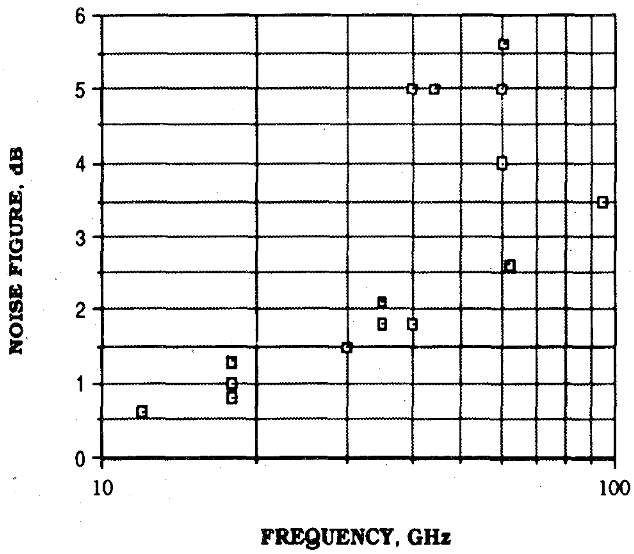


Fig. 9. FET, HEMT noise figure (1987–1988).

grammed performance modification to an active device such as a p-i-n diode filter or a transistor power amplifier. Second, however, the advances in digital IC's permit much more powerful signal processing and computer capabilities. This, in turn, can and will affect the architecture of microwave systems.

Sometimes technology advances can be a problem, especially if they provide an attractive alternative solution to a system requirement. Fiber optics is a good case in point. The advent of fiber as a preferred alternative transmission medium to microwaves has had a significant negative impact on the microwave industry's efforts to grow in the commercial arena. On the other hand, a whole new industry has developed around lightwave communications and, happily, there are many opportunities for major technical advances in electro-optics in concert with microwave technology. This is one technological wave of the future with which we need to stay in close touch.

So advances in technology tend to *push* the industry even if the technology is not directly in the microwave discipline. On the other hand, system designers are developing requirements for systems that are becoming increas-

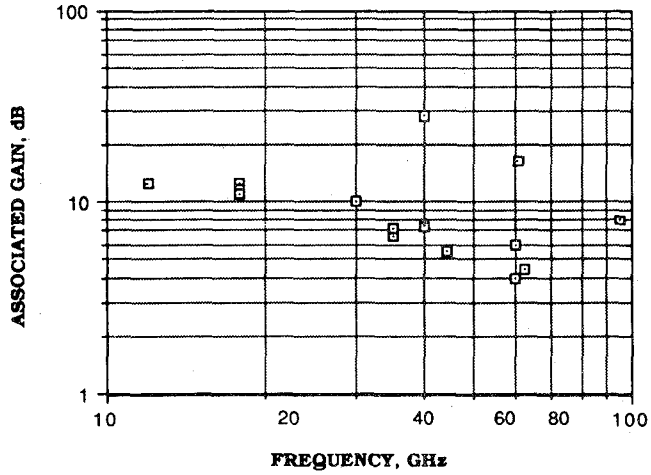


Fig. 10. FET, HEMT associated gain (1987–1988).

ingly sophisticated and complex and these requirements tend to *pull* the technology and the industry. As you know, it is difficult to discuss, in a public forum, many of these system concepts, so I won't try. They are important to our industry, however!

Let's spend a few minutes on the technology side of the equation.

Fig. 8 shows the number of publications on HEMT's and pseudomorphic devices over the last ten years and is directly representative of the level of activity in this area. Over the past two years the numbers are well in excess of 100 papers each year.

The fruits of these R&D efforts are impressive, as shown in Fig. 9. These data show noise figure as a function of frequency. Just a few short years ago no one would have thought we would achieve noise figures less than 3 dB at 35 GHz and higher.

Fig. 10 shows the associated gain data. Clearly it is sufficient to compensate for second-stage noise, so high-performance receivers well into the millimeter range are becoming feasible. Here we see gains of 10 dB up to 30 GHz, falling off at higher frequencies. I would point out that only recently gain performance at 30 GHz was only at the 5–7 dB range. We can expect that continued efforts will move the data up and to the right.

Interestingly, the gap between noise performance for discrete devices is not very great compared to a monolithic format.

Considerable progress in wide-band MMIC amplifiers is being made, as evidenced by the two-stage, 2–8 GHz distributed amplifier shown in Fig. 11. I chose this particular broad-band amplifier example to make a point. Fig. 12 shows the gain data obtained from a first iteration. The design specifications were met in every aspect—first time—no tuning. The efficacy of our design libraries, both active and passive, together with modeling and simulation capabilities, is of key importance to the future of MMIC's. The foregoing comments, of course, presuppose the existence of a solid MMIC manufacturing process, something the microwave semiconductor industry is learning.

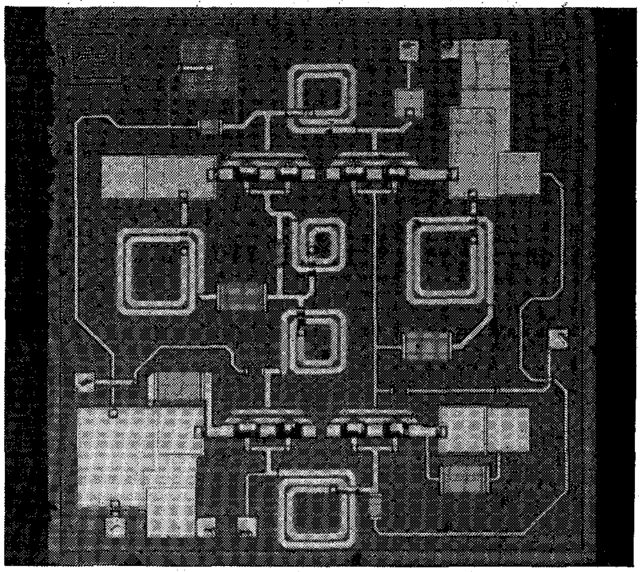


Fig. 11. Two-stage, 2–8 GHz distributed amplifier (courtesy of M/A-COM).

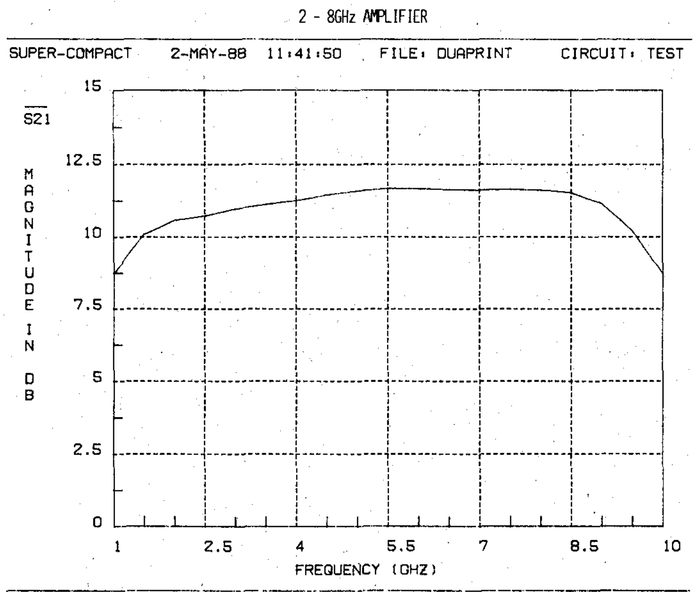


Fig. 12. First iteration gain, 2–8 GHz distributed amplifier (courtesy of M/A-COM).

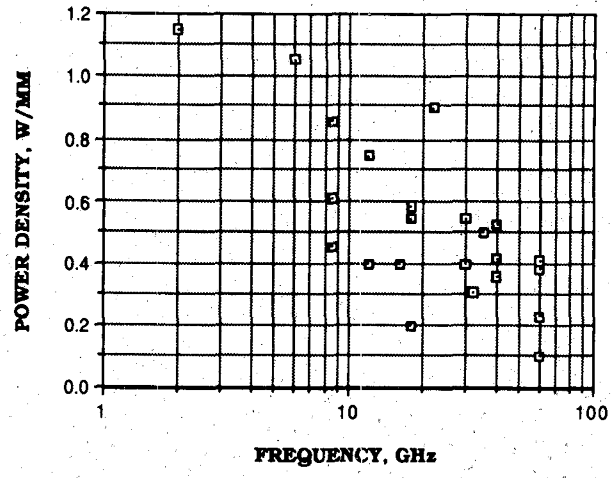


Fig. 13. Power density versus frequency.

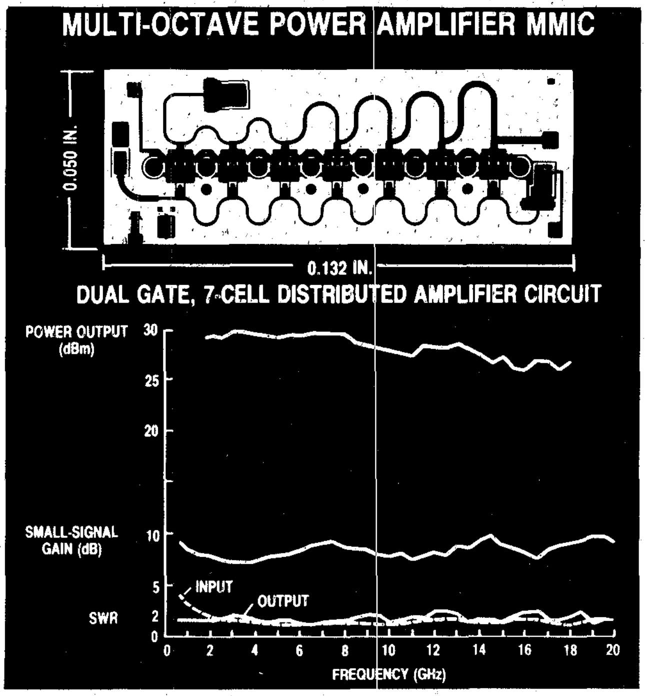
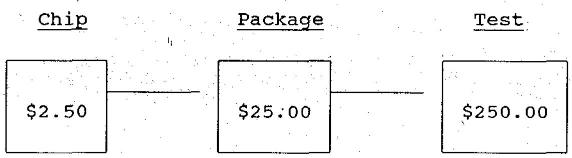


Fig. 14. Wide-band, seven-cell distributed amplifier (courtesy of Texas Instruments).

In fact, it's time for another assertion: *Simulation and modeling may be the most important item in microwave cost reduction*. Why do we say that? I can hear our good friend Sonny Maynard in his famous monologue about costs. "We produce a chip for \$2.50, package it for \$25, and test it for \$250."



The absolute numbers may not be exact but the proportions are in the right range. In hybrid MIC's this kind of cost structure is absolutely real. But it's not just test, it's *tune* and *test*, a very labor intensive proposition. MMIC's will not have that problem if our design capability is adequate. Tuning will be done during the design and simulation phases.

Similarly, developments in the power area are demonstrating adequate power capabilities for many applications and we can expect significant improvements in the future. Fig. 13, for example, shows power densities achieved in terms of W per mm of gate width as a function of frequency. Even higher power densities have been reported using pseudomorphic HEMT's. Progress will continue unabated.

Even in a monolithic format, progress in power generation is impressive, especially over wide frequency bands. For example, Fig. 14 shows a wide-band, seven-cell distributed power amplifier.

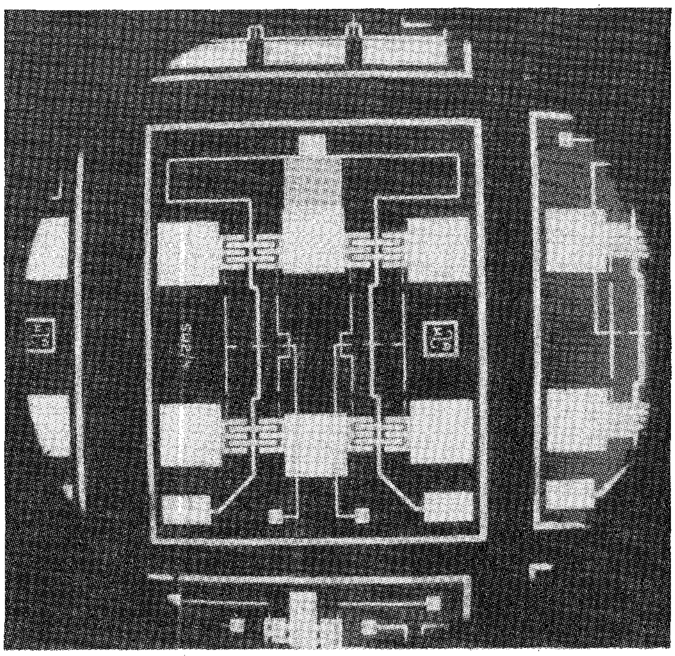


Fig. 15. *C*-band single-pole, double throw switch (courtesy of M/A-COM).

Everyone is aware of the very large DoD-sponsored effort on MMIC's, a multicontract effort that has a large number of industry participants aligned in various teaming structures, each with a different system applications focus. Eliot Cohen provided an excellent overview in his kickoff paper at this year's MMIC Symposium. This program, in a way analogous to the VHSIC project, is the most important R&D project our industry has ever seen and, like VHSIC, is aimed at an early insertion of technology. In this case, however, the systems envisioned cannot be viable without MMIC's at reasonable cost. The opportunities for technological progress seem almost limitless. That's the good news. And it is good news. What would we have to talk about this year if we didn't have MMIC's?

But where do we stand in MMIC's? Really? It is a fact that all of the functional building blocks necessary to realize the architecture of a microwave subsystem have been demonstrated in monolithic format, at least in a laboratory environment. Some circuit functions are already in production. While we may not have achieved all the desired performance levels in every case, we are beyond the existence proof stage, and moving forward rapidly. Our Symposium this week is reminiscent of the solid-state circuits conferences of the 1960's and 1970's, when the digital IC technology was developing at an explosive rate.

Circuit functions such as switches, limiters, attenuators, and phase shifters are production ready. Fig. 15 illustrates a *C*-band single-pole double throw switch using dual-shunt FET's. Insertion loss is 1.3 dB while isolation exceeds 40 dB up to 6.0 GHz.

A *C*-band receiver protector is shown in Fig. 16. This chip exhibits an insertion loss less than 0.5 dB and isolation greater than 40 dB over the band.

In Fig. 17 we see a 3 bit *X*-band phase shifter which has an average insertion loss of only 4.5 dB.

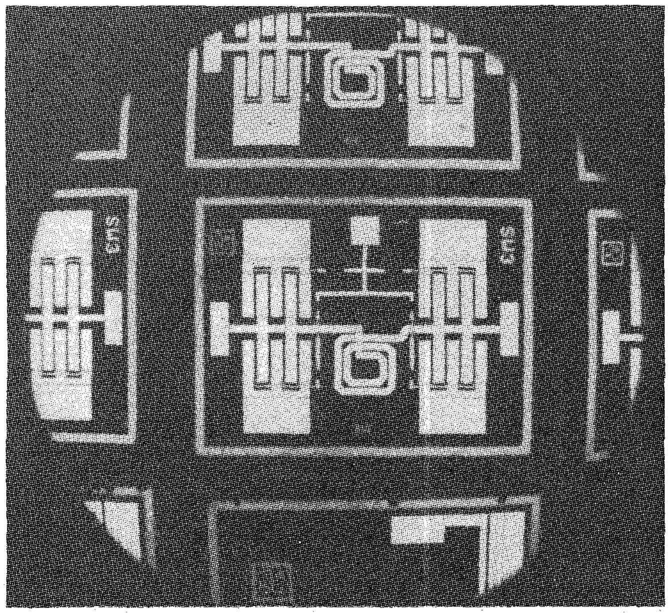


Fig. 16. *C*-band receiver protector (courtesy of M/A-COM).

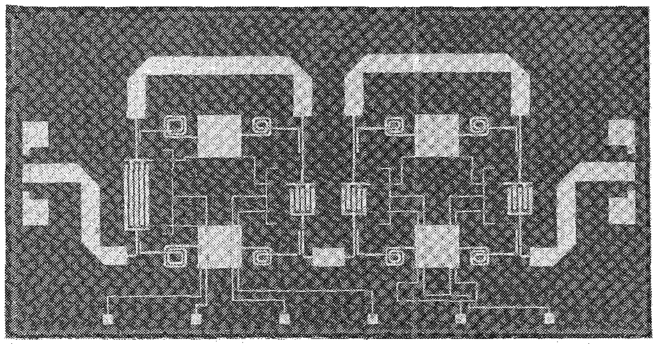


Fig. 17. 3 bit *X*-band phase shifter (courtesy of M/A-COM).

Fig. 18 shows the phase shift increments as a function of frequency. Again, these results reflect a first iteration design, fully in compliance with all requirements.

Fig. 19 shows an image rejection mixer at *X*-band utilizing monolithic Schottky diodes. Rejection is greater than 20 dB over a 15 percent bandwidth and is greater than 38 dB at band center. The mixer noise figure is 9 dB and conversion loss 8 dB. In cases where additional noise margin is necessary to meet system requirements one could use the *X*-band monolithic preamplifier chip shown in Fig. 20, which exhibits 26 dB gain with a 2.2 dB noise figure.

In the power area, Fig. 21 illustrates a monolithic, broad-band, 1/2 W power amplifier, and even better results have been demonstrated. The driving force for much of this MMIC work has been the long sought after TR module and there are many examples of a "TR on a chip" aimed at active array radar applications. Fig. 22 illustrates one applications concept for TR modules, in this case as a technology insertion into an existing avionics application.

In Fig. 23 we see one of the MMIC module configurations for radar applications. Another, similar idea is shown here in Fig. 24. In this case, the antenna is envisioned as

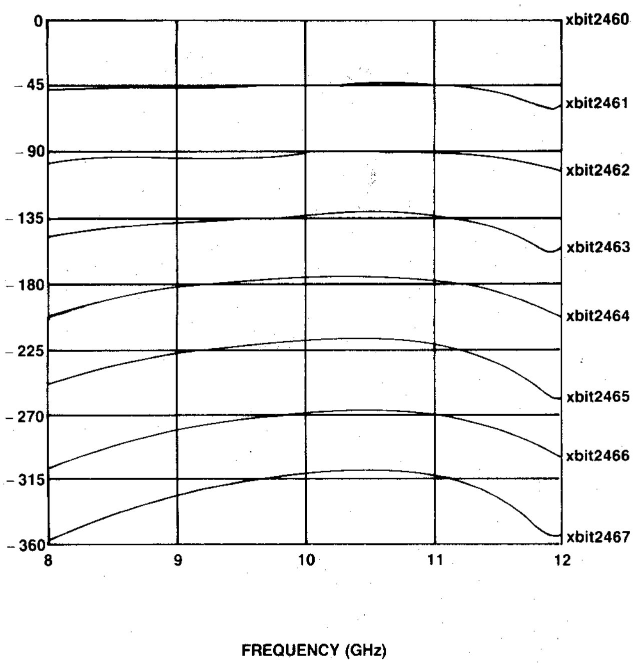


Fig. 18. First iteration phase shift increments; 3 bit X-band phase shifter (courtesy of M/A-COM).

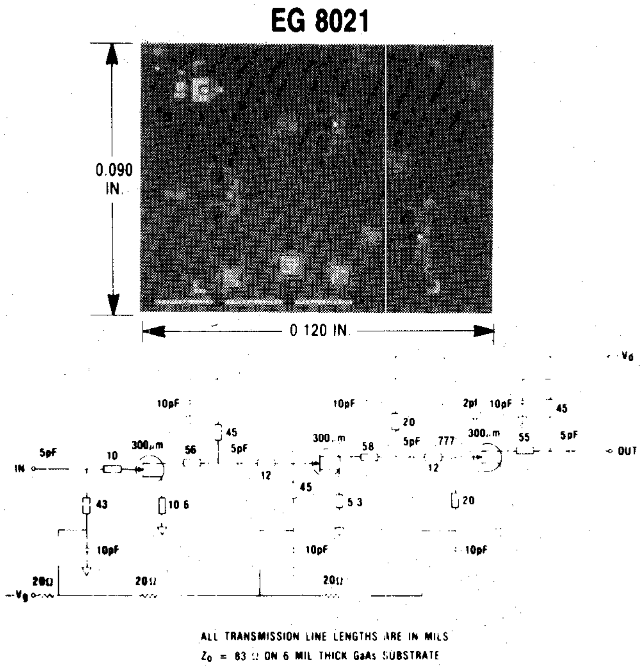


Fig. 20. Low-noise X-band amplifier (courtesy of Texas Instruments).

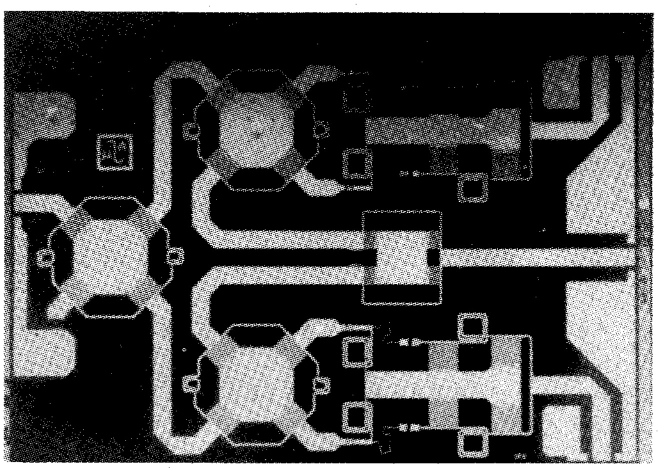


Fig. 19. X-band image rejection mixer (courtesy of M/A-COM).

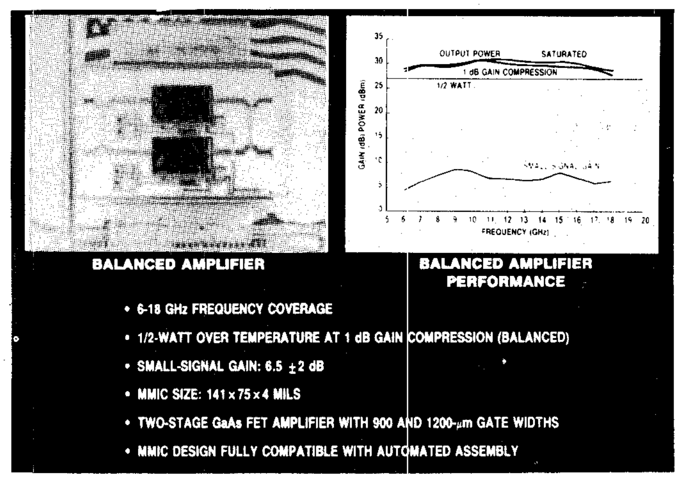


Fig. 21. Broad-band 1/2 W power amplifier (courtesy of Texas Instruments).

integral to the fuselage in a conformal arrangement. In the particular hybridized TR module shown in Fig. 24, efficiency is enhanced by applying bias to the power stages only when the unit is transmitting, an example of a "smart" module.

In each of these examples, note that the TR module comprises more than one monolithic chip in a kind of superhybrid MIC. Both of these TR modules reflect today's technology, where considerable cost savings can be realized over conventional hybrids. Going a step further, we see in Fig. 25 an example of a fully integrated TR "module on a chip" at X-band. Output power is 1/2 W and the receive noise figure is 3.5 dB. Gain of 30 dB is attained and a 5 bit phase shifter is included. This chip is an interesting laboratory achievement but RF yields are, at present, unacceptably low. In practice a chip such as this

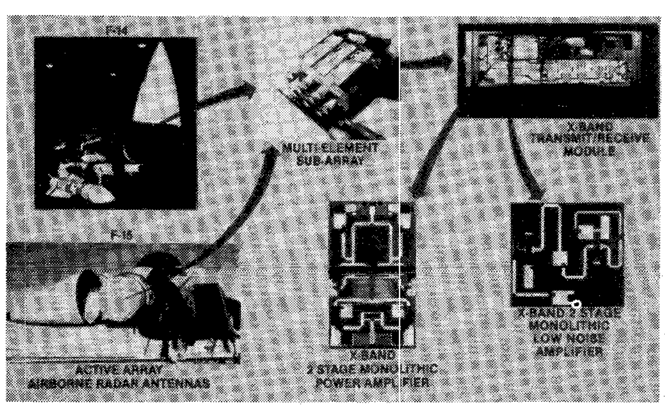


Fig. 22. X-band TR module (courtesy of Hughes Aircraft).

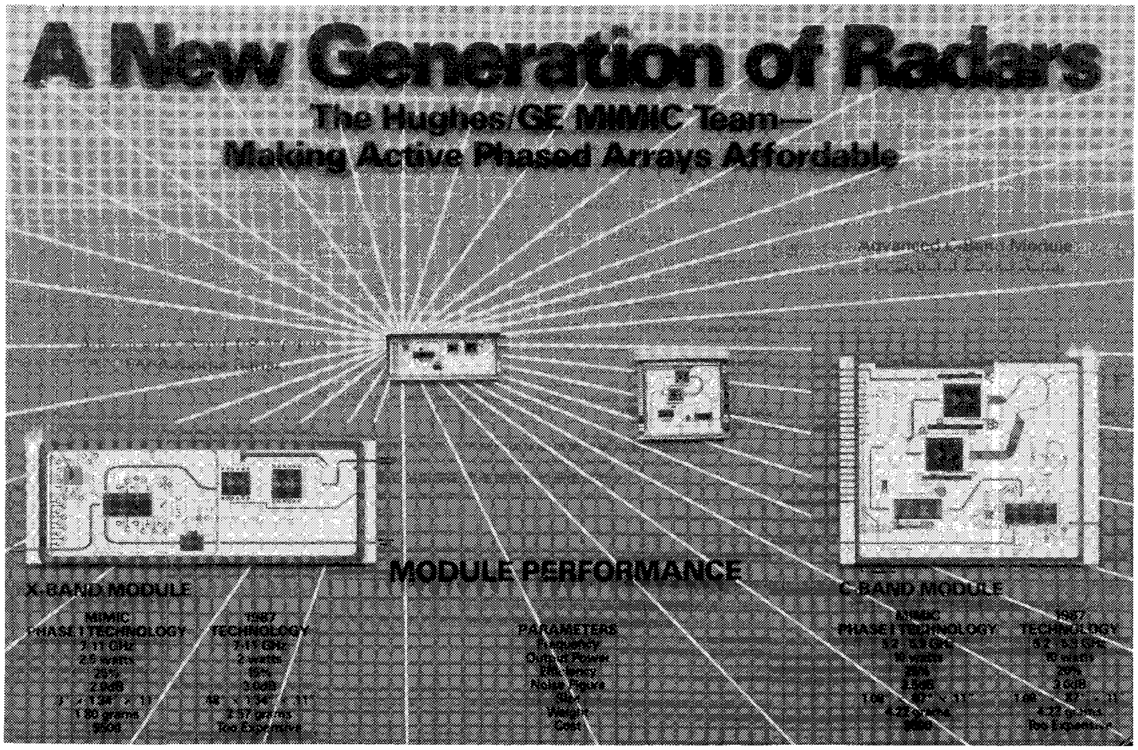


Fig. 23. MMIC TR module configurations for radar applications (courtesy of Hughes Aircraft).

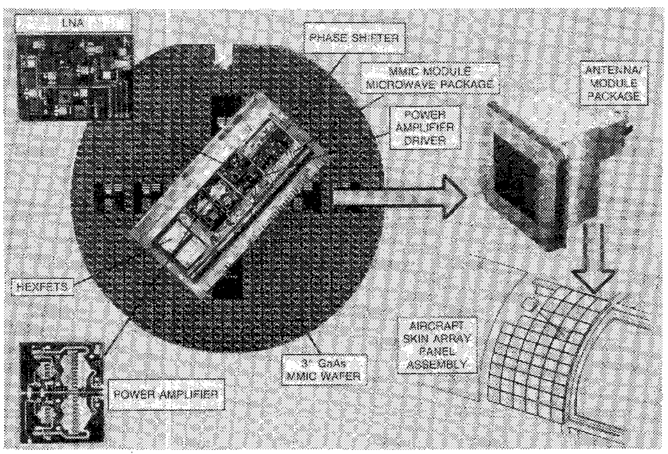


Fig. 24. MMIC TR module for conformal array applications (courtesy of Raytheon).

might be coupled to a separate power output stage.

One of the key features offered by MMIC technology is very significant size reduction compared to conventional integration techniques. To realize the full potential of MMIC's in this regard, one must consider other segments of a TR module. Fig. 26 shows a complete *S*-band module assembly. Note the size of the RF section in the center compared to the circulator on the right and digital controller and bias power conditioner on the left. These latter two packages limit the degree of miniaturization. They are expensive as well.

In Fig. 27 we see another example of MMIC technology insertion, this time in a tactical radar. Again we are not dealing with a TR on a chip, but rather a hybrid assembly of seven MMIC's to a module. Fig. 28 illustrates a more advanced version of the same concept. In this case, however, the number of chips has been reduced by two by integrating the phase shifter, low-noise amplifier, variable-gain amplifier and gain blocks into a single chip. In the example of Fig. 27, these functions required two extra chips.

Based on all of the foregoing, it would be very difficult to argue against the premise that MMIC's are here and will have a profound impact on the future. Clearly they represent the single most exciting element in our technological future.

There is also a flipside to MMIC's if one attempts to view all this exciting action through the eyes of a businessman as he contemplates his return on investment (ROI). ROI has a time horizon which depends on the nature of the investment. However, there is a limit as to how long a period can be tolerated before a return is realized. In recent years, these time horizons have been shrinking. I have some concern that MMIC's may stretch that time horizon beyond the elastic limit. Is the level of tolerance as long as ten years? I don't think so, at least not for much of the industry.

Both the upfront and the ongoing investment level to be a major league player in MMIC's are awesome and not something most of us have had to cope with in the past. It's the time horizon that is of real concern, and without direct and sustained government intervention in the form of R&D support and tax incentives for R&D I suspect we might see a different industry approach with respect to the urgency of technological progress. Without the program

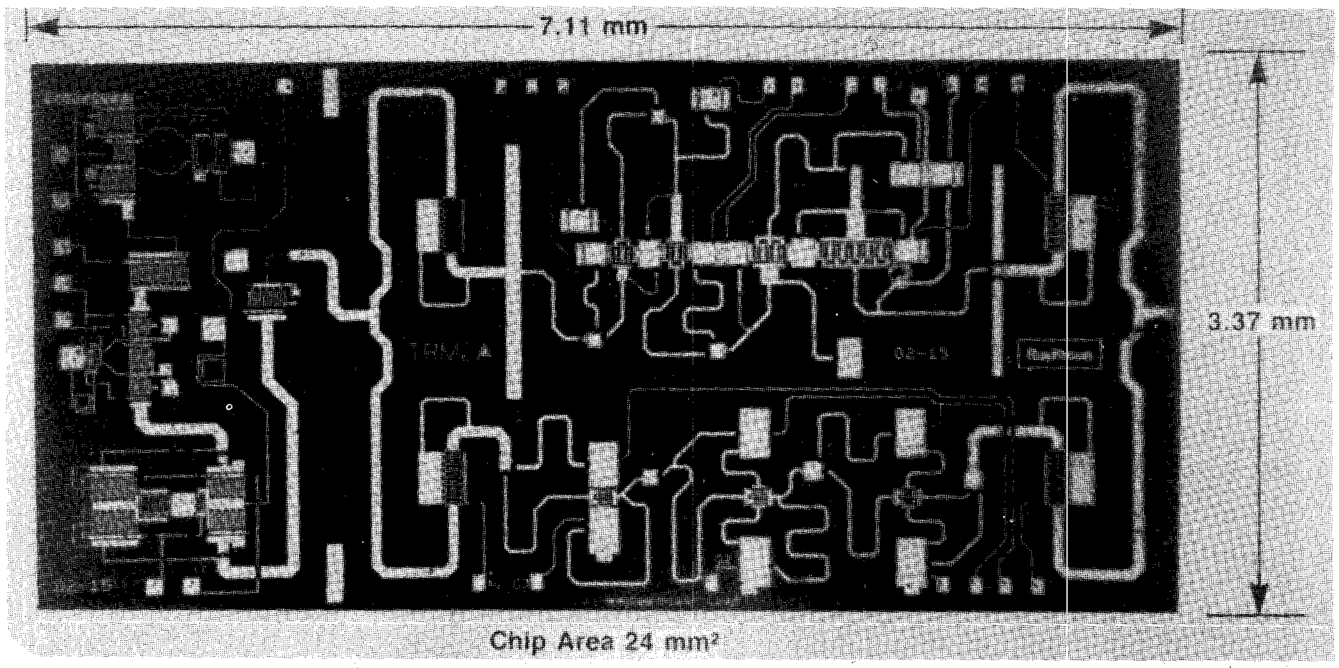


Fig. 25. *X*-band TR module on a chip (courtesy of Raytheon).

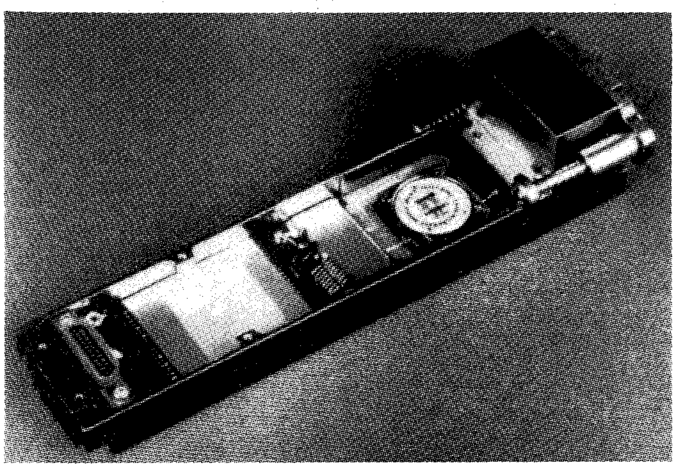


Fig. 26. Complete *S*-band TR module assembly (courtesy of Raytheon).

initiated by the DoD I believe the pace would be somewhat less frantic.

M/A-COM, like too many other companies, has made a major investment in GaAs technology aimed principally at MMIC applications. We based our MMIC investment decision on several factors. One of these factors was a defensive one. M/A-COM is the largest component supplier in our industry and we believed that the new MMIC technology would eventually erode our current base of business. We reasoned that we should focus on "self-obsolescence." For us, the decision was a sound one and we have design teams from all over the company working closely with our MMIC people to insert the new technology into existing business as rapidly as possible.

On the other hand, nothing happens overnight. Point contact diodes have been around for almost 50 years. Schottky diodes were supposed to make point contacts obsolete 20 years ago. Guess what? Last year industry shipments of point contact diodes approached 3 million units. Gunn diodes have been with us for some 25 years. FET's were supposed to replace Gunn's the same way transistors were to replace tubes. In 1987 our industry shipped some 5 million Gunn diodes. It is true that Schottky diodes and FET's are both growing but not so much at the expense of alternative technologies as one might think.

So my fourth assertion is that *new MMIC technology will replace old technology but not quite as fast as the hype which permeates our industry would suggest.*

MMIC's will absolutely change our industry as we have known it, but there is no reason for those of you who have not yet succumbed to commit suicide. Hybrids will be around for a long time with lots of growth opportunities. In addition, component companies, such as M/A-COM, will sell, into the general market, MMIC chips which perform complete circuit functions. These in turn could be combined into a module or subsystem using hybrid technology.

Alternatively, there are foundry services and even design capability available to do custom MMIC chips. So if a company wanted to be a subsystems integrator without the huge fixed asset investment, that option is open—at least for the moment.

Fig. 29 depicts the phase lags between R&D and production for our kind of business. It is the time lag for MMIC's to hit production that is of concern and there are two factors. One is the rate of basic technological progress. That is not the problem. The other is the rate of market development. That is the problem and our ability to predict this development is, at best, limited. Further, the market will be very cost sensitive, and the sophisticated systems of the future need relatively inexpensive MMIC's.

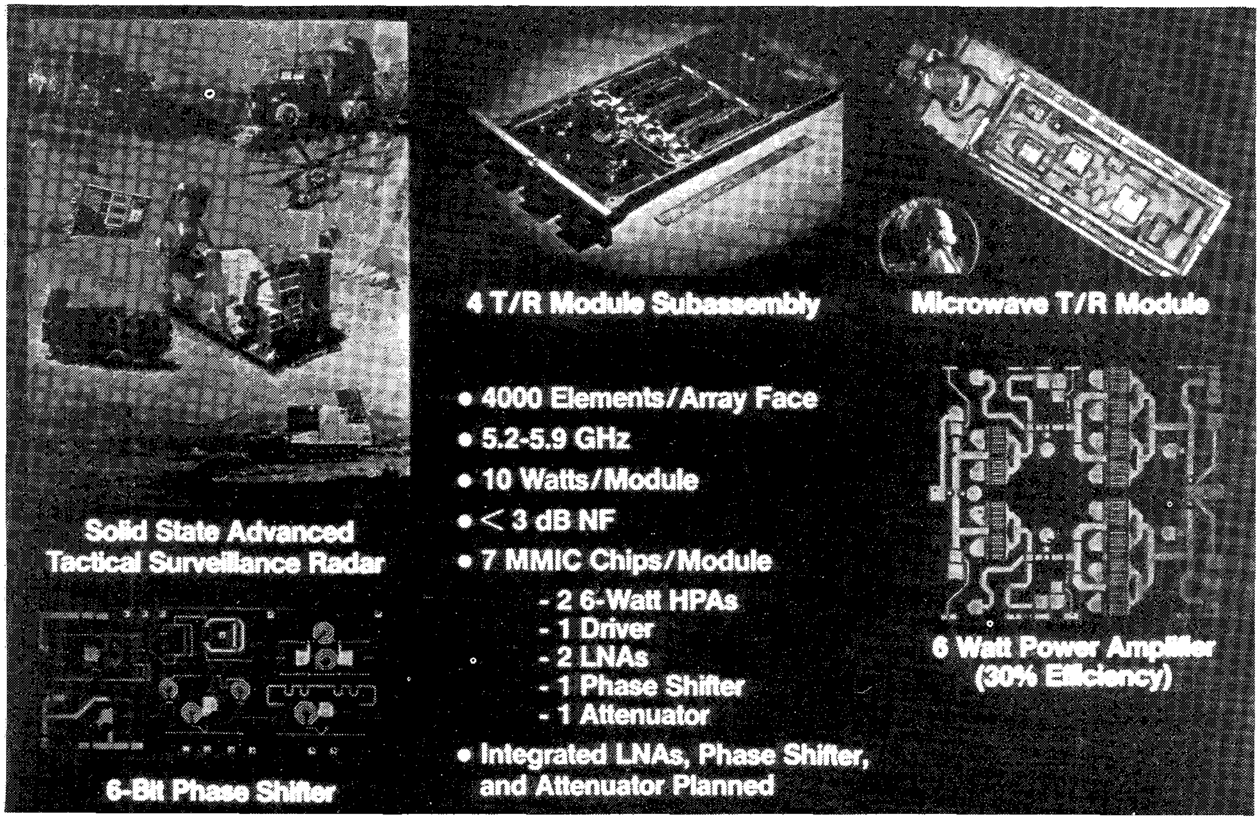


Fig. 27. MMIC technology insertion in tactical radar (courtesy of General Electric).

On the other hand, the cost of MMIC chips, like any other semiconductor, is very volume sensitive. So we have a classic chicken and egg situation.

Exacerbating the problem is the fact that our overall industry is facing a tightened economic environment since our largest customer, the defense establishment, is suffering budget pains which could well become acute.

Basically our industry, on a global basis, and locally as well, has an overcapacity and, at the same time, is in a period of very rapid technological change. This produces some interesting business dynamics.

Fig. 30 touches on part of these dynamics (or business trends). We show here three segments; components, systems, and users. Within each of these segments consolidation is taking place as mergers occur. In addition, it is likely that some companies will drop out. Moreover integration trends compound the problem as customers seek to acquire suppliers and as equipment manufacturers backward integrate, tending to make rather than buy. The situation with MMIC's is particularly interesting since virtually all the large OEM's have established substantial internal capability.

Clearly, as an industry, we have a dilemma. One could make the following observations:

- The free world needs the new systems that are on the drawing boards.
- We need to continue to push the technologies to support these systems.
- Because so many activities are "doing their own thing," the collective investment level is staggering. There is no chance for everyone to win.
- For most of our industry, 1994 is too far away to start realizing an ROI.
- We need to push MMIC's into today's business.
- We need to find commercial outlets for our technology.
- Perhaps most importantly, we need to find ways to work together more effectively—our governments, our industry participants, and our academic institutions—to find ways to make these systems affordable—sooner, not later.

I believe that, in addition to an industry consolidation, we will see an increasing trend to establish cooperative efforts among the various industry participants. This is a good thing and, in a way, the DoD MMIC effort is serving as a stimulus.

I want to reiterate a point made earlier—despite industry consolidation, the need for good engineers is great and will not weaken in the near future.

In conclusion then:

- The microwave industry, including the embryonic GaAs effort, is potentially unstable from a business point of view.
- Government support for R&D, process technology, and manufacturing methods is absolutely essential for the next several years.
- Developments in adjacent technologies, including the

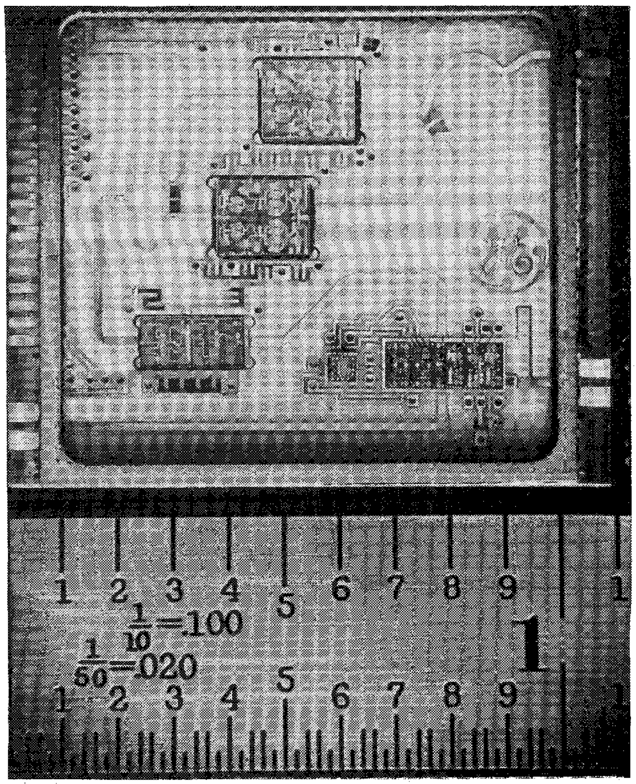


Fig. 28. Five-chip *C*-band MMIC module for tactical radar applications (courtesy of General Electric).

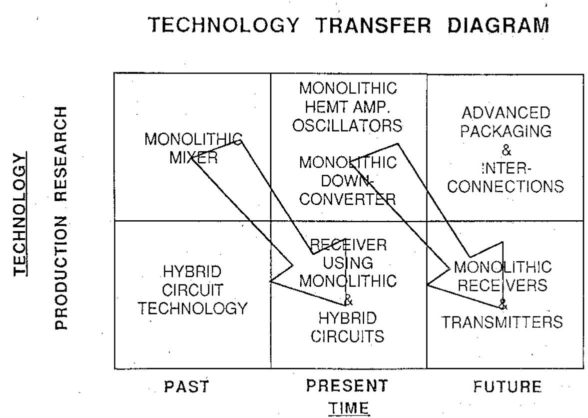


Fig. 29. Time delay between R&D and production.

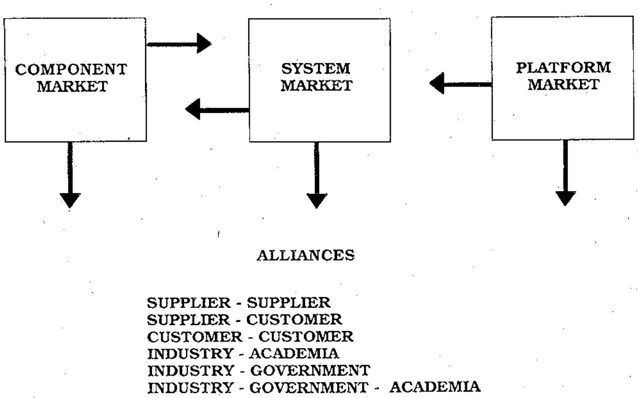


Fig. 30. Business trends in the microwave industry.

digital area (both Si and GaAs), integrated optics, and superconductivity, can have a significant impact on the industry.

- Our technological position is a good one, with great promise for both the near-term and the long-term future.
- While an immense investment has already been made by the industry, more is necessary. In the short term we need to come to grips with packaging, testing (at all levels), and some measure of standardization. Each of these is a major task. Our industry should apply unconventional wisdom in coming to grips with these challenges.
- The industry must become partners with itself, with institutions of higher learning, and with the governmental agencies. Strategic alliances are a wave of the future and a variety of vehicles can be envisioned, including joint ventures, teaming arrangements, and various kinds of coalitions.
- The future can and will be bright. As an industry we need to find answers to some of the issues raised above. We can. Will we?

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He joined the U.S. Army Electronics Command in 1950, carrying out research and development projects in various phases of physical electronics. From 1954 to 1960 he was responsible for the direction and management of all programs related to the development and application of high-frequency semiconductor devices. Until 1967 Dr. Brand directed all programs aimed at advancing the state of the art in microwave semiconductor and quantum electronic devices. In this capacity, he has made numerous personal contributions to the areas of microwave diodes, transistors, parametric amplifiers, and lasers. From 1967 to 1971, Dr. Brand was Chief, Integrated Electronics Division, responsible for all research, development, and application engineering efforts on integrated circuits carried out or directed by the U.S. Army Electronics Command. From 1958 to 1971 he taught part-time in the Electronic Engineering Department of Monmouth College. In April 1971, he joined Microwave Associates, Burlington, MA, as Vice President–General Manager, Semiconductor Operations. He has filled increasingly responsible managerial positions, including President, Microwave Associates, Chief Operating Officer of M/A-COM, and Acting Chief Executive Officer. Presently Dr. Brand is Senior Vice President and Chief Technical Officer.

Dr. Brand holds three patents and is the author of numerous technical papers in the fields of semiconductors, quantum electronics, and microwaves. He is a member of Eta Kappa Nu and of the Dean's Council of UCLA and a Fellow of Polytechnic University. He is also a Director of the NYPRO Corporation and Senior Associate Editor of the *Microwave Journal*.