# Novel Concepts in MMIC Design

**John Magarshack,**

**Consultant, Rueil-Malmaison, France**

## Abstract

This paper is a plea for more Imaginative design of MMIC circuits.

A survey of architectural development of MMIC circuit design will be given starting from initial extrapolations from Hybrid designs but using lumped rather than distributed components. After this the use of distributed-feed networks gave new possibilities for wide-band applications. Finally a logical extension is proposed for new architectures which could reach out to the KW chip, or the 16-bit Phase shifter. This is a super-modular approach for low cost, close packing density, improved reliability and faster testing. Examples for Amplifiers and Phase-shifters will illustrate the novel aspects of this approach.

This evolution has been made possible because of the improvements in production precision and reproducability, and also to the accurate design tools that are available today in this technology. There are now many possibilities for imaginative design of MMIC circuits with new design principles which were hitherto unrealistic. It is hoped that these reflexions will provoke new thoughts on basic MMIC design principles.

## Introduction

### A. *Initial standard Hybrid Circuit approach*

Probably 90% of present day MMIC circuits are based on strip-line circuit hybrid designs that were and are used on ceramic substrates, simply allowing for changes in $\varepsilon$ and thickness [1]. This works well on GaAs which is a very reproducable material being a mono-crystal, although problems are encountered due to the thickness variations with other than co-planar circuits. A significant addition to the Hybrid design tools for MMIC, is with their use of lumped elements which is possible because of improved accuracy and control of very small dimensions.

### B. *Distributed network designs.*

As designers grew more confident with first run successes in MMIC, above all being impressed by the remarkable reproducability of the phase, they started using a distributed-feed approach especially for wide-band amplifier circuits [2]. Indeed this type of circuit is very tolerant to active device variability and gives rise to remarkably high yields. Armed with this success we saw distributed circuits for functions other than amplifying, such as mixers and oscillators (indeed ring oscillators used for logic circuit assessment have been used for a long time on this principle) [3]. A disadvantage however is that the surface area is generally large due to the long distributed-feed lines required for phase match.

### C. *New Design Principles*

In addition to the distributed phase design principle new architectures have been proposed recently where the transistors are split and distributed over the chip. One can cite the array Power amplifier Stage with transistors arranged on a grid from the Telettra team [4], the work of different authors [5] on the same subject, and the interesting possibilities shown by T. Itoh using quasi-optics combined with Microwave IC's [6]. These illustrate that MMIC technology is not a simple continuation of the evolution of Microwaves but the start of a new way of thinking.

### D. *Cellular "Brick" Approach*

An extension of the distributed approach discussed earlier, is to build up functions from basic blocks (bricks), all the same design, but simply connected and parametrically matched. This "brick" is in general a multiple input and output block and is designed to optimise the specific requirements of the circuit. This is not a sort of "Sea of Gates" Logic Array but more a simplified Standard Cell approach as used in logic circuits. The bricks are custom designed for each application (although a library is eventually possible). Applications are with High Gain Ampliers (bricks in series), HPA's (bricks in series and parallel), Wide-Band Amplifiers; Mixers, Phase-Shifters, Switches . . ., but optimised for efficiency, power, surface area, production yield, reliability and cost.

The starting point is defined by using the 'easy on technolgy' principle. Take the example of a power amplifier. This is difficult to make for several reasons. The power discrete transistors have very low impedances, and so are difficult to match and parasitic losses in the circuit due to series resistance are signicant, and eventually prohibitative. The heat dissipation is a major problem due to the poor thermal conductivity of GaAs. Size is a major cost limiting factor, and yield is low due to the complexity. With MMIC, however, it is no longer necessary to think in terms of power transistors. The elemental transistors can be so closely phase matched that they dont need to be one on top of the other. They can be spread out and interconnected to conserve phase for combining later. The layout can be optimised so that matching is at conveniently high impedances, the DC power can be more easily dissipated and the placement can be made to avoid gaps on the surface and so give compact design in predefined shapes. There are no special demands made on technogy and higher yields are obtained. It is necessary to define these basic functions - bricks - in such a way that they can be readily interconnected and are compact. The approach will be more readily understood with the following examples.

### Examples of Brick Design

*A. Phase generator / shifter.*

In this case the brick is a Vector Summing Amplifier plus a Limiter at the output (this last is not always necessary). There are usually two inputs and one output equal in amplitude to the inputs whose phase is half the phase difference of the inputs. A 5-bit phase-shifter is illustrated in Fig. 1. where Σ denotes this function, and ΣΔ is a vector sum and difference brick with 4 outputs in quadrature. The other elements are the two switches which select the required phase. A full explanation can be found in[7].

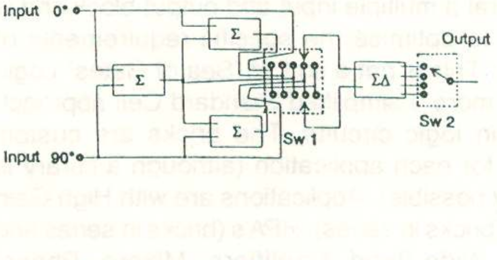


Fig1 5 bit Phase-shifter

*B. Power Amplifiers.*

Power amplifiers can also be very efficiently built up using an amplifier with with one input and two in-phase outputs (a split drain for instance) as the building brick. The schematic shown in fig. 2 is a 4-stage power amplifier and illustrates the differences with a hybrid version where each stage would have a single transistor which would grow in gate development as the signal level increased up to the final stage which has a large, high power transistor. This is very difficult to match and has need of good thermal management. In the modular version each brick is optimised for easy input and output matching for maximum gain, the maximum power match being at the passive combiner at the output. The power dissipation problem can now be treated separately as there is freedom to place the bricks in any position (see later). Mode suppression resistors and power supply feeds are not shown, but these do not need to be much different from standard circuits.

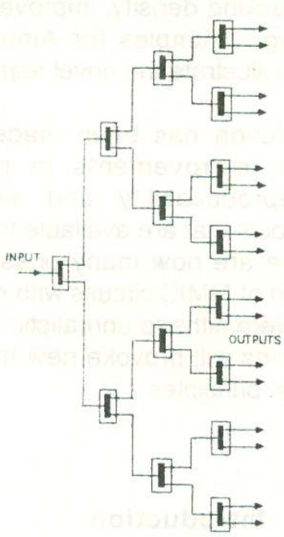


Fig 2 4 - Stage HPA

*C. Packaging, Reliability, Testing.*

Module packaging for a range of chip sizes can be obtained by having a fixed sized cavity in the package and the inputs and outputs at right angles and in fixed places both in the package and on the chip. This approach is simply achieved in brick architecture. This also avoids cross-talk. This would provide lower cost packaging, easy testing and convenient test jigs.

As each brick is similar and has been designed to be within easy production limits, the reliability and yield is very good. On-wafer functional testing is also easier and faster (very important for cost) as a representative brick will be included in the PCM pattern.

[3]

## Hardy Extrapolations

*A. Some Other Amplifiers.*

Some more hazardous ideas are given in the last three figures (3, 4 and 5). Fig. 3 is a high gain, 3-stage very compact, 'one-dimentional' amplifier. Successive stages are indicated by 1,2 3, on the figure. These have reversed inputs and outputs so the signal weaves backward and forth through the bar. For ease of bias the bar might meander so that the drain bias is a straight line feed and the sources are grounded by vias. In spite of its high gain this amplifier is less sensitive to unwanted feedback since all the signals have the same phase on each side of the transistor strip. A small positive feedback due to crosstalk would widen the bandwidth but if it is too big might cause instability (a good 3-D model is needed!).

In Fig. 4 a very high power chip is made in a 3-dimensional construction which can be up to **WSI** (wafer scale integration) dimensions. In this example the GaAs chip has power bricks scattered on its surface in such a manner that the heat is uniformly distributed on the surface (other strategies can be adopted of course). The input is in the centre fed by a coaxial lead at right-angles to the chip, and the signal progresses outwards towards the circumference of the chip (to N bricks at the outer rim). The output signals are collected off-chip by a multiple input cone combiner and the output coax is in line with the input The chip itself is mounted on a heat dissipation plate which is also a mechanical support and isolates input from output. The chip itself is shown in fig5. It is a 5-stage amplifier in this example. The successive stages have 4, 8, 16, 32 and 64 bricks in roughly concentric circles with the outputs arranged around a concentric resistive ring which is connected to the cone combiner. This system is no longer thermal or impedance limited so the power is limited only by the surface area and the production yield.

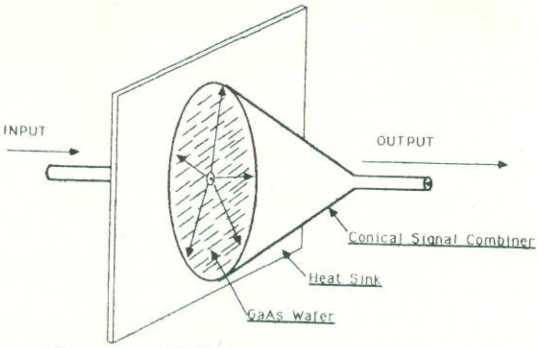


Fig 4 VHPA in 3 - Dimensional Construction

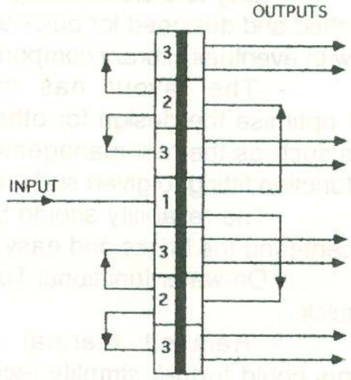


Fig 3 3 - Stage One - Dimensional Amplifier

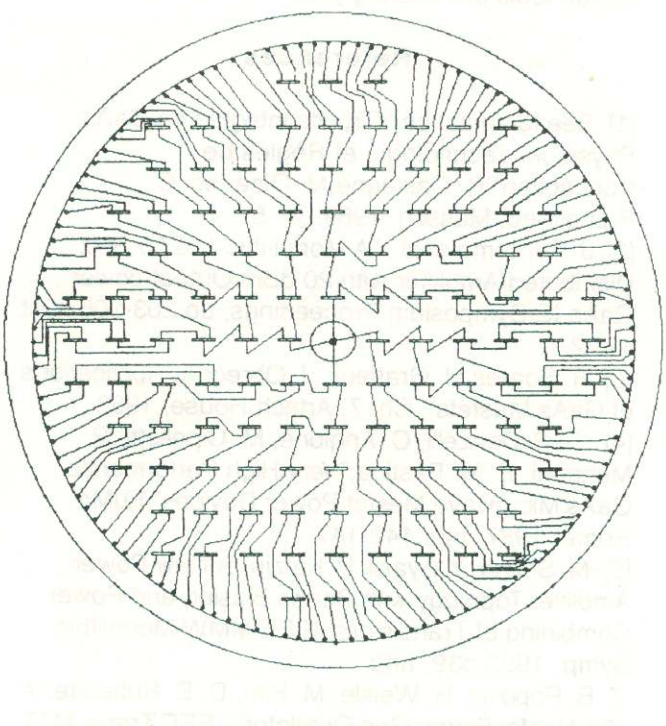

**Fig 5 Schematic of a 5-stage VHPA for Uniform Heat Distribution**

*B. Conclusions*

Some advantages have been presented of a Modular Brick contruction for Microwave circuits using MMIC technology. These can be summed up in the following points:

- Easy and Quick Design. The bricks are prematched and designed for quick and accurate simulation with eventually library components.
- The layout has much more freedom to optimise the design for other important parametres such as thermal management, surface reduction, function fitting to given surfaces etc.
- The reliability should be improved by design centering the bricks and easy technology.
- On-wafer functional Testing is also easy and quick.
- Relaxed thermal dissipation requirements could further simplify technology (no extra thinning for instance).

The examples given are perhaps far-fetched, day dreams maybe, but one day's dreams can become the next day's reality.

These ideas are presented also simply to point out that the opportunities available with MMIC now open up whole new horizons to original design. So, designers get to your terminals. These are wonderful times that present-day technology and design tools are offering you!

## References

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