A SiGe BiCMOS process evaluated for RADAR applications

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Abstract

Recent advances in silicon integrated circuit technology include the introduction of germanium into a BiCMOS process giving rise to very high speed bipolar transistors. This report examines one such process with regard to its application to RADAR and in particular to Phased Array Antennas.

Introduction

For many years silicon and gallium-arsenide have co-existed as integrated circuit material technologies. They have tended to occupy the lower and upper space, respectively, of the frequency spectrum. Over time, the frequency of the dividing line went up. In silicon, also, the price has come down, the geometries have got smaller allowing much more complexity to an extent not matched by gallium arsenide. The smaller geometries in silicon is what makes the electrical speed capability of the circuits that can be made go up.

Driving the advance in silicon technology to an extent not matched in GaAs has been a commercial hunger for the consumer market, in televisions, personal computers, mobile 'phones and various personal entertainment devices. These applications demand low prices but the volumes are very high and so are the profits. GaAs manufacturers, by contrast, have been content with a shrinking niche in military markets and a small corner of every mobile 'phone. But it is the ambition of every mobile 'phone manufacturer to do away with that expensive GaAs chip and put every function onto the one silicon chip.

In the past, advances in military electronics have fuelled advances in consumer electronics. These days the reverse is true. Now it is time to consider how the technology of the mobile 'phone and WiFi widget might be applied to military radar.

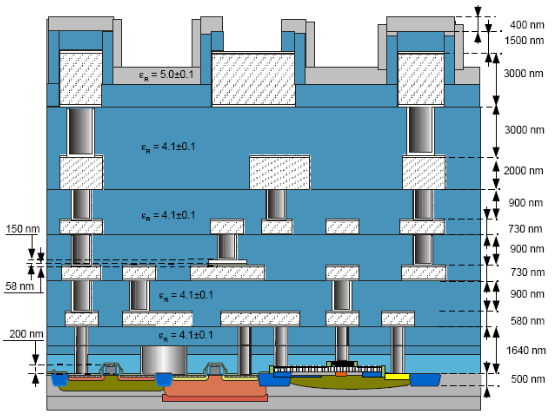
Phased Array Antennas with Active Elements

If the signal processing of a microwave phased array antenna can be done at each element then signals distributed across the array need not be at the microwave frequency, but at much lower frequencies. The advantages are lower loss of signal and lower cost of construction. The circuitry at each element needs to do:

- Low noise amplification at microwave
- High power transmission (in aggregate across all the elements)
- Carrier frequency generation (or up-down conversion if heterodyne)
- Logic for command-data.
- D to A for setting offsets in PLLs and A to D for measuring phase offsets.
- Subsidiary functions such as frequency synthesis with high-speed, and complex low-speed, logic, precision analogue etc.

If all that could be done on one Application Specific Integrated Circuit (ASIC), that would be good. Otherwise a MMIC module with a number of chips and other components has to be built for each element which may be prohibitive in size, not allowing the required array element spacing to be achieved.

The SiGe integrated circuit and what you can make on it.



<u>Bipolar transistors</u>

Useful to >100GHz. At 10GHz, NF~2.5dB. Logic to >50Gbits/sec

<u>CMOS</u>

<u>Digital</u>

Dynamic logic to 4Gbit, or a 2GHz divider

Dense, complex signal processing with low power consumption.

<u>Analogue</u>

Low power accurate functions. Combining with bipolar transistors gives low offset voltage to operational amplifiers.

<u>Resistors</u>

10 to 10M, tolerance +/-20%. High values are expensive on chip area.

<u>Capacitors</u>

C<10pF, expensive on chip area.

<u>Inductors</u>

Q<20, L<5nH. Expensive on chip area. Made on TopMetal2 and, if required, TopMetal1 for a transformer winding. Eddy currents in the conductive substrate limits the Q.

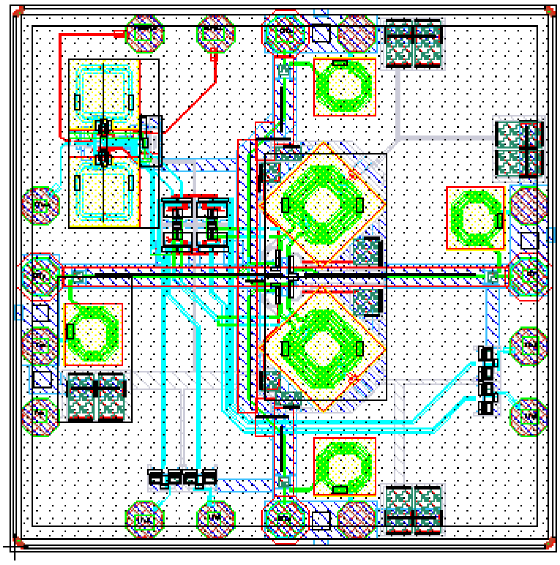
Feature comparison

SiGe BiCMOS vs	**GaAs**
Complex logic: Well established technology, the complementary transistors mean that static power consumption is low	Lack of a complementary transistor means that resistive loads must be used and this limits logic speed and imposes a minimum static power consumption.
Power output: Limited voltage swing. Low supply voltage because of small geometry. (Vsupply = 10*MOSgate length µm) Bipolar transistors do not function in a predictable way if Vcb < -0.2V (as a rule).	Supply voltage to 15volts, MESFET may be turned on hard.
Inductors: Q<20, L<5nH	Q<100, L<5nH
Transmission lines: Not feasible over bulk silicon due to the high conductivity of silicon. Top-metal over Metal1 has too high a loss to use for resonant features.	High quality due to high permittivity and low loss of GaAs substrate

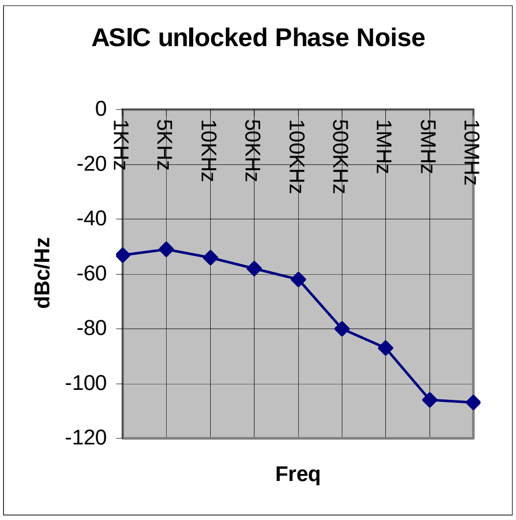
Experiments with a SiGe test chips made on the SG25H3 SiGe:C process by IHP [(1)]

1 - Voltage Controlled Oscillator

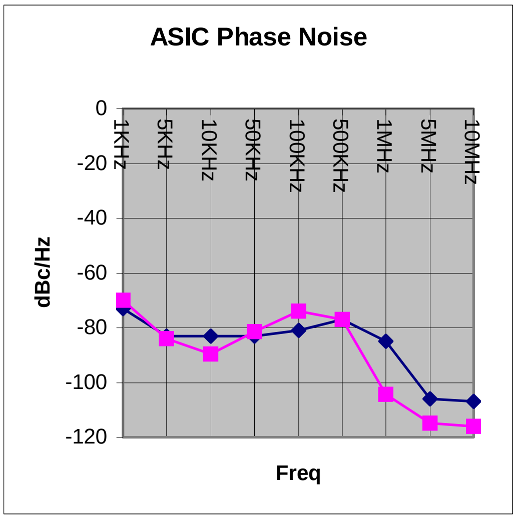
This chip has a 4-phase oscillator, divide-by-2 and mixers.



The phase noise of the oscillator was measured at the divider output and 6dB added to refer the result to the fundamental frequency.



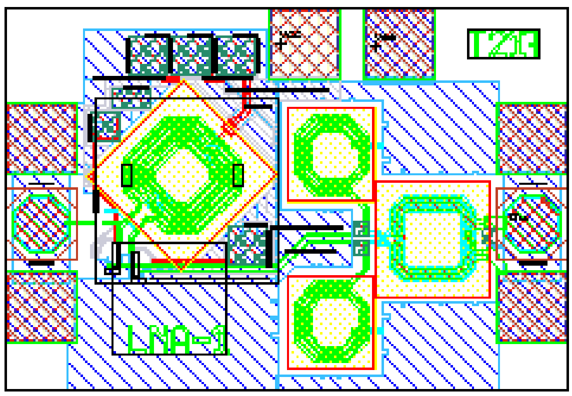
This measurement (below) was taken with the ASIC connected to other circuitry to phase lock the oscillator to a crystal oscillator with a control loop having a 1MHz bandwidth. The purple curve is a simulation taking into account the published data of components of the rest of the circuit.



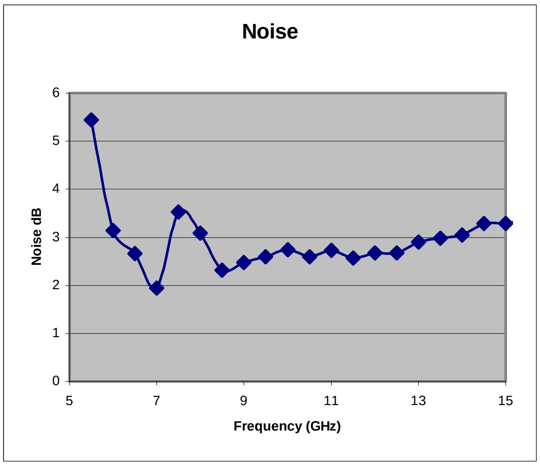
This would indicate that the phase noise of an on-chip oscillator, despite being inherently poor due to low circuit Q and, in this case, supply line noise breakthrough, it may be reduced to a required value by suitable synthesiser circuit design.

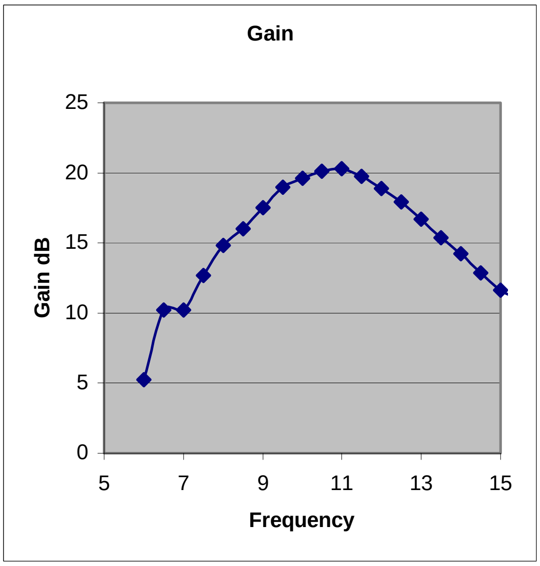
2 - Low Noise Amplifier

This chip was measured by being probed on-wafer.



The Noise and Gain of the Low Noise Amplifier was measured between 5 and 15 GHz. The results are shown in the next two graphs.





The challenge of S.O.C. design

Designing a System on Chip as is required at each element of such a phased array antenna pushes the capabilities of the Computer Aided Design techniques currently available. We need

- Logic design
- Analogue design
- R.F. design
- E.M. design

All on the one chip, preferably by the one software package.

The various sections of the circuit cannot be designed in isolation as unforeseen interaction can occur. It is not always possible to reduce a section of circuit such as an op-amp to a behavioural model and catch all the foibles of the complex circuit of which it is part.

Simulation of the entire system at once is practically impossible because of the difference in time frame between microwave circuits and control circuits.

These are irreconcilable factors at present.

Phased Array Antennas for Satellite Communication

The application of SiGe technology to radar antennas with active elements has advantages mentioned here, but the possibilities of active element phased array antennas applied to satellite communication are well understood. The civil application currently under development is a low profile, moderate cost Ku-band DVB-S antenna for trains, and other vehicles. High bandwidth military communication to LEOs with a low profile light weight antenna would also be possible.

Current status and future work

We are currently evaluating receiver and transmitter chips that will, at present assessment, require some further redesign. Some process issues are also evident.

Future plans include new designs for Ka- and X-band and inclusion of correlation transversal filters in the phase-alignment circuitry.

A radar should be possible using a scanned continuous beam which would be useful for short range security applications.

Forward with CMOS

As feature sizes reduce, speed and performance increase to the point where a silicon CMOS transistor matches a GaAs F.E.T. for noise and gain at microwave frequencies At present, the high tooling costs of <100nm processes prohibit their use except at very high volumes. Low supply voltages would impose power restrictions.

Conclusions

All the functionality required for a phased array antenna can be accommodated on a single SiGe BiCMOS ASIC The same is not true of GaAs, and the cost would be much higher even if it were.

SiGe devices are not so good at noise performance in LNAs, phase noise in oscillators and power output at microwave frequency.

The shortcomings of SiGe represent a design challenge rather than a prohibition for radar application.

Reference

(1) http://www.ihp-microelectronics.com/1.0.html

Acknowledgements

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