Evolution of Transceiver Design from Radar to Imaging

D C Pennington, R Hopper, R M Reeves.
Roke Manor Research, Romsey, Hampshire, SO51 OZN, www.roke.co.uk.

***Abstract* — Traditional transceiver design is based around designing sub-components specifically to achieve the required system performance. The approach taken in this work has been to determine whether there are transceiver designs that can achieve necessary overall system functionality while utilising parts not specifically designed for the purpose. This paper contrasts these two alternate approaches by considering a radar design and a millimetre wave imaging front end. It is demonstrated that this approach can provide a "proof of concept" validation of a system design enabling the further evolution of the system solution via custom design.**

I. INTRODUCTION

Roke Manor Research's (RMR's) GaAs design team has been involved in the design of MMICs for systems ranging from phased array radar systems to commercial power amplifier components. There is an ever increasing expectation from our systems groups that we will be able to deliver whatever MMIC functionality is required in short timescales and with 100% performance compliance. As a result the GaAs team have been investigating ways to help deliver functional system solutions without, in the first instance, going directly to custom design. This enables the overall system to be validated and trade-offs made in performance, cost and timescale.

The first section of this paper reviews the conventional approach to transceiver design where the MMIC designers are working with a well defined specification. The second part of the paper reviews a millimetre wave imaging front end designed and delivered in a 3 month timescale based upon "COTS" parts (Commercial Off The Shelf). The conclusion highlights the issues with this approach over the conventional approach and recommends where this approach is viable.

II. THE TRADITIONAL APPROACH: THE PHASED ARRAY RADAR SYSTEM.

The aim of the system design for a phased array radar system is to maximise the performance by using the best technology available. The system design has evolved over many years with the introduction of new component technologies while maintaining the same overall concept. No radical approaches have proved viable, to date, some may be adopted in the future as commercial communications based technology changes the cost performance trade-offs.

A. System Architecture:

The basic line-replaceable-unit (LRU) for a phased array radar system is shown in Fig 1. The basic operation concept is as follows: A radar pulse is directed towards a target by phasing the combination of signals from an array of antenna elements, each antenna then receives the radar return and beams are formed by appropriate phasing and then combining of these signals. In the simplified diagram for each antenna array there is a phase control element (additionally on receive there is amplitude control as-well) and for the transmit path a power amplifier and on the receive path a low noise amplifier and a limiter. It is clear that there must be significant protection of the receive path during transmit and that the phase and amplitude stability of the power amplifier must be well controlled.

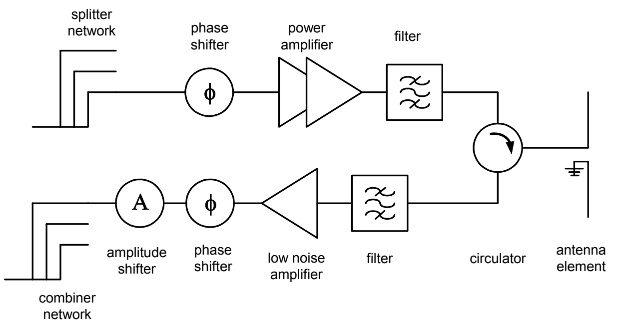

Fig. 1. Simplified Phased Array Radar Line Replaceable Unit (LRU)

The main chip components of a phased array radar system will be reviewed briefly in the context of specification requirements and the technology evolution associated with these components.

A photograph of one of the power amplifiers developed at RMR is provided in Fig 2. This design achieved >15W with a 20% 1dB bandwidth.

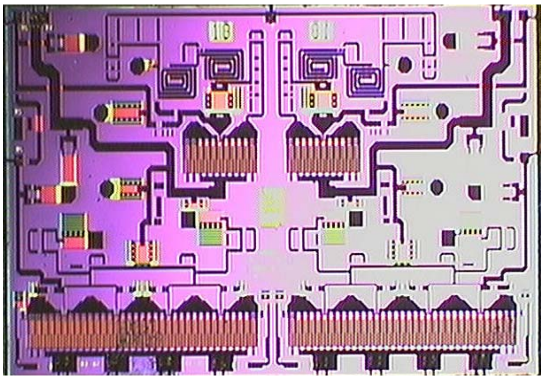

Fig. 2. Phased Array Radar Power Amplifier

B. Critical Components:

Radar Power Amplifier
Output Power: typ >10W compressed
Bandwidth: typ >10% 1dB bandwidth
Efficiency: >40%
Technology options
MESFET, HEMT, HBT, GaN/SiC

Radar Amplitude / Phase control
Gain Control: 4-6 bits, abs/rel accuracy specs
Phase Control: 4-6 bits, abs/rel accuracy specs
Technology options
HEMT

Radar low noise amplifier / limiter
Noise Figure: <1dB
IP3 high
Limiter: protect LNA from TX
Technology options
HEMT, Diode Limiter

The specification for each of the sub-components is clearly more detailed than indicated. The trade-off between given components of the system has been refined over many iterations to provide the optimum solution. If the system is to be improved then the specifications are only going to get tighter i.e. more power, tighter amplitude and phase control etc.

III. An Alternative approach

Historically the solution has been in the RF domain but does the pervasive nature of digital technology change the old paradigm that better RF performance means a better system. This is a large subject and will not be addressed for phased array radar systems but is there a case for new and evolving systems? Is it acceptable to a customer to deliver a solution that has the required overall performance achieved through adequate RF and "intelligent" system design rather than the overall performance just achieved through excellent RF performance. Indeed if you demonstrate a route to a rapid "prototype solution" then the system issues can be assessed before going to a customized design? Saving time and cost. This has proven to be a better approach for some systems that RMR have developed

The RMR GaAs team have been investigating ways to help deliver functional system solutions without, in the first instance, without going directly to custom MMIC design. The team have been looking more laterally at the problems we have been asked to solve, we don't just take the spec and run it through a design process even if there was one! The approach is to work with "standard" portfolios of devices to provide a cost effective solution, but this is either dependent upon accessing a wide range of "cots" parts or having a large internal portfolio to draw upon.

There are a number of pre-requisites that enabled this approach:

- Enough systems knowledge to be able to make the relevant trade-offs of system performance before getting anywhere near any simulators.
- Enough building blocks or advanced parts to be able to put a system together, and familiarity with them.
- Enough integration experience to know what you can and can't get away with.
- Enough other system components that make the whole system viable; antennas, dsp/ control, mechanical, etc

IV. Millimetre Wave Imaging Front End

As a practical example of this approach a millimetre wave imaging front end is considered. The requirement arose for a rapid prototype solution to enable a new imaging system concept to be developed in parallel with an existing development. A brief was provided by the system group and a basic block diagram agreed. This is shown in Fig 3.

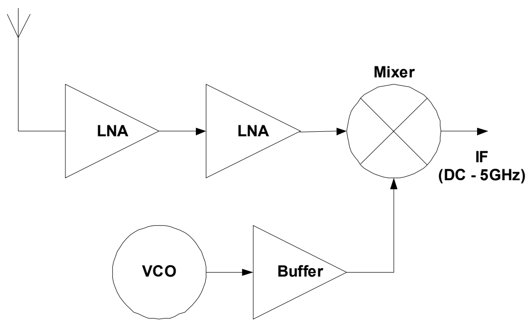

Fig. 3. Millimetre Wave Imaging Receiver

The basic functionality is that of a zero IF receiver with the main VCO tuning to the centre of the band 35-45GHz. Temperature compensation, calibration, gain linearisation, etc are not included in this realisation.

A. Component Choice:

The MMICs selected for use in the module were: [1]-[4]

- LNAs ALH376, 12-20dB gain, <2.5dB NF
- Mixer MDB171C, Image Reject
- Buffer APH403, 22dB gain, >23dBm P1dB at 40GHz.
- VCO CHV2243, 36.75-39.8GHz.

The LNAs have a noise figure of less than 2.5dB but significant gain slope across the frequency band 35GHz to 45GHz. At 45GHz the Gain from a single LNA MMIC is specified at typically 12dB with a minimum of 10dB. The addition of a mixer with an 11dB conversion loss after a single LNA with a gain of 10dB would have resulted in a significant increase in system noise figure compared with the noise figure of the LNA. For this reason a cascaded pair of LNAs were inserted before the mixer.

While the mixer is an image reject it only operates in this mode if both the IF outputs are used through an appropriate combiner. In this application the alternate IF port was appropriately terminated resulting in higher overall conversion loss but down-converting both sidebands.

B. System Design:

The plan was to produce a single assembly comprising all the MMICs without intermediate shielding. The suitability of the MMICs identified was validated using the manufacturers data in addition to measured data from the devices that had been previously used by the team.

A number of potential issues were avoided by design. Direct leakage from the VCO to the LNA was inevitable however the resultant signal at IF from this self mixing would result in a DC offset and since the IF chain was in fact ac coupled then there was only likely to be a problem if the LNA chain was driven into compression by the VCO leakage. Previous experience with similar systems indicated that there likely to be little risk from this effect.

C. Implementation:

The usual method for assembling MMIC circuits is to have the printed circuits made on ceramic with hole cut in the ceramic to mount the MMICs. The ceramic and the MMICs are then epoxy bonded or soldered to a metal carrier. Connections between the MMICs and from the MMICs to the ceramic circuit are made with bond wire. The process of manufacturing the ceramics is slow and expensive, typically taking 6 weeks and costing about 5000 euros for a circuit 50mm by 50mm. The method adopted for the production of this module was to use brass backed Rogers 5880 Duroid material with a very thin dielectric. The brass backing provides the rigidity for the board PTFE dielectric material of the PCB and the carrier on which to mount the MMICs. The dielectric was milled away to reveal the brass backing in the locations where the MMIC components were to be mounted. The cost manufacturing the PCB by this method was about 2000 euros for panel 450mm by 225mm. The tiny circuits required for the module were included in some spare space on a panel being made for another job.

This technique of mounting MMICs on a brass backed Duroid material has previously been used at Roke Manor for the auto RADAR project at 77GHz so there was little technical risk involved in using the same material and processes for 40GHz.

The resulting layout for this circuit is shown in Fig 4.

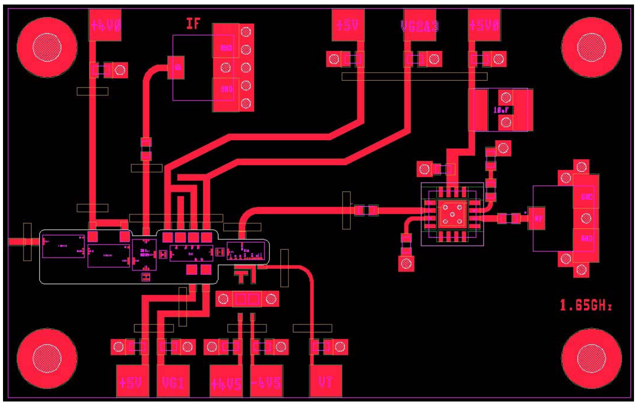

Fig. 4. Layout for Millimetre Wave Imaging Front End.

Provision for a prescaler to phase lock the VCO was also made on this implementation.

The final assembly is shown in Fig 5.

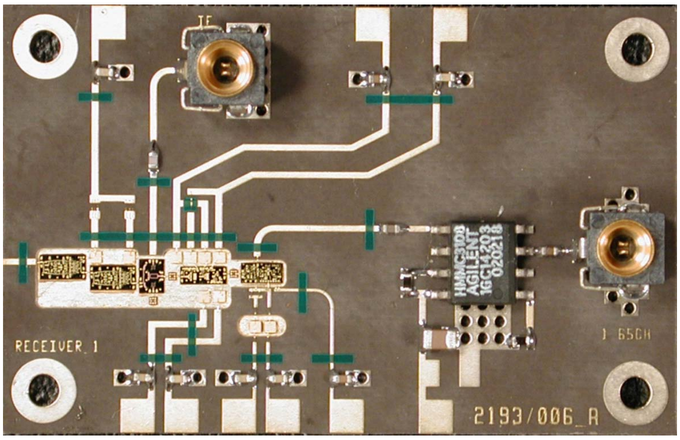

Fig. 5. First Prototype Board

The detail of the MMICs is shown in Fig 6.

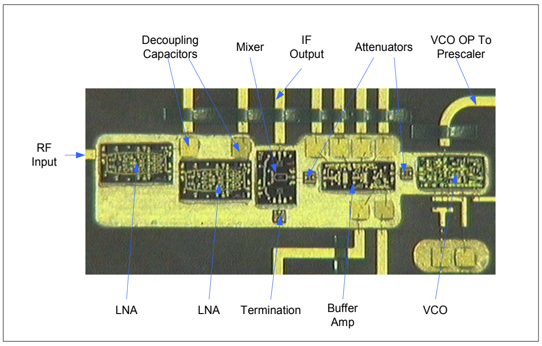

Fig. 6. MMIC detail

D. Measurement Results:

Initial performance results were not encouraging. A problem with the buffer amplifier was identified and simulations undertaken to verify that it was not a systematic problem, the die was replaced correct functionality was observed.

The gain response for the system was measured at different VCO frequencies to enable the optimum receiver operating point to be determined.

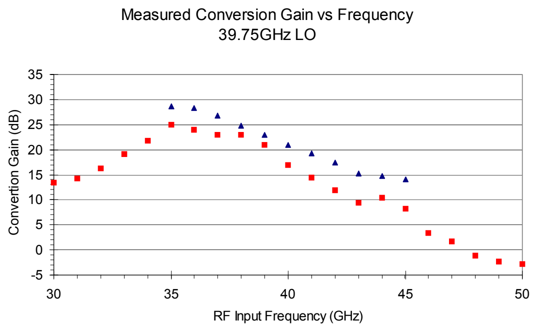

Fig. 7. Conversion Gain vs Frequency Measured-red, Predicted-blue

The predicted conversion gain does not take into account board loss from the substrate or mismatch loss between on the die.

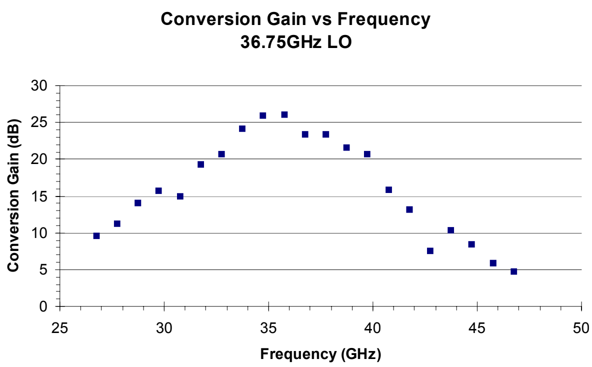

Fig. 8. Measured Conversion Gain with 36.75GHz LO

It is clear that operation of this front end over the range 30-40GHz will yield significant performance improvement over the 35-45GHz range.

V. Conventional vs Alternate Approach

An alternative approach to traditional transceiver development has been demonstrated. Where the specification is flexible and can accommodate performance trade-offs to validate the concept then this "COTS" based approach provides a low cost, rapid solution to a first prototype. The amount of trade-off is critical however and there are only a limited number of applications where for example you could choose to move you local oscillator by 3GHz! This approach is limited by the availability of "standard parts" and with more becoming available there may be more opportunity get closer to a final system solution.

VI. Conclusion

An alternative approach to validating a transceiver system has been outlined which is suitable for first functional demonstrator prototypes. For well defined system specification this approach is not valid as the functionality of the available "standard" parts is likely to mean significant compromises in performance. The application has been demonstrated in the context of a millimetre wave imaging front end.

Acknowledgement

The authors would like to thank AMS for permission to use photograph of a phased array radar power amplifier MMIC, Velocium and UMS for their foresight in developing standard products which have enable this approach and Roke Manor Research for supporting this investigation.

References

[1] Velocium product data sheet ALH376-0 HEMT low noise amplifier.
[2] Velocium product data sheet MDB171C 35-45GHz Image Rejection Mixer.
[3] Velocium product data sheet APH403 37-45GHz MPA.
[4] UMS produce data sheet CHV2243 Q-Band VCO.