An Ultra-Low Power Integrated T/R Module for Space-Based radar technology

Hooman Kazemi, ***Member, IEEE*****, Jonathan B. Hacker** ***Member, IEEE,*** **H. Xin** ***Member, IEEE,***
Mike Grace, ***Member, IEEE*****, Bill Norvell,** ***Member, IEEE*****, Kevin Higgins** ***Member, IEEE,***
Michael Gilbert, ***Member, IEEE*****.**

***Abstract*–The choice of InP HEMT technology is discussed for a highly efficient integrated T/R module. The module includes a receive path comprising of a low noise amplifier, phase shifter and amplifier consuming only 5mW of DC power at X-band. The transmit path combines phase shifters and amplifiers to provide 10mW of power per module at an efficiency of 50%. This is achieved by increasing the Cut-off frequency of InP HEMT devices and sacrificing their gain for lower DC power consumption. This provides both DC and PF performance criteria for the space based radar antenna design requirements. Future T/R module technologies are also discussed based on the Antimonide based material system which have already shown a factor of 3-4 reduction in DC power consumption compared to InP HEMT technology.**

***Index Terms*— Space-based radar, T/R modules, low noise amplifier, InP HEMT, Integrated high efficiency MMICs, antimonide-based compound semiconductor (ABCS) HEMT, InAs/AlSb HFET, millimeter-waves.**

I. INTRODUCTION

SPace based radars (SBR) have recently attracted considerable attention due to their capability to detect and track moving targets from space at any location around the globe. SBR designs, favor high gain and low power antennas where prime power is limited and large volumes allowable. Their performance requires engagement quality tracking which implies very high accuracy (<100m) measurements, minimal coverage gaps and large signal–to-noise ratio for feature recognition. These demands along side constraints such as cost, weight, and prime power place demanding criteria on all the components of the SBRs.

The T/R module is one key component which provides gain, power and phase control to both transmit and receive signal paths. Due to the enormous size of the SBR antennas many T/R modules (>100,000) are required to track targets efficiently. One major issue in designing the SBRs is the total power supply requirements by the T/R modules and their distribution across the length of the antenna.

Therefore in designing the T/R modules much effort has been placed in its efficiency while maintaining high performance. In this paper, we discuss the use of InP HEMT technology to design a totally integrated T/R module. The module will incorporate both transmit and receive chains separated by T/R switches at each end. The choice of the material system is InP HEMT technology since it provides very high efficiency for both transmit/receive cycles without compromising the performance criteria. The ultimate proposed integrated T/R chip will only consume 5mW of DC power in receive and 10mW in transmit mode. This is achieved by applying W-band quality InP HEMT devices to the X-band design module.

II. ACTIVE LENS ANTENNA

The design of the active lens antenna proposes an innovative design approach to space-based radar antennas that combines compact, lightweight, rigidized-inflatable space structures with advanced reconfigurable antenna electronics. The space-fed lens antenna features a very low aperture aerial density, high packing efficiency and design details that minimize RF losses in the antenna. It also incorporates an thermal management system for more reliable operation through the thermal cycling of the launch and the space environment The antenna is designed in order to distribute the T/R functions across the feed and lens structures resulting in the name "Active Lens". This design offers potential of lower mass, lower cost and even greater overall efficiency than a fully active array. Figure 1 is the schematic representation of the active lens antenna where its design and architecture is further discussed in [1].

Due to the unique design approach of including active elements in the lens as well as the array, the key to achieving

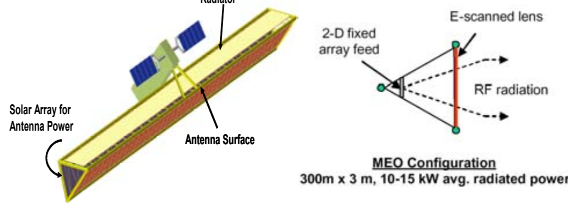

Figure 1- Schematic diagram of the of the space based radar antenna and the Active Lens architecture

Manuscript submitted September 30, 2003. This work was supported by SBIR under Contract No. F29601-02-C-0061

H. Kazemi, J. B. Hacker, H. Xin are with the Rockwell Scientific Company, 1049 Camino Dos Rios, Thousand Oaks, CA 91360, U.S.A. (e-mail: hkazemi@rwsc.com).

M. Grace, K. Higgins, M. Gilbert are with the Toyon Research Corporation, 75 Aero Camino, Suite A, Goleta, CA 93117-3139

Bill R. Norvell, Radar System Design Consultant

the efficiency and power performance goals is realizing the transmit/receive (T/R) functions in a single, high performance integrated circuit chip.

III. Choice of Technology for the Integrated T/R Chip

The goal for space-based radars is to reduce cost and power consumption as the aperture size grows, so as to maximize the power-aperture product performance for applications with limited prime power, cost, and weight budgets. This criteria directly corresponds to a highly efficient T/R cell performance. The aim is to develop a highly efficient T/R cell as a main gain component of the lens antenna with a power added efficiency (PAE) of at least 50%, a noise figure of 1.5 dB and 20 dB net-gain in transmit and receive modes respectively.

In order to choose the appropriate device technology a variety microwave materials and devices were considered, including GaAs MESFET, PHEMT, and HBT, InP HEMT and HBT, and SiGe BJT. Our analysis demonstrates InP material system provides the best option for the T/R module for SBR since it provides the best efficiency due to its electrical characteristics. This is mainly due to its comparatively higher mobility, saturation velocity, and sheet charge accompanied by the higher thermal conductivity and lower contact resistances of the InP material systems. Both InP HEMT and HBT transistors have demonstrated the highest cut-off and maximum operating frequencies among all types of transistors. Although InP HBTs have higher efficiency and lower dc power consumption than InP HEMTs, their noise figure is inadequate to meet the requirements. Other technologies, such as SiGe, would be attractive from a recurring-cost standpoint but would fail to meet the stringent PAE and NF requirements and therefore result in higher power consumption and less cost-effective comparing with InP HEMT devices in SBR applications.

IV. Integrated T/R Chip Architecture

Figure 2 shows a block diagram of the T/R cell illustrating the architecture of the transmit and receive sections of the system. Two low-loss T/R switches direct the path of RF current from

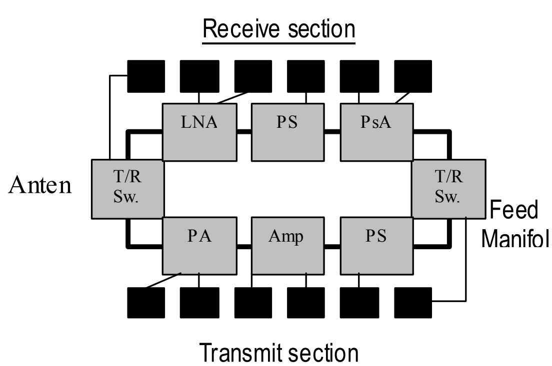

Figure 2- Integrated transmit/receive chip architecture for active lens SBR antenna

the source and the antenna in the transmit and receive sections, respectively. By virtue of its low loss and the inherent isolation between the control and input/output signal, a single HEMT will be used to perform the operation.

On the receive path, a 2-bit phase shifter is placed between and the LNA and a post amplifier. The LNA will have high gain with very low noise figure operating at low DC power. The phase shifter will be designed for minimum loss with 90 degrees of phase shift at 22.5 degree steps. The post amplifier, which adds the needed gain to match the system requirements, is placed after the phase shifter so as to reduce the size and dc power handling of the post amplifier. This reduces the receive power consumption since the output stage consumes the most bias power in order to handle the –20dBm at the LNA input. If the phase shifter was placed after the post amp then the post amp would require much higher bias power since it would have to handle 0 dBm plus the insertion loss of the 4-bit phase shifter which could be as high as 6 dB. This would then require the post amplifier to output a +10 dBm signal of power that would result in over 20 mW bias power in the post amplifier.

The transmit side includes a drive amplifier, phase shifter, and a power amplifier. For best efficiency, the phase shifter is positioned at the front of the chain to minimize the required output power of the drive amplifier. The phase shifter, identical to that on the receiver side, is replicated to avoid complex switching circuitry between transmit and receive modes and reduce power consumption. The T/R control pulse also switches off the bias voltages of the LNA and the PA during their inactive time.

V. Integrated T/R Chip Design

In order to achieve the power consumption criteria of the T/R chip, the InP HEMT device would need to have a very high gain per stage at the X-band and small gate periphery. This is to reduce the number of stages per block and DC current consumption respectively. The target DC power for the

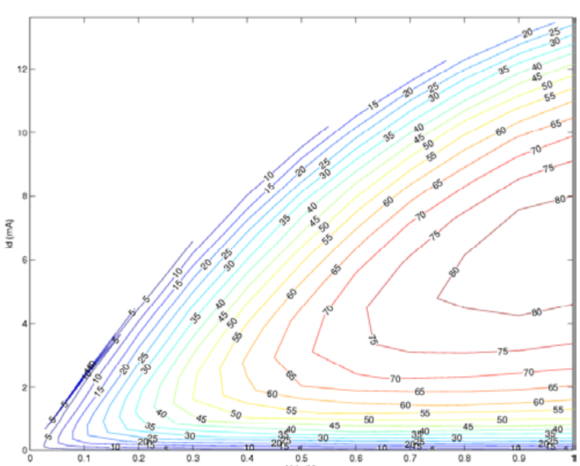

Figure 3- Contour plot of cut-off frequency of an InP HEMT as a function of its drain current-voltage

receiver chain is 3mW requiring the LNA to use only 1mW and the post amplifier 2mW of power while the Phase shifter will be designed as passive. Figure 3 indicates how this goal can be met by showing the contour plot of an InP HEMT device cut-off frequency (F_T) as a function of its drain current and voltage. By biasing the drain voltage at 1volt and controlling the gate bias of the device the drain current could be reduced to 1mA resulting in a 1mW power consumption. This method sacrifices the maximum available gain of the transistor for lower DC power. It is therefore essential for the device to be of W-band quality with F_T of 100GHz. The design frequency is at X-band and by reducing the drain current the F_T is reduced by factor of two yet very adequate for the amplifier design. The effective size of the device is also scaled to reduce the drain current respectively. The scale of this reduction is limited due to the rise in the value of the input impedance of the device presenting difficulties in impedance matching of the amplifiers.

Although the initial design of the integrated T/R chip will be made using the InP HEMT technology, the future device technologies have recently shown promise by further reduction of the DC power. Figure 4 represents a very similar plot to Figure 3 of F_T contours as a function of drain bias voltage and current using the antimonide–based compound semiconductor (ABCS) InAs/AlSb HEMTs. These transistors are particularly promising because of their combination of high electron mobility and peak saturation velocity, along with high electron concentration in the 2DEG that results in unparalleled speed-power performance. The InAs/AlSb HEMT device's inherent low-voltage operation, with Vds below 0.5V, can reduce dc power dissipation by an order of magnitude compared with a GaAs PHEMT device of equivalent performance [1–2], and by a factor of three to four compared to an equivalent InP HEMT device [3–4].

The T/R module are becoming more efficient however issues such as controlling and supplying low bias voltages to the modules across such large array structures will need to be addressed. These require advances in power supply technology and novel DC distribution design to take advantage of such advance technology.

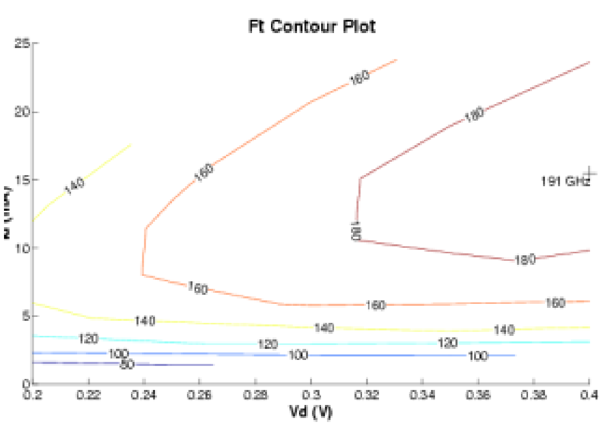

Figure 4 Contour plot of cut-off frequency of an Antimonide based HEMT as a function of its drain current-voltage

VI. Conclusion

The design architecture of a T/R module is discussed using InP HEMT technology. This technology is chosen due to its high efficiency and performance at X-band frequencies. While the InP HEMTs can provide high RF performance and outstanding low DC power consumption (receive mode=5mW), the antimonide based HEMT technology have shown a further factor of three reduction in DC power paving the way for the future T/R module architectures.

References

[1] M. Grace, B. Norvell, K. Higgins, M. Gilbert, H. Kazemi, "Active Lens: A Mass, Volume, and Energy Efficient Antenna for Space-based radar" to be published 2004

[2] Y. Kwon, D.S. Deakin, E.A. Sovero, J.A. Higgins, "High-performance Ka-band Monolithic Low-Noise Amplifiers using 0.2-µm Dry-Recessed GaAs PHEMTs," *IEEE Microwave and Guided Wave Lett.*, vol.6 no. 7, pp. 253–255 Jul. 1996.

[3] E. Heaney; F. McGrath, P. O'Sullivan, C. Kermarrec, "Ultra low power low noise amplifiers for wireless communications," *1993 GaAs IC Symp. Tech. Dig.*, pp. 49–51, Oct. 1993.

[4] D.C.W. Lo, R. Lai, H. Wang, K.L. Tan, R.M. Dia, D.C. Streit, P.-H. Liu, J. Velebir, B. Allen, J. Berenz, "A high-performance monolithic Q-band InP-based HEMT low-noise amplifier," *IEEE Microwave and Guided Wave Lett.*, vol. 3, no. 9, pp. 299–301, Sep. 1993.

[5] R. Lai, K.W. Chang, H. Wang, K. Tan, D.C. Lo, D.C. Streit, P.H. Liu, R. Dia, J. Berenz, "A High Performance and Low DC Power V-band MMIC LNA using 0.1 µm InGaAs/InAlAs/InP HEMT Technology," *IEEE Microwave and Guided Wave Lett.*, vol. 3, no.12, pp. 447–449, Dec. 1993.

[6] S. Fiedler, B. Preiss, "Geosynchronous Space Based Radar Concept Development for Theater Surveillance," *1996 IEEE Aerospace Applications Conference Proc.*, vol. 4, pp. 77–90, Feb. 1996.

[7] M. E. Davis, "Space Based Radar Core Technology Challenges for Affordability," *2001 Core Technologies for Space Systems Conference Dig.,* Colorado Springs, Colorado, Nov. 2001.