LIGHT-WEIGHT, TEMPERATURE COMPENSATED T/R MODULES FOR ACTIVE PHASED ARRAY RADAR APPLICATIONS

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***Abstract* — T/R modules are the key components for active phased array radar applications. This paper describes light-weight, temperature compensated T/R modules which have been developed at DaimlerChrysler Aerospace within the last months. The presented T/R modules are characterised by a three dimensional temperature compensation algorithm, light weight, and high efficiency, which are the main features for T/R modules used in space-borne applications. Besides highly sophisticated Gallium Arsenide monolithic microwave integrated circuits (GaAs MMICs), the key components for T/R modules, multilayer alumina (Al_2O_3) substrate technology has been applied to reduce module size and weight. The presented T/R modules are controlled by a highly integrated digital control electronics realised in MCM-D technology, i.e. multi chip module using bare chips on alumina substrate in thinfilm technology, in which the compensation algorithm is contained, and which is able to control two T/R elements independently, each consisting of one Tx and Rx channel. Applying these technologies, small-sized and light-weight duopack T/R modules have been built-up.**

Two different sophisticated duopack T/R modules designed and developed by Daimler-Chrysler Aerospace are presented within the next sections.

I. CONCEPT OF DUOPACK T/R MODULES

T/R modules (TRMs) for military earth observation synthetic aperture radar (SAR) applications must be able to meet the full polarimetric requirement, i.e. simultaneous reception of two polarisations. The polarisation agility can be met by using various T/R module architectures, which have already been discussed in [1].

T/R modules for a future space-borne earth observation satellite have been developed, manufactured, and tested within the EUCLID CEPA 9 RTP 9.3 program by DaimlerChrysler Aerospace. The block diagram of the T/R module architecture is shown in Figure 1. This diagram presents two complete T/R elements, consisting of one Rx and one Tx channel each, and applying the common-leg structure to reduce the number of MMICs within the T/R module. The common-leg contains variable gain amplifier (VGA) and phase shifter (PHS), both used for Tx as well as for Rx operation, and which are implemented on a highly integrated multifunction MMIC (Core Chip). Two T/R elements have been integrated into one single package to build-up a duopack T/R module.

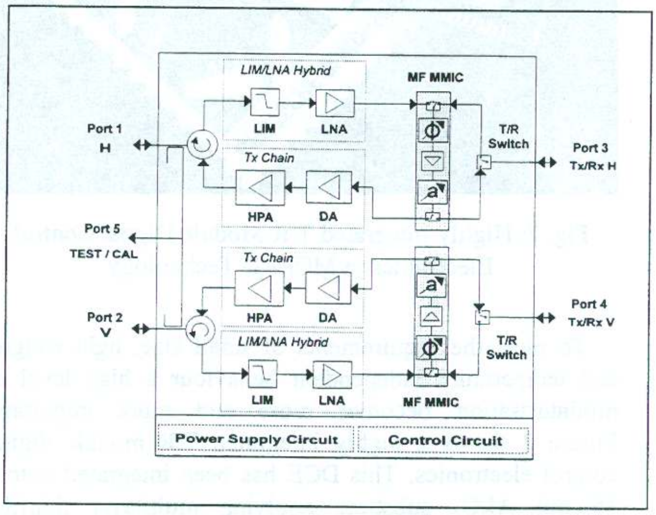

Fig. 1: Architecture of Duopack T/R Module

II. T/R MODULE TECHNOLOGY

Miniaturisation, low weight and low prime power consumption are the main requirements for T/R modules for space-borne applications. To meet these requirements sophisticated components in modern technologies have to be used ([2]).

A. Digital Control Electronics

All relevant processes inside the T/R module must be controlled by a digital control electronics (DCE). This control electronics also handles the handshake between column or array controller of the antenna and the T/R modules. A high resolution SAR system gives the need of high precision T/R modules which shall be stable in phase and amplitude over a wide temperature range. Due to manufacturing tolerances of GaAs MMICs the digital control electronics must be able to compensate these tolerances, as well as any kind of temperature dependent behaviour of all active and passive components within the RF paths. These supreme requirements for high resolution SAR applications are met by applying a temperature compensation algorithm using look-up tables. The values of the required phase and amplitude stability are $\pm$ 6° and $\pm$ 0.25 dB.

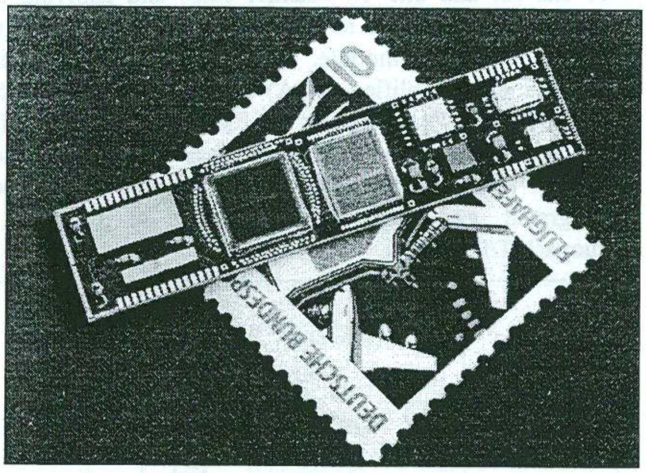

Fig. 2: Highly Integrated T/R Module Digital Control Electronics in MCM-D Technology

To meet the requirements of small size, light weight, and temperature independent behaviour a high level of miniaturisation becomes more and more important. Figure 2 shows a highly integrated T/R module digital control electronics. This DCE has been integrated onto a 15 mil Al_2O_3 substrate applying multilayer thinfilm technology (MCM-D), and using bare chips, mounted in Flip Chip and conventional bonding technology. Its size is 8.5 mm x 35 mm. The DCE is able to control two multifunction MMICs (Core Chips) individually. A three dimensional compensation algorithm using 4 MB storage capacity has been implemented to fulfil the supreme requirements of phase and amplitude stability given for SAR system T/R modules. Further functions are: reception of serial control data, decoding of the T/R module address, decoding of control signals and strobes, transfer of monitor data (bi-directional PCM bus), internal timing control, monitoring of RF circuit temperature and Tx output power level, conversion of logic levels from +5V/0V to -5V/0V, data correction of two 7-bit VGA and two 7-bit PHS data over a wide temperature range for setting two multifunction MMICs independently, and JTAG loading of firmware.

B. Duopack T/R Modules

Figure 3 depicts a photograph of the duopack T/R module which have been developed, manufactured, and tested within the EUCLID CEPA 9 RTP 9.3 program. The T/R modules have been designed based on the architecture given in Figure 1. As discussed previously, two complete T/R elements have been integrated into a single housing to build-up a dual channel T/R module (duopack). The two T/R modules shown in Figure 3 have been built-up identically, except the high power amplifiers (HPA) within the Tx chains, to compare the behaviour of state-of-the-art HPA MMICs realised in MESFET and HBT technology. The T/R module on the left hand side in Figure 3 applies HPA MMICs realised in MESFET technology while the T/R module on the right hand side applies HBT HPA MMICs manufactured by United Monolithic Semiconductors (UMS).

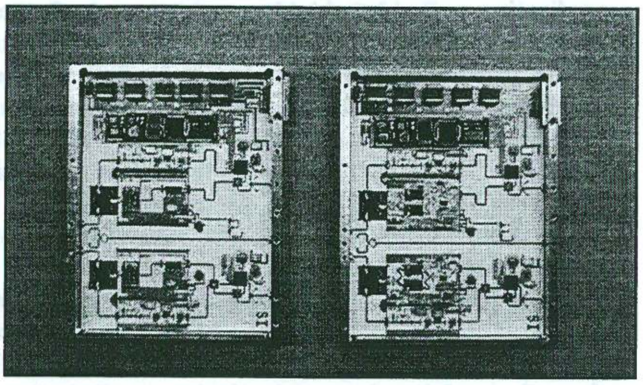

Fig. 3: EUCLID CEPA 9 RTP 9.3 Duopack T/R Modules (HBT & MESFET T/R Module)

Each T/R element contains a Tx chain, applying driver amplifier and HPA MMIC in the same technology. The output power level of the Tx chains reaches values between 9 W and 10 W, either by applying a single chip MESFET HPA or using two HBT HPA MMICs in a balanced configuration. The Rx chains contain non-reflective limiters and low noise amplifiers with less than 1 dB noise figure at ambient temperature. The phase and amplitude setting is done in the common-leg of each T/R element. The variable gain amplifier and all phase shifter elements, as well as interstage amplifiers and T/R switches have been integrated on a multifunction MMIC (Core Chip). This Core Chip has been developed by TNO Physics and Electronic Laboratory (TNO-FEL, NL), and is used for setting Tx and Rx phase, and Rx gain respectively. Between the T/R elements a test and calibration network has been added, needed for calibration purposes of the T/R module after integration into the active array antenna. Further on, a capacitor bank has been integrated into the package to store the pulse energy, and to avoid high current pulses on the external T/R module interface lines. For controlling the duopack T/R modules the DCE, shown and described in Figure 2 and Section 2.1, has been applied. Figure 4 shows a photograph of the MESFET T/R module in which the individual circuits can be seen.

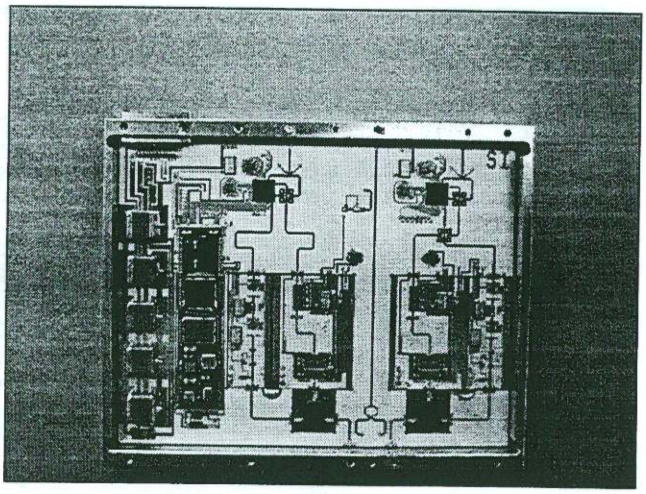

Fig. 4: EUCLID CEPA 9 RTP 9.3
MESFET Duopack T/R Module

The internal set-up of the T/R modules consists of a 15 mil alumina multilayer substrate realised in hybrid thin/thickfilm technology. This substrate provides all internal interconnections of the control area between DCE and Core Chips, as well as between all other components, except between the DCE and the Tx and Rx chains which are inserts. This technology ensures a safe interconnection between the single components of the T/R module, reduces any kind of coupling effects caused by crossed RF line bond wires, and minimises the number of required bond wires. In large quantity production this technology dramatically reduces the failure sources in the manufacturing procedure. Another advantage of this technology is the opportunity to combine multilayer technology together with extremely small line width, often required in directional coupler circuitries, e.g. for interdigital capacitors, and within the Core Chip region. The complete electronic circuitry (digital, power and RF) is mounted on a single Aluminium Silicon Carbide (AlSiC) carrier with two cut-outs for the circulators. To meet the mechanical requirements of the housing small diameter SMP connectors have been applied. Thus, a total height of the T/R module housing of only 10 mm could be achieved. The size of the complete duopack T/R module is 60 mm x 85 mm including all RF and control connectors. The weight has been measured as 74.3 g including a lid.

C. Test Results of Duopack T/R Modules

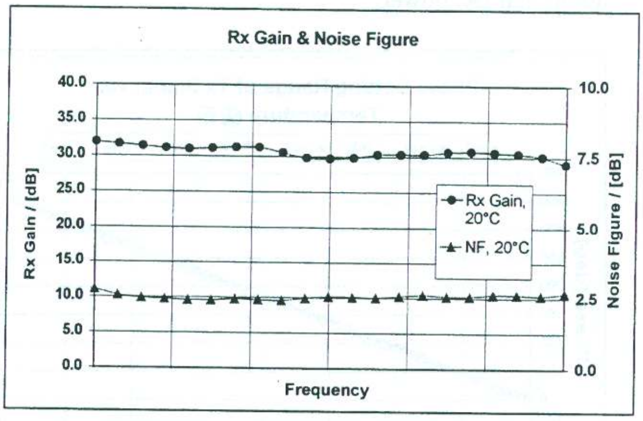

Fig. 5: Rx Gain and Noise Figure versus Frequency

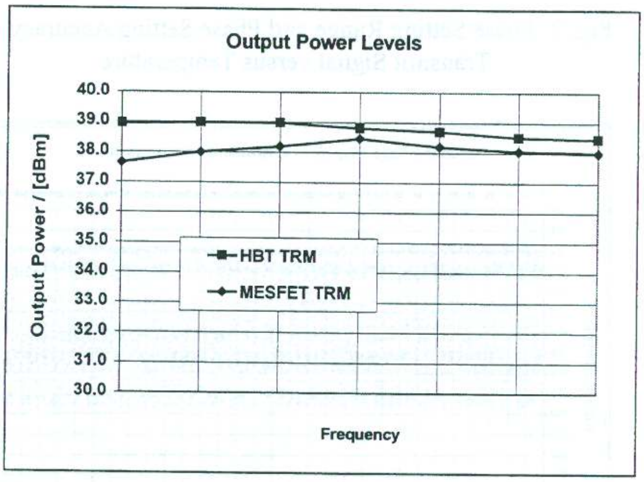

Fig. 6: Tx Output Power Levels of MESFET and HBT T/R Module versus Frequency

Figure 5 shows the test results of the Rx gain and noise figure versus frequency. Within the given frequency range of approx. 10 % bandwidth and at ambient temperature the noise figure has been determined as less than 2.6 dB, and the value of the Rx gain as 30.5 dB ± 0.5 dB. The Tx output power levels of both modules, HBT as well as MESFET T/R module, versus frequency at 10% bandwidth and ambient temperature are given in Figure 6. Although the MESFET T/R module uses a single chip HPA compared with a balanced configuration applied in the HBT T/R module the output power levels are nearly equal. While the MESFET T/R module reaches a value up to 38.6 dBm, the maximum output power level of the HBT module has been measured as 39.0 dBm (8 W). The corresponding overall power-added efficiencies

(PAE) are 17.0 % for the MESFET T/R module and 18.2 % for the HBT T/R module. These values could be reached, although an on-module temperature compensation circuitry has been applied which dissipates additional DC power.

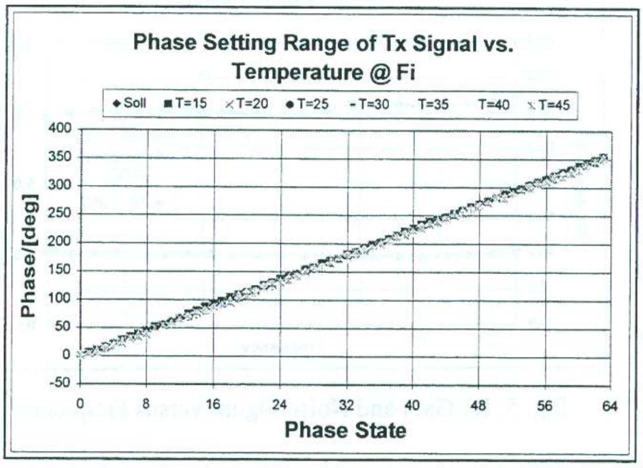

Fig. 7: Phase Setting Range and Phase Setting Accuracy of Transmit Signal versus Temperature

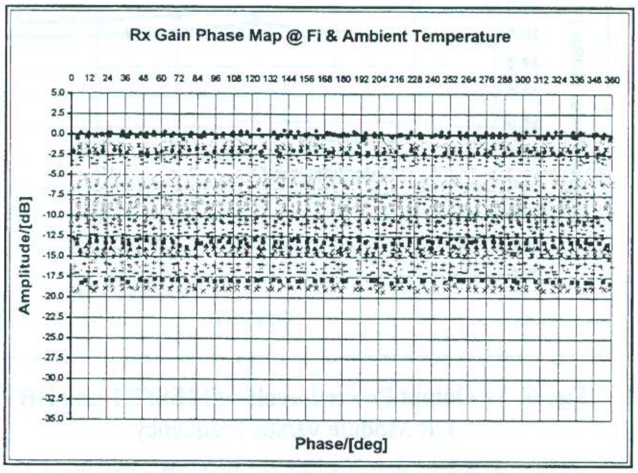

Fig. 8: Gain Phase Map in Receive Mode

The measurement results of the T/R modules applying the three dimensional temperature compensation algorithm are demonstrated within Figure 7 through Figure 10. Figure 7 shows the phase setting range and phase setting accuracy of the T/R module in transmit mode within the temperature range of 15 °C to 45°C. As depicted in this figure the total range of 0° to 360° can be set within an accuracy of less than ± 6°. Measurement results show that the maximum absolute phase errors are less than ± 5°.

In receive mode the behaviour of the temperature compensated T/R modules is demonstrated in Figure 8, in which the Rx gain phase map is given. As shown in this figure all required values within the phase setting range of 0° to 360°, and the amplitude setting range of 0 dB to –20 dB of an external 6-bit phase and 6-bit amplitude control can be reached with high precision. The accuracy in receive mode has been measured as less than ± 5° in phase and as less than ± 0.4 dB in amplitude.

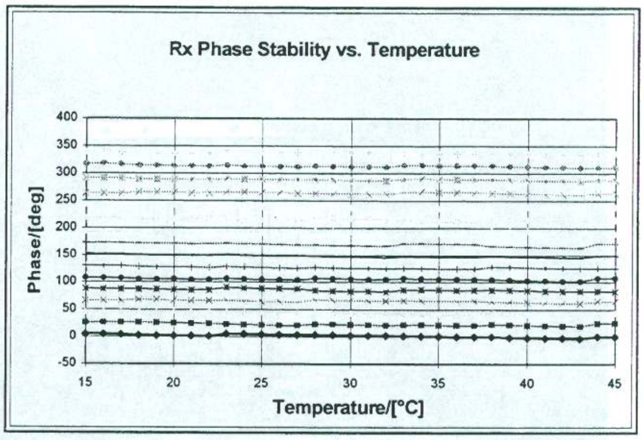

Fig. 9: Rx Phase Stability of Different Phase Settings versus Temperature

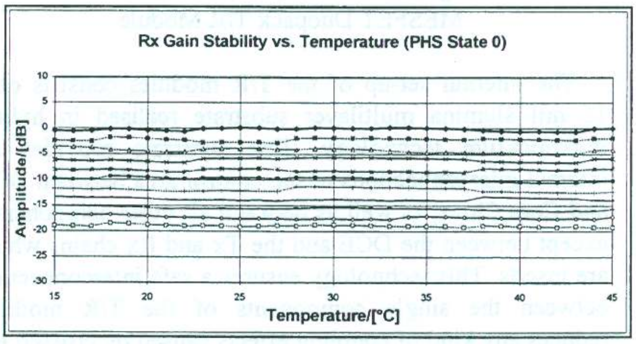

Fig. 10: Rx Amplitude Stability of Different Amplitude Settings versus Temperature

Figure 9 demonstrates the phase stability, and Figure 10 the amplitude stability of the T/R modules in receive mode versus temperature within the required phase, respectively amplitude setting range. As shown in these figures the phase and amplitude is stabilised within the given temperature range. The phase accuracy has been determined as less than a few degrees, while the amplitude accuracy is less than a few tens of a decibel. Consequently, the requirements in phase accuracy of ± 6° and in amplitude accuracy of ± 0.5 dB could be met.

D. Further Miniaturisation

Besides the previously described EUCLID CEPA 9 RTP 9.3 T/R modules a further duopack T/R module has been built-up by DaimlerChrysler Aerospace to demonstrate the technological status of T/R module development in terms of miniaturisation. Figure 11 shows a photograph of a further miniaturised T/R module. Similar to the EUCLID CEPA 9 RTP 9.3 T/R modules this sophisticated duopack T/R module also contains two complete T/R elements, applying the common-leg structure, and using Core Chips to control the RF signals. As shown in Figure 11 the digital control electronics, described previously, is placed between the adjacent T/R elements. The front-end consists of a miniaturised non-reflective limiter circuit, and an 8 W single chip GaAs HPA MMIC and a driver amplifier MMIC, both realised in MESFET technology, and LNAs having a noise figure of less than 1 dB. All interconnections of the individual circuitries within the T/R module are realised on a hybrid multilayer substrate, a combination of thinfilm and thickfilm technology, which also provides all RF structures, as well as all digital and power supply circuit resistors.

All input signals, RF as well as digital and power lines, are fed via a vertical feed-through which is placed into the baseplate at the underside of the multilayer substrate. This kind of connector is able to provide all input interconnections between T/R module and feed network within one single integration step. At the radiator side the RF lines are straight fed through the wall to demonstrate the option of integrating T/R module and radiating element in an ease way.

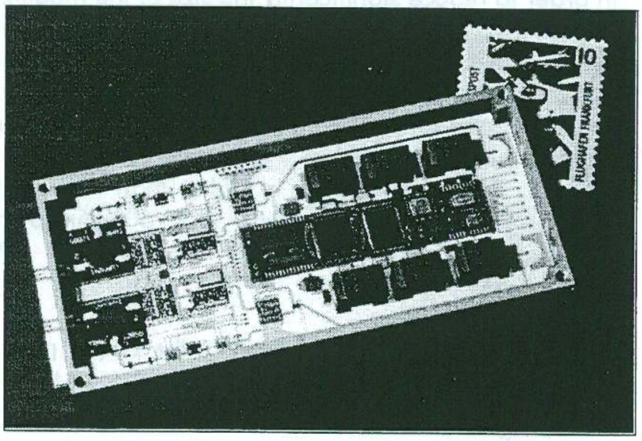

Fig. 11: Further Miniaturised Duopack T/R Module

Further weight reduction of the duopack T/R module could be achieved by exchanging all RF and control connectors by vertical and horizontal feed-throughs, as already described, and by removing the carrier plates formerly used. Thus, the multilayer substrate as well as the high power MMICs are directly mounted onto the base-plate of the housing. This plate is realised in AlSiC to ensure matched thermal expansion between alumina substrate and baseplate. The total size of the duopack T/R module including a lid, not shown in Figure 6, is 70 mm x 33 mm x 5 mm, having a total weight of less than 30 g. This module operates at X-band with 25 % bandwidth.

III. SUMMARY

Two miniaturised duopack T/R modules have been described in detail. The first one was developed within the EUCLID CEPA 9 RTP 9.3 program, while the second module is a T/R module technology demonstrator designed by DaimlerChrysler Aerospace. Both T/R modules apply a highly miniaturised digital control electronics in MCM-D technology providing a three dimensional temperature compensation algorithm to meet the high precision requirements for future space-borne SAR applications.

IV. REFERENCES

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