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Broadband 2-6 GHz polarization circuit for dual polarized phased array antenna

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Report title

Broadband 2-6 GHz polarization circuit for dual polarized phased array antenna

Abstract (not more than 200 words)

Modern phased array antennas need polarization diversity for much improved performance. In this report, an active polarization circuit for circular polarization of a broadband antenna array in the frequency band 2-6 GHz has been investigated and designed. The polarization circuit makes use of an active power splitter and two 90^{o} phase shifters to provide an independent control of the amplitude and phase of the signal at each antenna element. These circuits were simulated using software Libra from Agilent Corp. and designed using a specific fabrication process from OMMIC foundry (ED02ah). The phase error was less than ±10^{o}.

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Qamar ul Wahab
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Bredbandig 2-6 GHz polarisationskrets för dubbelpolariserade gruppantenner

Sammanfattning (högst 200 ord)

Moderna gruppantenner får kraftigt ökade prestanda genom flexibilitet i polarisationen. I denna rapport har en aktiv polarisationskrets för bredbandiga gruppantenner i frekvensbandet 2-6 GHz undersökts och konstruerats. Polarisationskretsen är uppbyggd av en aktiv effektdelare och två 90° fasskiftare för att kunna kontrollera fas och amplitud på signalen till varje enskilt antennelement. Kretsarna har simulerats med programmet Libra från Agilent Corp. och har designats i en process från OMMIC (ED02ah). Fasfelet för kretsen är under $\pm 10^{\circ}$.

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Contents

1. Introduction

Mobile and flexible nodes are considered to be key features for future Network Centric Warfare (NCW) concept. Important factors when operating an efficient and robust network will be access to secure communication channels, reliable sensor information, and a possibility to dynamically change the roles allocated to different nodes within the network. Multifunctional microwave RF-systems are judged to have considerable potential for cost-effective implementation of important functions related to e.g. radar, electronic warfare and communication in a large spectrum of military platforms. The key technology to achieve this vision is active phased array antennas. Active phased array antennas are receiving a great deal of attention for their use in both radar and electronic warfare (EW) systems. Principles of phased arrays have been applied in radar since World War II. However they did not become operational until the late seventies. They are used to achieve high scanning rate in order to operate simultaneously against several threats. Advances in monolithic microwave integrated circuits (MMICs) and high-density microwave packaging (HDMP) technologies have made possible the realization of phased arrays, containing many hundreds of T/R (transmit/receive) modules. Phased arrays can be of shipboard, land-based or airborne versions. One of the challenges facing the military platforms today is to increase the number of onboard RF functions, including radar, electronic warfare and communication, without degrading their stealth capabilities. All these functions are today being performed by separate systems. Multifunction phased array does not only require a broadband behaviour in terms of apertures, T/R modules, beam forming and beam scanning, it also requires polarization diversity in order to support the different polarization needed by the implemented functions. Therefore, a polarisation circuit is one of a number of key elements that have to be investigated to access the technical potential of multifunction RF systems.

In this report, an active polarization circuit for circular polarization of a broadband phased array antenna in the frequency band 2-6 GHz will be investigated and designed. The polarization circuit will make use of an active power splitter and two 90^o phase shifters to provide an independently control of the amplitude and phase of the signal at each antenna element.

2. Concept description

Figure 1 shows a schematic diagram of the proposed multifunction active phased array system. It is based on single RF front-end system and the concept of shared aperture. Figure 2 shows a schematic diagram of a broadband TR module including the polarization diversity block. The polarization block includes integrated active power splitter/combiner together with two-phase shifters covering $0\text{-}360^o$ to be able to independently control the amplitude and phase of the signal at each antenna element. Using single pole-double thru (SPDT) switches, the polarization diversity block can be used for transmitting (red lines) and receiving (blue lines) modes. The apertures used in this concept are shown in figure 3a and 3b for the frequency bands 2-6 GHz and 6-18 GHz, respectively. These apertures have been developed and evaluated at FOI [1,2]. A report has been published describing the requirement for a circular polarization using these apertures [3].

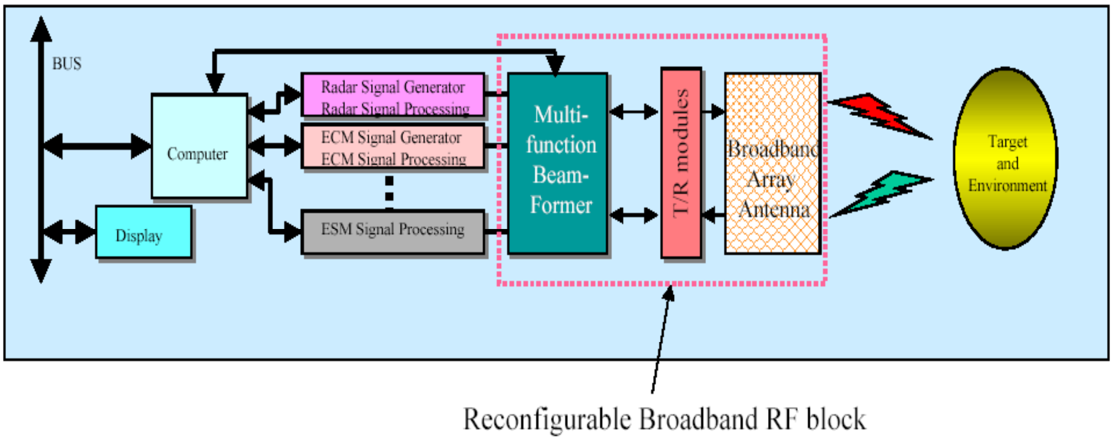


Fig. 1. Schematic diagram of a multifunction active phased array system

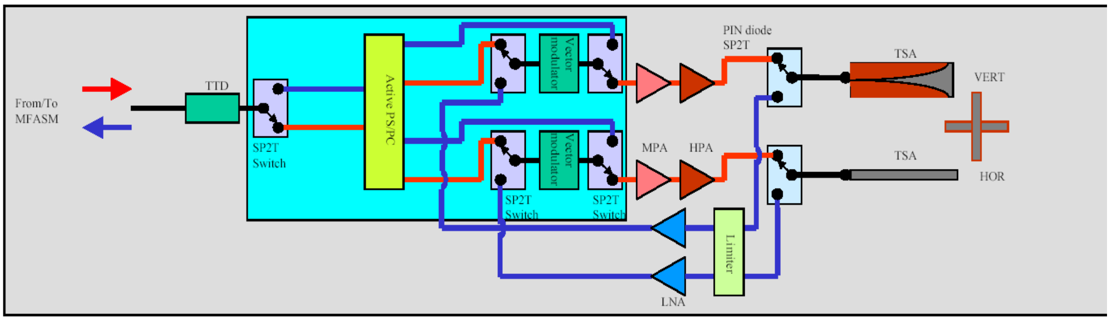
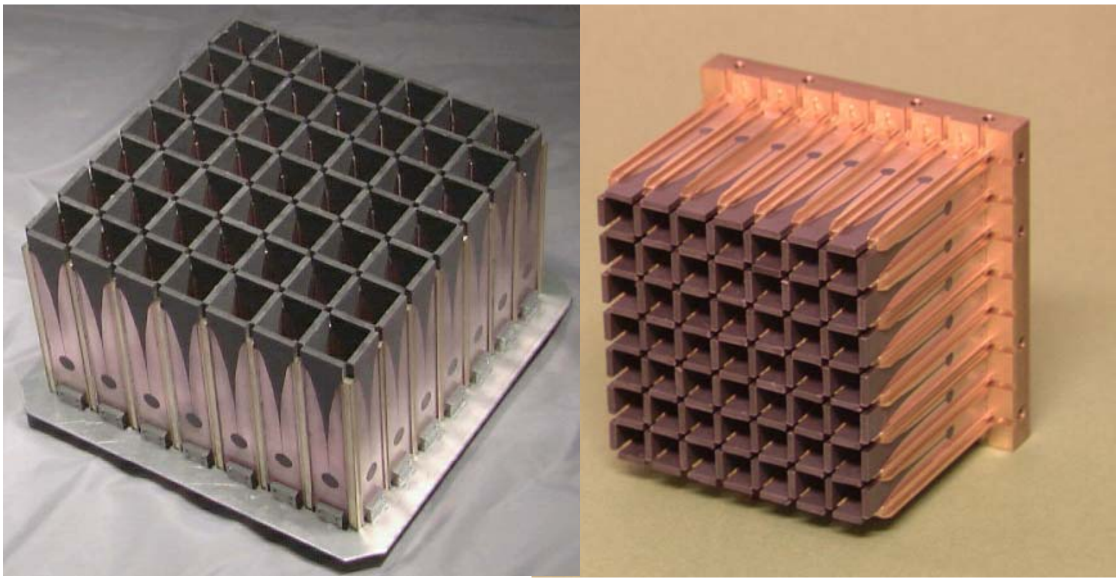


Fig. 2. Schematic diagram of the TR module including the polarization diversity block (green box)



(a) (b)

Fig. 3. 7 x 8 element dual-polarised tapered slot antenna array apertures developed at FOI. a) 2-6 GHz and b) 6-18 GHz.

3. Circular polarization circuit

Figure 4 shows a schematic diagram for an active circular polarization circuit. This circuit includes previously developed active power splitter/combiner [4] together with two 90^{o} phase shifters to be able to generate left- and right-hand circular polarizations. The phase shifter, as a microwave component, finds use in a variety of communication, radar systems, microwave instrumentations, measurement systems and industrial applications. Electronic phase shifters assumed special significance because of their potential utility and volume requirement in phased array antenna systems for agile beemsteering. MMIC phase shifters employing GaAs MESFETs and HEMTs are the most popular one in today antenna systems. The MMIC approach offers all the advantage of integration, cost and weight reduction [5-6].

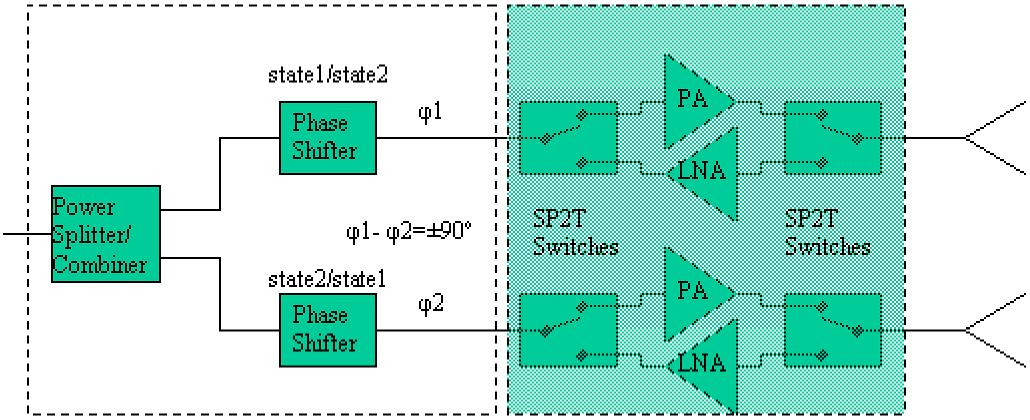


Fig. 4. Schematic diagram of the active circular polarization circuit containing power splitter/combiner and two phase shifter.

3.1 Phase shifter design

It is relatively a straightforward task to design a microwave phase shifter to meet a specified level of phase shift at a specific frequency. However, this task becomes more difficult if the appropriate level of phase shift has to be maintained across a very large frequency range. This difficulty is further compounded when this wideband relative phase shift performance is required to be continuously tuned over a large relative phase shift range. This three dimensional scenario has assumed that all the other device specifications, such as insertion loss and return loss, are kept within acceptable limits over the wide bandwidth and large tuning range. Wideband operation requires a specific architecture such as low pass/high pass filters.

The low-pass (state 1) and high-pass (state 2) technique employs switching between a low-pass filter and a high-pass filter. The filter networks use lumped inductors and capacitors, which are easily realized in monolithic form.

3.2 Circuit concept for low-pass and high-pass

In the first stage, an ideal phase shifter with low-pass and high-pass concept is simulated using foundry components. Figure 5 shows the state 1 and 2 using only lumped elements, capacitors and inductors. The topology was investigated for 2-6 and 6-18 GHz. This is supposed to be ideal with least losses. The absolute value of phase shift between the two states (low-pass and high-pass) is simulated for a phase difference of 90° and is shown in figure 6. The absolute value obtained was 90° ±10° in the frequency range 2 – 6 GHz.

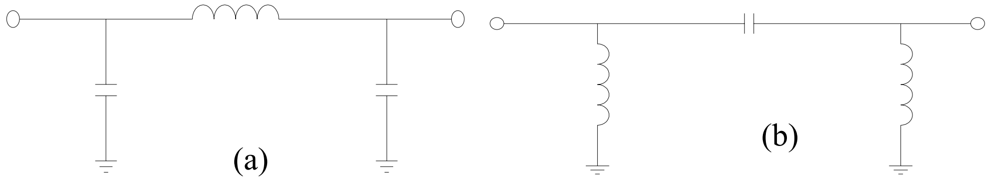


Fig. 5. Schematic diagram of a 90^o phase shifter a) state 1 and b) state 2.

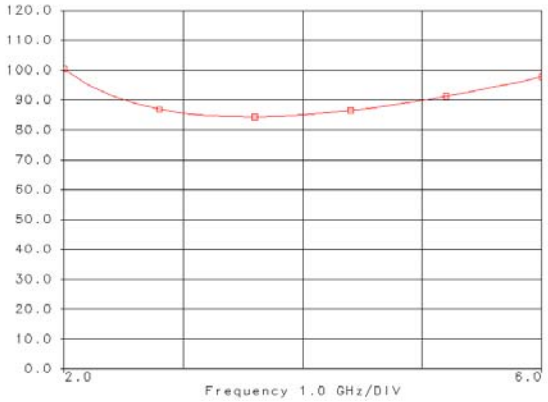


Fig. 6. Absolute value of phase difference between two states at frequency 2 – 6 GHz.

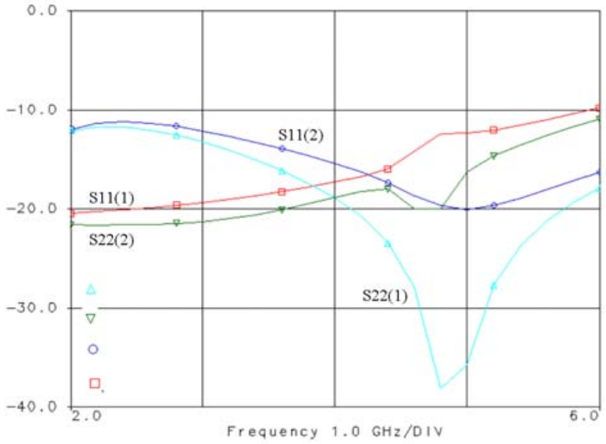
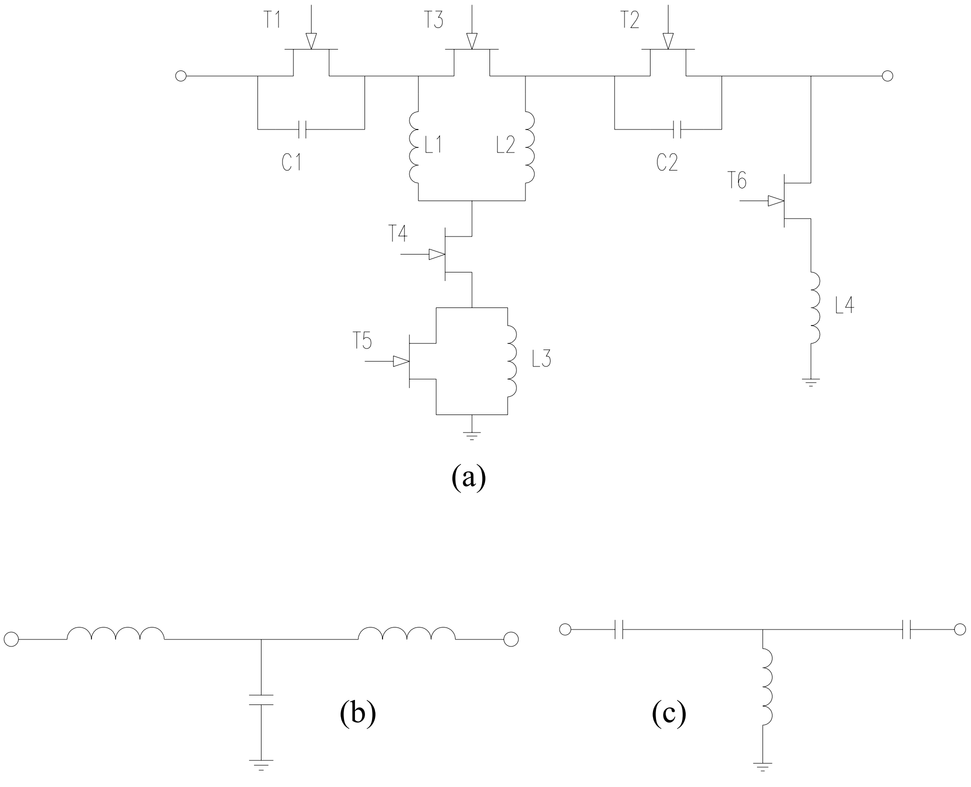


Fig. 7. Input and output (state 1 & 2) return loss in dB.

Figure 7 shows the input and output return loss of both states. S11(1) and S22(1) are the input and output return losses of state 1, respectively, while S11(2) and S22(2) are the input and output return losses of state 2, respectively. A return loss better than 10 dB was obtained.

3.3 Self-Switching concept

To be able to generate the low- and high-pass states using the same circuit, the self-switching concept is required. Figure 8a shows the circuit schematic for the self switched phase-shifter. This topology can be used for 45º, 60º and 90º phase shifters. The circuit uses six field effect transistors (FETs). Each FET is acting as a switch with two states: on-state (FET is equivalent to low resistance) and off-state (FET is equivalent to a capacitance). When FETs T1, T2 and T4 are in on-state and T3, T5 are in off-state, a T-type low-pass filter (state 1) is realized as simplified in figure 8b. To realize the high-pass filter, FETs T1, T2 and T4 are in off-state and T3, T5 are in on-state. In this case T1 and T2 are used as capacitive series filter elements and C1 and C2 are used to increase the capacitance across T1 and T2. Figure 8c shows the equivalent circuit for this state. The transistor T6 is in on-state in the high–pass case which makes the inductor L4 as an additional inductive shunt filter "element". In the low-pass case, T6 is in off-state and L4 has virtually no effect.



(a)

(b)

(c)

Fig. 8. a) Schematic diagram of self-switched 90^o MMIC Phase Shifter circuit. b) equivalent circuit in state 1, c) equivalent circuit in state 2.

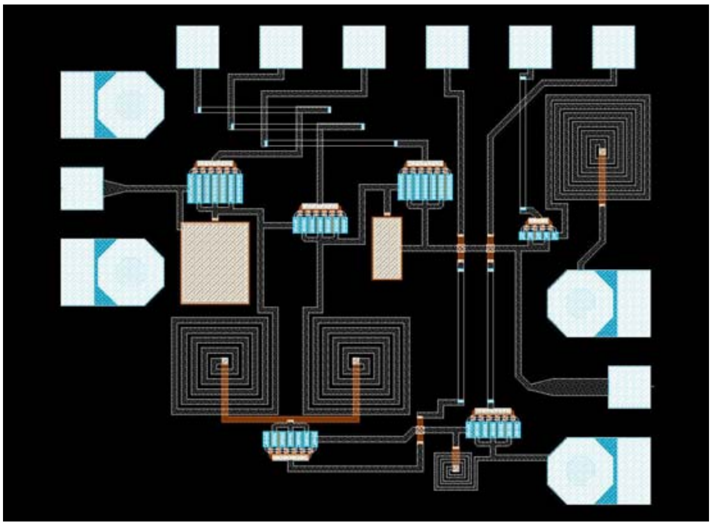


Fig. 9. Circuit layout of self-switched 90^o MMIC Phase Shifter.

Figure 9 shows the circuit layout of self-switched 90^o MMIC Phase Shifter. The RF input and output terminals are at the left and right side, respectively: The DC pads used for biasing the transistors are situated on the top-side of the layout. The results of the simulations performed on the above circuit are shown in figures 10-14.

Figure 10 shows the input and output return loss of the low- and high-pass states (State 1 & 2). The values are below 10 dB for the entire band of 2-6 GHz. Figure 11 shows the insertion loss for the two states. The losses are high at the lower side of the frequency band and a total loss of about 6 dB was observed at 2 GHz, while at around 6 GHz the losses are about 5 dB.

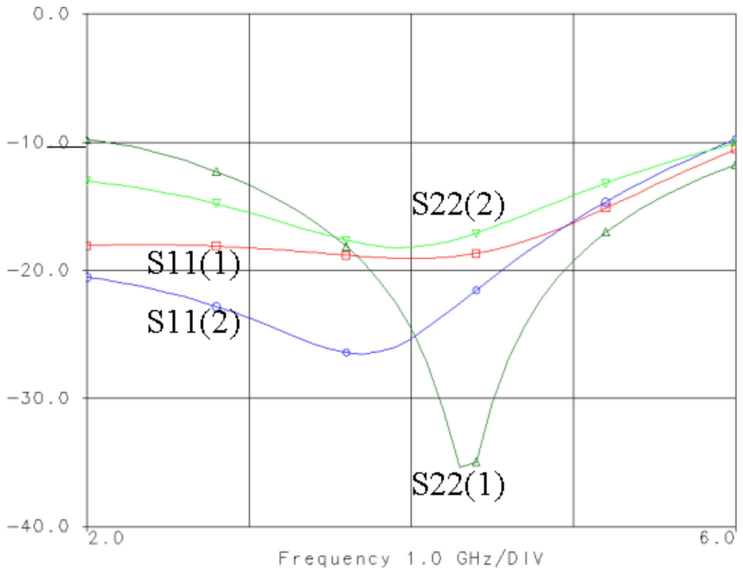


Fig. 10. Input and output return loss in dB of the self-switched 90^o MMIC phase shifter. State 1: (S11(1) Input return loss, S22(1) Output return loss). State 2: (S11(2) Input return loss, S22(2) Output return loss).

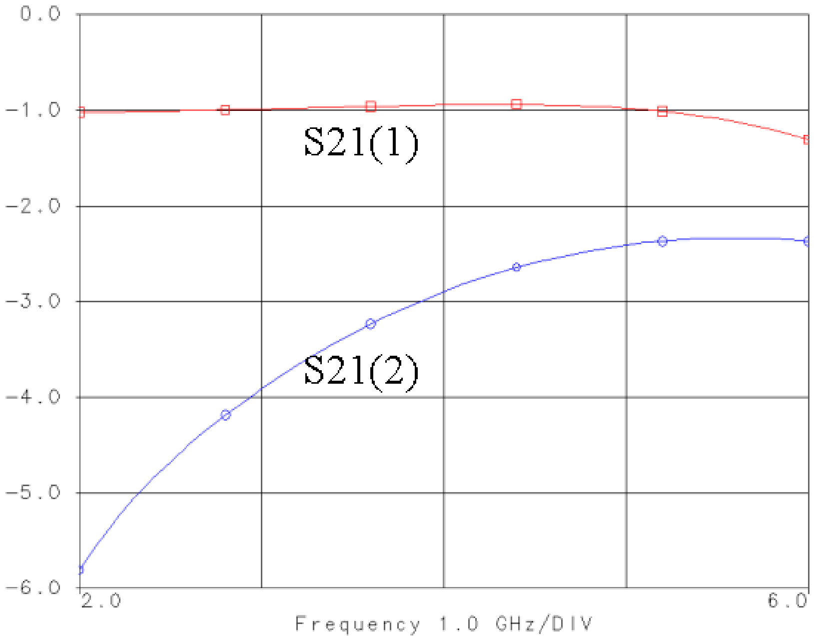


Fig. 11. Insertion loss in dB of the self-switched 90^o MMIC phase shifter. State 1: S21(1) and state 2: S21(2).

Figure 12 shows the absolute value of phase difference between the two states for 2-6 GHz frequency range. The curve is not flat and the deviation of ±10º is within the limit of demand. The phase deviation due to process variations has also been investigated and is less than 5º. The power handling capability of the phase shifter was also investigated since the circuit will be used both for transmit and receive modes.

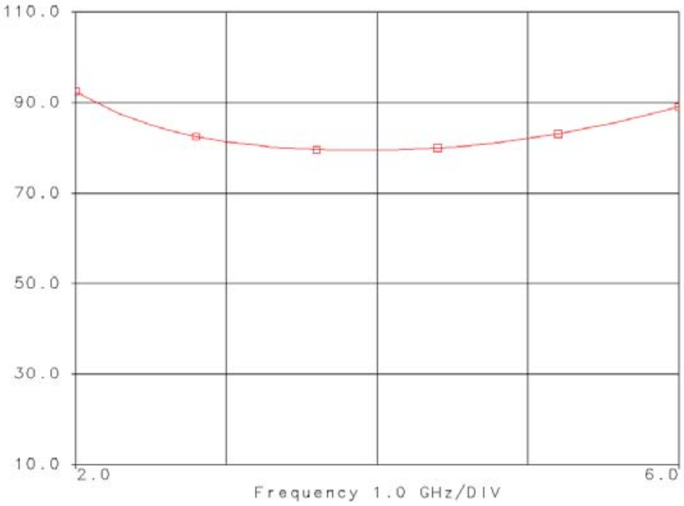


Fig. 12. Absolute value of phase difference between two states in the frequency range 2 – 6 GHz for the self-switched phase-shifter.

The input power at 1dB compression point is about 10 dBm at operating frequencies of 2 and 4 GHz while at 6 GHz it is about 8 dBm. The output power can be improved using high power process. Fig. 14 is showing the IP3 value in dBm for both states. A maximum value was around 23 dBm.

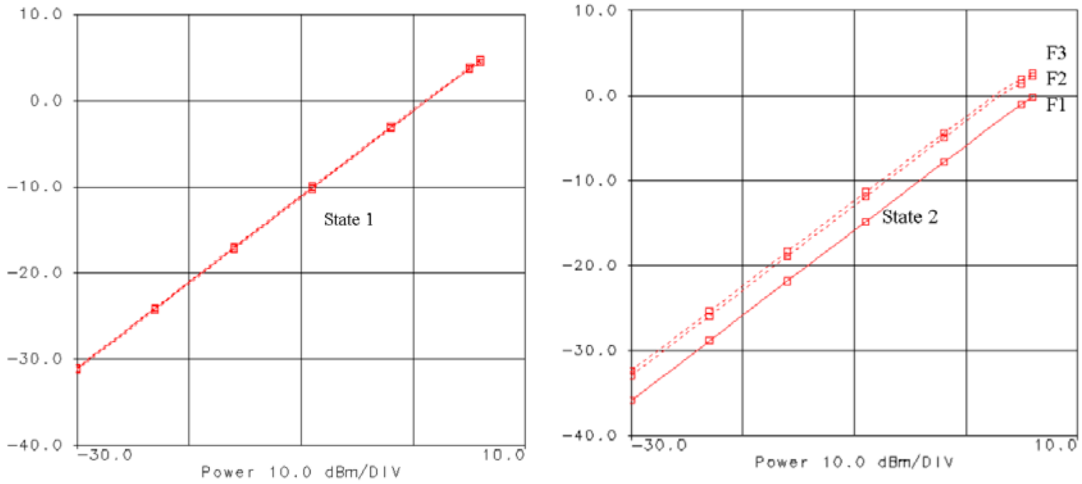


Fig. 13. Output power vs. input power simulated at 2 (F1), 4 (F2) and 6 (F3) GHz for both states.

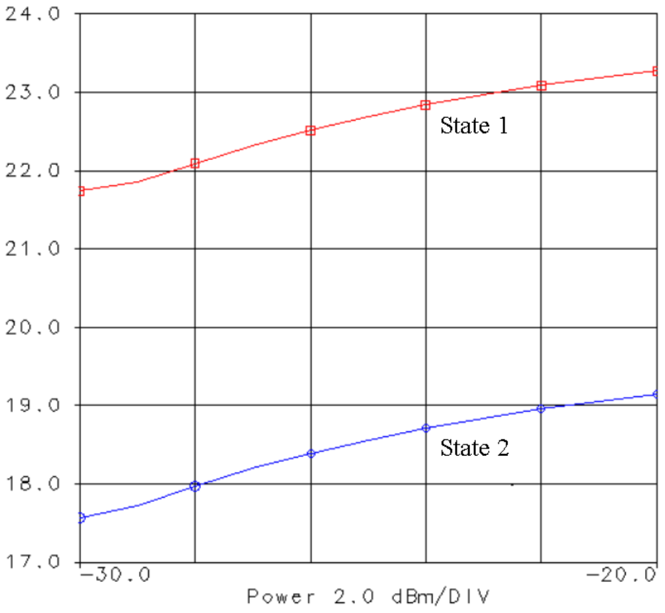


Fig. 14. Output IP3 values vs. input power simulated at 4 GHz for both states.

A little work has been done on the 90^o phase shifter in the frequency band 6-18 GHz. The initial investigations indicated that the performance is not that poor even the band is three times larger. The problems of losses are crucial only at the lowest frequency around 2 GHz. It is worthwhile to investigate some type of circuit topology for an entire band of 2 – 18 GHz.

3.4 Active power splitter

This section describes the performance of reconfigurable broadband active power splitter and combiner [4] intended for a two-dimensional beam former for ultra-wideband active phased array antenna and as a part of the polarization circuit.

Figure 15a and b show photographs of the realised reconfigurable power splitter and combiner, respectively. The occupied area is 2 x 1.5 mm^2 for each of them. The OMMIC ED02ah process has been used for the chip fabrication. Further improvement in chip integration can be achieved by integrating both designs on the same chip using different metal layers, as has been demonstrated in [7].

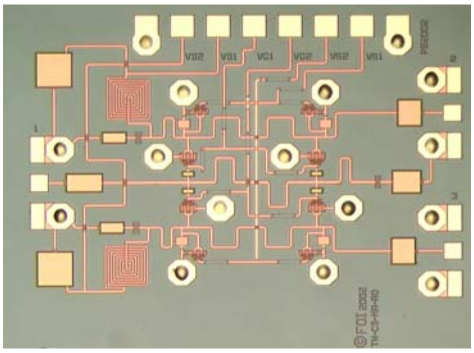


Fig. 15a. Picture of the reconfigurable power splitter.

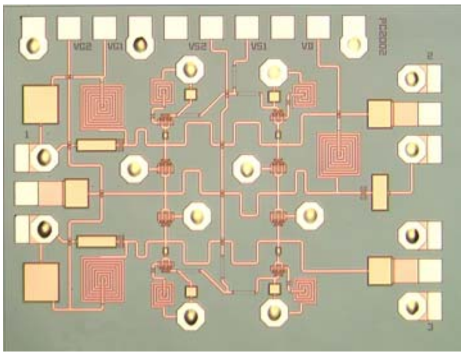


Fig. 15b. Picture of the reconfigurable power combiner.

Both the reconfigurable broadband active power splitter and combiner are based on the distributed amplifier technique. This gives the advantage of providing broadband amplification while still accomplishing power splitting or combining. The circuits are designed for a bandwidth of 2-18 GHz. The reconfigurability of these circuits provides four different states: (A) Both channels on, (B) Both channels off, (C) Channel 1 on and channel 2 off and (D) Channel 1 off and channel 2 on. The properties mentioned above will enable these circuits to fit into various applications.

Simulated and measured results for power splitter are compared in table I. The measured S-parameters of the active reconfigurable power splitter for state A are shown in figure 15a. These results are in good agreement with the simulations. The input and output return losses (S11 and S22) are better than -10 dB and the transmission gain (S21) is 3 dB ±0.5 dB from 2 to 18 GHz. The reverse transmission gain (S12) is lower than –30 dB. In state B, the transmission gains of both channels are below -25 dB and the return losses are better than -10 dB. Noise figure and output IP3 have been measured in state A. The measured value for the Noise Figure is 6.5 dB, this is in good agreement with the simulations.

	Frequency Range [GHz]	Gain in ON-state [dB]	Noise Figure [dB]	OIP3 [dBm]	Gain in OFF-state [dB]
Simulated Values	2-18	2.5-5	< 7.5	27	< -20
Measured Values	2-18	2.4-3.2	< 6.5* *(7.5-12 GHz)	21	< -25

Table 1: Measured and simulated data for the power splitter over the frequency band

Simulated and measured results for power combiner are compared in table II. The measured S-parameters of the active reconfigurable power combiner for state A are shown in fig 15b. These results are in good agreement with the simulations. The input and output return losses (S11 and S22) are better than -10 dB and the forward transmission gain (S12) is 4 to 5 dB from 2 to 18 GHz. The reverse transmission gain (S21) is lower than –25 dB. In state B, the transmission gains of both channels are below -20 dB and the return losses are better than -12 dB. Noise figure and OIP3 were measured in state A. The measured value for the Noise Figure is 7.6 dB, which agrees well with the simulations.

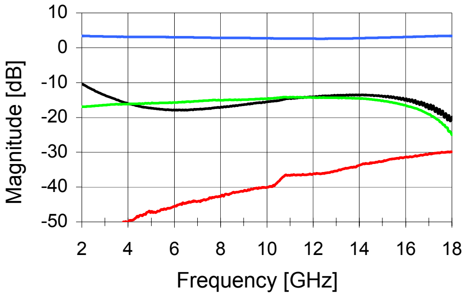


Fig. 16a. Measured S-parameters for one channel of the power splitter in state A.

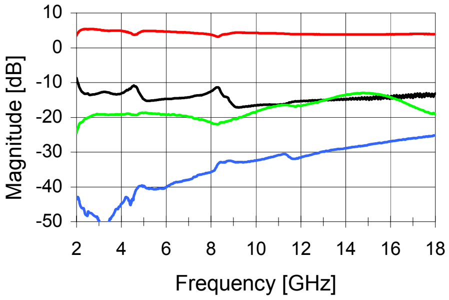


Fig. 16b. Measured S-parameters for one channel of the power combiner in state A.

	Frequency Range [GHz]	Gain in ON-state [dB]	Noise Figure [dB]	OIP3 [dBm]	Gain in OFF-state [dB]
Simulated Values	2-18	5-6	< 8.2	25	< -18
Measured Values	2-18	3.9-4.9	< 7.6* *(7.5-12 GHz)	20.6	< -20

Table 2. Measured and simulated data for the power combiner over the frequency band.

3.5 Polarization circuit layout

Figure 17 shows the complete layout of the active polarization circuit for a broadband dual polarized array antenna. It includes an active power splitter and two 90º phase-shifters. This allows independent control of both phase and amplitude at each antenna element. By extending this circuitry to include the active power combiner, this will also enable the receiving mode.

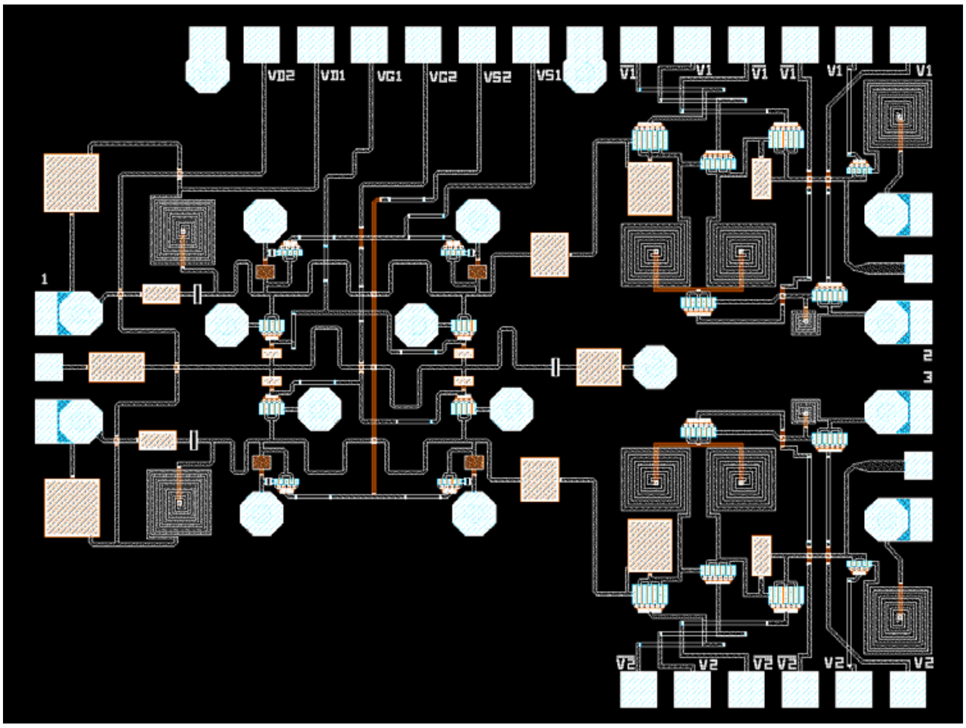


Fig. 17. A complete layout of the active polarization circuit. The chip size is 2.5x1.9 mm2.

4. Conclusion

In this report, we have investigated and designed an active broadband polarization circuit for a circular polarized broadband phased array antenna in the frequency band of 2-6 GHz. The polarization circuit used an active power splitter and two 90° phase shifters to provide an independent control of the amplitude and phase of the signal at each antenna element. These circuits were simulated using software Libra from Agilent Corp. and designed using a specific fabrication process from OMMIC foundry (ED02ah). The phase error was less than ±10º.

5. Future Research

Future research is under consideration in the following directions.

1. The current topology of the self-switched phase shifter was also investigated for 6-18 GHz. The initial investigations indicated that this topology could also be useful. Thus more investigation for this band will be considered
2. To investigate the phase-shifter topology for the entire band of 2-18 GHz.
3. A conventional architecture of a beamformer for broadband phased array antenna consists of power splitter, true time delay and power amplifier as shown in Fig. 18. A more compact design can be a one-chip solution for all three elements. Some investigations were started for a combined simulation of power splitter with distributed amplifier for 6-18 GHz range. Figure 19 shows the schematic of a combined power-splitter and distributed amplifier. In the distributed amplifier, five stages were included. The involvement of phase shifter circuit in this topology can create a one-chip solution. This one-chip solution can be very beneficial in several applications.

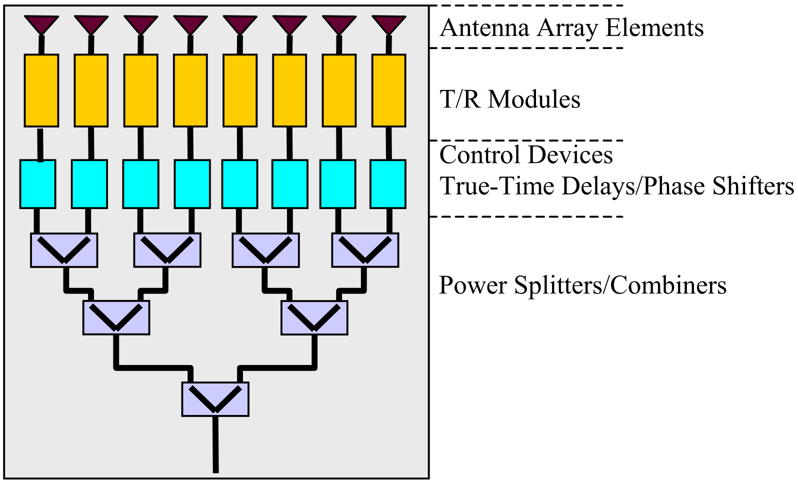


Fig. 18. One-dimensional active phased array

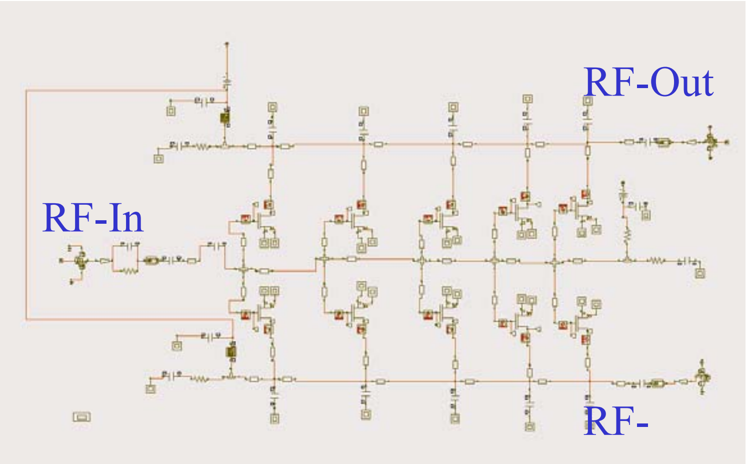


Fig. 19. Circuit diagram for a combined power splitter and five stage distributed power amplifier.

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