Key Circuits for a Reconfigurable and Bi-directional Beamformer for Ultra wideband Applications

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Abstract - This paper describes the performance of reconfigurable broadband active power splitter and combiner intended for a two-dimensional beamformer for ultra-wideband active phased array. The topology of the beamformer has been developed so that it allows bi-directionality and reconfigurability. Simulated performance of a broadband reconfigurable 8x8 active beamformer is also presented.

I. Introduction

Active phased array antennas are receiving a great deal of attention for their use in both radar and electronic warfare (EW) systems. 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 modules, with reduced antenna size, weight and cost. One of the future strategies to handle today's complex battle scenarios is the integration of communication, radar and EW functions using a single RF system with shared apertures in order to accomplish the objectives regarding platform survivability, low observability, low cost and low weight. Such a system does not only require a broadband behaviour in terms of apertures, T/R modules, beamforming and beamscanning, but also modular and reconfigurable architectures in order to, instantaneously, reconfigure the array to the required function(s) and other parameters such as effective radiated power (ERP) and beamshape. In this article, we demonstrate a reconfigurable broadband concept as a first step toward the realization a single RF system for multifunction purpose.

II. Beamformer concept

Fig.1 shows a conventional architecture of a one-dimensional active phased array. It is fully distributed e.g. instead of generating all the power in a single transmitter and then dividing it, we generate the power locally at each antenna element using solid-state amplifiers.

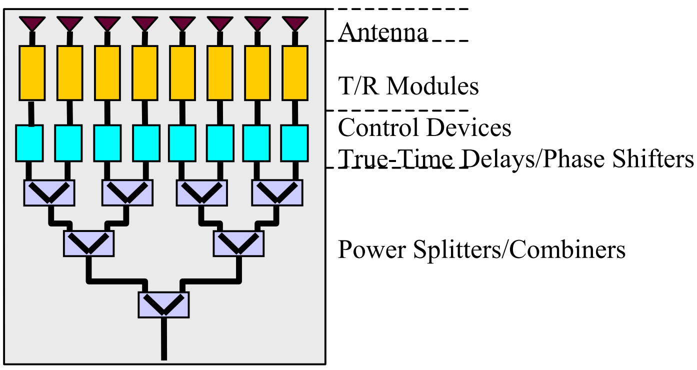

Fig. 1. One-dimensional active phased array.

The beamformer in our concept has been developed based on the following requirements:

a. Active power distribution instead of passive one. This allows very good control of the system power gain and linearity budgets.
b. The architecture of the power splitters should be broadband, reconfigurable and allow variable gain.
c. The system should be able to handle a broadband signal.

The requirements #a and #b are satisfied using our reconfigurable concept. In order for the system to handle a broadband signal, i.e. requirement #c, true time delays (TTDs) as control devices must be used instead of conventional phase shifters delivering a constant phase shift with frequency. Using TTDs eliminates the "beam-squinting" and "pulse-stretching" effects resulting from using conventional phase shifters. Figs. 2a and 2b 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 [1].

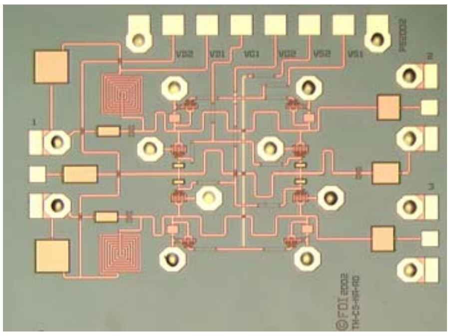

Fig. 2a. Picture of the reconfigurable power

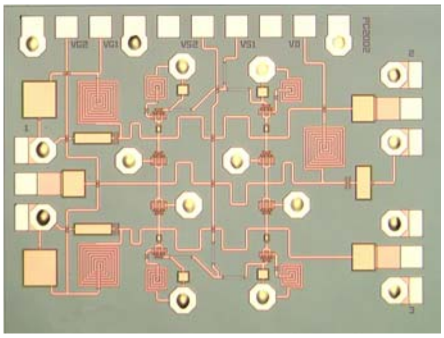

Fig. 2b. Picture of the reconfigurable power

III. DESIGN

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.

IV. RESULTS AND DISCUSSION

S-parameters measurements were done in the frequency range of 2 to 18 GHz using a HP8510 C network analyser. In this paper will only state A and B measurements be presented. Other parameters of interest such as noise and linearity are also presented in this paper. Measurements of the linearity has been done using a “two-tone” test. The noise figure was measured using a HP8970A Noise Figure Meter.

A. Power splitter

Simulated and measured results are compared in table 1. The measured s-parameters of the active reconfigurable power splitter for state A are shown in fig 3a. 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 OIP3 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 I. MEASURED AND SIMULATED DATA FOR THE POWER SPLITTER OVER THE FREQUENCY BAND.

B. Power combiner

Simulated and measured results are compared in table 2. The measured s-parameters of the active reconfigurable power combiner for state A are shown in fig 3b. 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 (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, this agrees well 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	5-6	< 8.2	25	< -18
Measured Values	2-18	3.9-4.9	< 7.6* *(7.5-12 GHz)	20.6	< -20

TABLE II. MEASURED AND SIMULATED DATA FOR THE POWER COMBINER OVER THE FREQUENCY BAND.

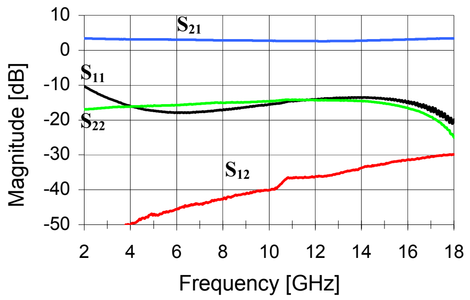

Fig. 3a. Measured S-parameters for one channel of the power splitter in state A.

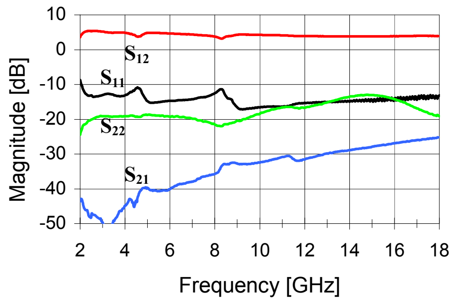

Fig. 3b. Measured S-parameters for one channel of the power combiner in state A.

C. Beamformer

To further evaluate the concept of the reconfigurable active powers splitters/combiners, some simulations of system performance has been done. Reconfigurable active powers splitters have been used in a 1:8 reconfigurable feed network. The case with reconfigurable active powers combiners has also been simulated, but is not shown in this paper. The 1:8 reconfigurable feed network is combined with TTDs in order to enable analog beamforming. In this setup the reconfigurability of the feed network provides the ability to switch branches and antenna elements on and off. This feature allows for example. the beamwidth to be kept constant at the different frequencies by changing the array size, as seen in fig. 5. The simulations have been done at the following frequencies: 6, 10, 14 and 18 GHz with the respectively array size of 8x8, 6x6, 5x5 and 4x4.

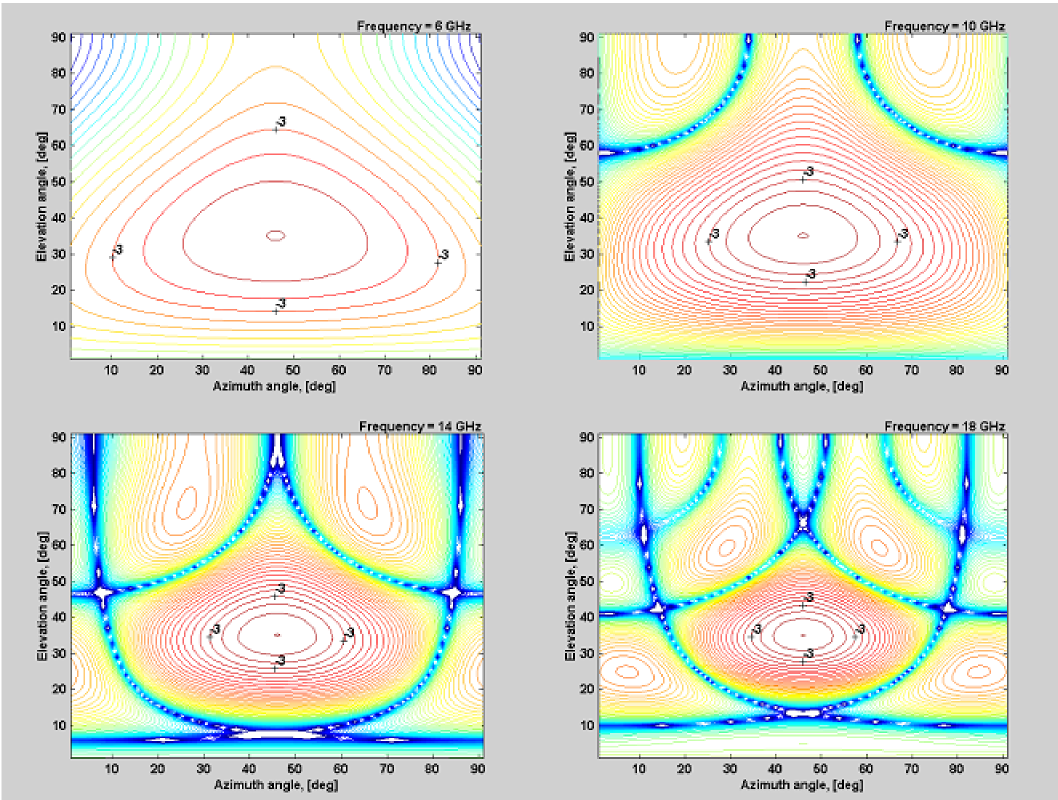

Fig. 4 Simulations of the beam width at different frequencies using a non-reconfigurable feed network.

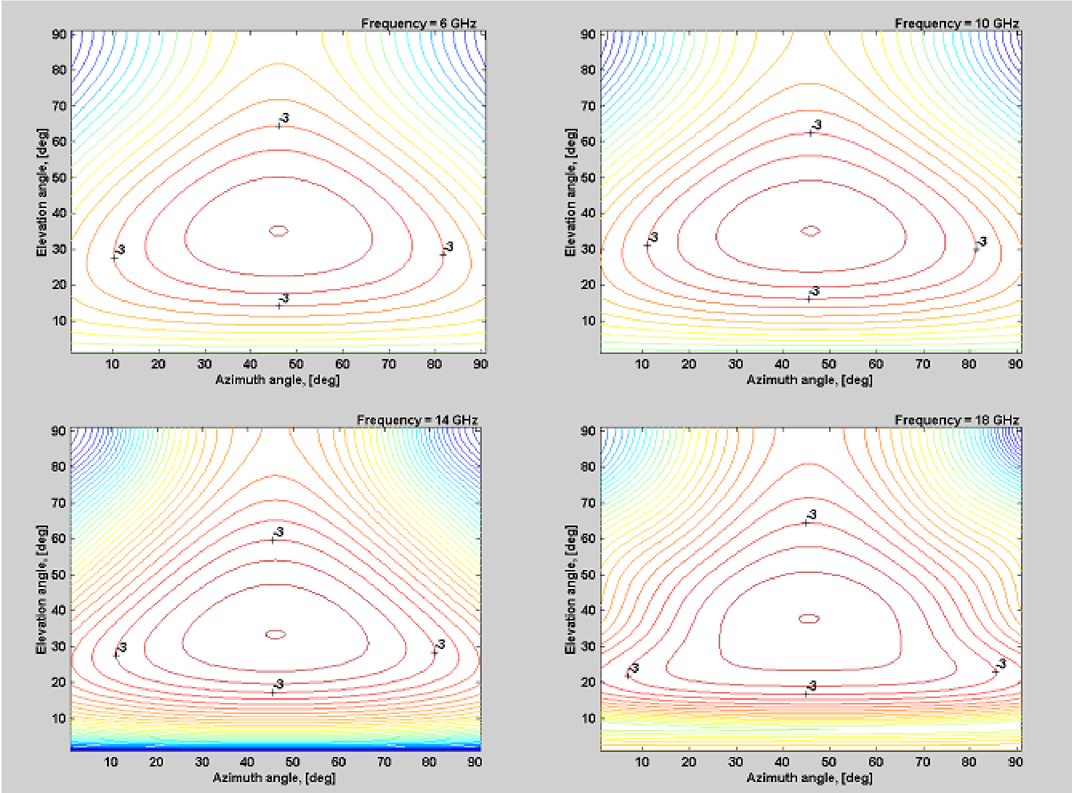

Fig. 5 Simulations of the beam width at different frequencies using a reconfigurable feed network.

V. CONCLUSIONS

This paper describes the performance of reconfigurable broadband active power splitter and combiner intended for a two-dimensional beamformer for ultra-wideband active phased array. Future work will be to integrate both the reconfigurable splitter and the combiner into one circuit that enables both bi-directionality and reconfigurability. The topology of the beamformer has been developed so that it allows bi-directionality and reconfigurability. Simulated performance of a broadband reconfigurable 8x8 active beamformer is also presented.

Acknowledgement

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References

[1] M Alfredson, A Ouacha, and R Jonsson, *Broadband bidirectional active MMIC power splitter and combiner for feed networks,* Asia Pacific Microwave Conference 2001, Taipei, Dec. 3-6 2001, Proceedings Volume 1, pp. 135-138.