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A Power Divider/Combiner Block for Switched Beam Arrays

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Abstract – **Switched active element arrays that produce radiation patterns with variable diversity gain, have been recently considered for countering the effects of multipath fading in industrial environments. The functionality of these arrays is highly dependent on the characteristics of their feeding network. Generating patterns with variable diversity gain requires a feeding network capable of driving different number of elements for each pattern. This paper presents a feeding network building block suitable for producing variable diversity gain in printed circuit switched beam arrays, using active elements with minimal mutual coupling characteristics. The use of this circuit design is illustrated on a seven-elements antenna array, producing numerous radiation patterns, with diverse directivity values.**

I. INTRODUCTION

There is a growing activity in the development of wireless systems for industrial applications [1]. Industrial wireless systems should be capable of supporting low bit-error-rate (BER) real-time communications between wireless terminals, in an environment that is characterized by severe multipath effects and high levels of co-channel interference. The use of smart antennas in industrial mobile terminals is one of the most effective ways to confront these inherent problems of the industrial environment.

Smart antennas are capable of controlling their radiation beams in order to attenuate the interfering and multipath signals. The optimum directivity of these beams depends mainly on the attenuation of the line-of-sight (LOS) signal between the transmitting and the receiving station. When the LOS signal is not severely attenuated, then the narrower the beam of the smart antenna, the better the quality of the received signal [2]. When the LOS signal is obstructed, the best-received signal quality is achieved by using omni-directional antennas on the transmitting and the receiving stations [3]. Therefore, in order to achieve optimum network performance in all cases, variable gain smart antennas should be used.

Switched arrays are considered the most suitable smart antenna systems for mobile terminals in terms of diversity gain, cost and complexity. Switched active element arrays capable of producing radiation beams of variable gain, have been recently reported [4]. Such arrays consist of elements that have minimum inter-element coupling characteristics, thus switching the elements does not affect the overall S-parameters of the array. On the other hand, the real challenge in switched arrays is to develop a feeding network that divides/combines the RF power to/from a variable number of outputs, in order to produce variable diversity gain beams, with acceptable circuit losses.

In this paper we present a feeding-network building block that is based on a modified Wilkinson power divider/combiner circuit [5]. The presented circuit uses high-speed *p-i-n* diodes, can either divide the RF signal to two equal segments, or pass the original signal to any of the outputs of the circuit with acceptable losses. This circuit can be used either in stand-alone or cascaded configurations, in order to produce large combinations of diverse number of outputs.

Section 2 describes the characteristics of switched antenna arrays that the proposed circuit focuses on. Section 3 describes the main principle of the proposed feeding network building block, shows simulated results on the performance of the circuit and presents an example of integrating the proposed circuit with a switched elements array. Finally, Section 4 summarizes the work presented in this paper.

II. SWITCHED ANTENNA ARRAYS

Switched antenna arrays use either parasitic or active elements in order to produce diverse radiation patterns. In switched parasitic arrays, the elements have large mutual coupling characteristics. Therefore, when they are switched in or out of resonance, the overall current distribution of the array changes, thus producing diverse patterns, and there is no need for routing the RF signal through power dividers or hybrids. Although the feeding network of such arrays is simple, switching the parasitic elements in/out of resonance has a severe impact on the return loss coefficient of the whole array. Thus, it is hard to implement variable diversity gain in switched parasitic arrays without driving the whole antenna out of resonance in the frequency range of interest.

The active antenna array in [4] uses elements that have very small inter-element coupling characteristics. In such arrays, switching one of the elements in or out of resonance does not have significant impact on the current distribution of the other elements and consequently on the S-parameters of the array. This characteristic makes the elements unsuitable for integration in a switched parasitic array, but on the other hand, when used in a switched active element array, feeding any combination of active elements will produce radiation patterns with variable

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diversity gain without driving the antenna out of resonance. Figure 1 shows an example of such an array. This array can produce an omni-directional pattern and directional patterns of 180 degrees beamwidth depending on the number of elements driven. Table 1 summarizes some of the variable diversity gain capabilities of this array.

Elements Fed	Beamwidth (deg)	Azimuth peek (deg)	Directivity (dBi)
1	360		5.50
1-2	181	177	5.98
1-3	171	126	6.23
1-4	174	57	6.15
1-5	166	350	6.37
1-6	184	315	5.90
1-7	157	240	6.60

Table 1: Examples of beam directivity for different feeding patterns.

In these switched active element arrays it is evident that the real challenge is to design a feeding network that can deliver the same power levels in different number of elements. For example, in the array of Fig. 1 the RF signal should be separated either to two equal segments, or be driven directly to the central element [4]. This problem is answered in this work, with the development of a feeding network building block having a variable number of outputs. The description of this feeding network is presented in the following section.

III. THE FEEDING NETWORK DESCRIPTION

In the previous section, the need for developing a new feeding network has been pointed out. Such a feeding network is required in order to equally divide/combine the power from/to the RF front end, either to/from 2, or 1 elements of the antenna array. Moreover, the antenna elements should be strongly isolated, in order to prevent the generation of undesirable radiation patterns. In this section, the power divider/combiner circuit that we developed in order to appropriately feed the seven-element antenna array [4], is described. In order to make this document more readable, the power divider/combiner circuit of the feeding structure, from this point on will be referred to as the power divider, although the circuit operates equally as a power combiner.

A commonly used power divider is the structure developed by Wilkinson [5]. In the simple case of a two-way Wilkinson power divider, the input power is equally divided into two output ports, with acceptable power losses, and the isolation between the two output ports is very high. The feeding network we propose is based on a modified Wilkinson divider. This modified structure block diagram and its layout are shown in Figures 2 and 3 respectively. The function of the proposed structure is controlled by three pin-diode switches (D1, D2 and D3) and operates either as a power divider/combiner or as a single-pole-double-throw (SPDT) switch.

When the input power should be equally divided between the two output ports, the control lines CNTL2 and CNTL3 are driven to negative voltage, while CNLT1 is driven to positive voltage. Therefore, diodes D2 and D3 are open-circuited, while diode D1 is short-circuited. In this case, the circuit has similar functionality to a Wilkinson divider circuit. On the other hand, when the energy should be switched only to one output port, for example if the RF signal should be driven from the input port to port RFO1, then control lines CNTL1 and CNTL2 are driven to negative voltage, while CNLT3 is driven to positive voltage. Therefore diodes D1 and D2 are open-circuited, diode D3 is short-circuited and the circuit functions as a SPDT switch.

In both configurations the return loss, transmission and isolation characteristics of the circuit should be optimal. These characteristics depend on the values of the input impedance Z_{in}, the output impedance Z_{out}, the resistance R and the impedance of the quarter-wavelength legs Z_T of the circuit. In the power divider mode optimum characteristics are achieved when [5]:

$$R = 2 \cdot Z_{out} \quad (1)$$

$$Z_{T1} = \sqrt{2 Z_{in} Z_{out}} \quad (2)$$

When the circuit operates in the SPDT mode, the one quarter-wavelength leg operates as an impedance transformer, while the other one as a short-circuited parallel stub. The parallel stub changes the sign of the imaginary part of the transmission line, but since the input impedance of the circuit is purely resistive, it has no effect on the impedance of the transmission line. Optimum performance of the quarter-wavelength impedance transformer is achieved when,

$$Z_{T2} = \sqrt{Z_{in} Z_{out}} \quad (3)$$

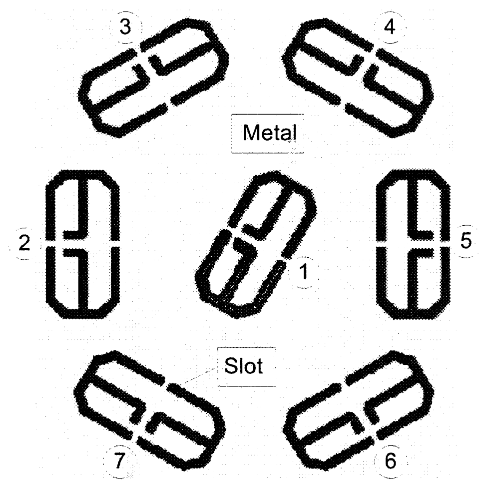

Fig. 1: The seven-elements antenna array.

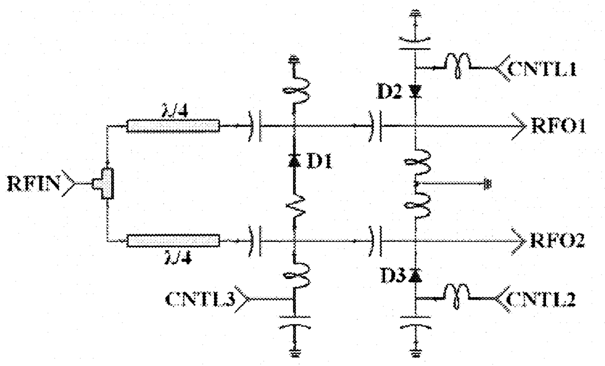

Fig. 2: The feeding network circuit.

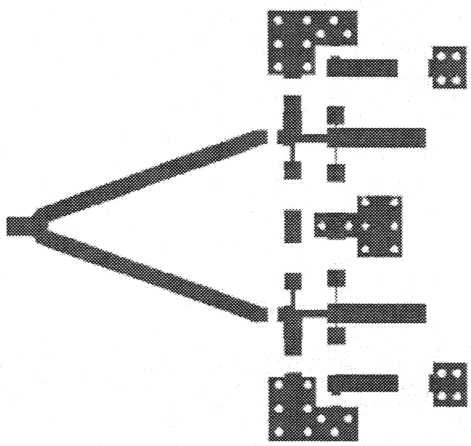

Fig. 3: Layout of the proposed circuit.

Since the circuit needs to operate in both modes, optimum operation would require

$$Z_{T1} = Z_{T2} \qquad (4)$$

From equations (2) and (3) it is evident that this is requirement cannot be achieved. Therefore, the circuit should have sub-optimum characteristics. We propose a compromising narrowband solution that approximates the optimum solution for both modes and this is,

$$Z_T = \sqrt{Z_{T1} Z_{T2}} \qquad (5)$$

For ideal transmission lines and components, we find that for $Z_{in} = Z_{out} = 50$ ohm, $Z_T = 59$ ohm. This approach gives the results shown in table 2.

	S_{11}	S_{22}	S_{12}	S_{23}
Divider Mode (dB)	-15.7	-21.0	-3.152	-21
SPDT Mode (dB)	-15.7	-15.7	-0.119	$-\infty$

Table 2: S-parameters of the ideal proposed circuit

By taking into account all the circuit components, it leads to a solution that gives similar characteristics to the ones described above. The simulated return loss, transmission and isolation characteristics of the proposed power divider building block for the 2.4 GHz ISM band, are shown in Figures 4 and 5.

The proposed power divider/combiner building block can be integrated to the array of Figure 1. In this example, RFO1 can be connected to the central element of the array, while RFO2 can drive one of the peripheral elements through an SP6T RF switch. Driving the energy of the RF signal to RFO1 only will produce an omni-directional pattern. Driving the RF signal to both outputs will produce directional patterns of 180 degrees beamwidth. The orientation of the directional beam is controlled by the state of the SP6T switch.

The proposed building block could be cascaded in order to support larger arrays with a larger variance in the array's diversity gain. A cascaded structure could divide the input signal to 2^n different outputs, where n = 0...N and N is the total number of cascaded levels.

IV. Conclusion

In this paper we presented a new power divider/combiner building block that is capable of dividing an RF signal to a diverse number of equal power outputs. The proposed circuit can be used as a feeding network in many active element switched antenna arrays that produce beams with variable diversity gain. The main concept of the proposed circuit was presented and an illustrative example of integrating the circuit with a switched antenna array was given.

V. Acknowledgments

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VI. References

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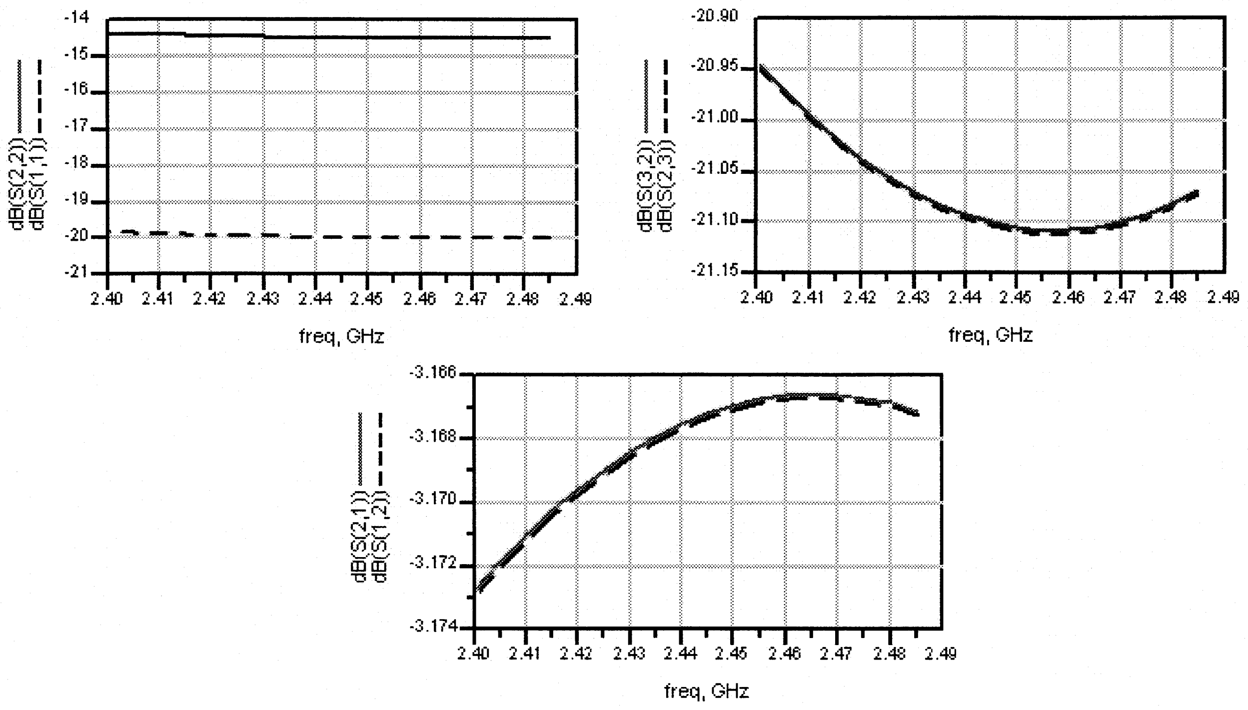

Fig. 4 S-parameters of the two-output case.

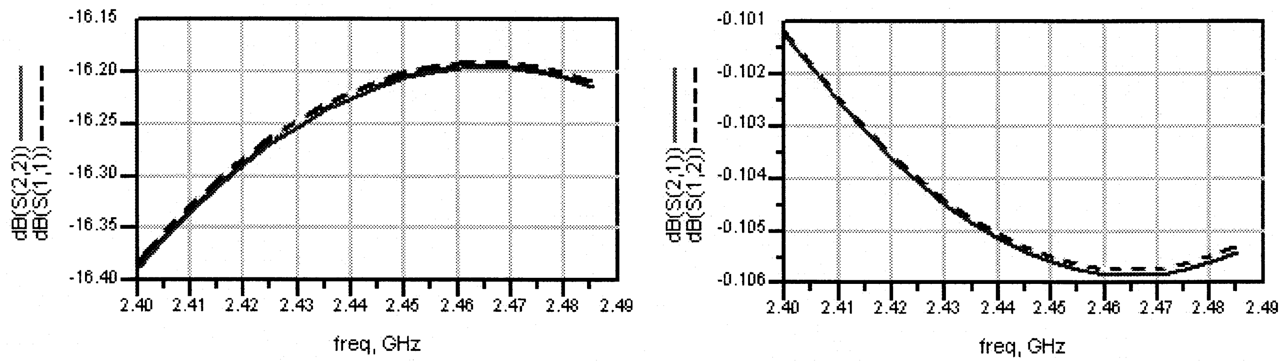

Fig. 5: S-parameters of the single output case