Vol-1, Issue-2 PP. 181-187 ISSN: 2394-5788

GLOBAL JOURNAL OF ADVANCED RESEARCH
(Scholarly Peer Review Publishing System)

Six-port architecture based on Rectangular Disk Quadrature Hybrid at X-band

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Abstract

Six-port architecture based on 3-dB rectangular disk in microstrip configuration is presented in this article. Novel 3-dB disk hybrid topology incorporating capacitive loading along with diagonal feed is realized and three similar disk couplers are cascaded with single Wilkinson power divider to realize complete 6-port architecture at X-band. This article discusses various disk coupler topologies and proposes a simple configuration to achieve the desired specifications at X-band. Also, the complete 6-port architecture based on the proposed rectangular disk along with the principle of operation is detailed. Experimental verification of the simulated topologies on alumina substrate is presented.

Keywords: Rectangular disk hybrid, Planar circuit, Six-port, Coupling, Capacitive stub, Microstrip

1. INTRODUCTION

Six-port architecture was introduced in 1960s by Cohn and Weinhouse and Einger and Hoer utilized this concept, later, for precise power measurement and measurement of complex voltage ratios [1]. It became an alternative for the measurement of complex two port S-parameters as implemented in network analyzers. Subsequently, six-port concept found applications in material analysis, microwave spectroscopy, load-source pull measurement and near-field antenna characterization. This concept was also found to be suitable in anti-collision radar, short range distance measurement and direction finding system [2-5]. In the current scenario of high speed wireless data links, six-port architecture concept is useful in the analysis of direction of arrival [6]. Also direct conversion receiver utilizes the 6-port principle to receive and demodulate QPSK and

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QAM modulated signals. Sony and Nokia companies utilized this concept to demonstrate direct conversion technique as a viable concept for mobile terminals [7].

Planar six-port configuration normally consists of either four quadrature hybrid couplers or power splitter with three quadrature hybrids for power and phase requirements [2]. The latter approach is preferred as length of the line for port termination plays a role in spurious feed which can be avoided in this approach [8]. Quadrature hybrid couplers can be easily realized using rat-race or branch line configuration. Compared to rat-race, branch line topology provides better performance due to easier routing and minimum inter-connection losses [9]. Conventional branched-line hybrid suffers from limited bandwidth and, in addition, the length variations due to fabrication tolerances lead to inaccuracies at higher frequencies. Also quarter-wavelength transmission line in series/shunt arms results in performance deterioration at higher frequencies due to parasitic reactances associated with junctions and unwanted interactions between strip conductors. This can be circumvented by utilizing circular or rectangular disk-shaped 4-port planar circuits. Compared to circular disk topology, rectangular disk is chosen with the reason as mentioned above in case of rat race coupler [10]. Inherent limitation of planar topology is its narrow band operation. To circumvent the losses and consequent performance degradation, associated with these topologies unequal open circuited stub symmetrically at the series arm is introduced with diagonal feeding at optimum angle [11]. This approach allows changing the overall impedance matrix resulting in flat coupling response at higher frequency bands.

In this article, a planar six-port architecture based on microstrip implementation is detailed. Quadrature hybrid coupler is realized as a Patch coupler in rectangular disk configuration for which various variants are studied. Planar circuit type 3-dB quadrature hybrid with diagonal feed and asymmetrical capacitive stub is presented along with gap coupling implemented on a capacitive stub. Three proposed quadrature disk couplers and single Wilkinson power divider (WPD) is implemented on alumina substrate and optimized for X-band operation. Experimental verification of the proposed topology is presented along with complete six-port architecture.

2. DESIGN ASPECTS

Initial parameters of 3-dB disk coupler for design can be taken from Fusco and Stewart [12] and optimized and tuned as per the specifications. Full wave EM simulations are carried out to predict and optimize individual circuit performances.

(a) 3-dB Patch Coupler

Disk coupler is realized using the approach suggested by Kawai and Ohta [7]. As proposed, the convex version with open circuited transmission line sections acting as capacitive stubs is incorporated; but implemented with varied widths. The design presented incorporates strip (gap) loading on a single stub version making it an asymmetrical topology. Various variants including with and without strip loading, symmetrical four strips, equal width for capacitive loading are simulated and results shown in Fig 1 (b). Gap coupling is introduced to optimize the performance at the desired frequency range by providing extra degree of freedom. Insertion of capacitive stub results in flat coupling and variation of gap reflects in the coupling flatness. Proposed topology of unequal capacitive line loading along with gap capacitive stubs performs better with regard to coupled losses and flatness compared to other reported topologies.

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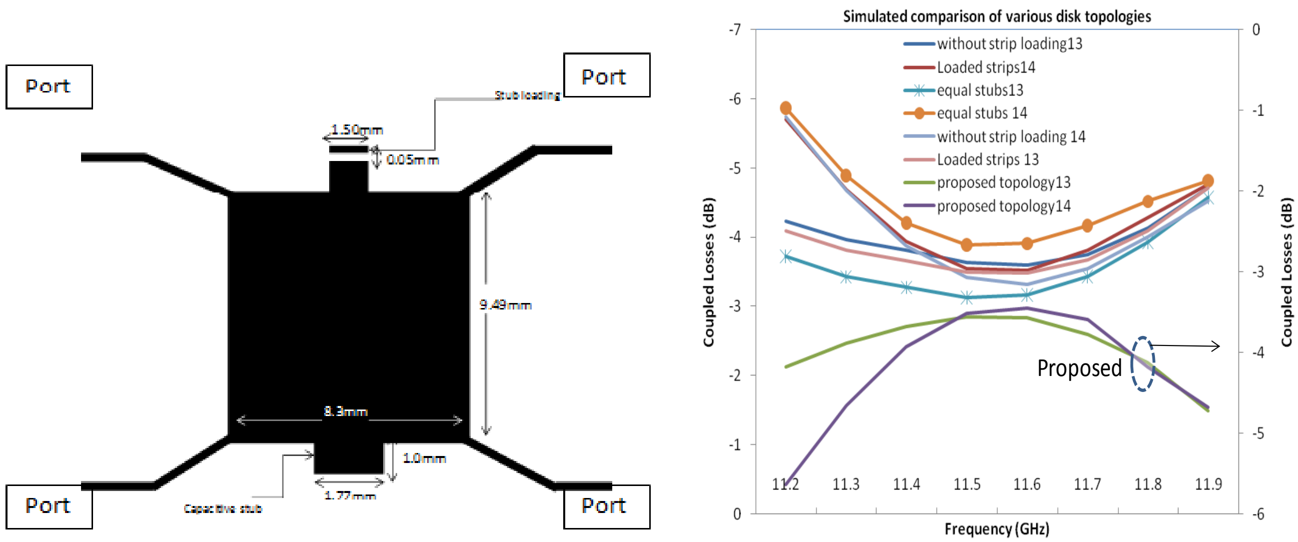

Fig1.0 Rectangular disk coupler (a) optimized layout of the finalized topology (b) Comparative study of various simulated topology

Feeding arrangement also plays an important role and it is found that angle of 45° makes the optimum performance.
Diagonal feeding as shown is better compared to straight line feeding as the field generation and distribution are more uniform thereby reducing the losses due to absence of sharp
discontinuity at the edges. Strip loading with varied widths have no effect but gap variation affects the shape of the coupling curve.

(b)Six-port architecture

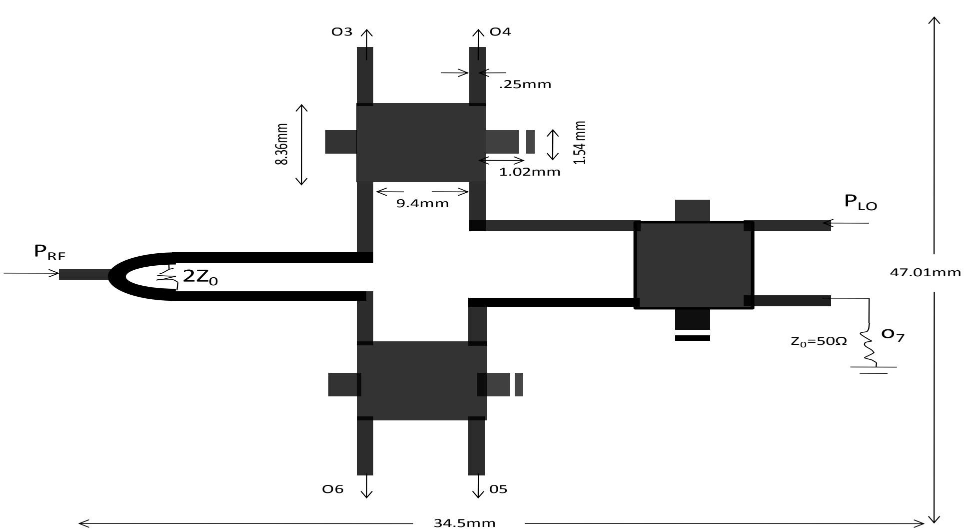

Fig2.0 Dimensional layout of the six-port architecture of RF module

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The 6-port architecture composing of single 3-dB Wilkinson power divider along-with cascaded three disk couplers which are arranged as shown in Fig2. WPD is optimized at the center frequency of 11.5 GHz before incorporation in the overall assembly. Phase difference arising due to inter-connected transmission lines plays an important role, so its incorporation and arrangement is optimized. Three similar disk couplers as proposed in Section (a) are cascaded in vertical and horizontal manner. The overall circuit is simulated with the MOM methodology resulting in the line losses of around 6 dB at the output ports, O_3-O_6.

3. PRINCIPLE OF OPERATION

The six-port architecture is based on the measurement of 4 independent output powers as shown in Fig2.0. These output powers are derived by the superposing of electromagnetic waves shown as P_{RF} and P_{LO} under different phase angles. Two input signals namely RF and LO are connected to ports P_1 and P_2 represented as P_{RF} and P_{LO} whereas port O_7 is matched terminated. The superimposed version of these signals can be measured at the output ports O_3 to O_6. As the total phase of one full wave period ($\varphi=2\Pi$) is divided into four parts shifted by $\Pi/2$, the relative phase difference between the two input signals are $n\times 90^o$ (where n=0,1,2,3) shifted at the corresponding outputs.

The signals at P_{RF} and P_{LO} can be written as below considering RF at Port 1 and LO at Port 2:

$$I_{LO}= A_1\, e^{j(\omega t+\varphi_1)} = |I_{LO}|\, e^{j(2\Pi f_{LO} t+\varphi_{LO})} \quad (1)$$

$$I_{RF}= A_2\, e^{j(\omega t+\varphi_2)} = |I_{RF}|\, e^{j(2\Pi f_{RF} t+\varphi_{RF})} \quad (2)$$

When these signals are fed into 6-port structure their phases will be rotated by multiples of $\Pi/2$, resulting in 4 RF output signals namely O_3 to O_6 as

$$O3= 0.5\,(-I_{LO}+j\, I_{RF}) \quad (3)$$

$$O4= 0.5\,(-I_{RF}+j\, I_{LO}) \quad (4)$$

$$O5=j\, 0.5\,(I_{LO}+ I_{RF}) \quad (5)$$

$$O6= 0.5\,(-I_{LO}+ I_{RF}) \quad (6)$$

If relation between input and output are known then the amplitude and phase of the input signal can be determined using above set of equations.

4. MEASURED RESULTS AND DISCUSSIONS

The 3-dB quadrature disk coupler along with complete circuit topology is realized on 10 mil alumina substrate. Choice of substrate depends on the frequency, loss and compactness of the overall assembly.

Standard MIC fabrication steps are implemented to realize disk and 6-port topology. Circuits are attached with conductive epoxy and connectors are soldered on to the pattern. Vector network analyzer (ZVA-40) is used for 2 –port S-parameter measurements after calibrating the equipment at the desired frequency range. Losses in this present assembly are higher than simulated values due to assembly related contributions. Flat coupling from 11GHz-12 GHz indicates broad band nature of the circuit. The complete layout with the incorporation of Wilkinson power divider along with the proposed disk couplers is shown in Fig3.0. Resistor ($2Z_0$) of 100 ohm is placed with conductive epoxy. Lay outing of the couplers are carried out with

Vol-1, Issue-2 PP. 181-187 ISSN: 2394-5788

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minimal bends so that the performance is not affected. Theoretical looses of the complete assembly should be ideally 6 dB but due to inherent metallic losses and incorporation of inter-connecting microstrip lines, the losses are higher.

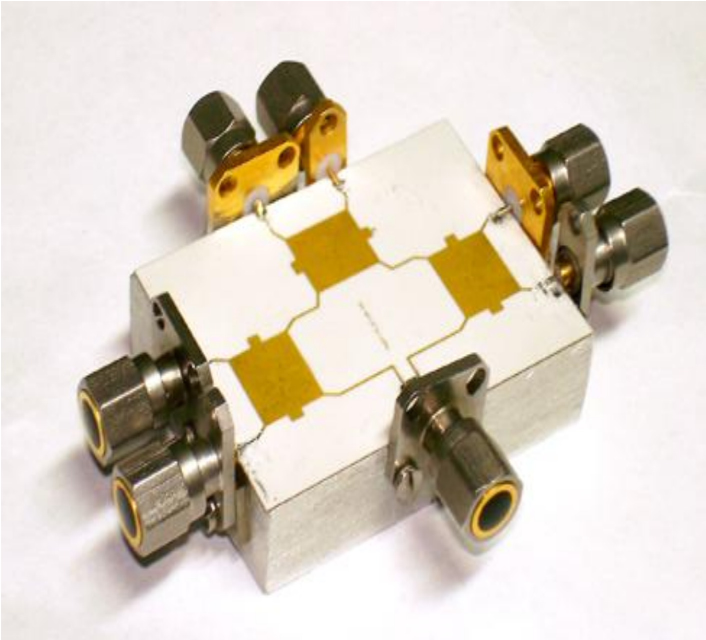

Fig3.0 Six port topology

Below table compares the simulated and measured performance of the realized topologies.

Table 1: Summarization of the results at 11.7 GHz

Parameters	Hybrid Disk		Integrated 6-port architecture	
	Simulated	Measured	Simulated	Measured
Max. Amplitude imbalance (dB)	± 0.4	± 0.8	± 0.35	± 0.5
Return Losses (dB)	-18 (min.)	-15 (min.)	-15 (min.)	-11 (min.)
Isolation (dB)	-20 (min)	-15 (min)	-15 (min)	13 (min)

It can be seen that the variation in measured performance is within acceptable limits. Phase differences at the respective output ports are measured which are as per the predicted ranges of 90 ±2°for disk coupler. Compared to single disk topology, the realized 6-port topology is narrowband (11.3 GHz-11.8GHz) due to incorporation of Wilkinson power divider and inter-connecting microstrip lines. Losses are slightly higher due to metallic and radiation losses associated with this topology.

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5. CONCLUSION

In this article a new concept of realization of patch coupler with diagonal feeding and unequal stub loading along with insertion of gap coupling capacitance is presented. As per the authors' knowledge, this is the first time a planar disk topology for 6-port architecture is presented on high permittivity substrate at X-band. Unlike conventional topologies, the proposed architecture is independent of fabrication tolerances and can be scaled easily for millimetric wave frequencies on various substrates. . The four outputs of the RF module can be converted to digital form by feeding to an ADC and digital output decoded to realize a direct conversion receiver. The simplicity of the proposed topology offers an attractive and low cost option for the future broadband RF module of direct conversion receiver at millimeter-wave frequencies.

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