Design and Development of a Dual Directional Coupler with Transformers for HF band applications

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Abstract— **Dual Directional Couplers have profound application in RF and microwave instrumentation. This paper presents the design and development aspects of a dual directional coupler operating in the HF band using transformers. The coupler was assembled and tested on a PCB and detailed measurements where taken using Network Analyser. It was successfully integrated into the Power Amplifier Unit of a Software Defined Radio Transmitter for VSWR and power monitoring. The performance analysis was done upto 150W of RF power.**

Index Terms—**DDC, SDR, VSWR, Transformer, HF, Power Amplifier, Directivity.**

I. Introduction

A directional coupler is a passive device that is used to provide a sample of the power in a transmission line, and is capable of discerning between the forward and reflected travelling waves.

A Dual Directional Coupler (DDC) employs two, 3-Port directional couplers, internally connected, in tandem, providing measurement of both forward and reverse power. They are ideal for simultaneously monitoring a system's forward and reverse power and for reflectometer measurements. The directivity of the DDC is unaffected by the loads on the coupled ports [1].

The type of application, operational frequency and power handling capability are among the important factors that dictate the type of the directional coupler that will be used in RF system [2].

The DDC was developed for VSWR and power sensing of the HF power amplifier unit, which forms part of the transmitter section of a Software Defined Radio (SDR). The HF frequency calls for a lumped component based design and the size of the core is dictated by the power handling capability. Base on these requirements, a transformer based design was selected.

II. Scattering-Parameters Based Design

An initial scattering matrix design was done based on the literature given in reference [3]. The circuit is shown in Fig 1. It consists of two tightly coupled transformers with magnetic core of turns ratio N1 and N2.

Design Requirements	
Frequency range	3 - 30MHz
Insertion loss	<0.3dB
Coupling factor	18-20 dB
Directivity	25dB min

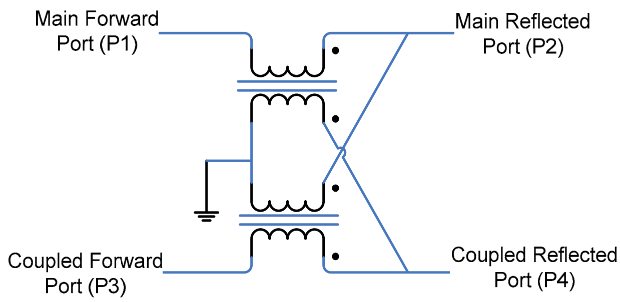

Fig 1: Directional coupler circuit

The s-parameter equation set obtained from reference [3]:

$$S12 = S34 = \frac{2 \cdot N_1 \cdot N_2}{d}(2 \cdot N_1 \cdot N_2 - 1) \tag{1}$$

$$S13 = -S24 = -\frac{2 \cdot N_1 \cdot N_2}{d}(N_1 + N_2) \tag{2}$$

$$S23 = \frac{2 \cdot N_2}{d}(N_1 \cdot N_2 - 1 - N_1{}^2) \tag{3}$$

$$where\ d = 4 \cdot N_1{}^2 \cdot N_2{}^2 + 1 + (N_1 - N_2)^2 \tag{4}$$

In this design, the turns ratio is taken to be the same for both the transformers. Hence $N_1=N_2=N$.

So the equations reduces to:

$$S12 = S34 = 1 - \frac{1}{2 \cdot N^2} \tag{5}$$

$$S13 = -S24 = -\frac{1}{N} \tag{6}$$

$$S23 = -\frac{1}{2 \cdot N^3} \tag{7}$$

A turns ratio of 9 was chosen, which when substituted in the above equations (5), (6) and (7) results in:

Insertion Loss: S12 = S34 = -0.05 dB (8)

Coupling factor: S13 = -S24 = 19.08 dB (9)

Isolation: S23 = 63 dB (10)

Directivity = Isolation - Coupling = 43.92 (11)

The directivity figure obtained above is under ideal conditions. In practical cases, the isolation performance is very much dependent on the physical layout and construction.

The results where also validated using RF and microwave circuit simulation software NI AWR Microwave Office. The simulation results of which are given below.

III. Simulation Results

The circuit simulation was done using two directional couplers connected in tandem to make it a DDC. The isolated port of first coupler and the coupled port of the second coupler are terminated at a characteristic impedance of 50Ω. Fig 2 shows the circuit used for simulation. The simulation was done over a frequency range of 1MHz to 51MHz.

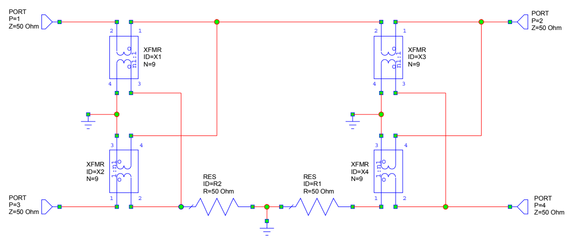

Fig 2: Circuit for Simulation

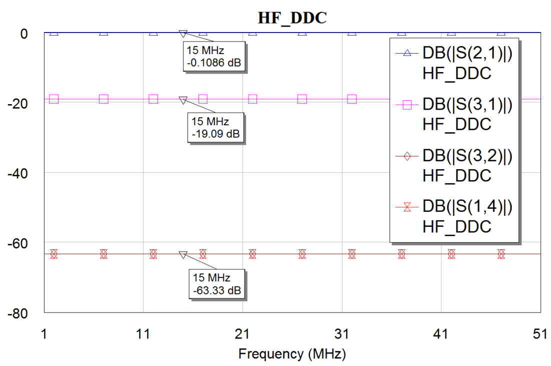

Fig 3: Simulation Results

Port 1 - Main Forward Port, Port 2 - Main Reflected Port, Port 1 - Coupled Forward Port, Port4 - Coupled Reflected Port.

Fig3 shows the simulation results. S21 trace is the insertion loss of the coupler. There are two directional couplers, so each coupler will contribute 0.05dB. S31 trace is the coupling factor which is 19.09dB. S32 is the isolation of the coupler which is 63.33dB. These results are found to agree with the s-parameter calculation done earlier.

IV. Experimental Results

The assembly of lumped elements and the mechanical construction play a major role in achieving a good directivity. The assembly is shown in Fig 4.

Detailed measurements were taken using Network Analyser. Fig 5 shows the Insertion Loss (I.L) of the assembled coupler. The simulation and theoretical calculations didn't take into account the ferrite core losses and interconnection losses. So although the simulation showed 0.1dB I.L, the actual obtained value was 0.23dB. But there was sufficient margin from the design requirement of 0.3dB.

Fig 6 shows the frequency response of the coupling factor. The coupling factor variation within the frequency of operation was only 0.16dB which is acceptable.

Fig 7 shows the Isolation performance of the coupler. The Isolation is very much dependent on the PCB layout and shielding. Directivity is dependent on the Isolation performance. Here precautions were taken in the PCB design and the achieved directivity of 28dB is well above the required specifications.

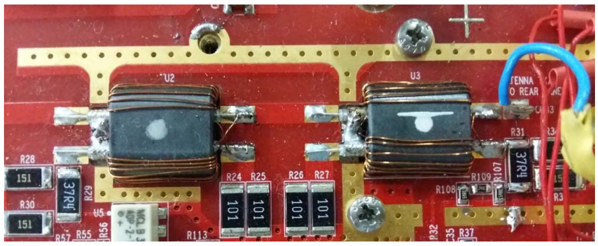

Fig 4: PCB Assembly

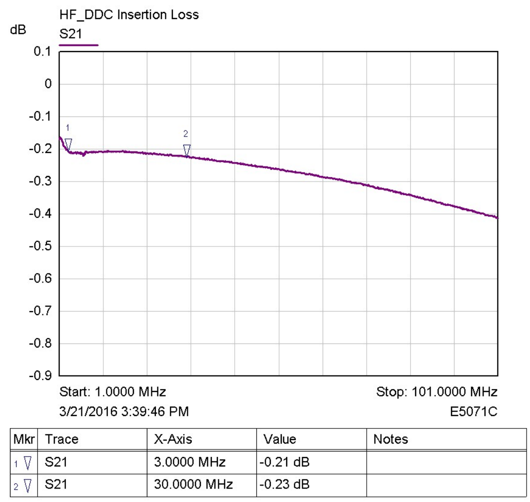

Fig 5: Insertion Loss

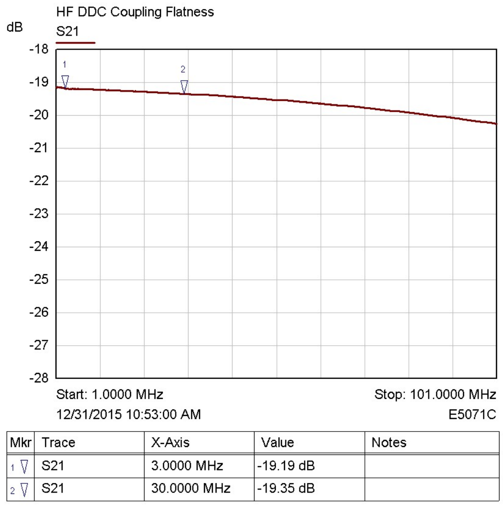

Fig 6: Coupling Flatness

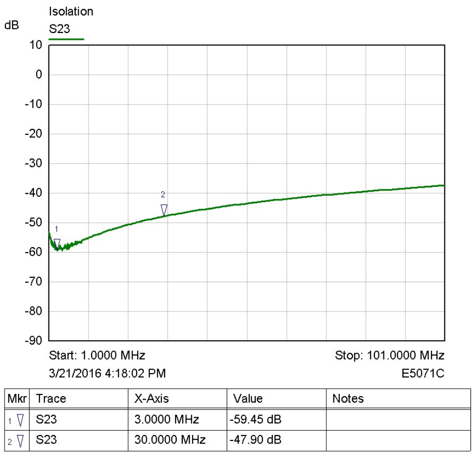

Fig 7: Isolation performance

V. Results

Frequency (MHz)	Insertion Loss (dB)	Coupling Factor (dB)	Isolation (dB)	Directivity (dB)
3	0.21	19.19	59.45	40.26
5	0.21	19.19	57.26	38.07
8	0.21	19.22	56.29	37.07
10	0.21	19.23	55.61	36.38
13	0.21	19.24	54.04	34.8
23	0.22	19.3	49.99	30.69
28	0.22	19.34	48.47	29.13
30	0.23	19.35	47.9	28.55

Overall achieved specifications:

Specifications		
	Requirements	Achieved
Frequency range	3 - 30MHz	3 - 30MHz
Insertion loss	<0.3dB	<0.23dB
Coupling factor	18-20dB	19.19-19.35dB
Directivity	25dB min	28dB min

Conclusion

In this paper, a complete design of a dual directional coupler operating in the HF frequency band (3-30MHz) is presented. The scattering matrix design was done based on the literature given in reference [1]. Further simulation was done using AWR MWO. The simulation results were found to match with the calculations. Further development was done using ferrite material 43 and measurements were taken using network analyser. A directivity of minimum 28dB was achieved. The coupling flatness was better than 0.2dB. The coupler was tested for its performance upto 150W. The design was successfully integrated into a 100W HF power amplifier unit for VSWR and RF power measurements.

References

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