A 300kHz-13.5GHz Directional Bridge

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***Abstract*—This paper presents a wideband directional bridge with a range of operating frequencies from 300 kHz to 13.5 GHz. The original topology of the directional bridge was designed, using the multilayer printed circuit board (PCB) technology, with the top layer of the laminated microwave dielectric Rogers RO4350, as resistive elements surface mounted (SMD) components are used. The circuit is designed for a nominal value of 16 dB coupling and an insertion loss of 1.6 dB.**

Keywords—directional bridge; frequency range; directivity; balun transformer; vector network analyser.

I. Introduction

Network analysis is the process by which RF designers and manufacturers measure electrical parameters of the components and circuits that are used in more complex systems. It is a well-known fact that a content signal in such complex systems must propagate from one point to another with maximum efficiency and minimum distortion. Vector network analysis is a method of accurate characterizing such components by measuring their effect on the amplitude and phase of swept-frequency and swept-power test signals [1].

One of the key elements of vector network analyzers (VNA) is a wideband directional coupler or a directional bridge. In spite of the general trend in the radio electronic industry toward using higher operating frequency, the main operation range is still X-band. Commercial measuring equipment manufacturers strive to improve the quality characteristics of devices, while reducing their cost. As a rule, coupled transmission lines directional couplers are more expensive and complex devices, than directional bridges. That is why using directional bridges is preferred. The main electrical characteristics of directional bridges are *directivity, return loss, direct line insertion loss and coupling*.

Presented directional bridge is used to form a complex signal, proportional to the reflection coefficient of the device under test. The main advantage of a directional bridge, compared to couplers on coupled transmission lines is its ability to work at frequency ranges below 500 MHz, while its size and weight will not be significantly different.

II. Theory and Design

The basis of the directional bridge is the measuring bridge of Wheatstone; the circuit is shown in Fig. 1.

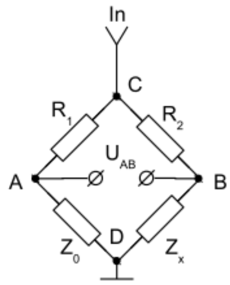

Fig. 1. Measuring bridge of Wheatstone circuit

Under the condition of the bridge balance ($R_1Z_X = R_2Z_0$) the potential difference between A and B points will be equal to zero. When changing Z_X, between A and B points the potential difference appears and it will characterize the value of this change.

The circuit shown in Fig. 1 may be represented as a directional coupler, which has a CD power leg as an input port (1), a BD leg – a test port (2) an AD leg – a load port (4) and an AB line – a measuring port (3). In this case, using resistances R_1, $R_2=R_1Z_0/Z_X$ from the condition of the balance of the bridge, you can set the desired division ratio of power between the test and measurement ports. It should be also noted that the CD line may be either a supply or measuring line and therefore the AB line may be either a measuring or supply, respectively.

The main disadvantage of this circuit is the impossibility of its use in unbalanced circuits, because by grounding one of the nodes in the AB line the balance of the bridge will be disturbed. To eliminate this drawback balun transformer was applied. A schematic diagram of the directional bridge is presented in Fig. 2.

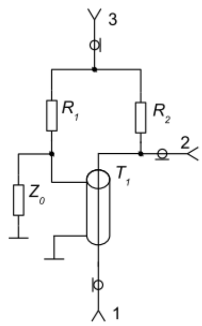

Fig. 2. Directional bridge circuit.

However the application of a balun transformer limits the operating frequency range both above and below. The low operation frequency restriction comes from an imbalance of the bridge that is due to the influence of the coil balancing transformer to the reference impedance Z_0. The high operation frequency restriction comes from the design of the directional bridge and related parasitic parameters.

To reduce the effect of the balun transformer, functionality of the directional bridge ports is selected so, that a decrease of the nominal value of the insertion loss will also decrease the reference resistance Z_0. In this case, the signal generator must be submitted to port 1, the test device is connected to port 2, and the measuring receiver is connected to port 3. The nominal value of the losses in the main channel and coupling can be calculated from the equation [1], [3]:

$$s_{21} = \frac{R_1}{Z_0 + R_1}, \; s_{32} = \frac{R_1}{R_2 + R_1}.$$

Resistors values are chosen from the condition of bridge balance $R_1^2 = R_2 \cdot Z_0$. The value of resistor R1 is constant and equal to the impedance of the generator, 50 Ohm, respectively. In this case, a directional bridge with a nominal value of a 16 dB coupling and a 1.5 dB direct line insertion loss will have resistors R_2 and Z_0 values 270 Ohms and 9.25 Ohms, respectively.

However, due to the influence of the balancing transformer, the value of resistor Z_0 must be increased to 10.3 Ohms (about 10 percent).

To design the PCB the divider topology of the directional bridge was simulated at first. The divider model of the directional bridge is shown in Fig. 3. The model's frequency characteristics are shown in Fig. 4.

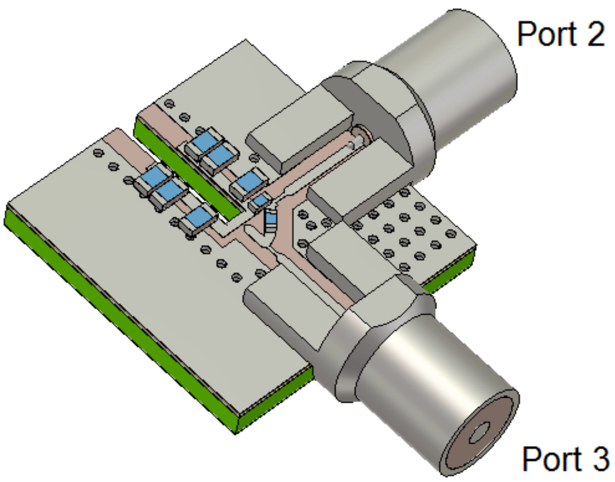

Fig. 3. Divider model of the directional bridge

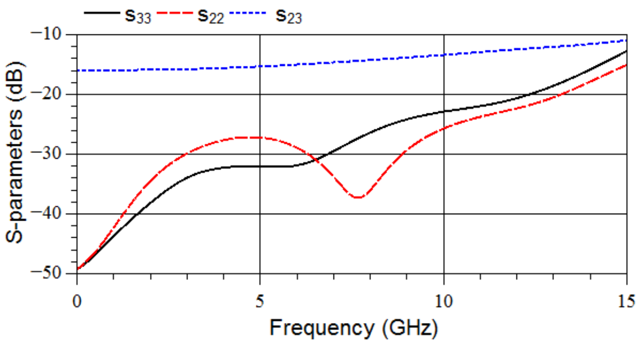

Fig. 4. Divider EM simulation results

III. Implementation and Results

The directional bridge PCB as well as its divider consists of several layers, the first layer is made of Rogers RO4350B microwave laminated material, with a thickness of 0.254 mm and the additional layers are made of FR-4 fiberglass and they are necessary only to increase the mechanical strength of the directional bridge. The topology is made on the microwave layer, the transmission lines are partially grounded coplanar. The PCB stack-up is shown in Fig. 5.

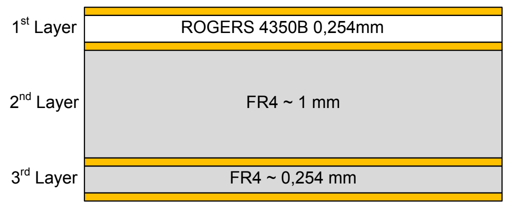

Fig. 5. A three layer PCB stack-up

The resistors R1and R2 are surface mounted components in a 0402 package. Resistor Z_0 is also surface mounted, consisting of six resistors connected in parallel in a 0603 package and an impedance of 62 Ohms. To improve the matching of the third and second ports on the strips of the transmission line, tapers are made. The PCB's total thickness is chosen with consideration of the width of connector mounting lugs, which will be installed on it, and is equal to 1.6 mm. An SMA type connector by Johnson (142-0761-861) is used as a microwave connector.

In the directional bridge a balun transformer with distributed parameters is used. Structurally, the transformer is a segment of Huber-Suhner EZ_47_AL_TP coaxial cable on the outer conductor of which ferrite beads, made of H10K material with an initial magnetic permeability μ = 10000, are put on.

The divider was assembled at the beginning of the directional bridge's development. Attention should be paid to the fact, that the balun transformer in the divider is replaced with a resistor in a 0402 package and an impedance of 50 Ohms. The divider's frequency characteristics are shown in Fig. 6, Fig. 7. Comparing the experimental (measured) frequency characteristics of the divider and the EM simulated ones, one can see a strong convergence between the measured and simulated results.

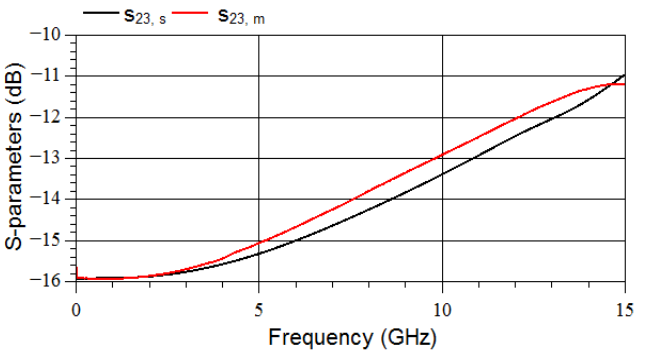

Fig. 6. The divider's EM simulated (s) and mesured (m) transmission factor

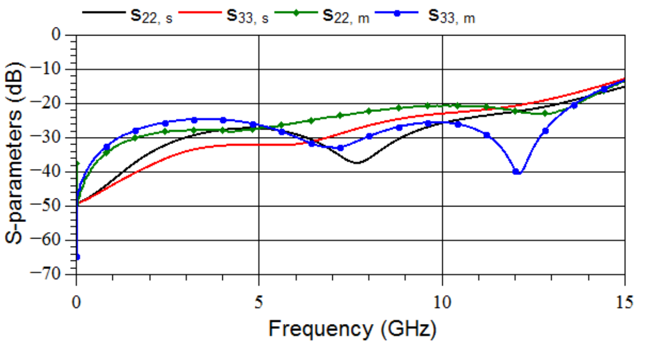

Fig. 7. The divider's EM simulated (s) and measured (m) return loss

However, after the first experimental research, the topology of the directional bridge divider was modified and tuned to improve the flatness of the direct line insertion loss. The photo of the experimental sample directional bridge is shown in Fig. 8.

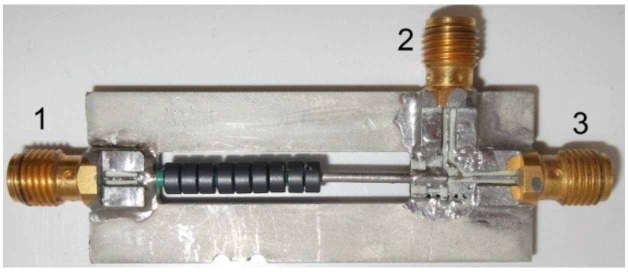

Fig. 8. Directional bridge experimental sample.

The measured insertion loss is shown in Fig. 9. The measured coupling factor is shown in Fig. 10. Measured directivity is shown in Fig. 11.

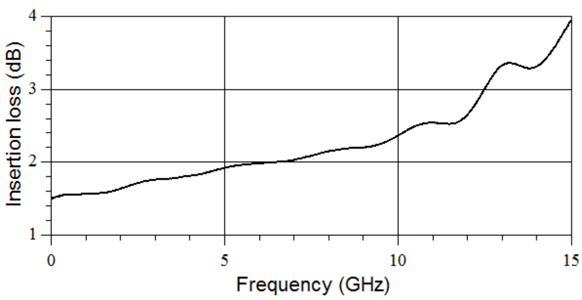

Fig. 9. Mesured results, direct line insertion loss

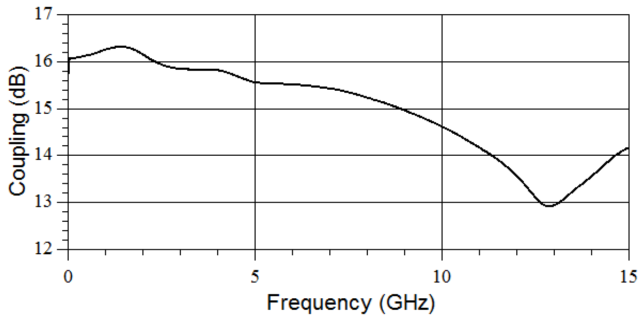

Fig. 10. Mesured results, coupling factor

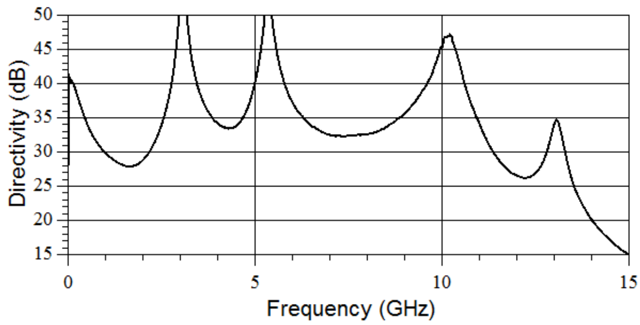

Fig. 11. Measured results, directivity

All measurements have been performed with a vector network analyzers R4M-18 (Micran) and Planar 304/1 (Copper Mountain), using SOLT calibration.

IV. Conlusion

The original topology and construction of an ultra-wideband directional measuring bridge have been designed, built, and tested. The following parameters have been obtained: a frequency range from 300 kHz to 13.5 GHz, directivity not worse than 25 dB, a coupling factor of 16±3 dB, a direct line insertion loss of -1.6+2 dB. The advantages of PCB technology and the use of SMD components are: the simplicity of the design, the ease of assembly and setup, and the low cost of the finished product in mass manufacturing. This directional bridge can be used in vector network analyzers, automatic gain control circuits, and power meters. TABLE I. shows the previously published wideband directional bridges parameters in comparison to this work.

TABLE I. Comparison of Directional Bridges

Publisher	f_{min}	f_{max}	**Directivity**	**Coupling**	**Insertion loss**
This work	300 KHz	13.5 GHz	25 dB	16±3 dB	1.6+2 dB
[5]	300 KHz	3 GHz	40 dB	16±0.3 dB	3±1 dB
[6]	300 KHz	9 GHz	20 dB	16 dB	1.6 dB
[7]	300 KHz	12 GHz	22 dB	16 dB	3.5 dB

ACKNOWLEDGMENT

The work was supported by the Ministry of Education and Science of the Russian Federation, contract № 02.G25.31.0091.

The authors are grateful to Dmitriy Yanchuk (Micran) for help with the experimental part.

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