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DC-coupled directional bridge front-end for vector network analyzer receiver in GHz-range

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Abstract: Most of the commercially available vector network analyzers have a high pass cut-off frequency in the higher kHz-range. One of the main reasons is the frequency limitation of the directional device used. In this paper, a simple directional bridge circuit with incorporated frequency conversion stage is presented. This DC-coupled circuit enables vector network analyzer receiver front-ends to work near DC, expanding the frequency range by several decades. The directivity is similar to these of directional bridges used in commercially available analyzers, but this in a frequency range down to DC.

Keywords: directional, bridge, isolation, reflection, network analyzer
Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Vector network analysers (VNA's) are high level measurement systems containing reference and measurement signal sources and a precision, multichannel receiver, precisely coordinated by an onboard computer. This enables the VNA to make detailed signal transmission and reflection measurements over a wide frequency range and large dynamic range, precisely defining the network parameters of a device-under-test (DUT) [1]. A directional device is used to separate the reflected from the transmitted wave information. This three port device has a measurement (M), test (T) and source (S) port. Its main characteristic is the high MS-isolation which is several decades higher than the TS- and TM-attenuation over the complete measurement bandwidth [2]. This way the signal reflected by or coming from the DUT appears at the measurement output without interference from the source. In the frequency range up to a few GHz, a directional bridge is commonly used, where in the frequency range above 8 GHz a directional coupler or a combination of the two systems is used [3]. In this letter, a new directional bridge circuit is proposed which expands the frequency range for measurements near DC.

2 Traditional directional bridge

The Wheatstone bridge has always been a very popular circuit for measurement of small resistive differences, as the slightest imbalance is readily detected. In balance, the measurement circuit is completely isolated from the voltage source, giving the Wheatstone bridge its directional properties. The directional bridge uses this circuit as its starting point. As one of the resistors is replaced by the DUT, balance can only be reached if the DUT is equal to the reference value. If the other bridge impedances are known with high precision, the same high precision can be achieved in the comparison. The main differences between the wheatstone bridge and the directional bridge are the voltage source, which has been replaced by an AC-power source, and the circuit measuring the imbalance. Traditionally such a circuit (Fig. 1) consists of one or multiple balun transformers converting the voltage difference into a single-ended signal with an amplitude proportional to the imbalance, which can be processed by the VNA receiver. This transformer needs to have the same differential impedance as the measurement port, in order to avoid reflections. For a 50 Ohm match at all ports, all impedances have to be chosen as 50 Ohm. Extra inductors can be added to compensate for the parasitic inductance to ground of the balun transformer, in order to provide a better isolation at lower frequencies [2]. The balun transformer can also be used to provide a DC-voltage for DUT biasing if extra coupling capacitors are added. Although this circuit is DC-coupled at the test port, it has an inherent measurement frequency limitation due to the use of a balun transformer, even when using state-of-the-art baluns [4]. Nowadays, new directional devices can perform at higher frequencies or in different applications [5], still there are no S-parameter testsets without inherent low frequency limitation.

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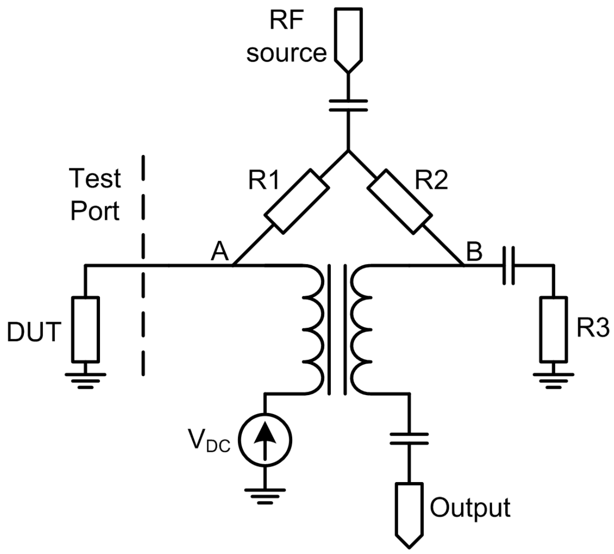

Fig. 1. Traditional directional bridge circuit

3 Directional bridge front-end

In the traditional circuit, a balun transformer converts the differential voltage V_{AB} into a single ended measurement signal. Although this conversion is commonly used, it is not really required for directional measurements. Nowadays, most electronic components have a differential alternative, able to perform its functionality on a differential input signal without the frequency limitations of a balun transformer. As most of the broadband directional bridges are used in a VNA receiver front-end, it might be interesting to use this degree of freedom to incorporate some of these front-end functionalities into the directional bridge. As the first step in such a front-end is frequency conversion to a fixed intermediate frequency (IF), the balun transformer can be replaced by a differential mixer (e.g. Gilbert-cell mixer). This circuit, shown in Fig. 2, can be used throughout the whole mixer input frequency range if two IFs are chosen in order to avoid mirroring problems, as the IF is inside the measurement frequency range. Afterwards the signal at the right IF has to be filtered, sampled and processed in the receiver. If conversion to a single ended signal is required, this can easily be done at the IF-port without limiting the measurement bandwidth. If the mixer has a high input impedance, a resistor R_4 can be added in parallel to provide the required input impedance Z_{AB}. This way the test port input impedance can be fixed at the required value. A drawback of this circuit is that mixers require a certain common-mode input voltage. A solution has been found without the use of coupling capacitors as these not only pose a limitation on the lowest measurement frequency, but also have very undesirable effects on directivity in the complete frequency range, especially when large electrolytic capacitors are used to obtain a large frequency range. Adding a bias voltage to the power and ground rails of the mixer in a way that the ground of the circuit is situatied at the right input DC-voltage level, enables measurements with high directivity near DC. This bias poses no problem at the local oscillator

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(LO-) and IF-ports as these signals are located at higher frequencies and can be AC-coupled. If the DUT requires no DC-bias, measurements at very low frequencies can be performed. If other bias test voltages are required, an external special purpose capacitor is to be added by the user. The mixer can be replaced by a symmetric differential amplifier in directional bridges where frequency conversion is unwanted. In this case the amplifier provides isolation between its output signals and the sensitive resistive bridge.

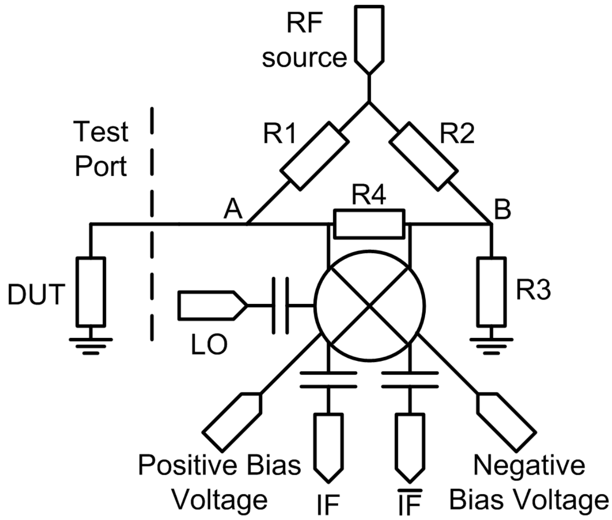

Fig. 2. DC-coupled directional bridge front-end circuit

4 Directional bridge measurements

The most important characteristic of a directional device is its directivity. This is the ratio of the leakage of the incident signal to the desired reflected signal. This way it defines the smallest reflection coefficient that can be measured by the device [6]. As the reflected signal is different for an open or short circuit DUT, it is best to measure with both open and short standards for total reflection, and a load standard for leakage measurements. Measurement results of a manually soldered 50 Ohm directional bridge are shown in Fig. 3. It has a directivity of more than 40 dB up to 1 GHz, which corresponds to the directivity of commercially available directional bridges [2]. In the lower frequency range, the directivity becomes even higher than 70 dB. These measurement results are obtained up to DC due to the use of 50 Ohm resistors with 0.1% tolerance. The frequency range can be expanded to the higher frequencies if parasitic effects are modeled and compensated, to maintain symmetry in the bridge at higher frequencies. Other important characteristics of directional devices are the power loss from source to measurement port and the test port match. As the only difference between the new directional bridge front-end and the traditional one is the implementation of the measurement port, and as the matching at this port is guaranteed by the 50 Ohm resistor in parallel with mixer with high input impedance, both characteris-

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tics are comparable to these of traditional directional bridges. This makes this device a great alternative for the traditional directional bridge.

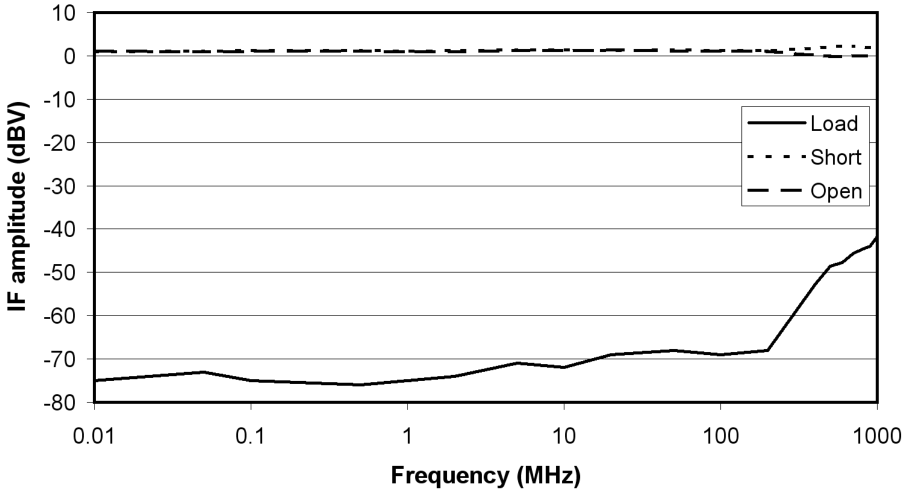

Fig. 3. Directional bridge load, short and open reflection characteristics

5 Conclusion

In this letter a new type of directional bridge has been presented which incorporates frequency conversion and directional functionality. The measurement results show that a large directivity can be maintained in a range from DC to the GHz range, while keeping the same characteristics as traditional bridges. The inherent frequency conversion and the obtained measurement results make it perfectly suited for incorporation in a network analyzer front-end.

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