BALANCED MIXER BASED ON A MICROSTRIP LINE

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The paper describes the design and implementation of a balanced mixer based on microstrip lines in the WiFi frequency range (2.4 GHz) for the purpose of evaluating the frequency ratio of the two frequencies near the signal. The introduction sets out the issues of microstrip lines and their design solutions. The next chapter analyses the coupler based on microstrip lines. The core of the paper is focused on the description of the balanced mixer and its involvement in the radio altimeter RV-5, including the production of mixers of this type and the results of laboratory measurements performed on these mixers. The conclusion shows the measurement results of the phase distribution ratios on the realised horn aperture.

Keywords: balanced mixer, circular couplers, microstrip line

1 INTRODUCTION

More and more advanced technologies are associated with the use of ever higher frequencies in the GHz spectrum. Today avionic systems operate in the frequency range of microwaves, i.e. in the GHz range and even higher. This fact, together with the allocation of the WiFi frequency band, led us to choose a typical frequency of 2.4 GHz. To evaluate the radiation of the electromagnetic waves it is necessary to create a circuit which is able to evaluate the ratio of the amplitude and phase of the electromagnetic fields in the vicinity of the antenna. Measurements of phase ratios are possible thanks to the design of the balanced mixer. Such mixer works by evaluating the instantaneous values of signals and by obtaining the information of their phase relation.

2 MICROSTRIP LINE

Suitable insulating materials with a high relative permittivity enabled the realisation of an asymmetric microstrip waveguides. Such microwave integrated circuits enable the operation on a very high frequency. The waveguide itself is made of a thin conductive strip and is separated from the base conductive insulator surface. The TEM wave propagates in a waveguide, see Figure 1, and applies the t << w, t h << and >> w. Such a waveguide is exposed on one side to possible installation of parts, or for minor modifications. Silicon is usually selected as an insulating material (ε_r = 11.8), but the highest possible permittivity is desirable. Particularly corundum ceramics Al2O3 and sapphire have ideal dielectric properties.

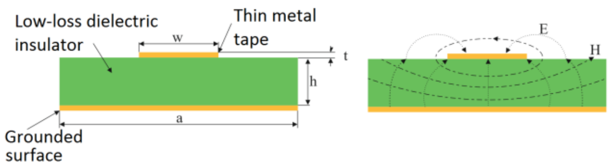

Figure 1. A microstrip waveguide

As shown in the Figure 2, the insulating layer is formed of two materials. The first one is a dielectric material and the second one is the air. This configuration affects the speed of propagation of the electromagnetic waves. The wavelength in materials can be calculated according to the equation (1); ε_r is the relative permittivity of the dielectric material and λ0 is is the wavelength of the signal in vacuum.

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \qquad (1)$$

Microstrip waveguides find use in all high-frequency devices used in aviation and in the private sector. Microstrip is produced with the printed circuit board technology and their small size is welcomed in today's miniaturization. Low weight and generally wide bandwidth also include amenities. Undesirable features include limited transmitted power and significant losses.

The basis of hybrid microwave circuits is a high quality dielectric substrate with a high relative permittivity and low dielectric loss. This decreases the vastness of the circuit. Conductive surfaces must have a perfect adhesion to the substrate and low electrical resistance. To achieve such conditions, more layers of different materials are combined. The grip is ensured by chromium or tantalum, and the conductivity by gold, silver or copper. Such structure is shown in Figure 2. The hybrid circuits may be implemented directly on the surface of the electronic parts. Capacitors are formed by slotted lines, inductance is realised in its own length of the waveguide and either the resistors are subsequently soldered or resistive films are applied.

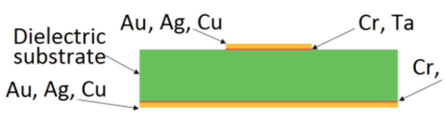

Figure 2. Materials used for microstrip lines

Monolithic microwave integrated circuits are formed by diffusion of passive and semiconductor materials. Thus the manufactured circuits achieve high density integration.

3 DIRECTIONAL COUPLERS

Directional couplers are passive microwave circuits used for dividing or for mixing of signals. The input signal is split into two or more output signals with a certain level of loss. Circuit with three outlets is also called a "T" splitter or a combiner. Couplers of four and more wires are referred to as a hybrid directional coupler. A hybrid ring coupler has two outputs; output signal is phase-shifted by 90° or 180 °. A hybrid directional coupler is a passive microwave component that is used to transfer, divide or mix the microwave signals. Hybrid directional couplers are a special case of 4-gate directional couplers. For the function of mixing and evaluating signals from two antennas we have chosen a 180 ° hybrid directional coupler, also called circular coupler. The coupler is designed as a four point terminal, therefore has two inputs and two outputs. The coupler itself is realised only by a microstrip line and no "internal" components are used. Its block diagram is shown in Figure 3.

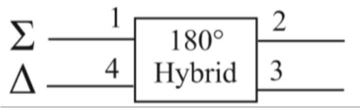

Figure 3. Block diagram of a 180 ° coupler

This circuit can be connected in several ways. In the first case, the port no.4 is isolated and input is only summation of the signal on the port no.1. Thus the connected circuit has on the ports no. 2 and 3 signals with the same phase. Their amplitude is, in ideal conditions, weakened by 3 dB. Another method is the involvement of the difference Δ port no.4 and the sum port no.1 is isolated. In this case, the signal output from the ports no.2 and 3 is phase-shifted by 180° each. The amplitude of the signals is also weakened by 3dB. The last connection method uses two input ports, ports no.2 and 3, and port no.1 outputs the sum and port no.4 the difference of the input signals. Summary output consists of the input signals without phase shift. Conversely differential output signals consist of the inputs to the phase shift of 180 °.

3.1 Analysis of a circular coupler

The ring coupler can be analysed in two boundary situations. The two cases are dealt by circuit divided by the axis of symmetry, thus simplifying the calculation. In the first case the so-called "even-mode" uses two identical input signals and considers the load to be empty. Subsequently, in the second "odd-mode" case is a short circuit in the circuit, thus the load is short.

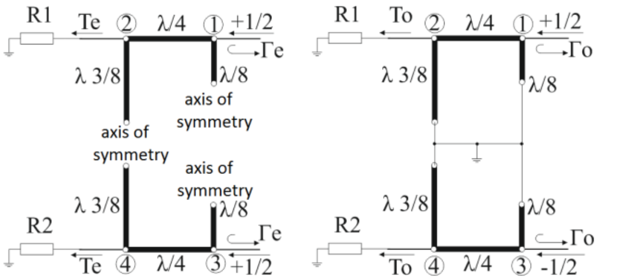

Figure 4. Equivalent circuit of a coupler

The equivalent circuit of the divided circular periphery is shown in Figure 4, where the direction of the transmission signal is denoted as "T" and the reflected signal as "Γ". The index "e" in indicates an empty load. To the right is a second mode of engagement, the grounded stubs. The signals differ only in their index.

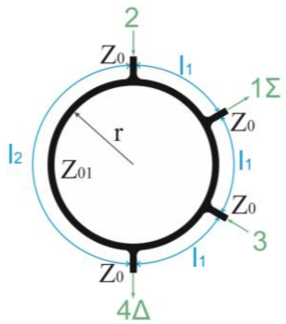

Figure 5. Principle of a circular mixer

Simplified principle of the operation of a 180 ° circular coupler can be described using Figure 5. For the purposes of comparing and evaluating the two signals need to be involved as a splitter mixer. This connection of the circuit is called the 180 ° hybrid coupler. Ports no.2 and 3 are marked by the green colour, the sum output port is the port no.1, the differential output is the port no.4 . The signals at output ports no.1 and 4 can be described as:

$$\Delta = \frac{1}{\sqrt{2}}(2\angle -270 + 3\angle -90)$$

$$\Sigma = \frac{1}{\sqrt{2}}(2\angle -90 + 3\angle -90)$$

The distances are marked by blue colour. Section l1 denotes the length of λ / 4, like one l_2 is the length proportional to the value of λ 3/4. Hence the circumference is equal to λ 3/2.

In terms of impedance, the circuit must be implemented in a way that all the inputs and outputs converge to Z_0=50 Ω. For the impedance Z_{01} applies the formula (2), where the binding attenuation is c = 3 db.

$$Z_{01} = Z_0 \cdot 10^{\frac{c}{20}} \quad (2)$$

4 REALISED COUPLER AND BALANCED MIXER

The proposed coupler is designed for only one operating frequency. The dimensions of the coupler determine the frequency to be f_0 = 2.4 GHz and the required bond is C = -3 dB. Other important parameters for a specific proposal are: properties of dielectric material substrate height h, the relative permittivity of the dielectric εr, the thickness of the coating characteristic impedance connected line Z_0=50ohm.

To measure the transmission properties of the microstrip line, we used a spectrum analyser Rohde&Schwarz FSH8 (model 18) with frequency range 9 kHz - 8 GHz. We used the coaxial line Nordix MWC 10/50 to connect the analyser to the microstrip line, which, according to the manufacturer, is appropriate up to 6GHz. This transfer line was of a length of 25 cm and two reductions from N to F connector of 0.44 dB attenuation at a frequency of 2.4 GHz were used.

We conducted the first tests on a circular coupler with a radius r = 2.5 cm. A graphic design of the coupler is shown in Figure 6. This figure also marks its dimensions in millimetres units.

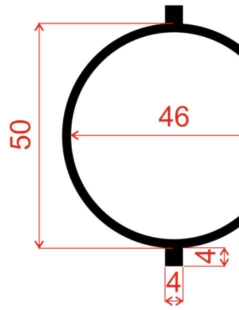

Figure 6. Mixer circuit

Thus the realised coupler has a centre frequency of 1.66 GHz. During the measurement we could see an outside interference and that is why we decided to shield the coupler, see Figure 7. This version has a modified design by terms of its dimensions. To achieve the desired frequency of 2.4 GHz, the outer radius of the ring had to have its dimension to be equal to 20 mm. This brought a positive result.

Figure 7. Produced mixer

The required minimum transmission parameters S14 and S23 of a coupler are screened in the following figures:

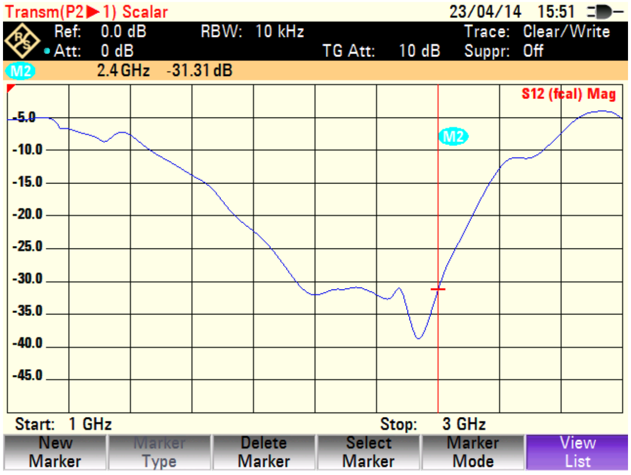

Figure 8. Transfer characteristic S14

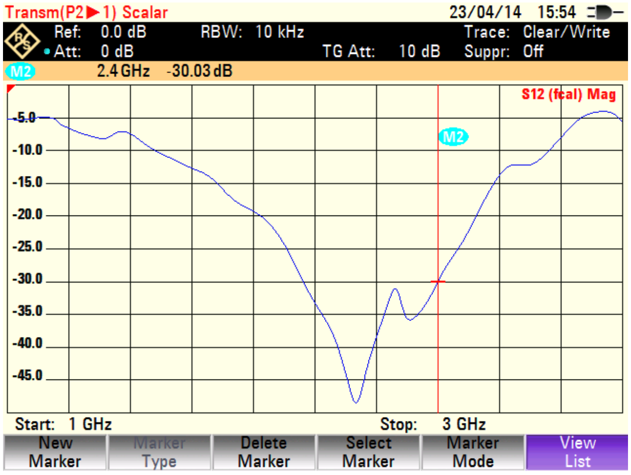

Figure 9. Transfer characteristic S23

It can be concluded from the measured data that the configuration of the mixer is suitable for circular junction of bandwidth from 2 GHz to 2.4 GHz.

The next step towards meeting the objective of the work was to design an appropriate balanced mixer. We found our inspiration in the circuit used in the radar altimeter RV-5. This circuit had been isolated from both sides of the same thickness of the dielectric material and then stored in a metal cover. The mixer uses diodes for the sum and difference detection at the output. In the immediate vicinity of the diode is placed on the empty stub with a length of λ / 4th. This stub is the frequency filter component of the diode.

5 PHASE SHIFT

To produce this type of a balance mixer, it was necessary to determine the appropriate type of the detection diodes. The only suitable commercially available diode type is the BAT_17. This component is from a series of the Schottky Barrier Diode. The SMD version allows mounting the housing directly to the surface of the ring coupler. The specified parasitic PN junction capacity is 1 pF, which makes this type of diodes usable in microwave circuit applications.

The designed final circuit form was divided into two parts; the special ring couplers and the diode array detector.

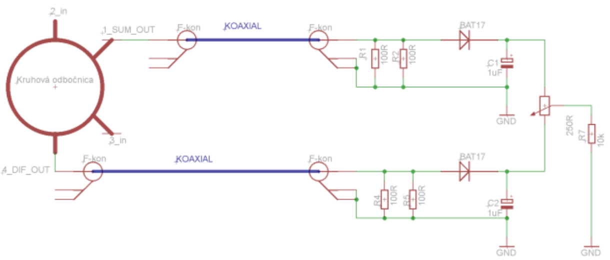

Figure 10. Functional interconnection circuit

On the constructed periphery we performed measurements using variable coaxial lines, resulting in a change in the phase. The results are shown in Table 1. The first column represents the voltage with the phase shifts of 0°, the second 90°, the third column 180° and the fourth column of 270°.

Table 1. Measured values of voltage

	$\lambda_a;\lambda_a$	$\lambda_a;\lambda_b$	$\lambda_a;\lambda_c$	$\lambda_a;\lambda_d$
$U_{add.}$ [mV]	50	3,3	0	3,4
$U_{sub.}$ [mV]	0	3,4	49	3,3
U_{conn}[mV]	26	3,2	25	3,3

To be able to test the different phase ratios, we decided to measure the change of the phase on an aperture horn antenna.

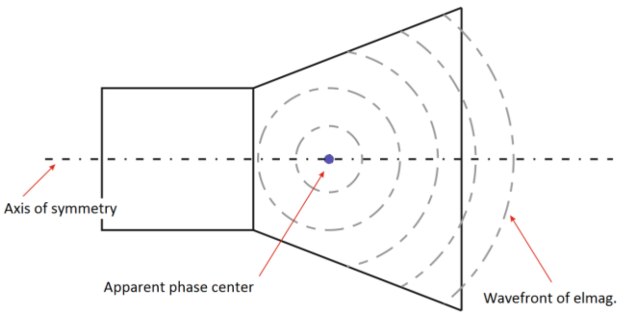

Figure 11. Plan view of the horn antenna

Different phase ratios are generated on the aperture horn antenna, while the phase of two equidistant points from the geometric centre remains zero. We used this principle to measure the phase ratios by an automated workplace, displayed in Figure 12.

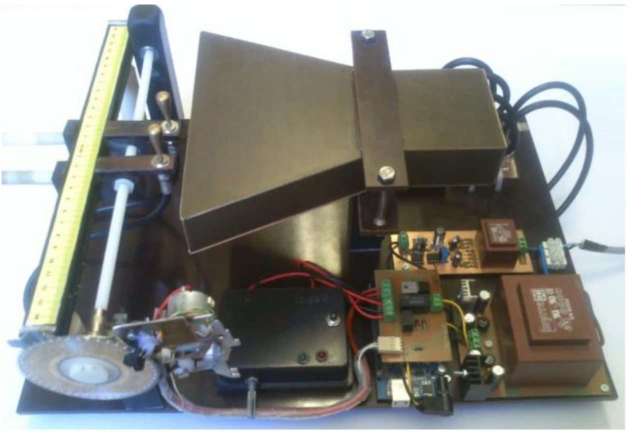

Figure 12. Automated measuring workplace

The measured transmission characteristic is shown the next figure. The corresponding width of the aperture of the antenna was 22 cm.

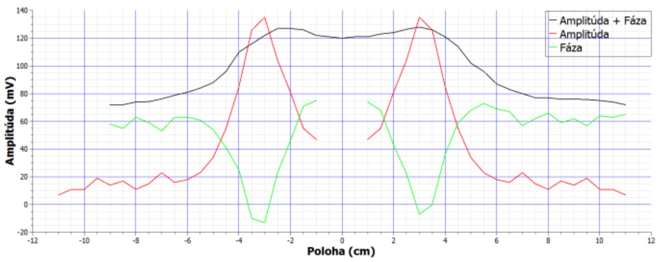

Figure 13. Amplitude and phase on the horn antenna

6 CONCLUSION

The designed and produced balanced mixer in its final form reaches the requirements imposed on a balanced mixer at given frequency, which is proved by the measurement of its transmission parameters. We can therefor declare that the balanced mixer is prepared to measure the phase difference of a signal on the aperture of the horn antenna.

The measurement method can be later on altered in the means of integrating the diode detector into the shielded case of the circular coupler. This solution has the ability to improve the accuracy of the measurement.

Another possible sequel to this work could be evaluation of the phase relations in case of multiples of the wavelength.

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