VHF Quadrature Hybrid Coupler

Veljko Crnadak and Siniša Tasić

***Abstract*— In this paper the improved design of the VHF quadrature hybrid coupler is presented. It is a continuation of the prior work of the same authors, about the design of VHF quadrature hybrid coupler. Knowing, before the production, what are the conditions that coupler has to satisfy, has enabled us to acquire, through computer simulation, the dimensions of the coupler that was later produced. Values of the S-parameters of the simulated coupler are being compared, to values of the S-parameters of the produced coupler to validate the design process. Coupler is designed as a broadside-coupled strip-line coupler, for frequency range from 150 MHz to 200 MHz, with central frequency at 175 MHz. It consists of two overlapping brass strips of equal widths, placed on the top and bottom surface of a Teflon substrate, which is sandwiched between the top and bottom of an aluminum casing and separated from them by air layers of equal thickness. Purpose of the coupler is to combine two input signals in quadrature, who each have 16 KW of power, in to an output signal of 32 KW.**

***Index Terms*—Broadside; coupler; hybrid; quadrature; strip-line; Teflon; VHF.**

I. INTRODUCTION

IT is well known from microwave theory, that every lossless reciprocal four port microwave network, matched at all ports, is a directional coupler [1, 2]. If port 1 is the input port, then port 2 is the through port, port 3 is the coupled port and port 4 is the isolated port, as it is depicted in Fig. 1. Directional coupler, with the coupling factor *C* equal to 3 dB, is known as hybrid coupler. Hybrid coupler, that has a phase difference of 90^0 between signals at ports 2 and 3, is called a quadrature hybrid coupler.

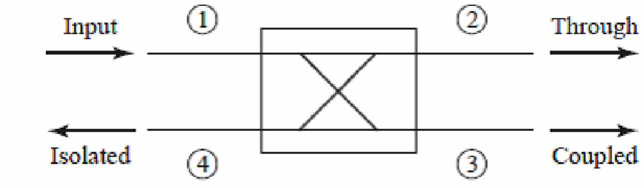

Fig. 1. Common symbol for Directional Couplers.

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II. DESIGN THEORY

The quadrature hybrid coupler, which has been designed, is intended to be used in a balanced power amplifier, which is shown in Fig. 2.

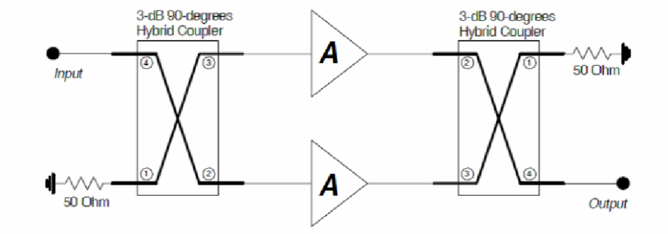

Fig. 2. Balanced power amplifier.

A balanced power amplifier consists of two identical quadrature hybrid couplers and two identical power amplifiers. Main advantage of a balanced power amplifier is that it has zero reflection coefficients at the input and the output [3]. In the previous design of the VHF quadrature hybrid coupler [7], the two broadside-coupled brass strips with different widths were placed in an aluminum casing filled with air, as it is shown in Fig. 3.

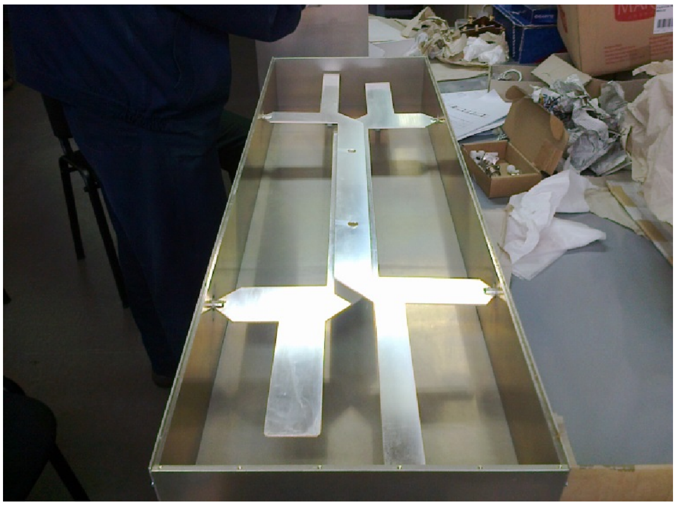

Fig. 3. The previous design of the VHF quadrature hybrid coupler.

Broadside coupling was chosen, instead of edge coupling, because of strong coupling that has to be achieved. Major problem in that design were hybrid's dimensions, 887.5 mm in length, 280 mm in width and 92.15 mm in height, which were seen as to large. Reduction in hybrid's dimensions was achieved through application of two broadside-coupled brass strips of equal widths that were placed on the top and bottom surface of a Teflon substrate, which is sandwiched between the top and bottom of an aluminum casing and separated from them by air layers of equal thickness, as can be seen on Fig. 4.

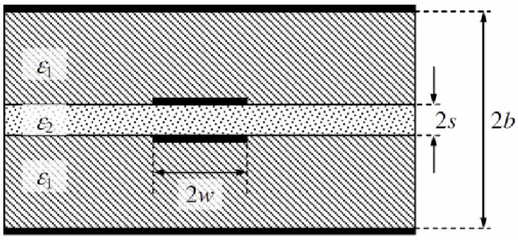

Fig. 4. The cross-sectional view of the new design of the VHF quadrature hybrid coupler.

The difference, between the realized hybrid and the hybrid shown on the Fig. 4, is that the lower strip of the realized hybrid, is actually entirely surrounded by layer of Teflon, except the bottom of the lower strip, which faces the air layer. Also, the left edge of the lower strip of the realized hybrid is moved horizontally to the right, relative to the left edge of the upper strip, for 16.4 mm. Relative permittivities are $\varepsilon_{r1} = 1$ and $\varepsilon_{r2} = 2.1$, while the strip width is $2w = 25$ mm, thickness of the Teflon layer is 2s = 6 mm and the height of the hybrid is 2b = 66 mm.

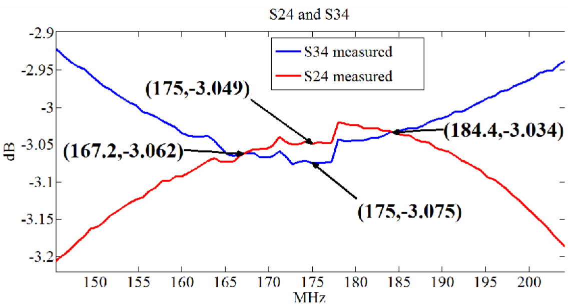

Fig. 5. Measured transmission coefficients S_{24} and S_{34}.

Fig. 5 shows the operation of the entire hybrid coupler. Points in Fig. 5, where the two plots intersect, should be equal to −3 dB in an ideal case, but for real hybrids those points have different values, as can be seen from Fig. 5. The insertion loss is the difference between the measured losses and the ideal losses at those points [6]. In the case of Fig. 5, the insertion loss is 0.062 or 0.034 dB. High power applications require the insertion loss to be less than 0.1 dB, so in our case that is fully satisfied. Another important parameter used to describe operation of hybrid coupler is amplitude balance. Amplitude balance is the difference between power levels at the output ports. Ideally amplitude balance should be 0 dB, but in real applications amplitude balance is frequency selective and different from 0 dB. High power applications require the amplitude balance to be less than 0.1 dB. From Fig. 5 it can be seen, that amplitude balance at 175 MHz is equal to 0.026 dB, which is less than 0.1 dB. In an ideal situation phase difference between the output ports of a hybrid coupler is 90 °, but in the case of real hybrid couplers there is a phase deviation of a few degrees, that is frequency selective. This means that phase difference between the output ports is not actually 90°, but slightly different. That phase deviation is called phase balance.

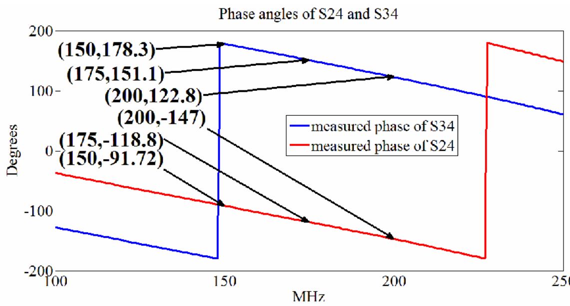

Fig. 6. Measured phase angles of S_{24} and S_{34}.

In Fig. 6, phase balance at 150 MHz is 0.02°, phase balance at 175 MHz is 0.1° and phase balance at 200 MHz is 0.2^0.

III. Simulation And Measurement Results

A. Simulation

Knowing the criteria that our coupler has to fulfill, we were able to get the final dimensions of the coupler through computer simulation. First, through the process of optimization, basic dimensions, like widths of upper and lower strip-line, vertical distance between them, distances between the strip-lines and the top and bottom of the casing and offset, were obtained. Second, through the process of trial and error, rest of dimensions were acquired. Both of the processes were realized using computer simulation. Axial view of the model of the quadrature hybrid coupler, that was used in computer simulation, is given in the Fig. 7, and lateral view of the model is given in the Fig. 8.

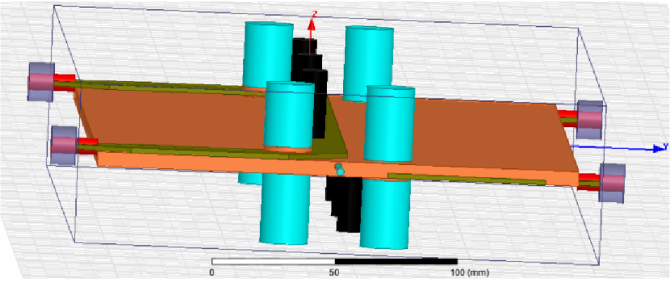

Fig. 7. Axial view of the model of the quadrature hybrid coupler.

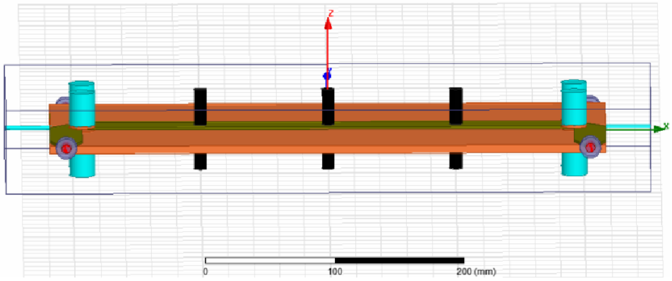

Fig. 8. Lateral view of the model of the quadrature hybrid coupler.

The coupler is intended to combine two input signals in quadrature (ports 1 and 4), each having 16 KW of power, in to an output signal of 32 KW of power (port 2 or 3), while canceling each other on the other port that is terminated with 50 Ω (port 3 or 2). If signal at port 4 has the phase delay of 90 degrees relative to signal at port 1, then 32 KW of power is delivered to port 2, while nothing is delivered to port 3. Otherwise, if signal at port 1 has the phase delay of 90 degrees relative to signal at port 4, then 32 KW of power is delivered to port 3, while nothing is delivered to port 2. Picture of the coupler that was finally produced is given in the Fig. 9.

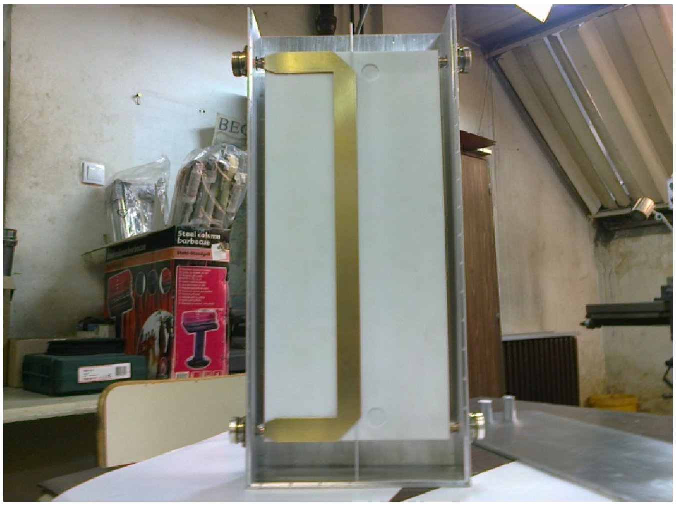

Fig. 9. The quadrature hybrid coupler that was produced.

As can be seen from Fig. 7, the coupler consists of two strip-lines of equal 25 mm of width, made of brass, one above the other, separated by 6 mm thick Teflon substrate. Thickness of the strip-lines is 2 mm. The upper strip-line lies on the top surface of the Teflon substrate, while the lower is placed in a channel 2 mm deep, which was dug out from the bottom surface of the Teflon substrate. The lower strip-line is shifted to the right of the upper strip line for 16.4 mm. They are placed in aluminum casing, where the top surface of the Teflon substrate is separated from the top of the casing by an air layer 30 mm thick, and the bottom surface of the Teflon substrate is separated from the bottom of the casing also by an air layer 30 mm thick. The length of the casing is 505 mm, the height of the casing is 66 mm and the width of the casing is 216.4 mm. The core-length of the strip-lines is 385 mm.

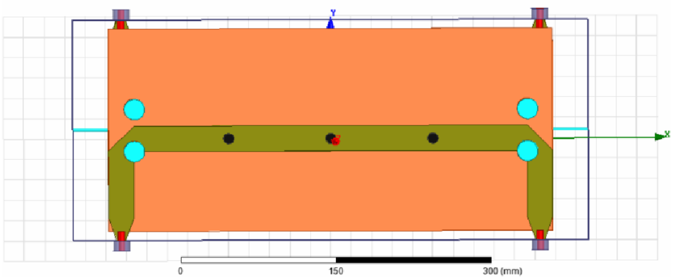

Fig. 10. The top of the VHF quadrature hybrid coupler.

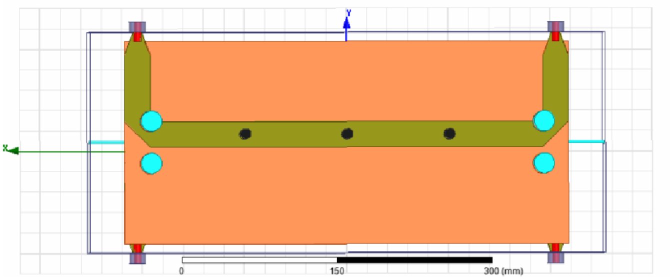

Fig. 11. The bottom of the VHF quadrature hybrid coupler.

As can be seen from Fig. 10 and Fig. 11, opposite every mitered corner of both strips, there is an aluminum cylinder, depicted in blue color, 20 mm in diameter, with a Teflon tip, 2 mm thick, who acts as a capacitor in order to compensate inductance, which was introduced by the mitered corner [8]. For every strip there are four aluminum cylinders acting as capacitors, two for the top and two for the bottom of the strip. Eight in total for the entire hybrid. In order to achieve a perfect isolation, because there is a difference between phase velocities of even and odd mode, we use two aluminum cylinders in opposite axial directions, 71 mm in length and 3 mm in diameter, also depicted in blue color. Thirty five millimeters of axial cylinder's length passes thru air and thirty six millimeters passes thru Teflon. There are six bolts, depicted in black color, made of polyethylene, 10 mm in diameter, that are used for the support of the strip-lines. Three for each strip, one in the center of the strip, and the other two 100 mm in front and behind the center. The length of the Teflon substrate is 435 mm, the width is 198.4 mm and the height is 6 mm. The coupler uses four 7/16-connectors.

B. Simulated and measured results

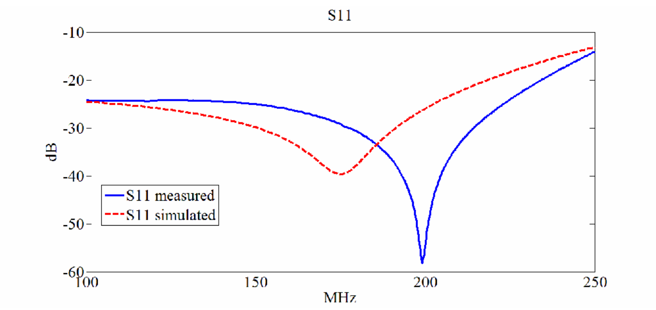

Fig. 12. Comparison of simulated and measured S_{11}.

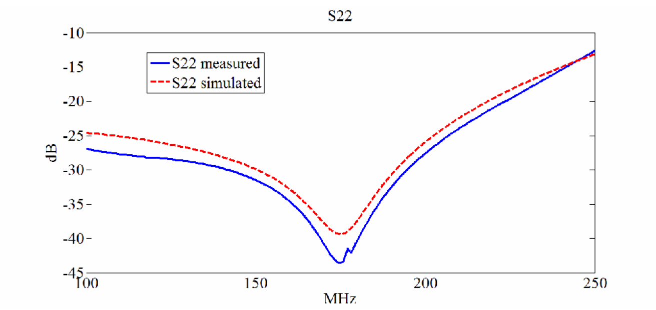

Fig. 13. Comparison of simulated and measured $\mathbf{S_{22}}$

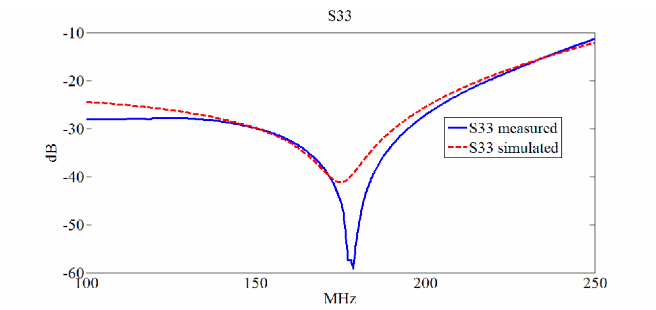

Fig. 14. Comparison of simulated and measured $\mathbf{S_{33}}$.

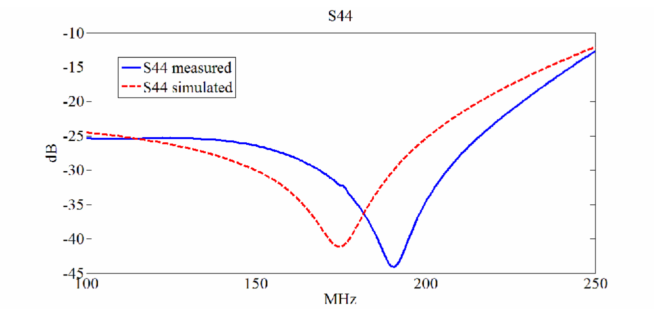

Fig. 15. Comparison of simulated and measured $\mathbf{S_{44}}$.

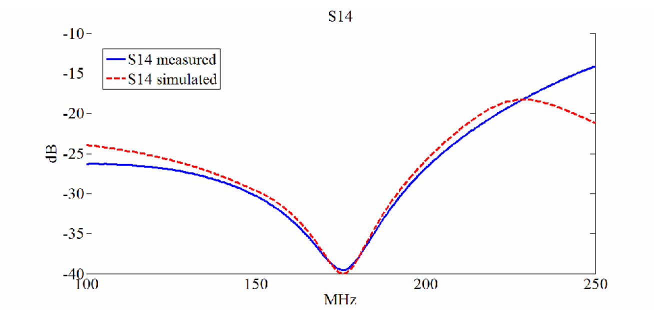

Fig. 16. Comparison of simulated and measured $\mathbf{S_{14}}$.

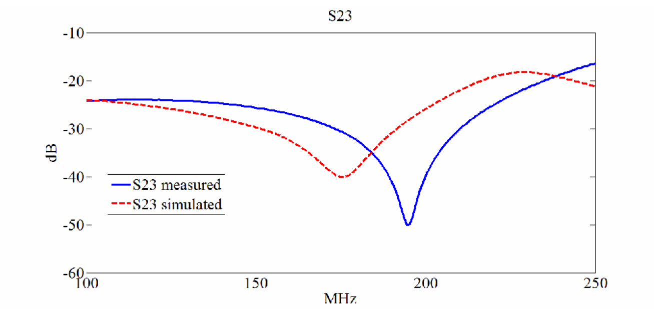

Fig. 17. Comparison of simulated and measured $\mathbf{S_{23}}$.

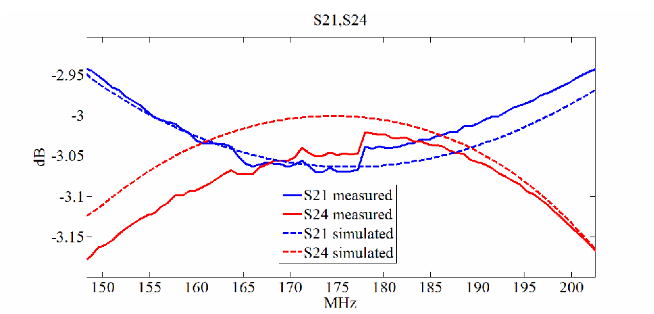

Fig. 18. Comparison of simulated and measured magnitudes of S_{21} and S_{24}.

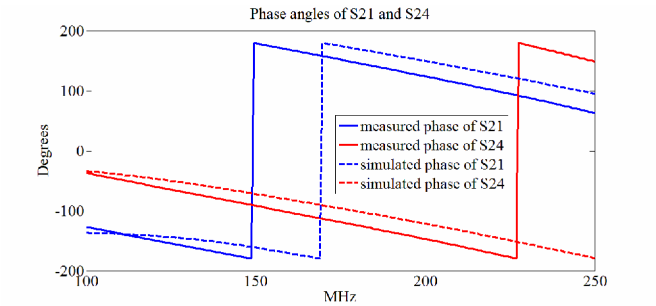

Fig. 19. Comparison of simulated and measured phase angles of S_{21} and S_{24}.

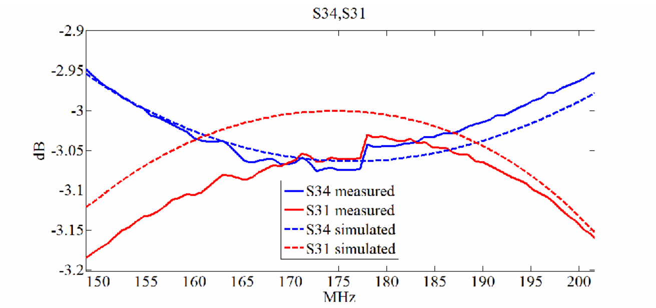

Fig. 20. Comparison of simulated and measured magnitudes of S_{31} and S_{34}.

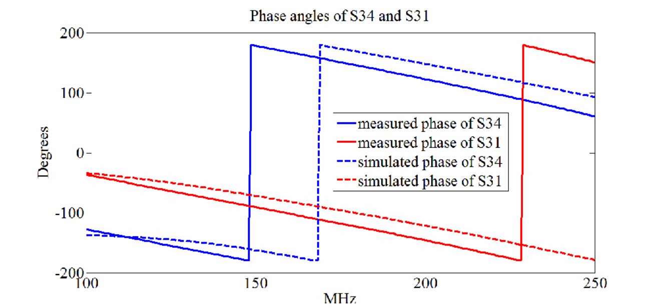

Fig. 21. Comparison of simulated and measured phase angles of S_{31} and S_{34}.

Fig. 12 shows that measured return loss S_{11} is always lower than −25 dB, over the frequency band of interest. Measured reflection coefficient S_{22} is always lower than −27 dB, over the frequency band of interest, as can be seen in Fig. 13. Measured return loss S_{32} is always lower than −27 dB, over the frequency band of interest, as can be seen in Fig. 14. Measured reflection coefficient S_{44} is always lower than −26 dB, over the frequency band of interest, as can be seen in Fig. 15. Measured isolation parameters S_{14} and S_{22} are always lower than −25 dB, over the frequency band of interest, as can be seen in Fig. 16 and Fig. 17. Measured magnitudes of S_{21} and S_{24} are in accordance with proposed values of insertion loss and amplitude balance, as can be seen in Fig. 18. Fig. 19 shows that there is a constant phase difference of approximately −90° (270°), between S_{21} and S_{24} over the frequency band of interest. Measured magnitudes of S_{31} and S_{34} are in accordance with proposed values of insertion loss and amplitude balance, as can be seen in Fig. 20. Fig. 21 shows that there is a constant phase difference of approximately −90° (270°), between S_{34} and S_{31} over the frequency band of interest.

IV. Conclusion

The process of designing quadrature hybrid coupler, that was presented in this work, proved to be very successful, because there is a great degree of similarity between simulation and measurement results, and it is an improved version of the previous design, especially having in mind reduced dimensions of the hybrid coupler. The quadrature hybrid coupler, that was designed, is unique in its frequency range and power level.

Acknowledgment

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