TEMPERATURE CHARACTERIZATION OF PASSIVE OPTICAL COMPONENTS FOR WDM-PON FTTX

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Abstract. *In this paper we report on the experimental test set-up for the temperature characterization of optical multiplexers/demultiplexers in the C - telecommunication band. Particularly the temperature change of transmission parameters like polarization dependent loss and insertion loss are investigated. The measurements were performed in the temperature range and under ambient air-conditions equal to the installation of passive optical elements in the external outdoor non–climatic environment.*

Keywords

Spectral multiplex, FTTx WDM-PON system, temperature sensitivity of parameters, insertion loss, polarization dependent loss.

1. Introduction

Overall reliability across the WDM-PON FTTx network depends on the reliability of each element but mainly on the weakest part of the communication system. The used redundant transmission systems enable on one hand the superior overall network reliability but on the other hand also increase CAPEX on networking. Another way to increase the overall network reliability and minimize the operating costs and maintenance is to increase the reliability of network components themself. In the case of passive optical devices, used in the communication network, the reliability is determined by the temperature independence of their transmission parameters.

The goal of this work is to provide comprehensive and independent laboratory testing services that help telecommunication carriers in selecting high quality and cost-effective products to build up their new WDM-PON FTTx access networks.

The first part of this work describes the experimental set-up to measure the temperature change of the passive optical components; in our case optical multiplexers/demultiplexers (MUX/DEMUX) based on arrayed waveguide gratings (AWGs). In the second part the evaluation of AWG transmission parameters, extracted from the measured transmission characteristics, together with the temperature change quantification of each parameter is discussed into the details. The final section presents the results of temperature change measurements of insertion loss (IL), polarization dependent loss (PDL) and their derived parameters for 32-channel, 100 GHz AWG designed and fabricated for WDM-PON FTTx systems.

2. Experimental Set-Up

Figure 1 shows the block diagram of the realized experimental set-up for temperature characterization of the IL and PDL spectral response of optical MUX/DEMUX. Polarisation dependent loss is measured by applying well known polarization states to the device under test (DUT). In this case, the PDL is measured with an optical power meter at four different well known polarization states. The Mueller / Stokes analysis is then used to calculate the PDL. An advantage of this method is that this way the arbitrary polarization states can be synthesized [1].

The spectral response of insertion loss is measured as an average value of the IL at four different polarization states from PDL measurement. The polarization controller AGILENT 8169A is used to set the known polarization state at the input DUT. The measurement over the testing spectral range is realized by narrowband tuneable laser source. Output optical power is measured by broadband optical power meter. In experimental set-up, shown in Fig. 1, we used tuneable laser source HP 81680B, which is tuneable in the C-telecommunication band from 1460 nm to 1580 nm. Broadband optical power meter HP 81634B can be used within dynamic range more than 110 dB. Device under test is placed in the climatic chamber Votsch Industrietechnik VC3 7034, which allows setting the temperature in the range from -72 °C to 180 °C. This is uncontrolled exposure criteria for passive optical components according Chapter 3.7.2 of Telcordia GR_1209_Corei04 (TELCORDIA) [2]. Figure 2 shows the photography of the realized experimental test set-up.

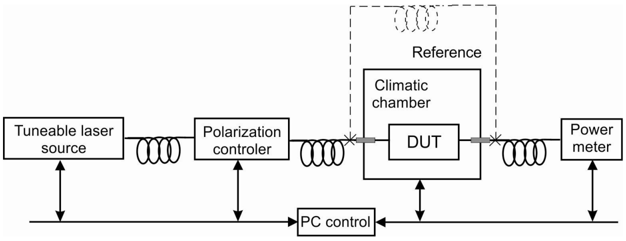

Fig. 1: Block diagram of the realized experimental set-up.

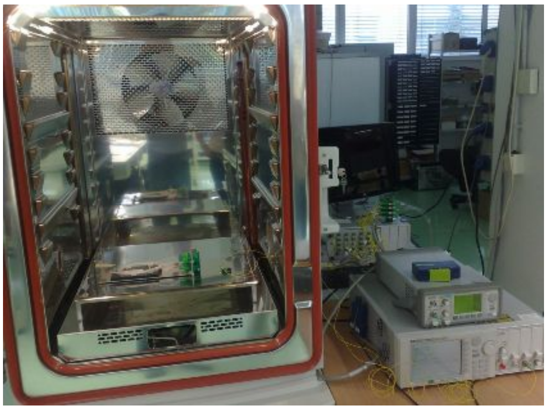

Fig. 2: The realized experimental set-up for temperature characterization of the IL and PDL spectral response of optical MUX/DEMUX.

3. AWG Parameter Evaluation

By analyzing the measured AWG spectral response of IL and PDL for both the transverse electric (TE) and the transverse magnetic (TM) polarization states (so called transmission characteristics), several AWG transmission parameters can be obtained. These parameters define the performance of an AWG and also determine its suitability for a particular application.

Some of these parameters will be now discussed.

3.1. ITU Passband

The International telecommunications Union (ITU) has adapted a standard called the ITU-Grid defining the ITU-wavelengths (or ITU-frequencies) that can be used for WDM optical transmission. These frequencies begin at 190,00 THz (channel 1577,86 nm). Each subsequent channel is obtained as an increment of the channel spacing in GHz or nm.

The ITU passband is defined as a symmetrical wavelength range surrounding the ITU-wavelengths (or ITU-frequencies) [3]. It usually equates to 25 % of the respective channel spacing. For example, for 100 GHz channel spacing (0,8 nm), the ITU passband is defined as 25 GHz (0,2 nm). Graphical representation of ITU passband for 100 GHz channel spacing is shown in Fig. 3.

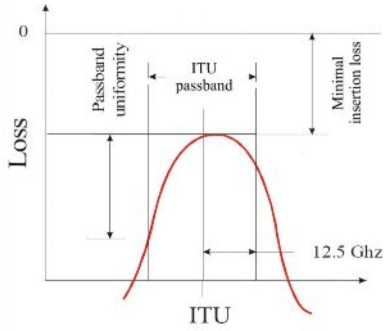

Fig. 3: Graphical representation of ITU passband for 100 GHz channel spacing [4].

3.2. Channel Center Wavelength Offset

Center Wavelength of a channel (CW) is defined as the average wavelength of the waveform at -3 dB drop from point of peak transmission [3]. The graphical representation of this parameter is shown in Fig. 4.

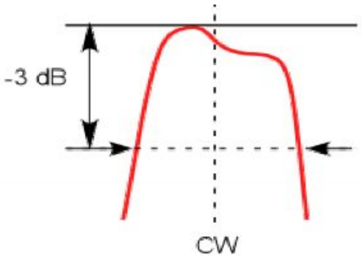

Fig. 4: Graphical representation of the channel center wavelength [4].

The center wavelength of a channel should be identical with a wavelength from ITU-Grid. According point 4.1.2 of TELCORDIA the allowed CW deviation from ITU-Grid is set to be less than 20 % of the channel spacing and temperature change of CW is set to be less than 4 pm/°C. The difference between the measured center wavelength of the channel and ITU-wavelength defines the temperature change of the CW offset.

3.3. CW Passband

The CW optical passband is defined, similarly to the ITU passband, as the symmetrical wavelength range around the measured channel center wavelength. It will be used for the comparison between AWG transmission parameters extracted over ITU optical passband and CW passband. The width of the CW optical passband is also taken 25 % of the channel spacing. Graphical representation of CW passband for 100 GHz channel spacing is shown in Fig. 5.

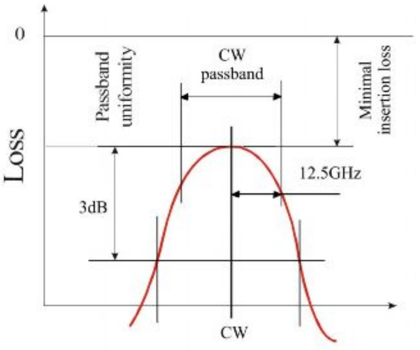

Fig. 5: Graphical representation of CW passband for 100 GHz channel spacing.

3.4. Insertion Loss

Transmission parameter Insertion Loss (IL) is defined as the maximum loss within the channel passband measured from 0 dB reference level for all polarization states. In this paper the IL is evaluated over both, the ITU and the CW passband.

3.5. Polarization Dependent Loss

Polarization Dependent Loss (PDL) is the variation in insertion loss within the passband, taking into account both polarization states. The PDL of a device is expressed in dB and is the worst case value for all output channels. In this paper the PDL is evaluated over both, the ITU and the CW passband.

3.6. Bandwidth

Bandwidth is the width of the transmitted optical signal at –*n* dB drop from the highest transmission point for any given channel (B@ndB). Bandwidth equals upper frequency minus lower frequency (taking into account Polarization Dependent Wavelength).

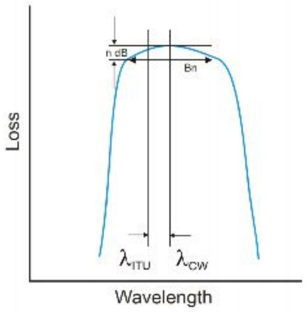

Fig. 6: Graphical representation of the bandwidth [2].

According to TELCORDIA:

- R4-3: the -1 dB bandwidth (B@1dB) shall be no smaller than 0,35 times the channel spacing,
- R4-4: the -3 dB bandwidth (B@3dB) shall be no smaller than 0,50 times the channel spacing,
- R4-5: the -20 dB bandwidth (B@20dB) shall be no larger than 1,5 times the channel spacing,
- R4-6: the -30 dB bandwidth (B@30dB) shall be no larger than 2,2 times the channel spacing [2].

3.7. Passband Uniformity

Passband uniformity (also known as Ripple) is the difference in insertion loss within the passband of just one channel. In this paper, passband uniformity is evaluated over both, the ITU and the CW passband.

4. Measurement

The sensitivity of IL, PDL and derived parameters on temperature of 32 ports AWG for DWDM-PON FTTx systems with 100 GHz channel spacing has been thoroughly examined. All measurements were performed in climatic chamber allowing defined set of temperature and environmental conditions for passive optical component under the test (in our case 32-channel, 100 GHz AWG designed and fabricated for DWDM-PON FTTx systems). The temperature in the chamber was gradually swept between three chosen temperatures: -30 °C, +23 °C and +70 °C to expose the DUT to temperature changes. Such temperature changes occur or may occur in the operation of DWDM circuits installed outdoors in Central Europe conditions.

The temperature range in which the manufacturer guarantees the transmission parameters is from 0 °C to +70 °C [5]. In our case, DWDM device was tested also under negative temperatures. Reaching the desired temperature in a climatic chamber and at DUT the temperature was kept constant for 20 minutes. This time was needed for DUT to get consistent measured data that did not change with time [6]. Figure 7 shows the measured IL spectral response of the 32-channel, 100 GHz AWG, under the test, achieved at room temperature. The detail of IL and PDL spectral response of the first port is shown in Fig. 8. IL and PDL spectral response is measured at three chosen temperatures: -30 °C, +23 °C and +70 °C. Figure 7 illustrates the alteration of CW offset, minimal value of IL, shapes of spectral response of IL and PDL changing the outside temperature of DUT. Figure 9 shows the evaluation of the bandwidth shift at -1 dB, -3 dB, -20 dB and -30 dB caused by the temperature alteration for the first port of AWG. The offset is measured at three temperatures and approximation is made.

The reason for different level calculations of CW is the investigation of the symmetry and the shifting linearity of the spectral response of the channel spectral filtering due to temperature change. The maximal temperature sensitivity of CW offset is for the bandwidth at -30 dB and equals 6 pm/°C. The minimal sensitivity is achieved for bandwidth at -1 dB and equals 2 pm/°C in the entire 100 °C temperature range going from -30 °C to 70 °C. For investigation of temperature sensitivity of -3 dB passband CW for left, middle and right ports of AWG we evaluated the CW offset to ITU grid positions for three chosen ports: 1 -st, 16 -th and 32 -nd. The graphical comparison is shown in Fig. 10.

Central (16 –th) AWG port is the most sensitive to the temperature changes, where -3 dB passband offset of CW is 6 pm/°C. Interestingly, temperatures for zero offset of CW relative to ITU grid positions are different for each chosen AWG port. The offsets of CW to ITU grid position of the 1 -st, 16 -th and 32 -nd port are zero at 70 °C , 23 °C and -30 °C, respectively.

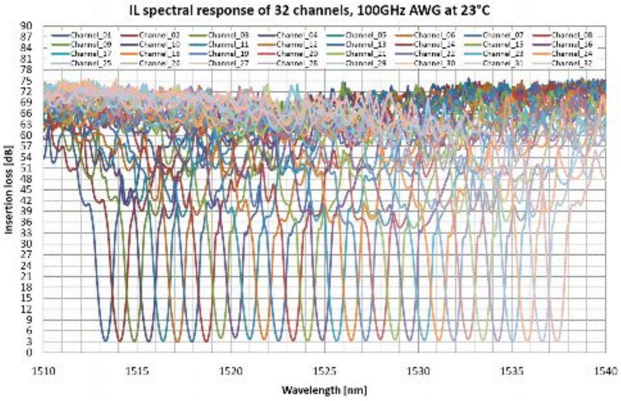

Fig. 7: IL spectral response of 32-channel, 100 GHz AWG at 23 °C.

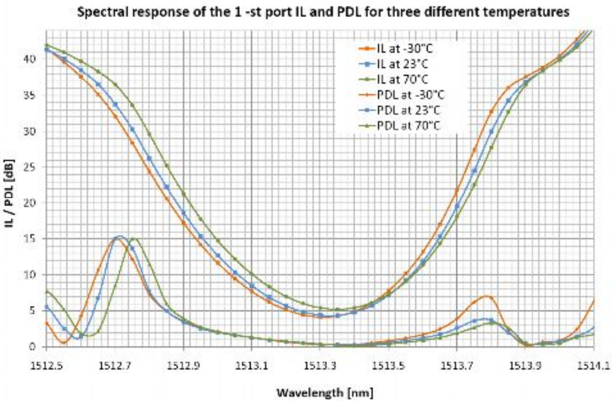

Fig. 8: Detail of IL and PDL spectral response of the first port of 32-channel, 100 GHz AWG presented in Fig. 7.

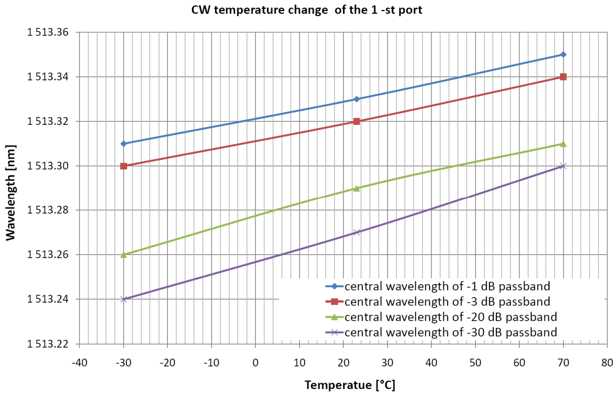

Fig. 9: CW Offset shift of the bandwidth at -1 dB, -3 dB, -20 dB and -30 dB caused by temperature change for the first port of 32-channel, 100 GHz AWG presented in Fig. 7.

The measured and evaluated -1 dB, -3 dB, -20 dB and -30 dB passband widths and their temperature change for the same three chosen ports as in previous experiments are shown in Fig. 11 and Fig. 12. According to TELCORDIA for 100GHz MUX/DEMUX, the -1 dB, -3 dB, -20 dB and -30 dB passband widths shall be no smaller than 0,28 nm, 0,4 nm, 1,2 nm and 1,76 nm, respectively.

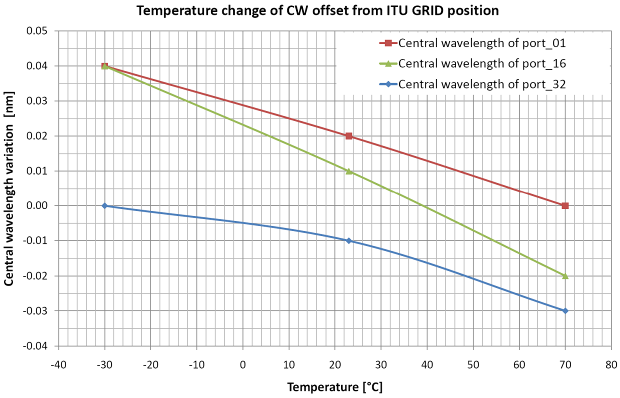

Fig. 10: Temperature change of offset CW from ITU grid positions of the 1 -st, 16 -th and 32 -nd AWG ports.

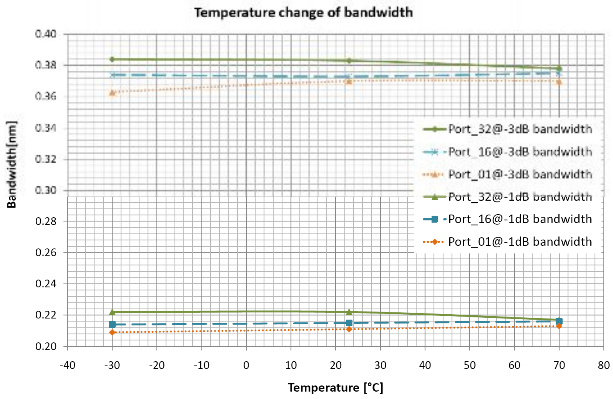

Fig. 11: Temperature sensitive of -1 dB and -3 dB spectral passband widths of the 1 -st, 16 -th and 32 -nd ports.

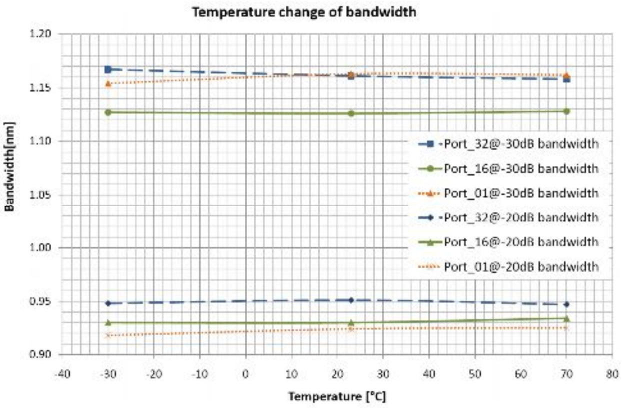

Fig. 12: Temperature sensitive of -20 dB and -30 dB spectral passband widths of the 1 -st, 16 -th and 32 -nd ports.

From Fig. 11 and Fig. 12 it is possible to observe that -1 dB and -3 dB bandwidth of tested AWG does not meet specification of TELCORDIA, however -20 dB and -30 dB bandwidth of tested AWG meets specification of TELCORDIA in the entire 100 °C temperature range from -35 °C to 70 °C.

The IL temperature sensitivities (Fig. 13) of the same three ports of tested AWG are evaluated over ITU (continuous lines) and CW (dotted lines) passband and also the minimal values of IL (dashed lines) of these ports are evaluated. The highest value of the IL is for ITU band due to mismatch of the CW and ITU grid spectral position for each port. From the measurements, dispersion of IL and temperature change in over the entire 100 °C temperature range are evaluated and summarised in Tab. 1. The IL temperature sensitivity of these three AWG ports is less than 0,0137 dB/°C over ITU passband, and it is less than 0,0151 dB/°C over CW passband. Temperature sensitivity of minimal value of IL is less than 0,0166 dB/°C for these three AWG ports.

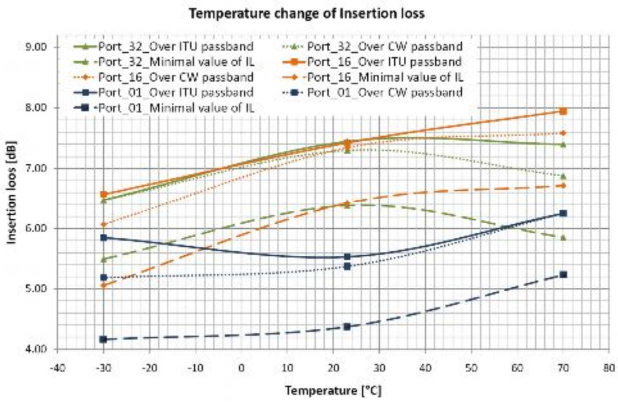

Fig. 13: Temperature change of IL of the 1 -st, 16 -th and 32 -nd ports.

Tab.1: Temperature sensitivity of IL of the 1 -st, 16 -th and 32 -nd ports.

AWG port	IL over/ of	Min value [dB]	Max value [dB]	Dispersion [dB]	IL temp. sensitivity [dB/°C]
1.	ITU band	5,5309	6,2490	0,7181	0,0072
	CW band	5,1835	6,2490	1,0655	0,0107
	Min. value	4,1590	5,2290	1,0700	0,0107
16.	ITU band	6,5719	7,9465	1,3746	0,0137
	CW band	6,0699	7,5844	1,5145	0,0151
	Min. value	5,0580	6,7200	1,6620	0,0166
32.	ITU band	6,4760	7,4445	0,9685	0,0097
	CW band	6,4760	7,2984	0,8224	0,0082
	Min. value	5,4950	6,3830	0,8880	0,0089
All	Maximal sensitivity – over ITU band				0,0137
All	Maximal sensitivity – over CW band				0,0151
All	Maximal sensitivity – of minimal IL				0,0166

Temperature change of the IL passband uniformity of the 1 -st, 16 -th and 32 -nd ports (Fig. 14) is evaluated over ITU (dashed lines) and CW (continuous lines) passbands. The passband uniformity over CW passband is smaller than passband uniformity over ITU passband due to mismatch between spectral position of CW and ITU grid spectral position of the port. CW passband is native passband of AWG so the passband uniformity over CW passband could be smaller than passband uniformity over ITU passband.

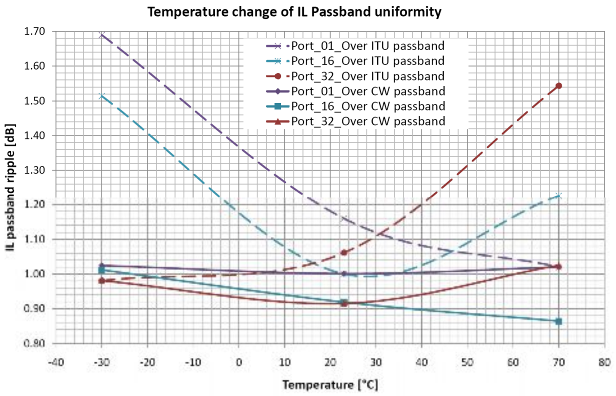

Fig. 14: Temperature change of the passband uniformity of the 1 -st, 16 -th and 32 -nd ports.

The PDL over ITU and CW passband for three chosen AWG ports are shown in Fig. 15. According to TELCORDIA, the PDL of AWG port over the optical bandpass shall not exceed 0,2 dB [1 – R4-55]. From Fig. 15 it is possible to observe that tested AWG does not meet this specification. Measured PDL of chosen three AWG ports over entire temperature range are reaching the values more than 4 times higher than TELCORDIA specification. The highest values of PDL reaching the outer ports of tested AWG. The temperature change of PDL is maximal of the central port of tested AWG.

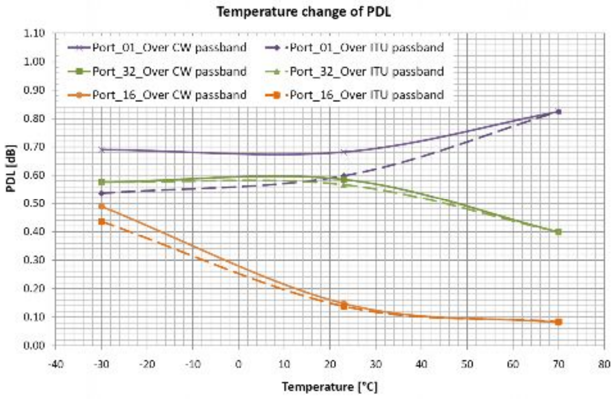

Fig. 15: Temperature change of PDL of the 1-st, 16-th and 32-nd ports.

5. Conclusion

Designed and implemented experimental set-up allows temperature change measurement of the insertion loss and polarization dependent loss of passive optical components for DWDM-PON FTTx systems in the spectral range from 1460 nm to 1580 nm, with maximum spectral resolution of 60 pm and dynamic range exceeding 85 dB in the temperature range from -72 °C to 180 °C.

The 32 channel AWG for 100 GHz DWDM was successfully characterised. Temperature change of IL and PDL were measured and evaluated for this AWG in the spectral range from 1510 nm to 1540 nm for three temperatures -30 °C, 23 °C and 70 °C.

Acknowledgements

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