Anti-Tampering Solution for E-Meter Application

TLV493D

3D Magnetic Sensor

Application Note

Revision 1.0 2015-07-24

Sense & Control

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1 Introduction

This application note describes a possible realization of an anti-tampering solution in an Electricity Meter. With the new product family of the 3D Magnetic Sensor (TLV493D), Infineon offers an innovative solution for three-dimensional magnetic position sensing. By allowing a measurement of all three components of a magnetic field at the same time, it enables a multitude of applications with different ranges. Furthermore the integrated temperature sensor enables the application to compensate possible temperature-dependent magnetic field changes.

2 Electricity Meter

In developing countries 10-40% of total electricity production is stolen by electric theft. It includes illegal tapping of electricity from the feeder, bypassing the energy meter, tampering the energy meter and several physically methods to circumvent payment for the electric utility company. According to extrapolations, energy utilities loose more than $25 trillion - India alone $4.5 trillion - a year in revenue.[1)]

To counteract the problem with tampering of E-Meter technical standards bellow are established (not a complete list):

- IEC 62053-22 (international electrotechnical standard)
- ANSI C12-202002 (American standard),
- IS13779 (India standard),
- IS14697 (India standard),
- CBIP-304 (India standard),
- etc.

These technical standards, for example, describe which manipulation methods have to be identified by an anti-tampering feature in the E-Meter and on which way the energy consumption has to be measured. The goal of the standards is to guarantee accurate measuring of the equipment. By implementing all technical standards for the anti-tampering feature in E-Meter Applications, energy theft has to be identified as far as possible and thus completely avoided for a long term.

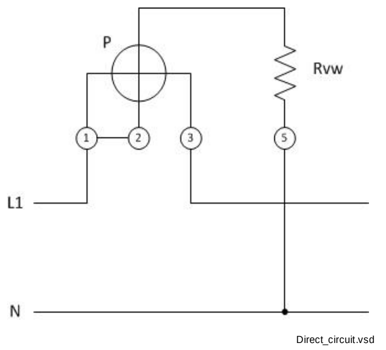
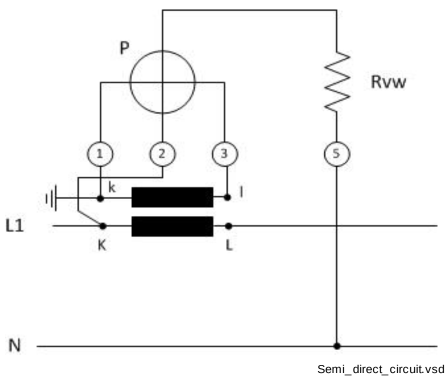
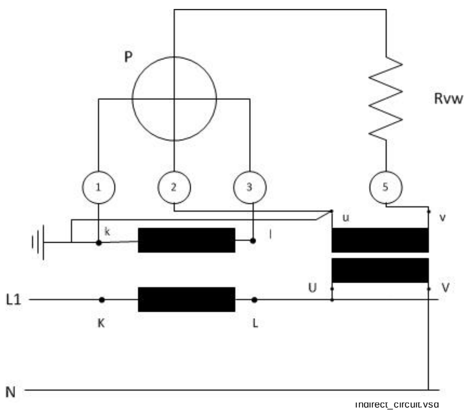
Due to new innovations in the semiconductor industry, new technical requirements can be fulfilled in a cost-efficient manner. In the next chapter more possibilities will be described.

2.1 Functionality of Power Consumption Metering

Several approaches are possible to measure the actual power consumption. Performance of measuring devices can therefore be switched to different ways in an alternating current circuit. Three different types of circuit are available according to their applications that depend on the size of the measured power. In all three circuit types, the measurement devices can either be connected in such a way that the current is not distorted or in such a way that the voltage is not distorted.

1) S. Depuru et al: “Electric theft: Overview, issues, prevention and a smart meter based approach to control theft”; in Energy Policy 39 (2011), p. 1007 - 1015

Table 1 Different Types of Circuit in Power Metering

Circuit Diagram	Description
Direct circuit 	The current is conducted directly via the coil current and the voltage is connected directly to the voltage coil.
Semi-direct circuit 	In the measurement circuit a current transformer is connected so that the current path of the power meter is located in the secondary circuit of the converter. The voltage is directly connected to the voltage transformer coil.
Indirect circuit 	The power meter is connected via current and voltage transformers. The performance (with the power meter constant C_p, the transmission ratios for voltage transformer k_u and current transformer k_i and the scale display) applies to: (2.1) $P = C_p \times k_u \times k_i \times \alpha$

In the case of Power measurement, depending on the circuit type, the losses occurring in the current and voltage path will be measured. Power, current and voltage cannot therefore be measured simultaneously correct.

Measurement and Calculation with the Counter of the E-Meter[1]

The mechanical counter is a calibrated measuring device with an error rate of less than 1% or 0.5%[2]. In a simple way it is thus possible to determine the power consumption of one or more connected devices. The electronic counter is more accurate. The base in the mechanical counter is a revolution of a counting disc, for electronic counters the pulses of an LED. The pulse length error defines the grade of E-Meters.

The mechanical counter applies to

$$\text{Meter constant } C_Z \text{ in } \frac{\text{revolutions}}{\text{kWh}} \tag{2.2}$$

Usual mechanical meter constants C_Z are:

- 75, 96, 120, 150 (three-phase meter)
- 375, 450, 480, 600, 750 (single-phase electricity meter)

The electrical counter applies to

$$\text{Meter constant } C_Z \text{ in } \frac{\text{impulses}}{\text{kWh}} \tag{2.3}$$

Usual electrical meter constants are:

- 100 up to 1000 (three-phase meter)
- 1000, 2000 up to 10000 (single-phase electricity meter)

For the power metering, revolutions or pulses will be measured in a defined time and then projected to revolutions per hour or to frequency of pulses per hour. Then the power consumption will be calculated as follows:

$$P = \frac{n}{C_z}\text{ ; n in } \frac{\text{revolutions}}{\text{hour}} \text{ or } \frac{\text{impulses}}{\text{hour}} \tag{2.4}$$

1) http://www.didactronic.de/El-Grundlagen/zaehler.htm
2) The mentioned error percentage is related to the chosen Meter class.

2.2 Possibilities of Tampering

Regardless on the applied technology of the power measurement in E-Meters, different approaches to manipulate the E-Meter exist. For this reason you will find different possibilities of an anti-tampering feature, which shows an attempt of tampering. In the following section we will concentrate on attempts of tampering with external magnets.

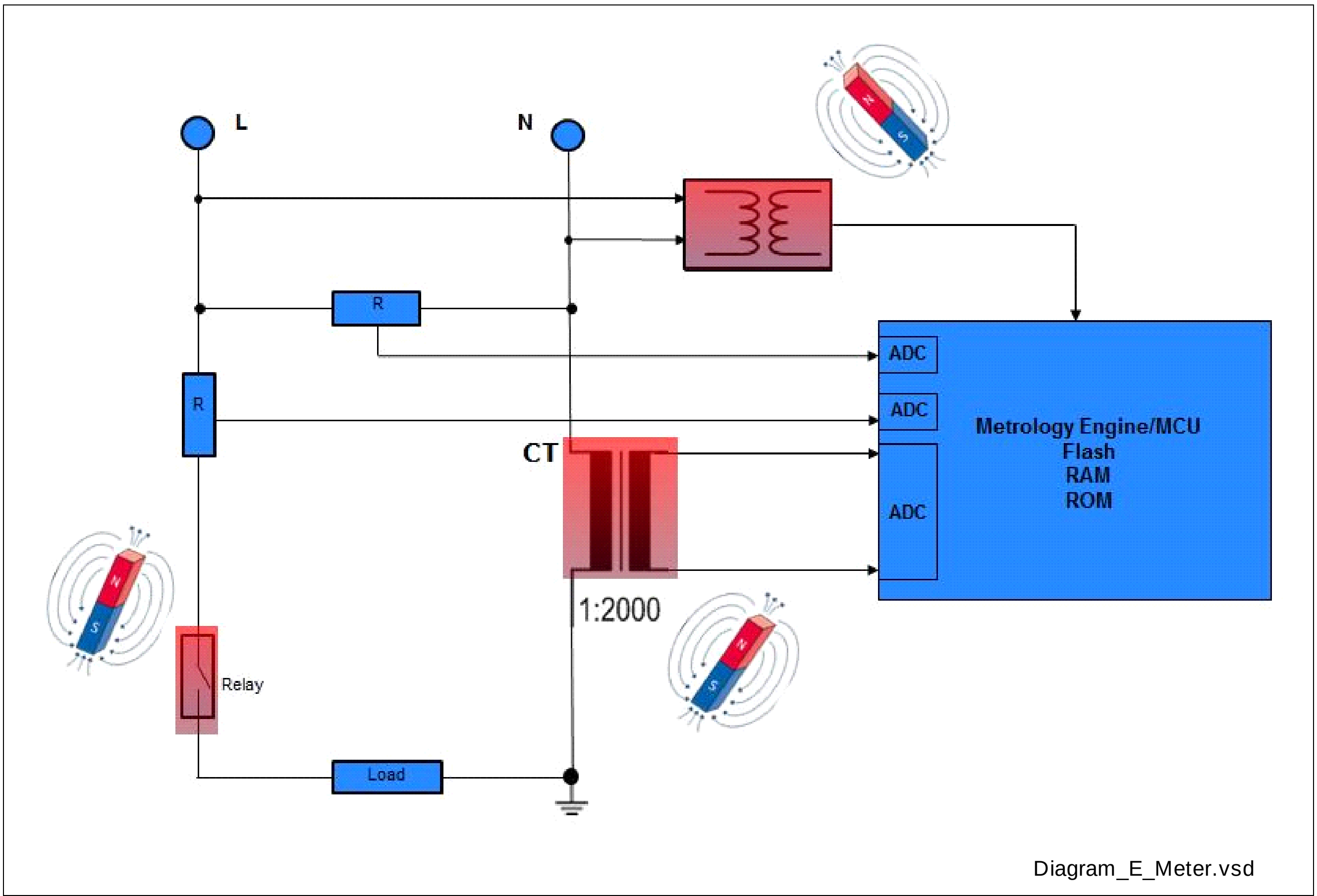


Figure 1 Simplified Schematic Diagram of an E-Meter with Different Approaches (relay, current transformer, coil and shunt) for Power Metering

For better explanation of potential possibilities of manipulation, in the figure above, a simplified Diagram of E-Meter is shown. Regardless which principle is used for consumption measurement in the E-Meter, a magnet can be used to affect the application negatively. The external magnetic field causes a disturbed counting of the revolutions or of the pulses. Despite the same power consumption, it is present manipulation of the application and that is the place where a theft of energy appears. As described in the previous chapter, the measured power consumption depends on the number of revolutions per hour or number of pulses per hour and of the meter constant of the application. By using a very strong magnet, the measured energy consumption can be reduced or set down to 0kWh.

Although there are many other ways to manipulate the functioning of an E-meter, in the following chapter you will find an approach, how you can protect this application against external manipulation by using magnets.

2.3 How to implement Anti-Tampering

To determine manipulation attempts by using magnets, Hall effect technology based solutions are offered. **Table 2** indicates the key requirements for Hall effect sensors used in an E-Meter to detect tampering:

Table 2 Key Requirements for Hall Effect Sensor Used in an E-Meter to Detect Tampering

Parameter	**Value**
Magnetic field range	±5 mT to ±150
Resolution	0.5 mT
Gain error	±20%
Offset error	2.5 mT
Supply voltage	3.3 V
Power consumption (sequential approach for X, Y, Z) Operation Mode Sleep Mode	 < 4 mA < 1 µA
Output	Digital linear output
Interface	I^2C or SPI

2.3.1 State of the Art Solution and the Disadvantages

Figure 2 shows an example of a way in which an anti-tampering feature can be implemented in an E-meter.

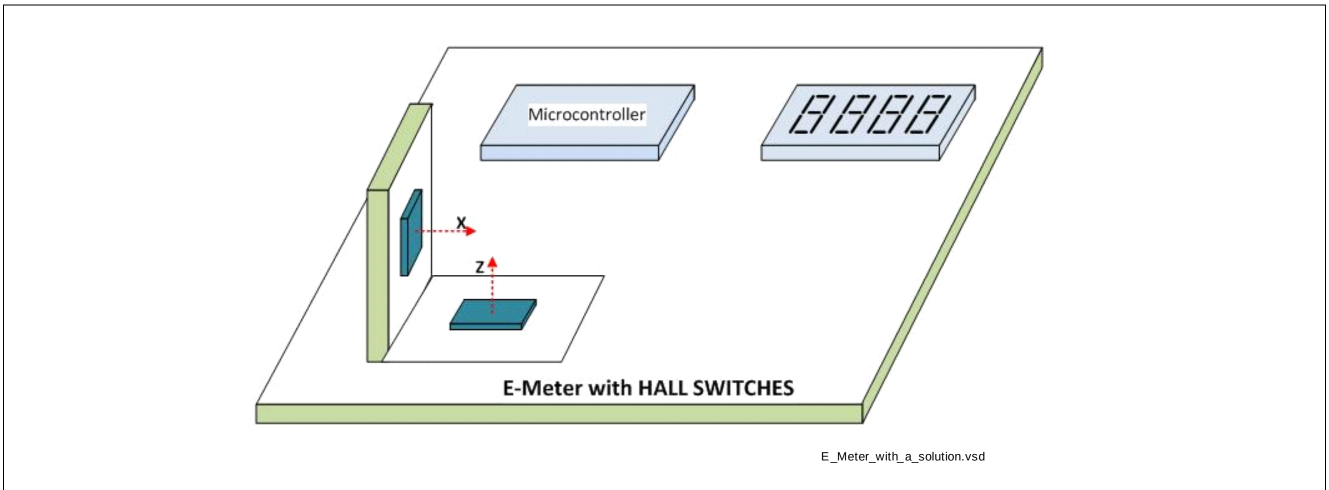


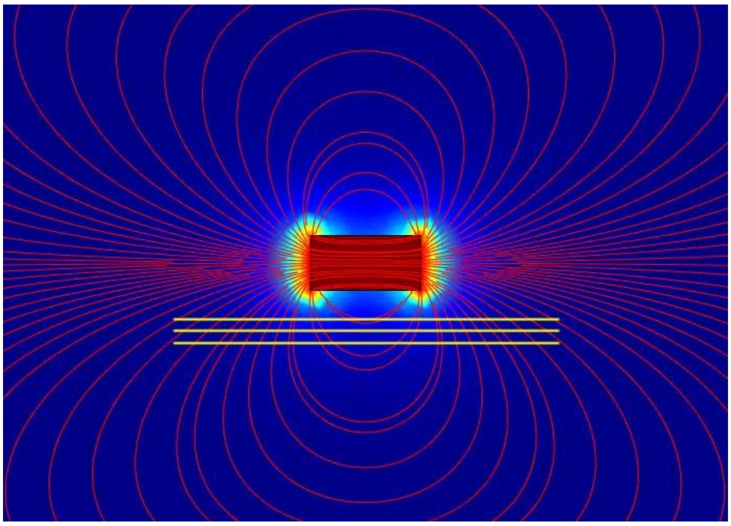
Figure 2 E-Meter with a Solution Based on Two or Three Hall Switches

In order to identify the detection of an external magnetic field, two or three Hall effect sensors will be installed. With this approach, the whole environment of the sensor or rather the E-Meter can be detected on magnetic field change. In the production of the E-meter is also required either a complex mechanical structure (see figure), or other costly process steps, such as

- additional holes on the printed circuit board or
- different types of sensor placement on the printed circuit board

However, with this approach, only fixed magnetic switching thresholds can be detected, so that a tampering attempt is detected only when a predetermined magnetic threshold is crossed. A subsequent change of the switching thresholds is not possible because the thresholds are set by the simple Hall effect sensors through the manufacturing process. Before selecting the Hall effect sensors that will be used, a complex analysis is required, since the detected height of the threshold values is different regarding to the positioning of the single Hall effect sensors.

Due to this approach that threshold values are exceeded, a variety of "dead zones" may appear, but it has a large manipulative effect on the current measurement. The location of an external disturbance factor, such as a magnet, is dependent on whether it can be recognized or not. In the figure below, the magnetic field is shown as an example. It can be noted that in some areas there is a high magnetic field strength and thus the strength of the magnetic field depends on the position of the magnet to the sensor.



Magnetic flux distribution.vsd

Figure 3 Magnetic Flux Distribution Simulation (yellow lines show range of movement for different air gaps)

By the use of linear Hall sensors, it is possible to eliminate the disadvantage of the simple Hall effect sensors. With the linear Hall sensors, the range of the height of the magnetic field can be measured. Further processing of the data is then carried out using a microcontroller, when tampering occurs. Two or three linear Hall sensors are needed to monitor the entire environment from the E-meter for manipulation attempts. This approach has never been able to enforce due to the high cost of the linear Hall sensors, which leads to higher system cost.

Since the E-Meter must be operated by an external battery, which is also a high cost driver. In the overall application, power consumption is a big disadvantage to use simple Hall effect switches or linear Hall sensors. Due to the number of sensors, which must simultaneously operate for the detection, increased power consumption is present. Since lifetime prescribed by manufacturer and the technical standards are achieved, a large battery must be used.

In summary, it can be stated that the previous approach, in which two to three Hall sensors are used, severe technical standards for this application could fulfill only with

- increased system costs,
- a high power consumption and
- an inflexible system

2.3.2 New Approach: 3D Magnetic Sensing

With the possibility to detect simultaneously three magnetic field directions with only one sensor, new possibilities for the E-Meter in the design are obtained. The temperature sensor is integrated in order to recognize and compensate possible variation in temperature. Moreover, the 3D Magnetic Sensor provides a solution to overcome the disadvantages discussed in previous chapter.

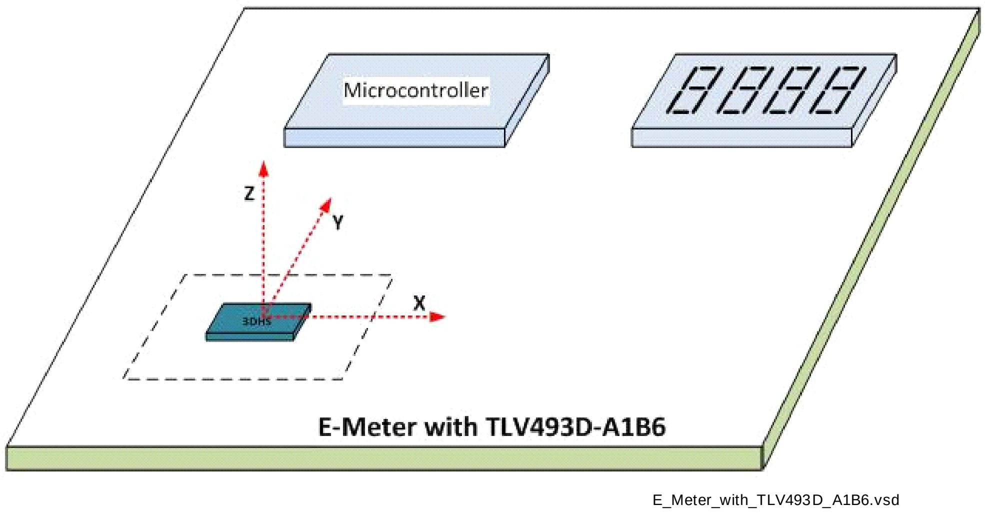


Figure 4 E-Meter with a Solution Based on Two or Three Hall Switches

In order to fulfill the hard technical standards, only one 3D Magnetic Sensor is required. By reduction of complexity of production process and the use of only one sensor, at the same time a cost-effective solution for the anti-tampering feature is offered. In contrast with the simple Hall effect sensors, a resolution of 100 µT in X, Y and Z directions in a range of ±150mT will be detected here, similar to the magnetic field range of the linear Hall sensor. Each measured value - as well as the temperature - is stored as a digital measurement in a separate register. The measurement evaluation can be customized to individual needs via the I^{2}C interface. More customization features are possible by means of the dynamic data acquisition. In addition to the specified 3 power modes, the end user furthermore has the possibility to adapt the read-out rate of his own needs.

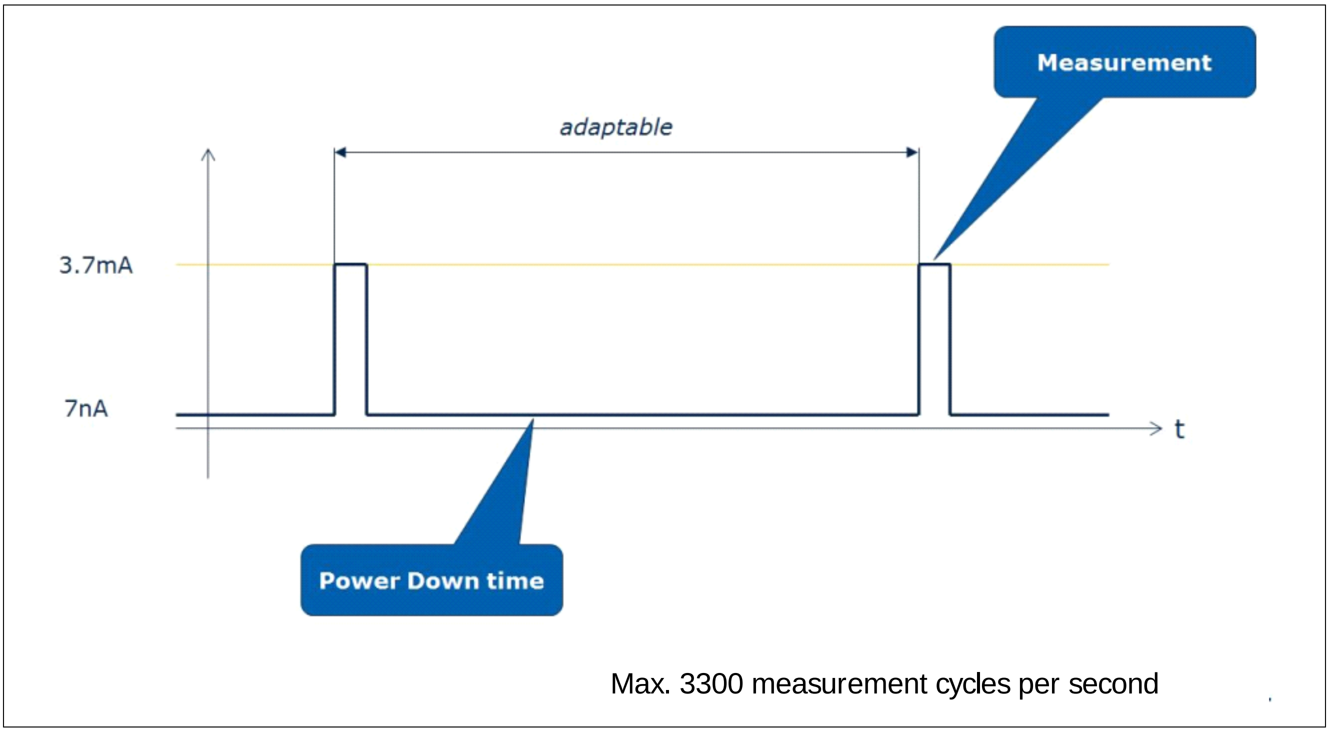


Figure 5 Continuous Interrupt Function

If a tamper attempt is detected, it is possible to define increased sampling rate measurement cycles to perform a more accurate detection.

Through the use of (multiple) 3D Magnetic Sensors, the amount of manipulated power of the E-Meter and consequentially the real power consumption can be calculated. By being able to measure a linear magnetic range in a redundant design, the microcontroller can determine, by using several sensors, how high the influence on the measurement of the power consumption is, that is influenced by the magnet.

2.4 Résumé

There are several ways how to secure against energy theft. For an E-Meter, in this Application Note, two approaches have been described as a possible attempt of tampering that can be detected. In summary the following advantages for the use of 3D Magnetic Sensor can be observed for the anti-tampering feature in an E-Meter:

- Only one sensor is used to implement the functions on this page for detecting tampering
- Simplified production process
- Linear magnetic field measurement
- Integrated temperature sensing
- Reduces system complexity
- Using I^2C Interface is an individual adjustment of the sampling rate and the signal processing in the microcontroller possible
- Lower Costs for tests + simulations
- Very low power consumption

For more information, please visit the website or contact the nearest Infineon Technologies office. We can attend to your concerns and help you most like to work together to find a solution to your concerns.

http://www.infineon.com/3dmagnetic

3 Revision History

Revision	Date	Changes
1.0	2015-07-24	Initial Release

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