FEATURE

Stabilized Power Supplies Part2

Looking at the hardware required to implement fix and variable regulators.

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Last month we gave a general overall survey of regulated power supplies and saw how the circuitry consists essentially of an automatic series control element which, in turn, is protected against overload by feedback control.

This month we look at a series of circuit systems which start with the simple Zener diode stabilizer and build up to hints and tips on the full blooded regulators available for fixed voltage applications in convenient integrated circuit form.

Zener Stabilizer

The Zener stabilizer is the most basic of all regulators. A Zener diode is essentially identical with the ordinary p-n junction diode, but is designed to operate continuously in the reverse-bias condition beyond the point at which reverse breakdown occurs; see Fig. 2.1.

In an ordinary diode, great care has to be taken to ensure that the applied reverse voltage never gets close to, let alone exceeds, the breakdown point. If it does and the condition is not immediately rectified, a very large reverse current will flow and the diode will burn itself out before you can say "Eek!" or words to that effect.

Zeners, on the other hand, are deliberately operated with an applied reverse voltage which is greater than the breakdown, but with the proviso that the current through the junction is kept within bounds by the use of a resistance in series with the junction. Without such a limiter, the Zener will go the way of all flesh in a remarkably short space of time.

The Zener voltage is usually marked on the body of the device; this can range from about 2.5V up to 200V. The values are marked off in the usual "preferred" series: 2.7, 3.0, 3.3V and so on, and in general have a tolerance of plus or minus 5%.

The cathode end of the Zener, like ordinary diodes, is marked with a coloured band (and sometimes a "k" on circuit diagrams). Zeners also come in a range of power ratings, typically 400 or 500mW, 1.3W, 5W, 1.3W, 5W, and 20W.

The basic Zener stabilizer circuit is shown in Fig.2.2 where the essential components are resistor R and Zener diode Z. Notice that the diode has its cathode (k) connected to the positive rail. The transformer T1, bridge rectifier REC1 and reservoir capacitor C are components common to most power supplies and are not our particular concern here.

At the particular voltage for which it has been designed, the Zener diode Z will break down and thereafter, as Fig.2.1 shows, the voltage across the junction will remain substantially constant, irrespective of the (reverse) current flowing through it. This reverse flow is limited to a safe value by resistor R and, providing the applied voltage Vs does not drop below the breakdown level Vb, the Zener behaves as a current reservoir.

Referring to Fig. 2.2, it is not difficult to understand how the diode provides a constant output voltage Vo at terminals A and B in spite of variations in either the input voltage Vs or in the load current Io flowing through Rl. Suppose the input voltage across C increases for some reason, then the current through the Zener increases but as the voltage across it remains constant, the increase in voltage appears across R.

If the input voltage falls, the Zener surrenders the extra current and the voltage across R also falls. In either situation, the input variation is absorbed by resistor R and the output voltage is unaffected.

Suppose now the load current Io increases for some reason. The Zener current will decrease by the same amount. Likewise, if the load current decreases, the Zener current will increase by the same amount. This time the Zener takes up the excess current and sheds the current difference required by the load, so acting as a current reservoir.

Zener Selection

Whenever you plan to use such a simple system (which is nevertheless sufficient and practical for quite a number of projects requiring a stable supply) a number of points have to be taken into consideration. We will illustrate with some typical figures.

First, choose the Zener diode to suit the output voltage you want. For a 9V supply, you will use a 9.1V Zener, or two 4.7V types in series will do.

Then you will need to know what power rating is necessary. A 500mW (0.5W) Zener rated at 9.1V will be dissipating its maximum permissible power when the current through it is 0.5/9.1A, or 55mA. Remember, W = V x I. Hence, under no circumstances must the Zener current Iz exceed 55mA.

If you look at Fig. 2.2 again, the greatest Zener current flow will occur when the load Rl is removed; hence from a knowledge of what voltage you have across capacitor C, you can calculate the value of the series resistor R so that it is impossible for a current greater than 55mA to flow.

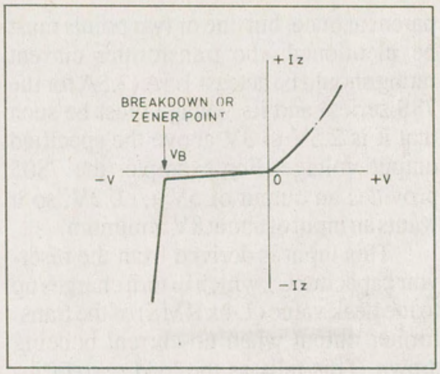

Fig. 1. Zener diode characteristics.

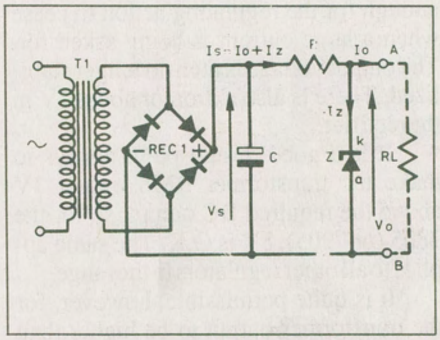

Fig. 2.2. The basic Zener regulator circuit diagram.

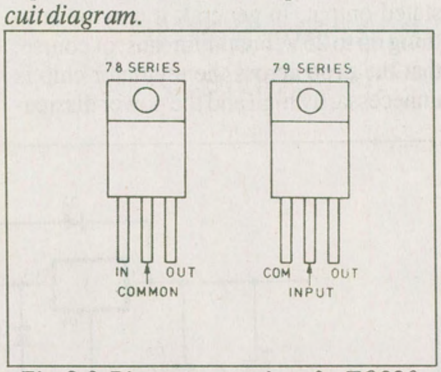

Fig. 2.3. Pinout connections for TO220 style 78/79 series regulators.

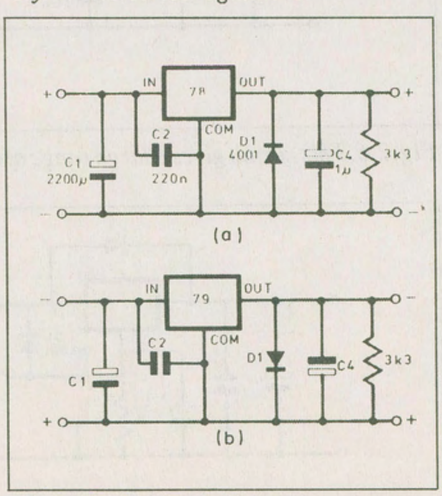

Fig. 2.4. Basic circuit diagrams for the positive 78 series and the negative 79 series.

Suppose the input DC voltage across C is 15V; this voltage, of course, must always be greater than the output. Then to restrict I to 55mA, we can calculate resistor R to be (15-9.1)/55 X 10 = 107 ohms.

This is not a preferred value, so to play safe we go to a higher value (not lower) and choose 120 ohms. This value will restrict our maximum Zener current to 50mA whatever happens.

Now, when the load (Rl) is connected, current Io will flow into it and current Iz will fall. If Iz falls too far (typically below a milliamp or so) the Zener actions ceases because the diode is no longer in its breakdown region. We must never allow the load to draw so much current that the Zener is starved; it won't be damaged by this but it won't be doing its job either.

The greatest permissible load current is therefore Is-Iz(minimum). In our example above, this would reasonably be 45mA. Always be generous with tolerances; never work things on their theoretical edges.

So with this circuit we could draw any current from zero to about 45mA and the voltage would remain almost (but not quite) constant at 9.1V. The slight variation occurs because the breakdown characteristic is not precisely a vertical line but exhibits a slight slope which is the same thing as saying the Zener has an internal resistance.

Zener diodes rated at 5W and above are usually bolted to suitable heatsinks; 0.5W and 1.3W types can generally go directly on to circuit boards without any additional heat precautions other than that provided by the board copper itself.

Fixed Voltage Regulators

Getting away from the simple Zener diode, the easiest way to build a stabilized power supply — provided you don't want to vary the output voltage — is to use one or more of the many integrated regulators now available at prices ranging from fifty pence to a few pounds. Most of these regulators are housed in three-terminal T0220 or TO3 packages.

The voltage ranges available cover most common applications; 5V for TTL logic systems and 12V to 24V for CMOS and operational amplifier projects. These regulators contain up to 20 transistors, two reference diodes and 20 resistors and are available in both positive and negative output polarities.

The popular 78L and 79L series are housed in plastic T092 style cases and are made for low power applications where the device is mounted directly onto a printed circuit board and there is normally no need for heatsinking. The maximum current rating for this series is 100mA and this is sufficient for most small project supplies.

The 78 and 79 series proper are housed in plastic T0220 packages and are used where greater output currents are required. The standard rating for the basic range is 1A, but the 78S and the 78T series provide outputs of 2A and 3A respectively. All types feature internal limiting and overload protection.

The pin connections for these regulators are shown in Fig. 2.3; in all cases the heatsink surface is connected to the centre pin. When bolted to a heatsink, the usual insulated mounting must be used as for a power transistor.

Although apart from the transformer and reservoir capacitor, the whole of regulated power supply is neatly built into the IC, a few precautions are necessary whenever these devices are put to use. As mentioned above, both positive and negative polarities are available, the 78 series for positive and the 79 series for negative. Basic circuits for both types are shown in Fig. 2.4(a) and Fig. 2.4(b) respectively.

The simplicity of these circuits is apparent at once, but one or two points must be mentioned: the transformer current rating should be at least 1.5A (2.5A for the 78S series) and its voltage must be such that it is 2.5V to 3V above the specified output voltage. For example, the 7805 provides an output of 5V +/- 0.2V, so it wants an input of about 8V minimum.

This input is derived from the reservoir capacitor C1 which in turn charges up to the peak value (1.4 x RMS) of the transformer output when no current is being drawn. This falls as the load current increases and it is possible for it to drop far enough for the regulating action to cease when a large current is being asked for. The output voltage is then no longer stabilized. There is also a drop of about 1V in the rectifier.

It is a good design point always to make the transformer RMS output 3V above the required DC output, so for the 7805 (or 7905), 8V is O.K. The same applies to all other regulators in the range.

It is quite permissible, however, for the transformer output to be higher than that giving a 3V differential relative to the stated output. In general, it may be anything up to 25V, but this means, of course, that the drop across the regulator chip is unnecessarily high and the power dissipation is consequently greater for a given current level.

Ripple Rating

Another point to watch is the ripple rating of C1; this must be at least 1A for the 78/79 series or 2A for the 78S series. If you can make it 50 per cent higher, so much the better.

The 220nF capacitor C2 should be placed as close to the relevant package pins as possible, not wired simply in parallel with C1. Its job is to prevent any self-oscillation and reduce noise.

On the output side there is nothing to be gained by making C4 greater than 10uF; a solid tantalum should be used in preference to an ordinary electrolytic. The diode D1 (a 1N4001 is suitable) protects the regulator against reverse voltages being applied at the output terminals. This might seem an unlikely event, but inductive devices in the connected circuitry can produce reverse voltage spikes at switch-off; capacitor C4 discharging suddenly into a short-circuit can also generate a short term negative voltage.

It is the writer's experience that these integrated regulators are very sensitive to reverse voltages. They are also sometimes sensitive to short-circuits on the output,

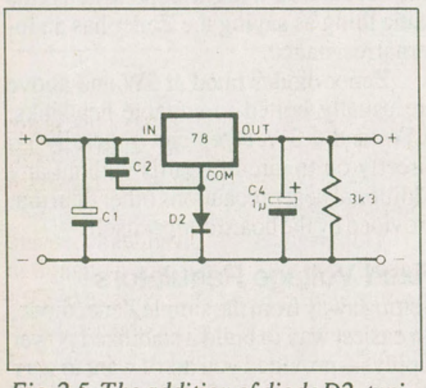

Fig. 2.5. The addition of diode D2, typically a 1N4148, gives a small increase in output.

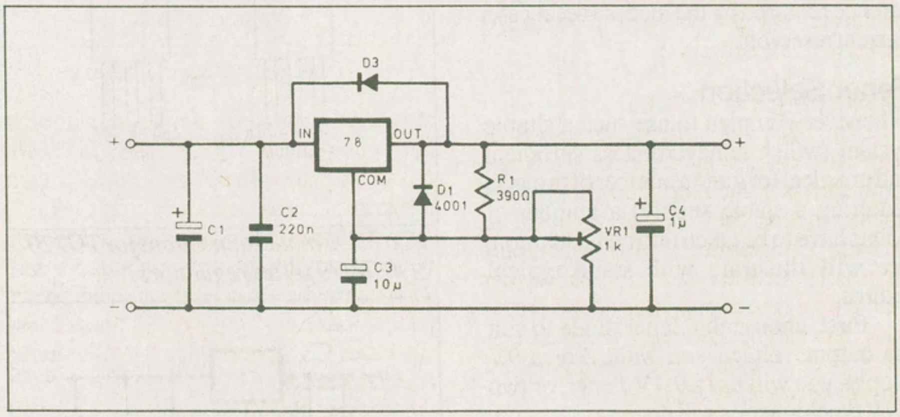

Fig. 2.6. This circuit gives a large range of output voltages.

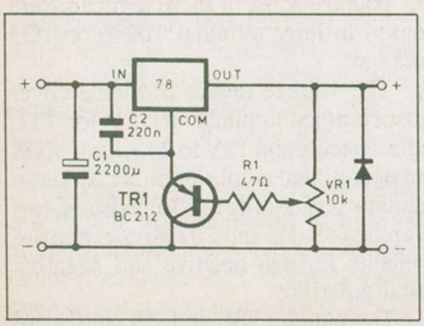

Fig. 2.7. Circuit diagram for improved regulation.

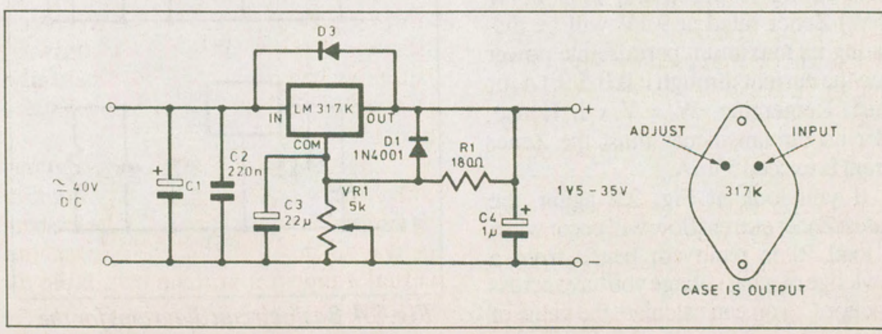

Fig. 2.8. Practical circuit diagram for variable voltage output. Note that an insulating kit should be used for mounting the regulator IC.

something that occasionally happens even on the best organized electronics bench.

The manufacturers claim that their regulators are overload protected by automatic "foldback" if a short-circuit or excessive overload appears; that is, the current quickly drops back to a safe level after the overload is applied. For the 7805, for example, the short-circuit current is stated to be 750mA.

Provided this actually happens, there's no problem, but the writer is aware from personal experience of at least two cases where the current rocketed to over 2A and the devices were damaged. This was under deliberate test conditions and perhaps I was just unlucky. However, it does show that unless the regulator is being used in a piece of equipment where the load current is fixed, care should be taken where overload conditions might occur in the course of experimenting or setting things up.

A heatsink is necessary for all regulators, except the 78L series. Normally a piece of 16-gauge blackened aluminium measuring 100mm by 75mm will be sufficient; very often the instrument case itself can be used to extend the available area. If you buy a ready made finned heatsink, a rating of 4 to 5°C/W is suitable for the 78 series, but something a bit larger, say 3°C/W for the 78S (2A) series will be adequate.

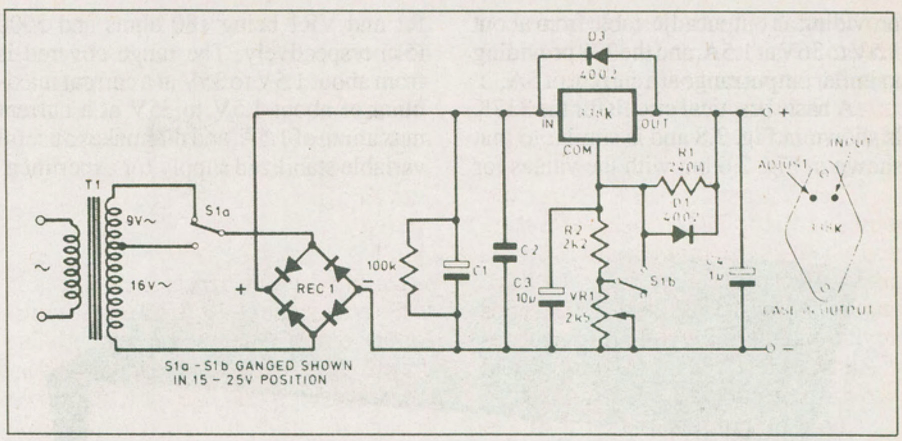

Fig. 2.9. Practical circuit diagram for a 0-25V 5A stabilized supply.

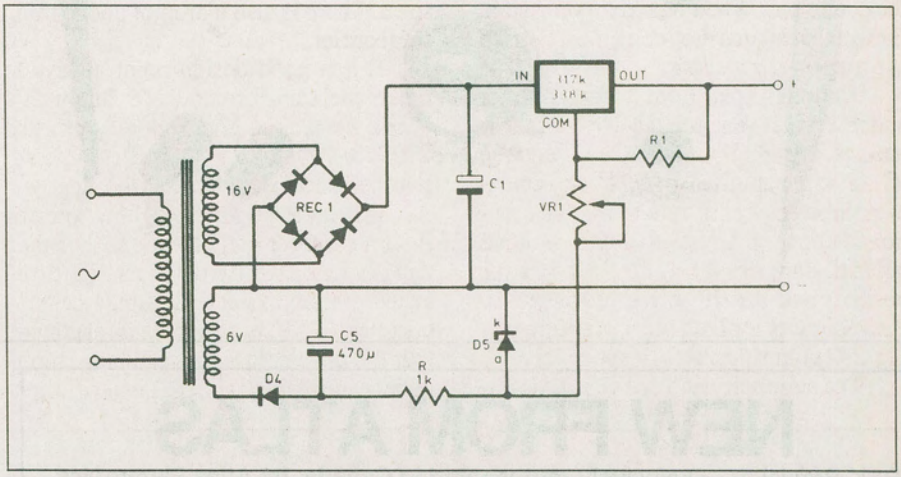

Fig. 2.10. Modification that enables the output to be reduced to zero.

Changing the Output

The fact that the 78/79 series of regulators are designed for fixed voltage applications in the range 5V to 24V does not mean that they cannot be made to provide odd intermediate voltage outputs such as 9V, or that one needs to buy other than the 5V type in order to get higher outputs. This can be done by external adjustment to the internal reference diodes by way of the common terminal.

For small increases, a diode or a small resistance can be used as show in Fig. 2.5. If a diode D2, typically a 1N4148, is placed in the common line, the output voltage will be increased by about 0.7V, equal to the forward voltage drop of the diode. A 7805 will therefore give an output of about 5.7V. Notice the polarity of the diode, it must be in the normal forward direction and would be reversed if used with a 7905. The same output can be obtained by using a resistor of about 1000 in place of the diode D2.

This method is no use if substantial voltage increases are wanted, say, raising the output of a 5V regulator to 9V or more. A better arrangement would be to use the system shown in Fig. 2.6. here the common terminal is taken to a potential divider made up of a resistor R1 and preset VR1.

With the values shown, the output can be set to anything between about 5V and 15V using the 7805 package. The preset potentiometer VR1 is bypassed by capacitor C3 which improves the ripple rejection and diode D1 gives protection in the manner already discussed. A second diode D3 across the regulator itself prevents a reverse voltage developing between input and output. The preset potentiometer VR1 should be set midway before switching on, and then carefully adjusted until the required output is obtained.

It is NOT a good idea to put this control on the front panel and use the circuit as an adjustable power supply. There are better ways of doing this and in any event the actual range of voltage available is restricted.

An alternative method of adjustment is shown in Fig. 2.7. This is rather better than the previous method as it gives an improved regulation figure. here a transistor TR1, with an adjustable base voltage acts as an effective resistance in the regulator common connection.

This arrangement provides a measure of feedback, with gain, since a change in the output affects the base voltage of TR1 which in turn adjusts the feedback into the common terminal in such a direction that the change is reduced. With the values shown, a range of about 8V to 12V is possible using the 7805 regulator.

The transistor has to be a PNP type and a 2N3906 or BC447 is suitable. For a 7905 regulator (negative output), an npn is needed and a 2N3904 or BC107 is suitable here. The diode must also be reversed in this case, of course.

Variable Voltage Regulators

Regulators are available which are designed to provide an adjustable output over a wide range. These are usually found in TO3 packaging and have to be mounted on heatsinks in the same way as power transistors. Commonly available types are the LM317K and the 338K, the 317K

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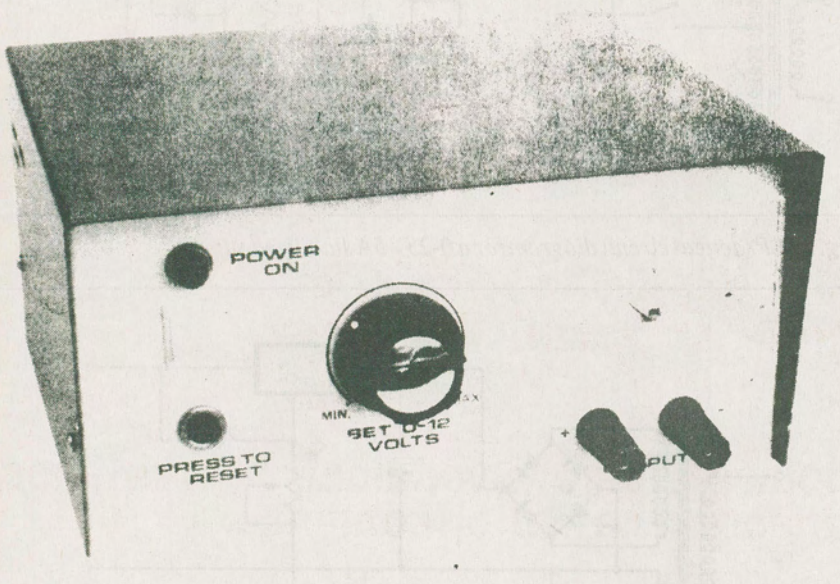
providing an output adjustable from about 1.5V to 36V at 1.5A, and the 338 providing a similar output range at a current of 5A.

A basic practical circuit for the 317K is shown in Fig. 2.8 and is similar to that shown in Fig. 2.6 but with the values for R1 and VR1 being 180 ohms and 5000 (5k) respectively. The range covered is from about 1.5V to 35V at a current maximum of about 1.5V to 35V at a current maximum of 1.5A, and this makes a useful variable stabilized supply for experimen tal work.



It is possible to get down to zero volts output by providing a negative supply, but we will come to this aspect in due course. A 2°C/W heatsink is necessary; a piece of 14-gauge blackened aluminium 150mm by 100mm is suitable.

By using a 338K regulator, an output of about 1.5V to 25V at a current of 5A can be obtained using the circuit of Fig 2.9. Here again the basic arrangement is similar to Fig. 2.8 but a switching system is introduced to break the output into two ranges: 1.5V to 15V and 15V to 25V.

The purpose of this range switching is to avoid excessive power dissipation in the regulator which would come about if large currents were being drawn at low output voltages. For instance, suppose the transformer provides a single output winding of 25V RMS.; this appears across the reservoir capacitor C1 as about 30V DC on average.

If the output is set to, say 5V, then there is a drop across the 338K of 25V which, at a current of 5A, represents a dissipation of 125W. This would call for a massive heatsink. By restricting the transformer output to 16V or thereabouts on an output range of 1.5V to 15V, low voltage output levels, even at 5A current, lead to a much lower internal dissipation.

Getting Down to Zero

It is not usually inconvenient that the outputs of the circuits discussed above do not go down to zero, but if you are a purist who likes to see a complete range coverage on your power supply, a simple modification will put things right. The circuit arrangement to achieve this is shown in Fig. 2.10.

A small additional winding on the transformer of about 6V RMS is rectified by a single diode D4 and smoothed by capacitor C5. The current requirement is very small and a 470 uF capacitor is adequate. This then connects to the circuit systems of either Fig. 2.8 or Fig. 2.9; only the relevant connections are shown.

A 3V Zener diode D5 is suitable for this circuit, but the value of resistor R may need adjustment depending upon the actual d.c. level you get from the rectifier. The notes at the beginning of this article should enable you to do this without difficulty.

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