

The Valve Wizard

How to design valve guitar amplifiers!

Rectifiers

Bridge Rectifier

A bridge rectifier is used to rectify AC from a transformer with a single winding (i.e. no centre tap) or which conduct while the other two are switched off. Notice that all the diodes 'point' towards the positive output. You can either build a bridge rectifier from individual diodes or buy a single package. High-current bridge rectifiers are available (see the [smoothing](#) page). Under light loading, the DC output voltage will be equal to:

$$V_{dc} = 1.4 \times V_{rms}$$

However, at *full load* this will usually fall to about:

$$V_{dc} = 1.3 \times V_{rms}$$

The difference is due to the AC waveform being somewhat deformed under heavy loading (the peaks of the voltage (V_{rms}) will *also* sag as the load current increases. Typically, when the loading is light the transformer voltage is close to its 'advertised' value. Only when loaded to its full capacity does the AC transformer voltage fall to its advertised value).

For example, if you buy a transformer rated for "300Vac 200mA" then you can expect it to produce approximately 300Vrms. After rectification this will produce a DC voltage somewhere between:

$$1.4 \times 315V_{rms} = 441V_{dc}, \text{ to } 1.4 \times 330V_{rms} = 462V_{dc}$$

If you need better accuracy then you either need to measure the off-load transformer voltage by hand or use a multimeter. (Some reason they don't put off-load voltages on data sheets).

When the transformer is fully loaded to its 200mA rating the AC voltage will fall to the nominal value of 300Vrms. $1.3 \times 300V_{rms} = 390V_{dc}$

You will also lose two diode drops (about 1V each for power diodes), so the actual voltage may be close to 388Vdc. This is a voltage supply. However, on a low voltage supply (for DC heaters, say) the diode drop represents a significant percentage of the total voltage.

Don't forget about adding [fuses](#)!

Required Diode Ratings

The diodes in a bridge rectifier need to have an average forward current rating that exceeds the maximum average current. The 1N4007 is rated for 1 amp, which is far more than the maximum HT current in any guitar amp. However, diodes also have peak and surge current ratings, but you don't have to worry about these as they are always well in excess of what you need.

The diodes must also have a Reverse Repetitive Maximum (V_{rrm}) rating that exceeds the peak AC voltage. The peak AC voltage is equal to $1.4 \times V_{rms}$. The popular 1N4007 is rated for 1000V. This corresponds to an average mains voltage of about 230V. It's a good idea to allow for a variation in mains voltage, and knock off another 10% to allow for the transformer voltage being high if it is. The peak voltage is greater than 580Vrms. Fortunately, you don't see such high voltages in guitar amps. The story is different for valve amps.

Hybrid Bridge Rectifier

Ordinary full-wave valve rectifiers cannot be set up as a bridge since they have a single shared cathode. You can use two diodes to complete the bridge. Under light loading the DC output voltage will again be equal to:

$$V_{dc} = 1.4 \times V_{rms}$$

However, under heavier loading you will lose a lot more voltage across the valve diodes. As a rough approximation, the voltage drop will normally be between 1 and 1.2 times the advertised transformer voltage. You can read about more accurate methods for estimating the voltage drop.

Valve rectifiers can't handle the high current levels that silicon diodes can. For example, the GZ34 is rated for 100mA. The vast majority of valve guitar amps still use two-phase rectifiers even when they need more current, partly because a centre-tapped transformer makes it easy to generate a negative [bias supply](#).

Two-Phase Rectifier

The two-phase rectifier is used with a transformer that has a centre tap. Really it is a pair of half-wave rectifiers. One diode is on and the other is off. (Beginners sometimes call the two-phase rectifier a 'full-wave rectifier'. There are others.)

Vintage power supplies used two-phase rectifiers because it requires only two diodes which could be in a single package. The vast majority of valve guitar amps still use two-phase rectifiers even when they need more current, partly because a centre-tapped transformer makes it easy to generate a negative [bias supply](#).

Two full-wave rectifiers orientated in opposite directions creates a bipolar supply (positive and negative rails). This looks like a bridge rectifier (and you can indeed use a bridge rectifier diode package), but it is best to think of it as two separate rectifiers.

The same basic principles hold for the two-phase as for the bridge rectifier. Under light loading, the DC output voltage will be equal to:

$$V_{dc} = 1.4 \times V_{rms}$$

A bridge rectifier is used to rectify AC from a transformer with a single winding (i.e. no centre tap) or where one diode conducts while the other two are switched off. Notice that all the diodes 'point' towards the positive output. You can either build a bridge rectifier from individual diodes or buy a single package. High-current bridge rectifiers are available in TO-18 packages (see the [TO-18](#) page). The first capacitor in the power supply - the reservoir capacitor - will be charged up to the peak value of the AC (see the [smoothing](#) page). Under light loading, the DC output voltage will be equal to:

However, at *full load* this will usually fall to about:

The difference is due to the AC waveform being somewhat deformed under heavy loading (the peaks go down). The RMS voltage (V_{rms}) will *also* sag as the load current increases. Typically, when the loading is light the transformer voltage is close to its 'advertised' value. Only when loaded to its full capacity does the AC transformer voltage fall to its advertised value.

$$1.4 \times 315V_{rms} = 441V_{dc}, \text{ to } 1.4 \times 330V_{rms} = 462V_{dc}$$

If you need better accuracy then you either need to measure the off-load transformer voltage by hand or some reason they don't put off-load voltages on data sheets).

When the transformer is fully loaded to its 200mA rating the AC voltage will fall to the nominal value of 3V. $1.3 \times 300V_{rms} = 390V_{dc}$

You will also lose two diode drops (about 1V each for power diodes), so the actual voltage may be close to the voltage supply. However, on a low voltage supply (for DC heaters, say) the diode drop represents a significant fraction of the total voltage.

Don't forget about adding **fuses**!

The diodes in a bridge rectifier need to have an average forward current rating that exceeds the maximum HT current. The 1N4007 is rated for 1 amp, which is far more than the maximum HT current in any guitar amp. However, diodes also have peak and surge current ratings, but you don't have to worry about these as they are always well in excess of the maximum HT current.

The diodes must also have a Reverse Repetitive Maximum (V_{rrm}) rating that exceeds the peak AC voltage. The peak AC voltage is equal to $1.4 \times V_{rms}$. The popular 1N4007 is rated for 1000V. This corresponds to an average variation in mains voltage, and knock off another 10% to allow for the transformer voltage being high if the transformer is a bit off. The peak AC voltage is equal to $1.4 \times V_{rms}$. The popular 1N4007 is rated for 1000V. This corresponds to an average variation in mains voltage, and knock off another 10% to allow for the transformer voltage being high if the transformer is a bit off. The peak AC voltage is equal to $1.4 \times V_{rms}$. The popular 1N4007 is rated for 1000V. This corresponds to an average variation in mains voltage, and knock off another 10% to allow for the transformer voltage being high if the transformer is a bit off.

Ordinary full-wave valve rectifiers cannot be set up as a bridge since they have a single shared cathode. diodes to complete the bridge. Under light loading the DC output voltage will again be equal to:

$$V_{dc} = 1.4 \times V_{rms}$$

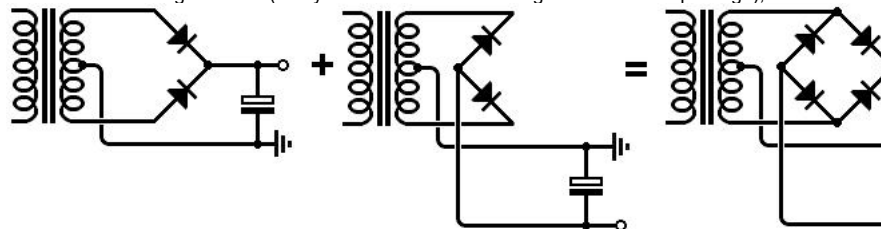
However, under heavier loading you will lose a lot more voltage across the valve diodes. As a rough approximation, the voltage drops across the diodes will normally be between 1 and 1.2 times the advertised transformer voltage. You can read about more accurate methods of determining the correct transformer voltage in the next section.

Valve rectifiers can't handle the high current levels that silicon diodes can. For example, the GZ34 is rated at 100mA and sometimes also need current-limiting resistance to protect them (see shortly) from excessive ripple and you only need one such resistor since it is shared by both valve diodes.

The two-phase rectifier is used with a transformer that has a centre tap. Really it is a pair of half-wave rectifiers. One diode is on and the other is off. (Beginners sometimes call the two-phase rectifier a 'full-wave rectifier'. It is not. There are others.)

Vintage power supplies used two-phase rectifiers because it requires only two diodes which could be in only one [heater](#) supply. The vast majority of valve guitar amps still use two-phase rectifiers even when it's partly because a centre-tapped transformer makes it easy to generate a negative [bias supply](#).

Two full-wave rectifiers orientated in opposite directions creates a bipolar supply (positive and negative this looks like a bridge rectifier (and you can indeed use a bridge rectifier diode package), but it is best



The same basic principles hold for the two-phase as for the bridge rectifier. Under light loading, the DC

$$V_{dc} = 1.4 \times V_{rms}$$

At full load this will usually fall to about:

$$V_{dc} = 1.3 \times V_{rms}$$

Remembering that the transformer voltage will also sag by 5 to 10% between no-load and full load.

Required Diode Ratings

The diodes in a two-phase rectifier need to have an average forward current rating that comfortably exceeds the average current of the transformer. Again, you don't have to worry about peak and surge current ratings, provided the diodes are modern silicon diodes.

The diodes must also have a Reverse Repetitive Maximum (V_{rrm}) rating that exceeds the **peak-to-peak** AC voltage of the bridge rectifier. This is equal to $2.8 \times V_{rms}$. A 1N4007 is rated for 1000V. This corresponds to an AC voltage of about 290Vrms. In other words, we should not use a diode with a lower rating.

What if the transformer voltage is higher than this? The best option is to buy diodes with higher voltage rating. A classic alternative is to use two or more diodes in series, so they share the burden. However, this is not a good idea as the diodes will not share the voltage equally. This can be done by adding a 10nF to 100nF capacitor in parallel with each diode. However, it is a lot easier to find 1kV-rated ceramic capacitors than 1kV-rated resistors.

Valve Rectifiers

Ordinary valve rectifiers contain two diodes which share the same cathode (and heater), in one bottle. The maximum RMS transformer voltage that the valve can withstand in an ordinary two-phase rectifier circuit is given in modern data sheets. The GZ34 data sheet quotes 550-0-550Vrms (although personally I wouldn't trust a valve rectifier). The data sheet will also quote the maximum average DC current that the valve can handle. For the GZ34 the maximum average DC current is 100mA, but the limit is reduced for higher transformer voltages. The limit is 100mA at 550V, but it is reduced to 50mA at 650V. The limit is 25mA at 750V. The limit is 10mA at 850V. The limit is 5mA at 950V. The limit is 2.5mA at 1050V. The limit is 1.25mA at 1150V. The limit is 0.625mA at 1250V. The limit is 0.3125mA at 1350V. The limit is 0.15625mA at 1450V. The limit is 0.078125mA at 1550V. The limit is 0.0390625mA at 1650V. The limit is 0.01953125mA at 1750V. The limit is 0.009765625mA at 1850V. The limit is 0.0048828125mA at 1950V. The limit is 0.00244140625mA at 2050V. The limit is 0.001220703125mA at 2150V. The limit is 0.0006103515625mA at 2250V. The limit is 0.00030517578125mA at 2350V. The limit is 0.000152587890625mA at 2450V. The limit is 7.62939453125e-05mA at 2550V. The limit is 3.814697265625e-05mA at 2650V. The limit is 1.9073486328125e-05mA at 2750V. The limit is 9.5367431640625e-06mA at 2850V. The limit is 4.76837158203125e-06mA at 2950V. The limit is 2.384185791015625e-06mA at 3050V. The limit is 1.1920928955078125e-06mA at 3150V. The limit is 5.9604644775390625e-07mA at 3250V. The limit is 2.9802322387695312e-07mA at 3350V. The limit is 1.4901161193847656e-07mA at 3450V. The limit is 7.450580596923828e-08mA at 3550V. The limit is 3.725290298461914e-08mA at 3650V. The limit is 1.862645149230957e-08mA at 3750V. The limit is 9.313225746154784e-09mA at 3850V. The limit is 4.656612873077392e-09mA at 3950V. The limit is 2.328306436538696e-09mA at 4050V. The limit is 1.164153218269348e-09mA at 4150V. The limit is 5.82076609134674e-10mA at 4250V. The limit is 2.91038304567337e-10mA at 4350V. The limit is 1.455191522836685e-10mA at 4450V. The limit is 7.275957614183425e-11mA at 4550V. The limit is 3.637978807091712e-11mA at 4650V. The limit is 1.818989403545856e-11mA at 4750V. The limit is 9.09494701772928e-12mA at 4850V. The limit is 4.54747350886464e-12mA at 4950V. The limit is 2.27373675443232e-12mA at 5050V. The limit is 1.13686837721616e-12mA at 5150V. The limit is 5.6843418860808e-13mA at 5250V. The limit is 2.8421709430404e-13mA at 5350V. The limit is 1.4210854715202e-13mA at 5450V. The limit is 7.105427357601e-14mA at 5550V. The limit is 3.5527136788005e-14mA at 5650V. The limit is 1.7763568394002e-14mA at 5750V. The limit is 8.881784197001e-15mA at 5850V. The limit is 4.4408920985005e-15mA at 5950V. The limit is 2.2204460492502e-15mA at 6050V. The limit is 1.1102230246251e-15mA at 6150V. The limit is 5.5511151231255e-16mA at 6250V. The limit is 2.7755575615627e-16mA at 6350V. The limit is 1.3877787807813e-16mA at 6450V. The limit is 6.9388939039065e-17mA at 6550V. The limit is 3.4694469519532e-17mA at 6650V. The limit is 1.7347234759766e-17mA at 6750V. The limit is 8.673617379883e-18mA at 6850V. The limit is 4.3368086899415e-18mA at 6950V. The limit is 2.1684043449707e-18mA at 7050V. The limit is 1.0842021724854e-18mA at 7150V. The limit is 5.421010862427e-19mA at 7250V. The limit is 2.7105054312135e-19mA at 7350V. The limit is 1.3552527156067e-19mA at 7450V. The limit is 6.7762635780335e-20mA at 7550V. The limit is 3.3881317890167e-20mA at 7650V. The limit is 1.6940658945084e-20mA at 7750V. The limit is 8.470329472542e-21mA at 7850V. The limit is 4.235164736271e-21mA at 7950V. The limit is 2.1175823681355e-21mA at 8050V. The limit is 1.0587911840677e-21mA at 8150V. The limit is 5.2939559203385e-22mA at 8250V. The limit is 2.6469779601692e-22mA at 8350V. 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The limit is 3.1554436208835e-29mA at 10650V. The limit is 1.5777218104417e-29mA at 10750V. The limit is 7.8886090522085e-30mA at 10850V. The limit is 3.9443045261042e-30mA at 10950V. The limit is 1.9721522630521e-30mA at 11050V. The limit is 9.8607613152605e-31mA at 11150V. The limit is 4.9303806576302e-31mA at 11250V. The limit is 2.4651903288151e-31mA at 11350V. The limit is 1.2325951644076e-31mA at 11450V. The limit is 6.162975822038e-32mA at 11550V. The limit is 3.081487911019e-32mA at 11650V. The limit is 1.5407439555095e-32mA at 11750V. The limit is 7.7037197775475e-33mA at 11850V. The limit is 3.8518598887737e-33mA at 11950V. The limit is 1.9259299443869e-33mA at 12050V. The limit is 9.6296497219345e-34mA at 12150V. The limit is 4.8148248609672e-34mA at 12250V. The limit is 2.4074124304836e-34mA at 12350V. The limit is 1.2037062152418e-34mA at 12450V. The limit is 6.018531076209e-35mA at 12550V. The limit is 3.0092655381045e-35mA at 12650V. 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The limit is 7.7787690973235e-61mA at 21150V. The limit is 3.8893845486617e-61mA at 21250V. The limit is 1.9446922743309e-61mA at 21350V. The limit is 9.7234613716545e-62mA at 21450V. The limit is 4.8617306858272e-62mA at 21550V. The limit is 2.4308653429136e-62mA at 21650V. The limit is 1.2154326714568e-62mA at 21750V. The limit is 6.077163357284e-63mA at 21850V. The limit is 3.038581678642e-63mA at 21950V. The limit is 1.519290839321e-63mA at 22050V. The limit is 7.596454196605e-64mA at 22150V. The limit is 3.7982270983025e-64mA at 22250V. The limit is 1.8991135491512e-64mA at 22350V. The limit is 9.495567745756e-65mA at 22450V. The limit is 4.747783872878e-65mA at 22550V. The limit is 2.373891936439e-65mA at 22650V. The limit is 1.1869459682195e-65mA at 22750V. The limit is 5.9347298410975e-66mA at 22850V. The limit is 2.9673649205487e-66mA at 22950V. The limit is 1.4836824602744e-66mA at 23050V. The limit is 7.418412301372e-67mA at 23150V. The limit is 3.709206150686e-67mA at 23250V. The limit is 1.854603075343e-67mA at 23350V. The limit is 9.273015376715e-68mA at 23450V. The limit is 4.6365076883575e-68mA at 23550V. The limit is 2.3182538441787e-68mA at 23650V. The limit is 1.1591269220894e-68mA at 23750V. The limit is 5.795634610447e-69mA at 23850V. The limit is 2.8978173052235e-69mA at 23950V. The limit is 1.4489086526117e-69mA at 24050V. The limit is 7.2445432630585e-70mA at 24150V. The limit is 3.6222716315292e-70mA at 24250V. The limit is 1.8111358157646e-70mA at 24350V. The limit is 9.055679078823e-71mA at 24450V. The limit is 4.5278395394115e-71mA at 24550V. The limit is 2.2639197697057e-71mA at 24650V. The limit is 1.1319598848529e-71mA at 24750V. The limit is 5.6597994242645e-72mA at 24850V. The limit is 2.8298997121322e-72mA at 24950V. The limit is 1.4149498560661e-72mA at 25050V. The limit is 7.0747492803305e-73mA at 25150V. The limit is 3.5373746401652e-73mA at 25250V. The limit is 1.7686873200826e-73mA at 25350V. The limit is 8.843436600413e-74mA at 25450V. The limit is 4.4217183002065e-74mA at 25550V. The limit is 2.2108591501032e-74mA at 25650V. The limit is 1.1054295750516e-74mA at 25750V. The limit is 5.527147875258e-75mA at 25850V. The limit is 2.763573937629e-75mA at 25950V. The limit is 1.3817869688145e-75mA at 26050V. The limit is 6.9089348440725e-76mA at 26150V. The limit is 3.4544674220362e-76mA at 26250V. The limit is 1.7272337110181e-76mA at 26350V. The limit is 8.6361685550905e-77mA at 26450V. The limit is 4.3180842775452e-77mA at 26550V. The limit is 2.1590421387726e-77mA at 26650V. The limit is 1.0795210693863e-77mA at 26750V. The limit is 5.3976053469315e-78mA at 26850V. The limit is 2.6988026734658e-78mA at 26950V. The limit is 1.3494013367329e-78mA at 27050V. The limit is 6.7470066836645e-79mA at 27150V. The limit is 3.3735033418322e-79mA at 27250V. The limit is 1.6867516709161e-79mA at 27350V. The limit is 8.4337583545805e-80mA at 27450V. The limit is 4.2168791772902e-80mA at 27550V. The limit is 2.1084395886451e-80mA at 27650V. The limit is 1.0542197943226e-80mA at 27750V. The limit is 5.271098971613e-81mA at 27850V. The limit is 2.6355494858065e-81mA at 27950V. The limit is 1.3177747429032e-81mA at 28050V. The limit is 6.588873714516e-82mA at 28150V. The limit is 3.294436857258e-82mA at 28250V. The limit is 1.647218428629e-82mA at 28350V. The limit is 8.236092143145e-83mA at 28450V. The limit is 4.1180460715725e-83mA at 28550V. The limit is 2.0590230357862e-83mA at 28650V. The limit is 1.0295115178931e-83mA at 28750V. The limit is 5.1475575894655e-84mA at 28850V. The limit is 2.5737787947327e-84mA at 28950V. The limit is 1.2868893973664e-84mA at 29050V. The limit is 6.434446986832e-85mA at 29150V. The limit is 3.217223493416e-85mA at 29250V. The limit is 1.608611746708e-85mA at 29350V. The limit is 8.04305873354e-86mA at 29450V. The limit is 4.02152936677e-86mA at 29550V. The limit is 2.010764683385e-86mA at 29650V. The limit is 1.0053823416925e-86mA at 29750V. The limit is 5.0269117084625e-87mA at 29850V. The limit is 2.5134558542312e-87mA at 29950V. The limit is 1.2567279271156e-87mA at 30050V. The limit is 6.283639635578e-88mA at 30150V. The limit is 3.141819817789e-88mA at 30250V. The limit is 1.5709099088945e-88mA at 30350V. The limit is 7.8545495444725e-89mA at 30450V. The limit is 3.9272747722362e-89mA at 30550V. The limit is 1.9636373861181e-89mA at 30650V. The limit is 9.8181869305905e-90mA at 30750V. The limit is 4.9090934652952e-90mA at 30850V. The limit is 2.4545467326476e-90mA at 30950V. The limit is 1.2272733663238e-90mA at 31050V. The limit is 6.136366831619e-91mA at 31150V. The limit is 3.0681834158095e-91mA at 31250V. The limit is 1.5340917079047e-91mA at 31350V. The limit is 7.6704585395235e-92mA at 31450V. The limit is 3.8352292697617e-92mA at 31550V. The limit is 1.9176146348809e-92mA at 31650V. The limit is 9.5880731744045e-93mA at 31750V. The limit is 4.7940365872022e-93mA at 31850V. The limit is 2.3970182936011e-93mA at 31950V. The limit is 1.1985091468006e-93mA at 32050V. The limit is 5.992545734003e-94mA at 32150V. The limit is 2.9962728670015e-94mA at 32250V. The limit is 1.4981364335008e-94mA at 32350V. The limit is 7.490682167504e-95mA at 32450V. The limit is 3.745341083752e-95mA at 32550V. The limit is 1.872670541876e-95mA at 32650V. The limit is 9.36335270938e-96mA at 32750V. The limit is 4.68167635469e-96mA at 32850V. The limit is 2.340838177345e-96mA at 32950V. The limit is 1.1704190886725e-96mA at 33050V. The limit is 5.8520954433625e-97mA at 33150V. The limit is 2.9260477216812e-97mA at 33250V. The limit is 1.4630238608406e-97mA at 33350V. The limit is 7.315119304203e-98mA at 33450V. The limit is 3.6575596521015e-98mA at 33550V. The limit is 1.8287798260508e-98mA at 33650V. The limit is 9.143899130254e-99mA at 33750V. The limit is 4.571949565127e-99mA at 33850V. The limit is 2.2859747825635e-99mA at 33950V. The limit is 1.1429873912817e-99mA at 34050V. The limit is 5.7149369564085e-100mA at 34150V. The limit is 2.8574684782042e-100mA at 34250V. The limit is 1.4287342391021e-100mA at 34350V. The limit is 7.1436711955105e-101mA at 34450V. The limit is 3.5718355977552e-101mA at 34550V. The limit is 1.7859177988776e-101mA at 34650V. The limit is 8.929588994388e-102mA at 34750V. The limit is 4.464794497194e-102mA at 34850V. The limit is 2.232397248597e-102mA at 34950V. The limit is 1.1161986242985e-102mA at 35050V. The limit is 5.5809931214925e-103mA at 35150V. The limit is 2.7904965607462e-103mA at 35250V. The limit is 1.3952482803731e-103mA at 35350V. The limit is 6.9762414018655e-104mA at 35450V. The limit is 3.4881207009327e-104mA at 35550V. The limit is 1.7440603504664e-104mA at 35650V. The limit is 8.720301752332e-105mA at 35750V. The limit is 4.360150876166e-105mA at 35850V. The limit is 2.180075438083e-105mA at 35950V. The limit is 1.0900377190415e-105mA at 36050V. The limit is 5.4501885952075e-106mA at 36150V. The limit is 2.7250942976037e-106mA at 36250V. The limit is 1.3625471488019e-106mA at 36350V. The limit is 6.8127357440095e-107mA at 36450V. The limit is 3.4063678720047e-107mA at 36550V. The limit is 1.7031839360024e-107mA at 36650V. The limit is 8.515919680012e-108mA at 36750V. The