Virtual Ground (regulated!) - and Rail Splitter Circuits!

Sonic Wonder · Mar 7, 2013

Mar 7, 2013 at 8:53 PM | Thread Starter | Post #1 of 125

Sonic Wonder
Member of the Trade: Goldpoint Level Controls

Joined: Dec 6, 2010
Posts: 44
Likes: 12

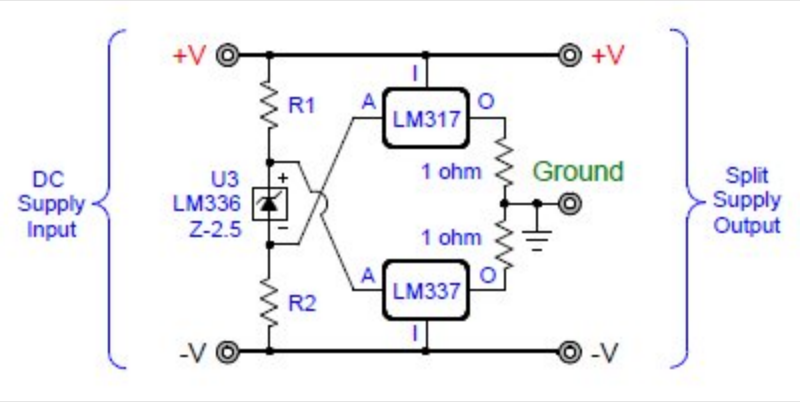
Virtual Ground Circuits from Voltage Regulators

These circuits enable a two conductor DC power supply, DC wall adapter, or a battery to function as a split supply with a three conductor output (i.e., positive, negative AND ground). This sort of circuit is called a "Virtual Ground" and/or a "Rail Splitter".

The inexpensive LM317/LM337 circuits below are capable of delivering up to +/-18V at more than 1.5 amps, 75 times the current of a TLE2426 rail splitter chip. The DC Supply Input can be [illegible] can handle a watt or more without heatsin[illegible]: Output = +/- 9VDC @ 50mA.

Both the LM317/LM337 **Basic** and **VG1 Circuits** below draw quiescent current of only 4 or 5

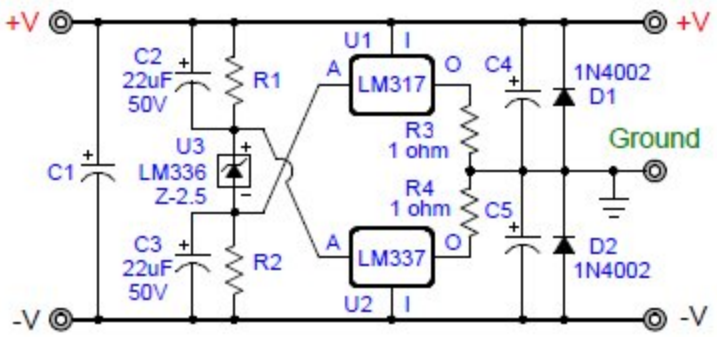
milliamps - great for battery use!



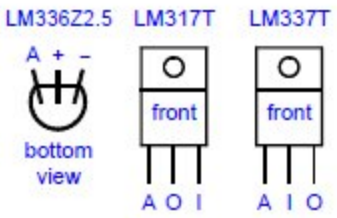
Basic Circuit with Adjustable Voltage Regulators

How it works: The LM317 (positive) and LM337 (negative) adjustable voltage regulators operate in parallel with their outputs tied together through small resistors to create a virtual ground. The LM336BZ-2.5V voltage reference compensates for the LM317's (+1.25V) internal reference and the LM337's (-1.25V) internal reference. So when the LM317/LM337 adjust pins are connected inside the R1/R2 voltage divider as shown, each voltage regulator output voltage becomes 1/2 of whatever the rail-to-rail voltage happens to be. Thus, together, the voltage regulators "split the rails", creating a "rock solid" virtual ground.

Although a simple and inexpensive virtual ground solution, some audio designs will sound better when using it. For example, when powering a headphone amplifier with this circuit the bass notes may sound considerably clearer and more life like. The reason for this unusually good performance may be that the voltage regulators create an "unbudgable ground" - holding the ground point in place very firmly compared to other circuits, *virtual or not.*



DC Supply	As Split Supply	R1, R2
7.5 VDC	+/- 3.75V	866
9 VDC	+/- 4.5V	1.62K
12 VDC	+/- 6V	2.32K
18 VDC	+/- 9V	3.90K
24 VDC	+/- 12V	5.36K
30 VDC	+/- 15V	6.81K
36 VDC	+/- 18V	8.00K



VG1 Virtual Ground Circuit

All parts for these various circuits are easy to find - and can be ordered from Mouser.com or Digikey.com.
Resistor and capacitor values are not critical - you can substitute near or alternate values.

VG1 Parts List:
R1, R2 - (see chart above) - ** dependent on DC Supply voltage
R3, R4 - 0.75 ohm to 1 ohm - 1/2W or 1W
C1 - 470uF/50V** - Panasonic P/N EEU-FM1H471
C2, C3 - 22uF/50V - Panasonic P/N EEU-FM1H220
C4, C5 - 1000uF/25V** - Panasonic P/N EEU-FM1E102
D1, D2 - 1N4002 - (or similar)
U1 - LM317TG - TO-220 package (On Semiconductor)
U2 - LM337TG - TO-220 package (On Semiconductor)
U3 - LM336Z25 - 2.5V voltage reference (Fairchild)

NOTES:
1) The values for R1 and R2 shown in the chart above yield about 2mA of current through the LM336BZ-2.5V. The formula used to determine the values is: R1 or R2 = (Vrr - 2.5) / .002 / 2 For example with a 12V power supply:
(12 - 2.5) / .002 / 2 = 2375. So use a 2.37K resistor for R1 & R2. Also: I = (DC supply - 2.5) / (R1+R2).
2) The adjust pin on the LM336 voltage reference is not used, so leave it unconnected; only connect the 3 leads to the pins.

3) When using an AC powered DC supply, "proper power supply design" recommends C1, C2, C3, C4, C5, D1,
and D2 be installed. But when using a 9V battery for a low current application you can skip installing C1, C2, C3, C4, C5, D1, and D2 altogether - and simply use the Basic Circuit as shown at the top of the page!

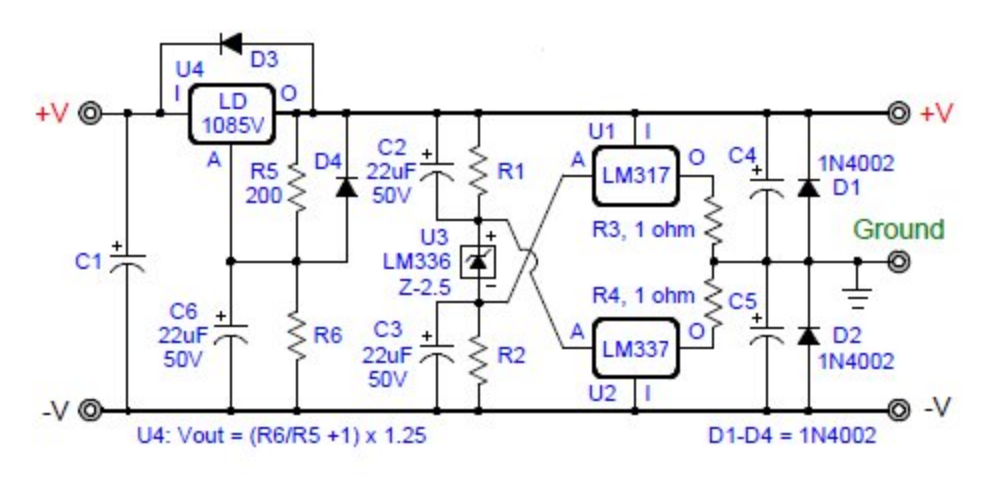
4) A "no load test" of the VG1 Circuit with an Eveready Gold 9V alkaline battery (it actually measured 9.3V) and 1.62K R1/R2 resistors yielded the following results: The ground remained perfectly centered (+/- 4.65V), while the total current being drawn was only about 4.5mA. This shows that with 2mA through the voltage divider section, the rest of the circuit was consuming only an additional 2.5mA. And that says if we add a 20mA load to the output, and if the 9V battery could supply 350mAH to 550mAH, the battery would last about 12 to 20 hours or more of continuous use.

5) You may be able to reduce the size of the 1 ohm output resistors to 0.75 ohm or less by minimizing the current through the LM336BZ-2.5 (by using larger value R1/R2 resistors). A small ground point voltage offset, if it happens, is usually acceptable. An LM336BZ-2.5V can operate with 0.5mA to 10mA of forward current.

6) The LM317/LM337s require about 1.5 to 6mA of load current to maintain regulation - and they will continue to regulate with an Input voltage as low as 3.7 volts.

7) Increasing the size of C1, C4 and C5 can be sonically advantageous. They can be 220uF to 12,000uF, (or as much as you can afford or have room for.) Generally, electrolytic capacitor rated voltages should be at least 30 percent higher than whatever their power supply voltage is.

If you are using the virtual ground with an audio circuit and your DC power supply has an AC source, adding another voltage regulator in front of the rail splitter section can further improve sound quality. An LD1085V, 3A LDO (Low Dropout Voltage) voltage regulator sounds better for this purpose than others I've compared by listening tests. When using this additional voltage regulator (U4), be sure that your DC Supply (input voltage) is always 1.5V (or more) higher than your desired LM317/LM337 rail-to-rail voltage - because the LD1085V needs at least 1.3V across it to stay in regulation. note: The maximum DC Input Voltage for a LD1085V is 30VDC. (This three regulator circuit draws twice the current (or more) compared to the VG1 Circuit, so it may not be as well suited for battery use.)



Enhanced Virtual Ground for Low Noise Audio Applications

Development Credits:

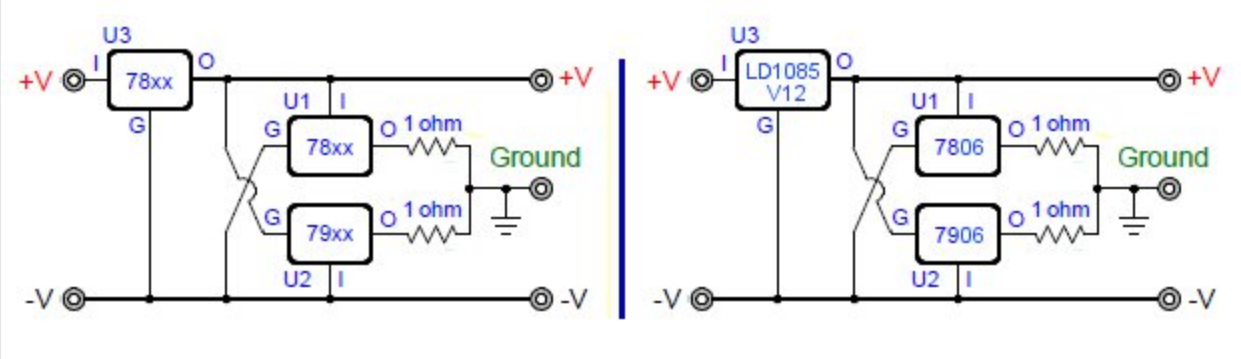
Arn Roatcap: (Founder of Goldpoint Level Controls www.goldpt.com) - Prior to the LM317/LM337 circuits, built virtual grounds using fixed value voltage regulators (see circuits below). Integrated new ideas, constructed all of the prototypes and performed extensive listening tests.

John Broskie: (GlassWare www.glass-ware.com and Tube CAD www.tubecad.com) - Suggested many virtual ground circuit ideas from 2006 to 2013. Directed the use of 1 ohm output resistors on the rail splitter voltage regulators.

Kim Laroux: (www.head-fi.org forums) - Had the ingenious idea to offset the LM317/LM337 internal voltage references by using a single 2.5V zener diode.

KT88: (www.head-fi.org forums) - Contributed the key idea to use a LM336 voltage reference, instead of a zener diode, to compensate the LM317/LM337 internal voltage references.

Shown here because of their simplicity, the following two circuits use fixed value voltage regulators to create a virtual ground. They MUST have a third voltage regulator (U3) to keep the U1/U2 rail-to-rail voltage from going up or down. Some possible fixed value U3/U1/U2 voltage regulator combinations are:
[+10V, +5V, -5V], [+12V, +6V, -6V], [+18V, +9V, -9V], [+24V, +12V, -12V].



Basic Circuit with Fixed Value Voltage Regulators

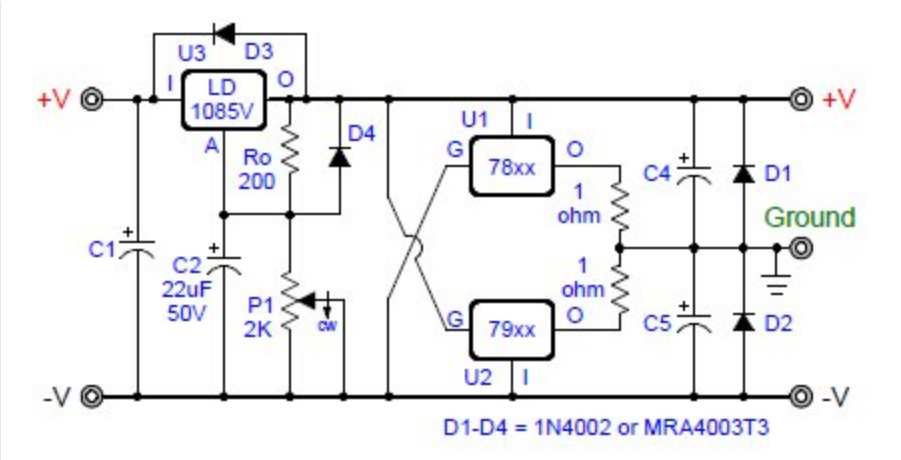
When a "complimentary pair" of fixed value voltage regulators are used to create a virtual ground this way, the absolute values of their output voltages are each 1/2 of the rail-to-rail voltage. And the rail-to-rail voltage must remain at a set, unvarying voltage which is the sum of the absolute values of both of the rail splitter regulators output voltages. You therefore must use the third voltage regulator (U3).

Without U3, the rail-to-rail voltage could go up or down with load changes, battery drain, as the AC line voltage went up or down, etc. And if the rail-to-rail voltage went up or down, the two fixed value regulators would begin to compete with each other to establish different ground points, one or both constantly wasting current (and possibly overheating or burning up). So U3 is essential to ensure that fixed value regulators U1 and U2 do not interact with each other.

The output of U3 needs to be close to the value of U1 added to the absolute value of U2. As the output voltages of common fixed value voltage regulators vary by as much as 5% from their rated values, buying extra ones and pre-testing them to find their actual output voltages lets you select them to meet the desired **U3 = U1 + |U2|** .

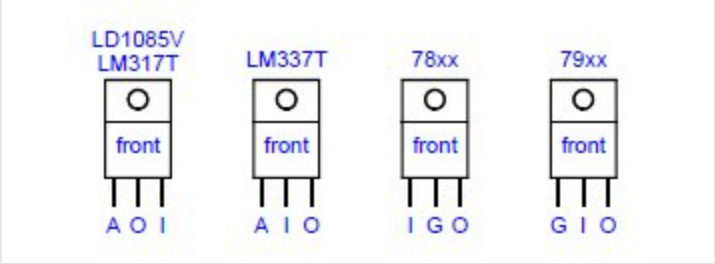
Because U3 consumes twice as much power compared to U1 or U2, a good choice for it is an adjustable voltage regulator such as 3 amp LD1085V or a 5 amp LD1084V. This also gives the advantage of allowing the use of any value fixed voltage regulators for U1 and U2. With an adjustable output voltage regulator for U3, the virtual ground does not have to be centered between the rails. For example, you could make a +5V/-12V split supply by setting the adjustable voltage regulator U3 to 17V, selecting U1 as a 7805 (+5V), and U2 as a 7912 (-12V).

However, it is still a good idea to pre-test U1 and U2 to find their actual output voltages - then adjust the output voltage of U3 (via P1) to meet the the desired U3 = U1 + |U2| before powering up.



Fixed Value Voltage Regulators for Rail Splitter Section Only

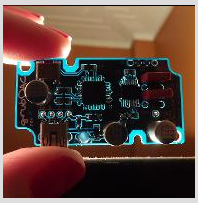
An alternate way of setting P1 above to the correct voltage is as follows:
1) Insert an ammeter between the +V or -V input and the DC power supply.
2) Set the ammeter on a high scale, such as the 10A scale.
3) Turn on the DC power supply.
4) Quickly adjust P1 to give the lowest quiescent current. If it is below 2A, switch to the 2A scale. If it is then seen to be below 200mA, (you're aiming for perhaps 5mA to 50mA), switch to the 200mA scale.
5) Then use a voltmeter to test the output voltages relative to the ground point.



A 3 terminal fixed value voltage regulator rated for 12V could operate as low as 11.5V or as high as 12.5V.
The LD1085V is an inexpensive ($1), adjustable (1.25V to 28.5V), 3A positive voltage regulator.

The 78xx/79xx, LM317/LM337 voltage regulators are all commonly available and inexpensive (about $0.25).

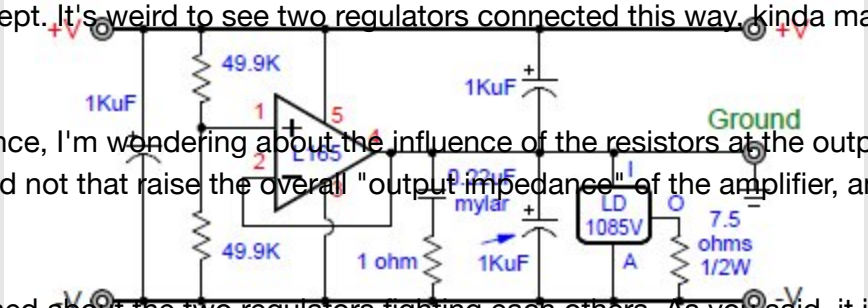
Here is a rail splitter virtual ground circuit which "works", but is a second or third choice sonically. While it does center the virtual ground point perfectly, it requires a constant current source (the LD1085V) hung on its output to sound any good when powering audio circuits. Furthermore, both



KimLaroux
1000+ Head-Fier

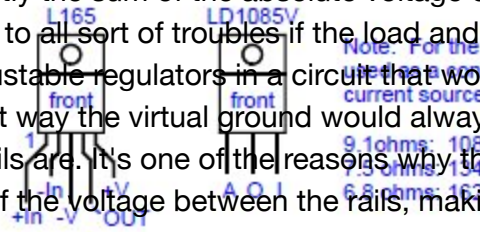
Joined: Aug 2, 2011
Posts: 1,090
Likes: 69

Interesting concept. It's weird to see two regulators connected this way, kinda makes your head spin.



As for performance, I'm wondering about the influence of the resistors at the output of the regulators. Would not that raise the overall "output impedance" of the amplifier, and lower overall performances?

I'm also concerned about the two regulators fighting each others. As you said, it is very important that the input voltage be exactly the sum of the absolute voltage output of each linear regs. It just seems unsafe.. and open to all sort of troubles if the load and source is variable. I bet it would be possible to use adjustable regulators in a circuit that would compensate for the varying loads and input voltages. That way the virtual ground would always be halfway between the rails, no matter what voltage the rails are. It's one of the reasons why the rail splitter circuit is so popular: it works regardless of the voltage between the rails, making it usable with batteries.



Audio-gd NFB-12 ~ DIY Tube hybrid ~ Carrie USB DAC/AMP ~ Modified Shure SRH440 ~ AKG Q701 ~ Sennheiser
Power Opamp Rail Splitter

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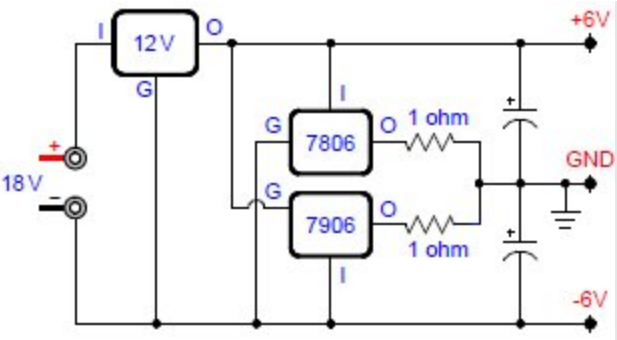
Sonic Wonder
Member of the Trade: Goldpoint Level Controls

Joined: Dec 6, 2010
Posts: 44
Likes: 12

Yes, the resistors on the outputs of the two fixed value voltage regulators DO raise the output impedance, but not by very much. They serve to "take up the slack" of minimal output voltage differences between the two complimentary fixed regulators. But the regulators do not fight each other. (The minimal amount they "disagree" is swamped by the use of the output resistors.) I have had no problems at all using this ground. This virtual ground sounds great - because it is regulated.



The adjustable pre-regulator from the original circuit (beginning of thread) could possibly be replaced by a single fixed value regulator, so no potentiometer adjusting would be necessary. In that case, all three regulators should be pre-tested and selected so that U2's output voltage is close to the absolute value of U3's output voltage and U1 is close to U2 + |U3|. If necessary, R2 and R3 could be increased from 1 ohm to 2 or 3 ohms.

But you are right - I would really like a way to use adjustable regulators where they "self adjust" to 1/2 of whatever the rail-to-rail voltage is. Anyone want to design that?

Mar 8, 2013 at 4:48 PM — Post #4 of 125

tangent

Top Mall-Fi poster. The T in META42.
Formerly with Tangentsoft Parts Store

Joined: Sep 27, 2001
Posts: 5,969
Likes: 56

Quote:

> kimlaroux said:
>
> As for performance, I'm wondering about the influence of the resistors at the output of the regulators. Would not that raise the overall "output impedance" of the amplifier, and lower overall performances?

That's what those monster 10 mF caps are doing on the output: reducing the virtual ground impedance to near-zero.

You can think of the 78xx and 79xx in this circuit as doing nothing more than providing the tiny trickle currents to the big rail capacitors needed to maintain the virtual ground voltage.

A particularly nice feature of this circuit is that it effectively hides the dropout voltage of the 78xx and 79xx in the half-supply drops they are there to provide anyway. I suspect this circuit wouldn't work well with low-voltage versions of these regulators because there isn't enough voltage room for the dropouts to hide in.

The 2V drop across the preregulator hurts enough that I don't think I'd want to use this in a

battery powered circuit. The inability to get below a 12V supply also argues against using this in battery-powered amplifiers. That means either a wasteful 12-cell pack at minimum, since that lets you drain the pack to 1V per cell, getting maybe 80-90% of the energy out of the battery. If you want to get to 0.8V per cell to fully use the energy in the battery, you need 15 cells at minimum.

I don't mean to dismiss this circuit. This idea of using 78xx regulators to provide the midpoint of a vground supply has been kicking around as long as I've been involved in audio DIY — about a decade now! — and it's probably older than that. This is the first implementation I've seen that actually makes sense.

With your permission, goldpoint, I may include this in an update to my vgrounds article.

"Give a man a fish and he eats for a day. Teach a man to fish and he knows what tackle to buy."

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Mar 8, 2013 at 9:21 PM Post #5 of 125

Sonic Wonder
Member of the Trade: Goldpoint Level Controls

Joined: Dec 6, 2010
Posts: 44
Likes: 12

Hello Tangent,

The TO-220 78xx/79xx devices actually heat up if you are drawing much more then 50mA to 100mA. They DO pass current. They actively hold that ground point in place under load, and **solidly**. I believe it sounds so good with my headphone amp circuit mainly because the ground is a fairly STIFF = a **regulated** virtual ground. It does sound better, by far, than any other virtual ground I've tried. But yes, although the big output caps are not essential, I believe that they do make this virtual ground sound better. Actually, in my headphone amp circuit they're each 11,700uF (3 x 3,900uF, 16V Panasonic low ESR **FM series** caps).

I bet the circuit would work just fine with any complimentary set of Pos/Neg regulators - you would only need to adjust the rail-to-rail voltage appropriately via an adjustable regulator in front. For +/-3.3V regulators, the pre-regulator would be set to about 6.6V of course - that should work just fine. (I am guessing that you could even use non-complimentary regulators. For instance, if you used a +5V with a -12V, you would adjust the pre-regulator to 17V. In that case the virtual ground would not be in the middle of the rails and you would have a +5/-12 power supply.)

TO-220 or TO-247 package by one of the custom linear I/C companies. That would be so slick! It would be a 3-terminal "power rail splitter virtual ground" - and be so handy. Like a beefed up Texas Instruments TLE2426. One other thing I would like about such a device is that its internal regulators would not draw much battery current in quiescent mode [little or no load current] - unlike many other virtual ground circuits.)

I have seen your article many times when searching for virtual ground ideas - and I say "yes" - you should include this one there too.

By the way, I tried a similar back-to-back complementary regulators circuit work a few years ago - but could not get it to work. The secret to why this circuit DOES work is the pre-regulator to adjust the rail-to-rail voltage and use of those 1 ohm output resistors on the fixed voltage regulators. The 1 ohm value can be lowered or increased as needed.

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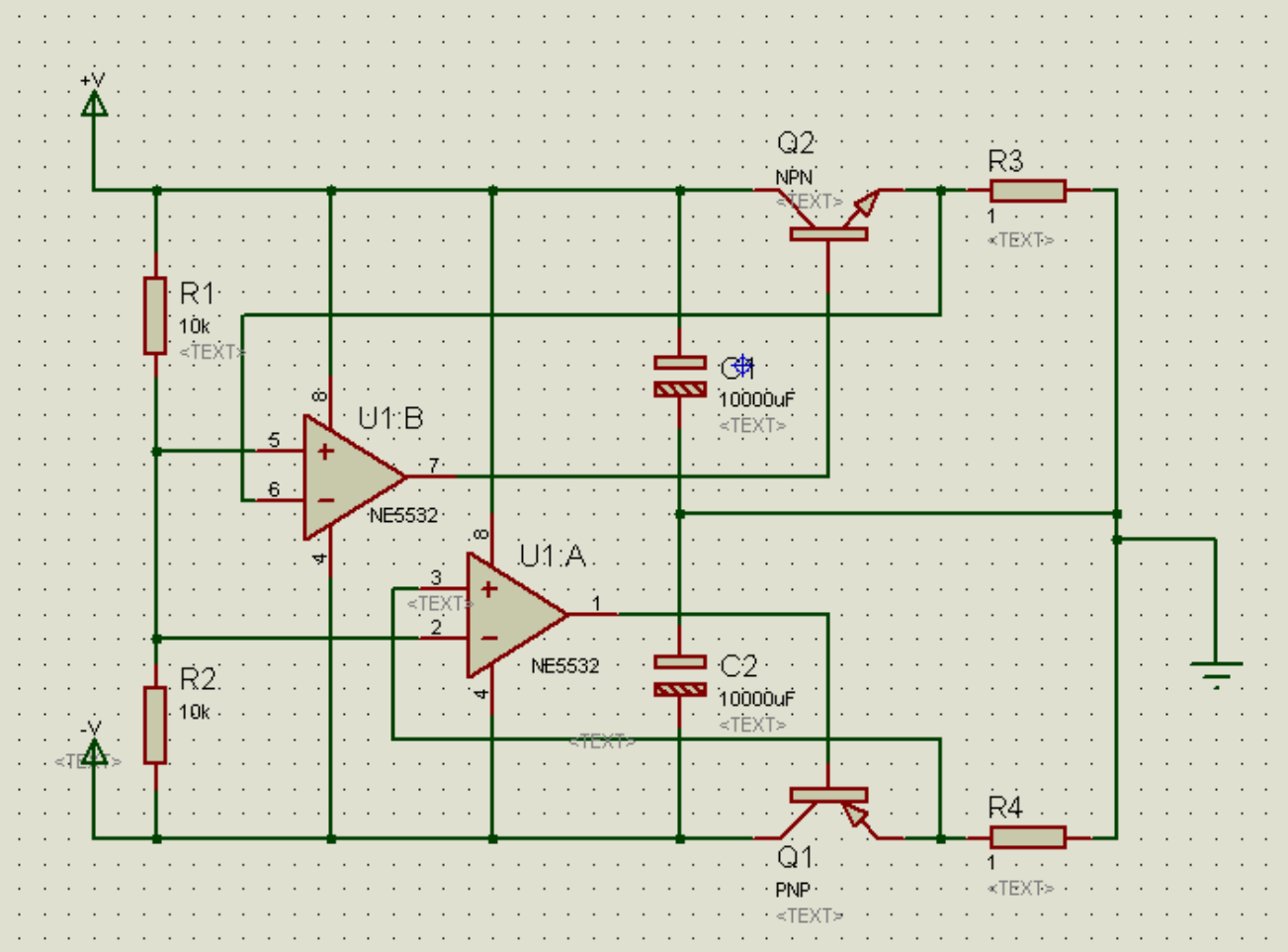
Mar 8, 2013 at 11:39 PM Post #6 of 125

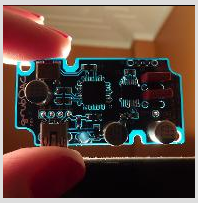
wakibaki
1000+ Head-Fier

Joined: May 26, 2011
Posts: 1,088
Likes: 68

Somebody else look at this and tell me if it works, it's 4:25 am here:-



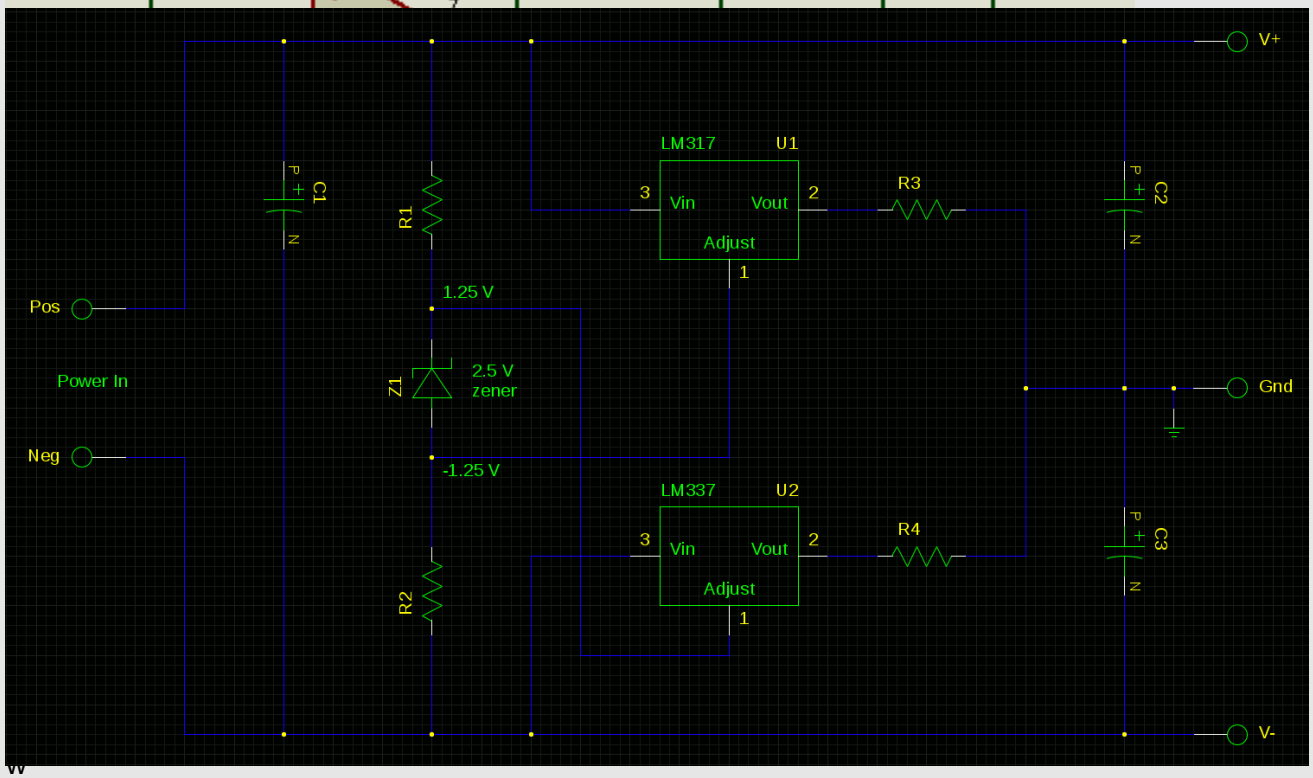
Maybe you could even get away with this:-



KimLaroux
1000+ Head-Fier

Joined: Aug 2, 2011
Posts: 1,090
Likes: 69

This schematic came to me in the middle of the night. I suppose insomnia is good for something after all...



The idea is simple:
Mike zerO Romeo Oscar November
http://wakibaki.com
You can adjust an LM317 simply by driving a voltage to its adjust pin. The output is always 1.25 V higher than the voltage at the adjust pin. If you ground the adjust pin, you have 1.25 V out. If you drive -1.25 V into the adjust pin, you get 0 V out. This is because the regulator has an internal reference voltage of 1.25 V that shows up between Adjust and Out. Same for an LM337, just reverse the signs.

R1 and R2 are your voltage divider that sets your 0V virtual ground. Since each adjust pins needs a max of 100µA, we can assume the voltage divider is pretty much unaffected by the loads on the PSU.

The 2.5 V zener is there to create the 1.25 V and -1.25 V needed to compensate for the regulators' internal Vref. The zener sits across the 0 V reference, creating a 1.25 V at the cathode

and a -1.25 V at the anode, with reference to the virtual ground. Connecting the Adj pin of the LM317 to the -1.25 V will have it output 0 V. Connecting the LM337's Adj pin to the 1.25 V will have it output 0 V.

My last concern is that each reg has a minimum load requirement to maintain regulation: 3mA for the LM337 and 4mA for the LM317. It's something to take into account, which has not be dealt with in this schematic.

Now I really wish I had a 2.5 V zener and a lm337 to test it out.

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Mar 9, 2013 at 3:40 PM **Post #8 of 125**

Sonic Wonder
Member of the Trade: Goldpoint Level Controls

Joined: Dec 6, 2010
Posts: 44
Likes: 12

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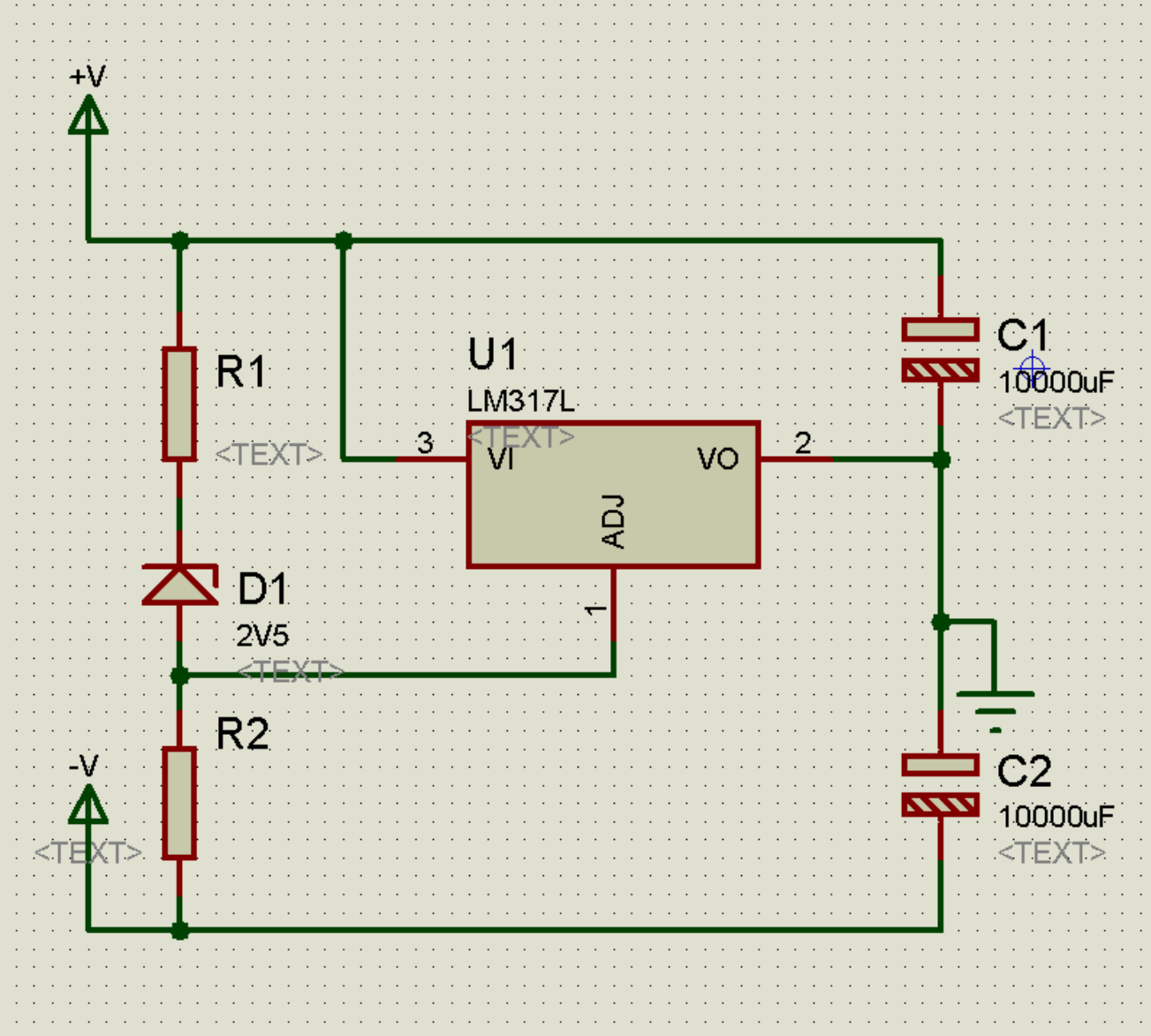
Mar 9, 2013 at 4:47 PM **Post #9 of 125**

wakibaki
1000+ Head-Fier

Joined: May 26, 2011
Posts: 1,088
Likes: 68

Looks good to me Kim, but maybe some of it is unnecessary...



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Mike zerO Romeo Oscar November

http://wakibaki.com

Post #10 of 125

Sonic Wonder

Member of the Trade: Goldpoint Level Controls

Joined: Dec 6, 2010
Posts: 44
Likes: 12

Actually that does not work. (Only 1/2 of the ground is regulated, believe it or not...)

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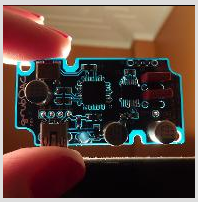

KimLaroux
1000+ Head-Fier

Joined: Aug 2, 2011
Posts: 1,090
Likes: 69

Quote:

> sonic wonder said:
>
> Oh my Gawd! Did you do it?
>
> Oops - nope - I think you must have the output of the LM317 be 1/2 of the rail-to-rail voltage and the LM337 also be 1/2 - but negative!

Can you explain? I fail to see how it's different than your circuit in the 1st post.

The LM337 is just a mirror to what the LM317 does. It's all a question of what you use as a reference. If you decide to use the virtual ground as a reference, then V- is half of the rail-to-rail voltage, but negative. The virtual ground is then 0 V. The LM337 is configured to "regulate" a negative voltage using V- as an input. Here I just configure it to output 0 V. If I didn't have the zener in there, and just connected the adjust pins to the middle of the resistor divider, then the LM317 would output 1.25 V and the LM337 -1.25 V, referred to the virtual ground.

Quote:

> wakibaki said:
>
> Looks good to me Kim, but maybe some of it is unnecessary...
>
> Click to expand...

It was my first thought when I read the 1st post. I've been thinking about it ever since, and I'm not sure if using two complementary regulators is necessary, even in the original design. If it works using only the LM317, then the original design should work without the 79XX, no?

Goldpoint, can you explain why you used two regulators in your design instead of a single one?

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Mar 9, 2013 at 5:29 PM Post #12 of 125

wakibaki
1000+ Head-Fier

Joined: May 26, 2011
Posts: 1,088
Likes: 68

Quote:

> sonic wonder said:
>
> Actually that does not work. (Only 1/2 of the ground is regulated, believe it or not...)

There is only one ground. How can half of it be regulated?

Mike zerO Romeo Oscar November
http://wakibaki.com

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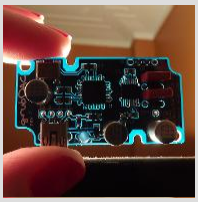
Mar 9, 2013 at 5:47 PM Post #13 of 125



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1000+ Head-Fier

Joined: Aug 2, 2011
Posts: 1,090
Likes: 69

I think I see what he means.

The 78XX regulates the difference between the ground and V-. It make sure this voltage is stable.

The 79XX regulates the difference between ground and V+. It make sure this is stable.

If you remove the 79XX, you have a regulated ground relative to V-, but nothing regulates the difference between the ground and V+. Sure since he uses a pre-regulator, then you'd take for granted that V+ be whatever is left over the ground. But I think this creates an unbalanced PSU

where one rail is more stable than the other. If you suddenly load V+ creating a drop, the 78XX would not care, and ground would stay the same voltage with reference to V-, while V+ would fall closer to ground.

My modification is different. I'm not regulating the difference between the rails. The resistor voltage divider sets the ground reference point, and the regulator just output a regulated voltage with reference to that. The ground will always be halfway between the rails, even if their load changes. The resistor voltage divider is unaffected by the change in loads between the rails. If one rail is suddenly loaded, it'll created a voltage drop that also drops the voltage divider. Since the voltage divider is connected across the rails, the LM317 would simply adjust it's output so it stays halfway between the rails.

Beautiful. biggrin.gif

Audio-gd NFB-12 ~ DIY Tube hybrid ~ Carrie USB DAC/AMP ~ Modified Shure SRH440 ~ AKG Q701 ~ Sennheiser Momentum On-ear

wakibaki
1000+ Head-Fier

Joined: May 26, 2011
Posts: 1,088
Likes: 68

I think that with just 1 regulator the sinking impedance and the sourcing impedance *may* not be symmetrical. This would have to be tested, at least in simulation. The advantage is that there are no problems with matching and no necessity for the ballast resistors with a consequent lower output impedance and no possibility of power being wasted if the two regulators end up producing slightly different voltages.

It just illustrates IMO, the reasons to stay away from virtual grounds

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I actually tried that circuit. It seems to work when you have a very small load.

If your load is connected to the virtual ground and the negative rail, it will work correctly. In that case it works just like a regular positive voltage regulator circuit - up to the current (amperage) limits of the LM317 regulator.

But if you connect a load from the positive rail to the virtual ground, the ground point will actually move - it will be pulled upwards towards the positive rail as the load increases. see?

You need both regulators there to "hold the virtual ground point steady" - to keep it from "moving". (One does it in one direction and one in the other direction, so to speak.)

But there are substantial advantages to using virtual grounds in certain situations - and no reason not to use them if they are properly designed.

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