

# Simple circuits reduce regulator noise floor

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October 15, 2013

In the old days every instrument or system had a power supply board with discrete, homemade regulators on it to power the system. Then IC's like the LM7805 series of voltage regulators changed everything. No longer were system designers required to spend their time designing the power supply section also. These modern IC's even incorporated much improved current limiting and thermal protection. As such, the reliability of everything electronic improved overnight.

These venerable old regulators continued to change to match our design needs which led to low dropout varieties, improved transient response parts and now lower noise designs.

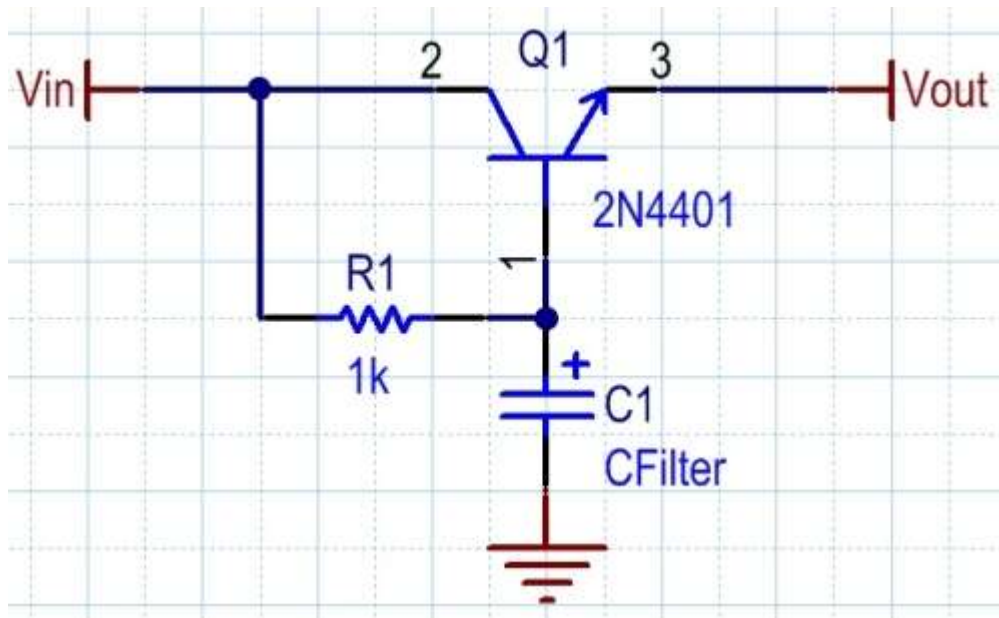


Noise has always been a constant and the LM7805 of 1972 has the same noise as the LM7805 purchased today. What has changed is our system's need for lower noise. This is especially true in RF Communications where we need low-phase-noise oscillators to be able to transmit and receive our complex digital communications. In data acquisition we commonly have 24-bit A/D converters which naturally demand low-noise support circuitry to be able to achieve their data sheet performance. Although not to be forgotten are our Audiophile friends who always worry about the "sound of noise" in their systems.

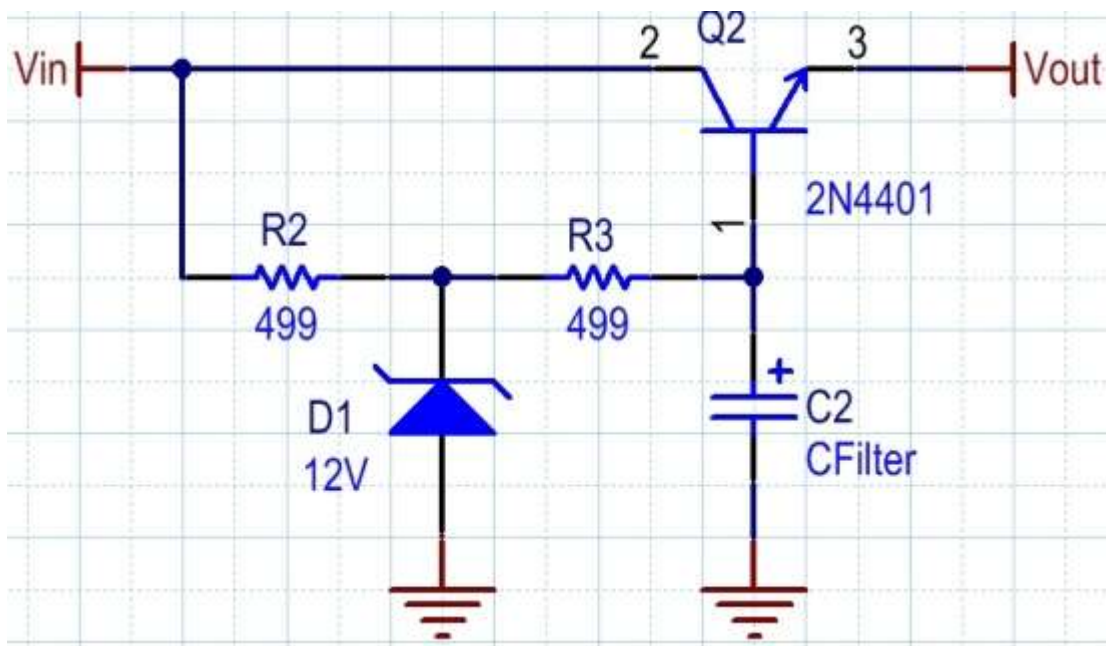
These advances have all gone a long way in helping us to design systems that meet specifications and are, small, cost effective and perhaps most importantly for those who pay our wages: they help us to stay on schedule.

## Discrete noise reduction circuits

Over the intervening years between the first regulators and the newest low-noise varieties there have been a few discrete circuits that have cropped up to lower the noise floor of our power supplies even further. As shown in **Figures 1 and 2**, the most common forms are the very popular "capacitance multiplier."

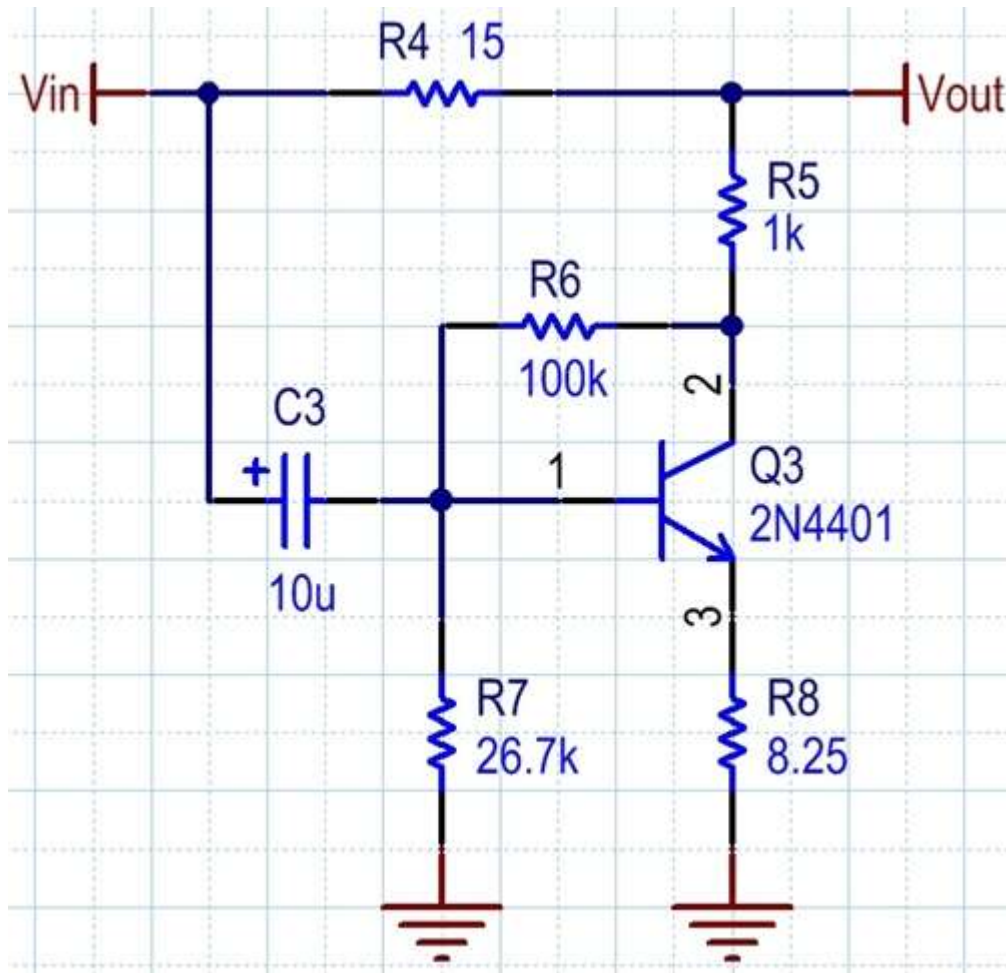


**Figure 1** The capacitance multiplier works by isolating the filter capacitor C1 from the load directly by the transistor current gain (beta), thereby making the capacitor value appear to be multiplied by the beta of the transistor.



**Figure 2** A variation of Figure 1 with an added Zener diode to improve line regulation. Zener diodes have quite a bit of noise themselves, but this circuit still reduces the resulting Zener + raw supply noise well.

**Figure 3** shows the less well known “active regulator” [1]. There have also been a number of other active regulators proposed over the years, but most of them have been focused on ripple reduction, not noise floor reduction [2].



**Figure 3** The active regulator, while not as popular as the capacitance multiplier, it does show up from time to time in published circuits. I first saw this circuit on Charles Wenzel's website [1]. Typically R4, R5 and or R8 need to be adjusted to get the noise reduction gain optimized for each circuit where this circuit is applied.

#### How they work

The capacitance multiplier as shown in Figure 1 works by isolating the load's influence on the capacitor by the current gain (or beta) of the transistor; hence whatever capacitor is used for C1 is multiplied in value by upwards of 100 times. The circuit of Figure 2 is a slight modification that strangely adds a noisy Zener diode [3] for improved line regulation, but in practice still can produce a low-noise output if R3 and C2 are chosen properly.

In most audio types of applications you will see these circuits implemented with a 1000uF or larger aluminum electrolytic capacitor. Here I took the more RF-oriented approach and used what might be found on a typical small PCB, and used a 10- or 100-uF/25V Tantalum [4] for C1. No special exotic or expensive parts were used in any of the testing.

The active regulator of Figure 3 works by sensing any noise at the input; transistor Q3 then amplifies and inverts the noise and subtracts it by adding an equal and opposite current across resistor R4. Thus in theory the noise reduction is perfect, but in practice greater than 40 dB noise reduction can be achieved.

The active regulator also has a high-frequency limitation because the transistor is working as an amplifier – it will have a gain-bandwidth limitation as well, which limits the circuit's effectiveness at higher frequencies. In practice I find that bandwidths of 1 MHz are not difficult to achieve and at that point the standard capacitor bypassing is very effective at keeping the noise floor low.

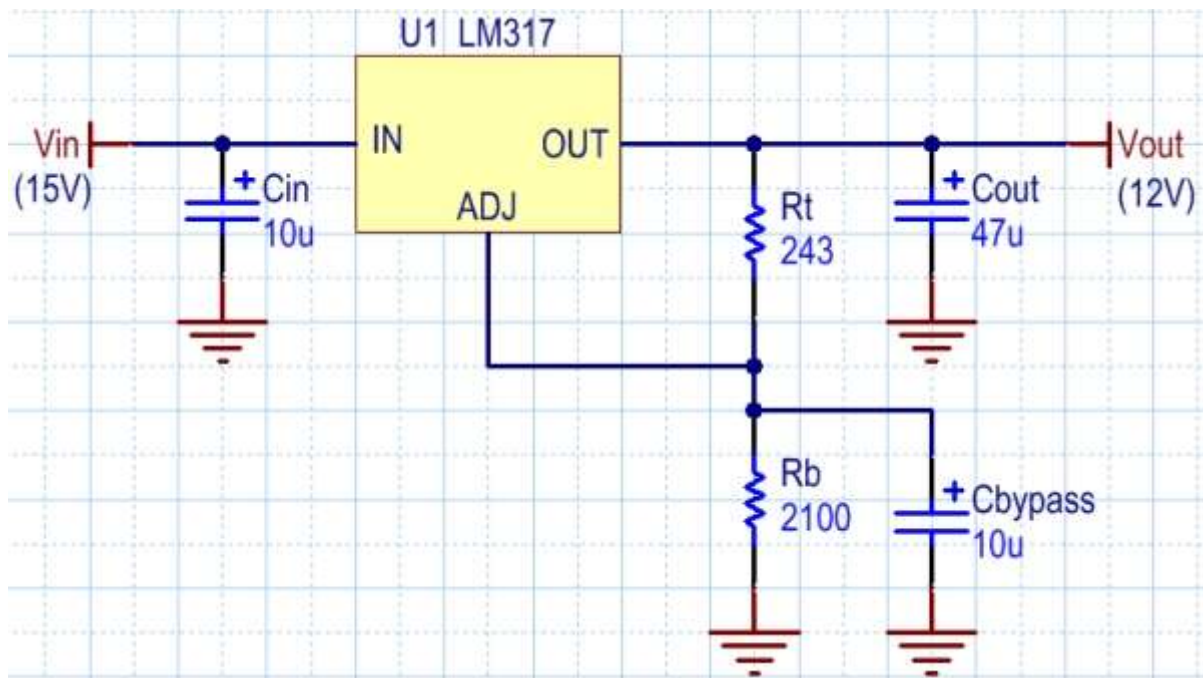
Note that while the capacitance multiplier usually works without any modification, the active regulator of Figure 3 must usually be optimized for every application.

To get optimum noise reduction, the gain of the transistor stage must usually be adjusted and the easiest way to do that is to temporarily replace R8 with a 10- or 20-Ohm potentiometer. The potentiometer is then adjusted for optimum in-circuit gain that results in minimum output noise; the potentiometer can then be replaced with a fixed resistor.

### A high noise source for testing

To test the noise reduction capability of the circuits I used an LM317 because this is typical of what might be used in a system. The LM317 has a bad reputation as being a particularly noisy regulator. However, this reputation is not totally deserved as we will see later.

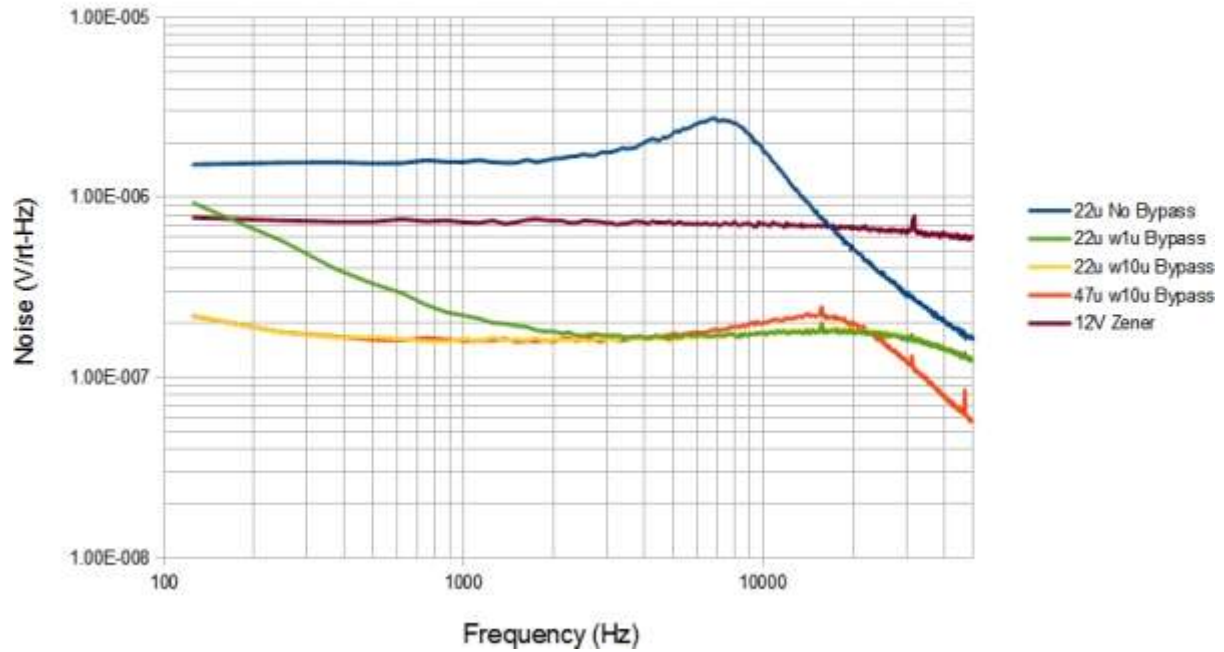
The LM317 is an excellent noise source for testing the regulator circuits as the noise was fairly flat over the 120 to 50,000-Hz test frequency range. It drives the test circuits well and the noise is constant enough with load to make the testing valid. **Figure 4** shows the test circuit and its components.



**Figure 4** A LM317 regulator biased up for 12V operation was used as the noise source for testing the noise reduction regulators.

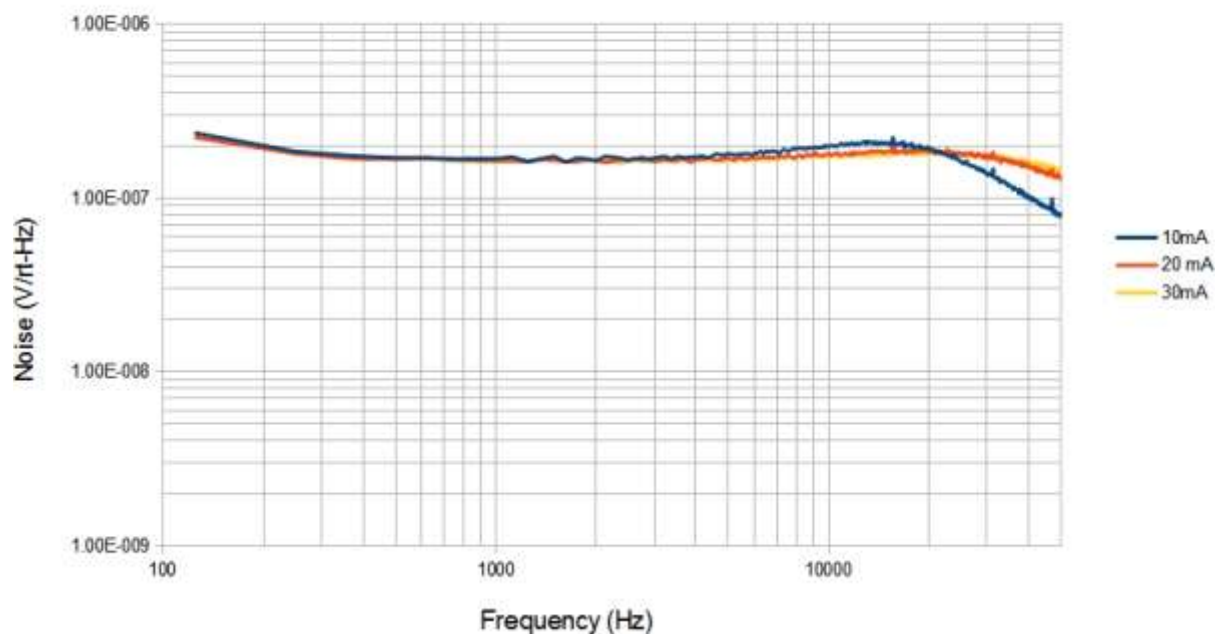
**Figure 5** shows the results of testing the LM317 with various values of bypass capacitor. Finally, Figure 6 shows the results of testing the noise of the LM317 versus load.

## LM317 Noise With Various Bypass Capacitors



**Figure 5** The LM317 was tested with various combinations of Cout and Cbypass capacitors (see Figure 4). For comparison a 12V Zener diode biased at 1 mA is also plotted. The LM317 sometimes gets a reputation in print as being an unacceptable regulator to use in low noise circuits, but with proper bypassing it is actually about 4 time lower noise than a 12V Zener which shows up in many published low noise designs (especially audio circuits).

## LM317 Noise Vs Load



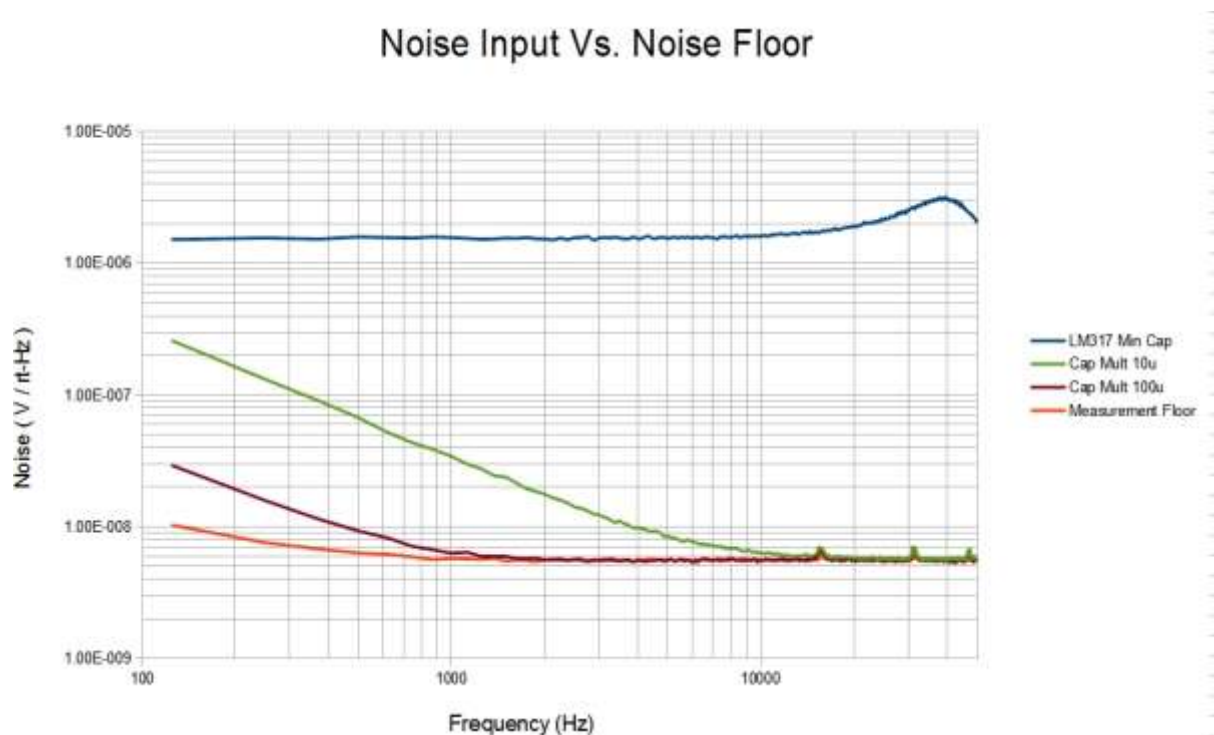
**Figure 6** The noise of the LM317 was tested versus various load values to make sure that the noise was consistent and stable with load current.

For my noise testing purposes, I made Cbypass equal to zero to maximize the noise input to the test circuits to maximize the measurement dynamic range.

### Testing the noise reduction regulators

Since many of these circuits end up being used as cleanup regulators for circuits such as VCOs and various RF and audio preamps, I used a standard load value of 600 Ohms because in a nominal 12V circuit this gives us a load current of 20 mA, which is a typical load for such circuits.

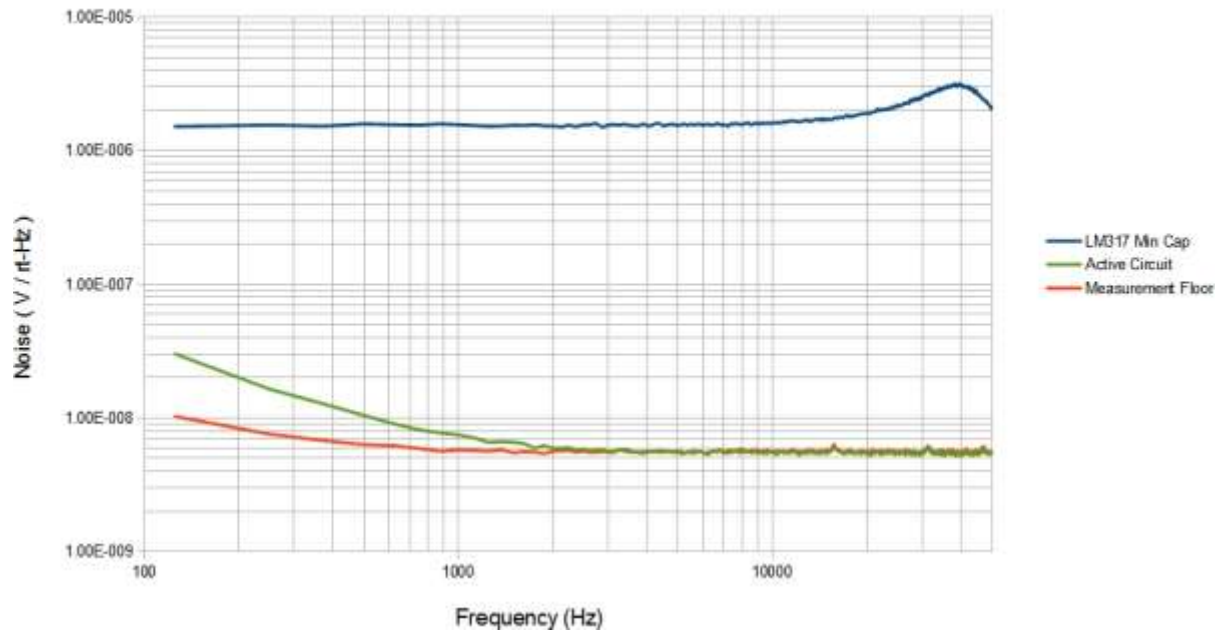
**Figure 7** is a comparison of the performance of the capacitance multiplier of Figure 1 and the LM317 used as a noise source. The capacitance multiplier can be seen to work well in reducing the noise from the LM317 regulator rather dramatically.



**Figure 7** A dramatic reduction in noise is apparent after testing the circuit of Figure 1 with a load of 20 mA and various combinations of capacitance. The LM317 with minimum capacitance was used as the noise input (blue trace), the measurement system noise floor is also shown (orange trace). Capacitance multiplier of Figure 1 was then measured with capacitance values of 10 and 100 uF (green and burgundy traces).

**Figure 8** is a similar test using the active regulator of Figure 3.

## Noise Input Vs. Noise Floor

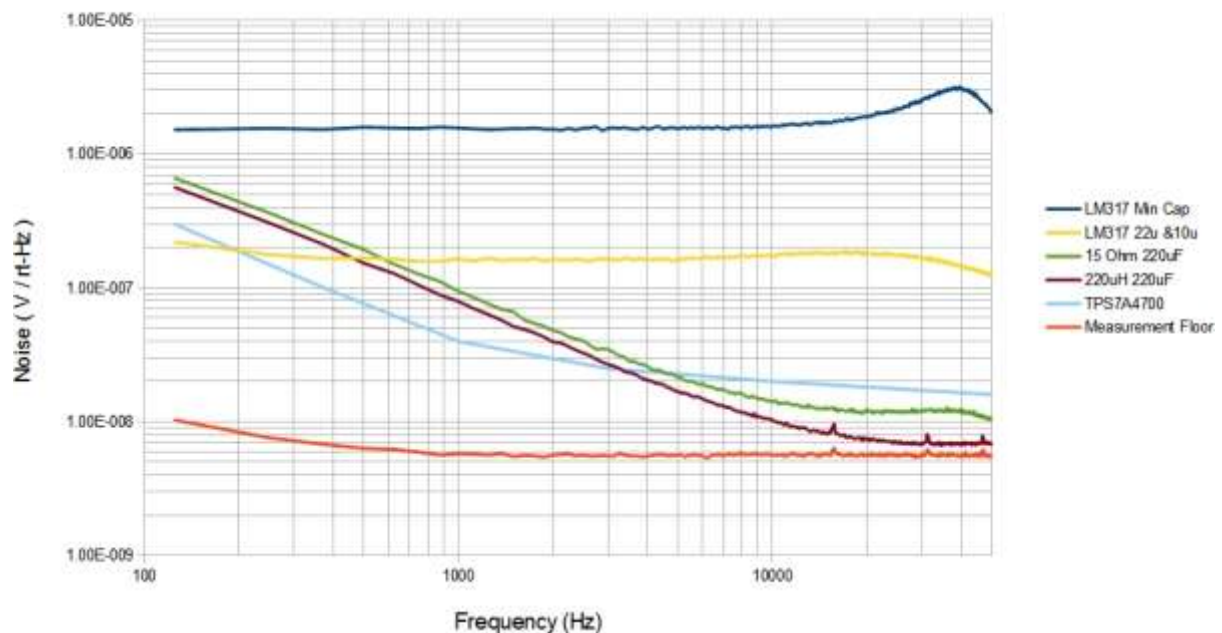


**Figure 8** Testing the optimized active regulator of Figure 3 (green trace) also shows a dramatic reduction of the LM317 input noise (blue trace). The measurement system noise floor is shown in the orange trace.

## Potpourri

**Figure 9** is a comparison of many different regulators and possible discrete filter circuits.

## Noise Input Vs. Noise Floor



**Figure 9** Grab Bag Comparison plot of the LM317, a TI TPS7A4700 ultra low noise regulator and a few passive filters made from a 220-uH / 220-uF LC combination and a 15-ohm / 220-uF RC combination.

The LM317 with minimum bypassing is shown along with the LM317 with recommended bypassing. The addition of one small 10-uF tantalum capacitor from the adjust pin to ground reduces the LM317 noise by nearly 10 times!

For comparison the ultra-low-noise Texas Instruments TPS7A4700 regulator is also plotted (from data sheet values, not measured). As can be seen this state-of-the-art low-noise regulator is nearly 10 times lower noise at 10 kHz than the LM317 with the recommended bypassing and nearly 100 times lower noise than the hastily applied LM317 without the bypass capacitor.

A few small passive circuits were also built and tested for comparison. The 220-uH inductor 220-uF capacitor was chosen to be about the same physical size as the active regulator circuit of Figure 3, with a very small 220-uH inductor that was chosen to have a series resistance of around 15 ohms. Then a 15-Ohm, 220-uF capacitor combination was also tested.

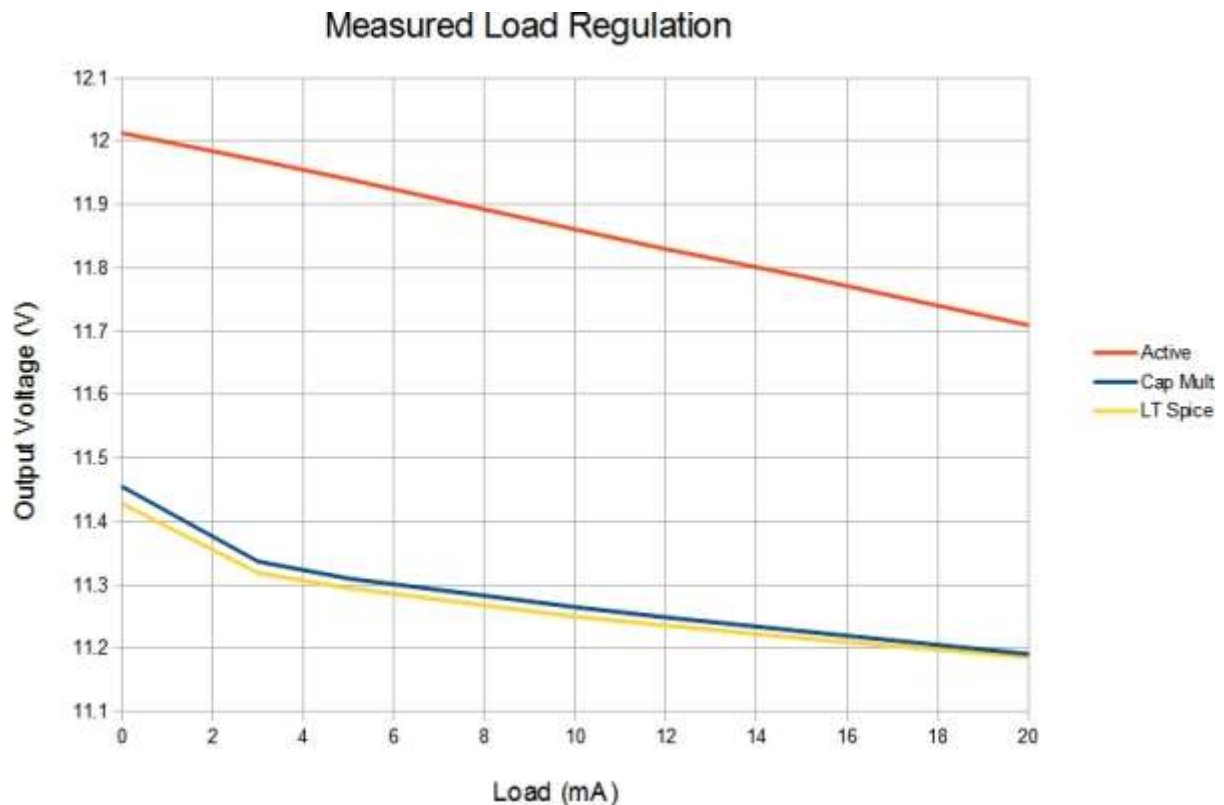
These passive circuits do indeed reduce the higher-frequency noise, but the corner frequency is quite a bit higher than any of the transistorized circuits. As can be seen, the combination of these circuits with an LM317 does start to approach the performance of the TI TPS7A4700 by itself, which is pretty good for such an old part as the LM317 (developed around 1970 [5]).

While newer ultra-low-noise regulators may be 10 to 100 times lower noise than the generations-old regulators commonly in use, these transistorized noise filtering circuits can still improve the noise performance of even the lowest of the low-noise regulators available today.

### **Load regulation**

Since most of the preamp/VCO applications where these sorts of noise reduction circuits tend to be applied are class A, they tend to consume a constant amount of supply current. In this situation dynamic response is not as important as the voltage drop across the circuit. This voltage drop can be a problem if you have to apply these circuits later in the design cycle and you may find yourself with insufficient voltage to power your circuits.

As can be seen by inspection, the capacitance multiplier (Figure 1 and Figure 2) has a transistor base-to-emitter junction in the power path; this causes the circuit to have a 0.6-volt drop even with little load applied to it (see figure 10).



**Figure 10** Load regulation of the circuits of Figure 1 and Figure 3. As can be seen the simple and small capacitance multiplier has a diode drop in the power path (blue trace) while the Active regulator only places a 15-ohm resistor in the power path, with no offset voltage (orange trace). The trade-off is increased power loss for simplicity and smaller size. Just for fun I simulated the capacitance multiplier with LTSpice and it matched the actual measurement quite well (yellow trace).

The active regulator of Figure 3 has no such offset voltage, but simply adds 15 ohms to the power path (and this resistor is adjustable, it can be made bigger and smaller depending on the application).

The trade-off is that the capacitance multiplier is simpler, fewer parts and usually smaller PCB area than the active regulator circuit.

Output resistance (or the slope of the line in Figure 10) as measured by:  $\Delta V / \Delta I$  from 5 to 20 mA for each circuit shows that the capacitance multiplier has 8 ohms output resistance, while the active regulator has whatever value R4 in Figure 3 is, or in this example, 15 Ohms.

While you may be stuck with the regulator noise in a system, that doesn't mean that your circuit's performance has to suffer. When added LC filters get simply too big to work at very low frequencies, one of the transistorized circuits described here may make a marginally performing system into one that exceeds expectations simply with the addition of a few parts. Additionally these timeless circuits also can provide improvements to even the latest ultra-low-noise regulator ICs.

## References

1. Wenzel, Charles: "Finesse Voltage Regulator Noise"
2. Feng, Sander & Wilson, "Small-Capacitance Nondissipative Ripple Filters for DC Supplies," IEEE Transactions on Magnetics, March 1970.
3. Hageman, Steve, "White noise source flat from 1Hz to 100kHz"
4. Typical, standard grade Tantalum capacitors are the Kemet T491 series, the AVX TAJ series, or the Vishay T83 series.
5. History of the LM317, Wikipedia