Appendix C

Understanding and Reducing Noise Voltage on 3-Terminal Voltage Regulators

Erroll H. Dietz, Senior Technician,
National Semiconductor Corporation

The usual approach to reducing noise on 3-terminal voltage regulators has been to simply place capacitors on the output and on the adjust pin for adjustable regulators. As it turns out, the addition of output capacitance on most voltage regulators may reduce the noise over a broad frequency range but may increase noise within a narrow frequency range. Since the output impedance of most 3-terminal regulators is inductively reactive over a certain frequency range, one can surmise that adding output capacitance to improve noise performance and transient response can also have other effects. The examples given in this appendix will use the LM317 adjustable voltage regulator, but this information can be scaled and then applied to all other kinds of 3-terminal voltage regulators.

As shown in Figure C.1, the output impedance of the LM317 over the 1 kHz to 1 MHz frequency range is inductive. This has nothing to do with long wires, but is simply another way of looking at the fact that the gain of any operational amplifier or

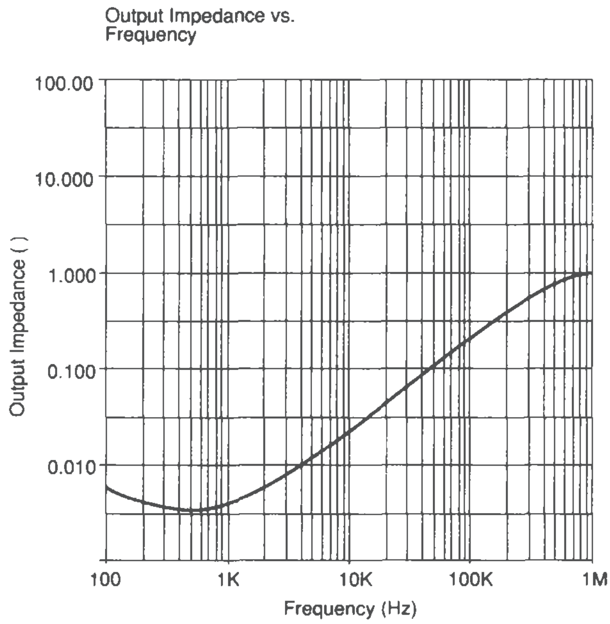

Figure C.1. LM317's output impedance vs. frequency at I_L = 500 mA.

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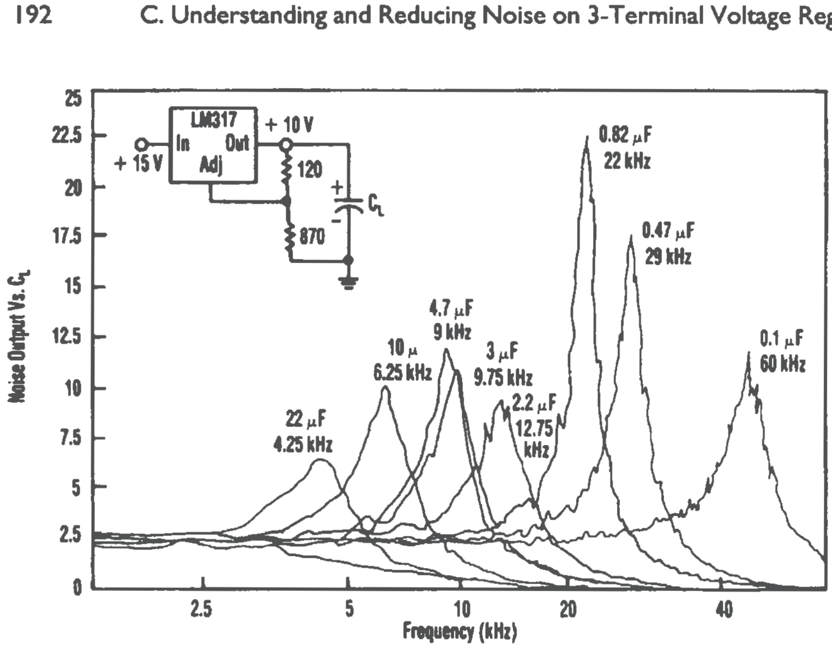

Figure C.2. Typical noise peaks produced by an LM317 and various capacitive loads.

regulator is designed to roll off at 6 dB per octave. This condition is usually not of much concern to the average user of IC regulator circuits. However, this inductive output impedance coupled with an output capacitor to ground can produce a noise peak within a narrow frequency range. This noise peak coincides with the resonant frequency of the inductive output impedance of the regulator and the load capacitance on the output. Figure C.2 shows typical noise peaks produced by an LM317 and various capacitive loads. The frequency range of the noise spike does not extend much above 100 kHz nor below 10 kHz due to ohmic losses in the added output capacitance and the inductance of the regulator. The frequency is predictable according to $1/(2\pi\sqrt{LC})$.

The magnitude of this noise spike will vary with the Q of the resonant circuit, which is mainly dominated by the series resistance of the output capacitor and is proportional to the gain of the reference voltage. For example, a good 1 μF polypropylene capacitor with an ESR of 20 mΩ at 30 kHz will have a noise peak three times greater than that of the same value tantalum capacitor which has an ESR of 1 or 2 Ω. The noise peak is also reflected back to the input of the regulator and is about 20 dB down from the output level.

It is a little-known fact that the output impedance of 3-terminal regulators can vary greatly with load current and the programmed output voltage, which in turn varies the noise peak resonant frequency. As load current increases, the gm of the regulator's output transistor will also increase. This in turn causes, as indicated in Figure C.3, the output inductance to decrease until the current-limit resistance, bond-wire resistance, and lead resistance becomes the dominant resistance at the output. This is true for positive and negative regulators, for adjustable and fixed regulators, and for large and small regulators. In the past it has been assumed that Z_{out} vs. Frequency was a fixed curve, but really there is a family of curves at different current levels (see Figure C.4).

In conclusion, the typical values of output bypass capacitance that users of 3-terminal regulators have traditionally used may provide the expected noise reduction at some frequencies, but not at every frequency. In most cases, a few microvolts of power-supply noise peaking at 5 or 10 kHz will not cause any problems. However, if

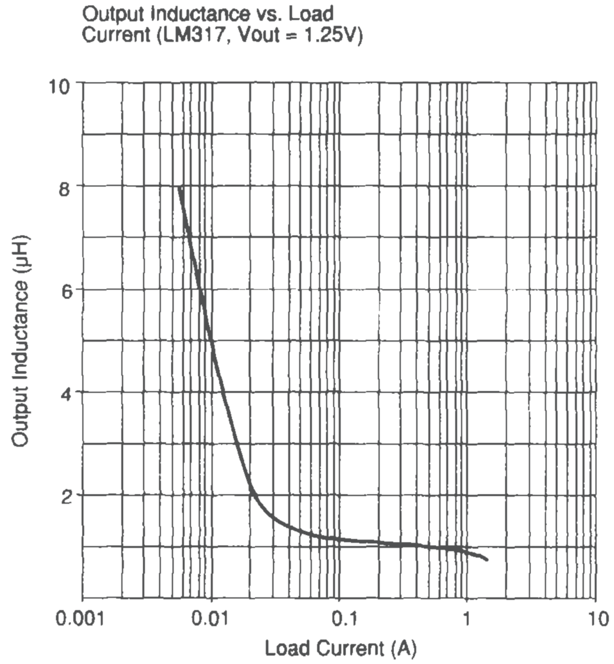

Figure C.3. LM317's output inductance vs. load.

the application circuit is extremely sensitive to excess noise on the supply at one particular frequency, then the user can easily select an appropriate output bypass capacitor and engineer the regulator's circuit so that the noise peaking will fall outside the critical range. Capacitors that fall into the range of 0.1 to 20 μF should be avoided in low-noise applications, especially those with low ESR. The most effective noise reduction can be realized when an electrolytic capacitance of 50 μF or greater is placed at the output, and at least 1 μF at the ADJUST pin, for adjustable regulators. The user should also be aware that changing the load current or output voltage can change the output inductance, so the circuit must be evaluated over the complete range of load currents and output voltages over which the regulator will be operated.

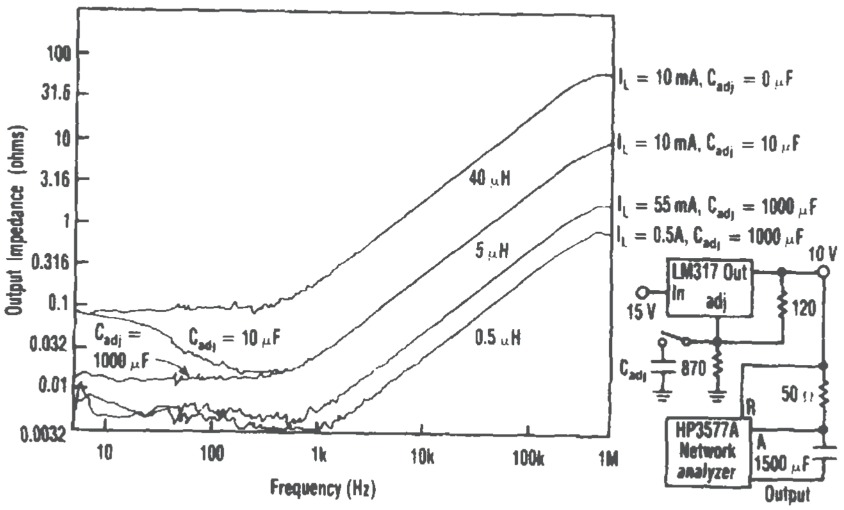

Figure C.4. Output impedance vs. frequency at different current levels.