Simple Techniques Minimize Cross-Coupling in Distributed Power Systems

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Introduction:

Distributed power supplies convert the AC line voltage to a lower unregulated DC voltage by using a transformer and a diode-bridge rectifier. As shown in *Figure 1*, this unregulated DC voltage is then converted to two or more tightly regulated DC voltages by using switching and/or linear regulators.

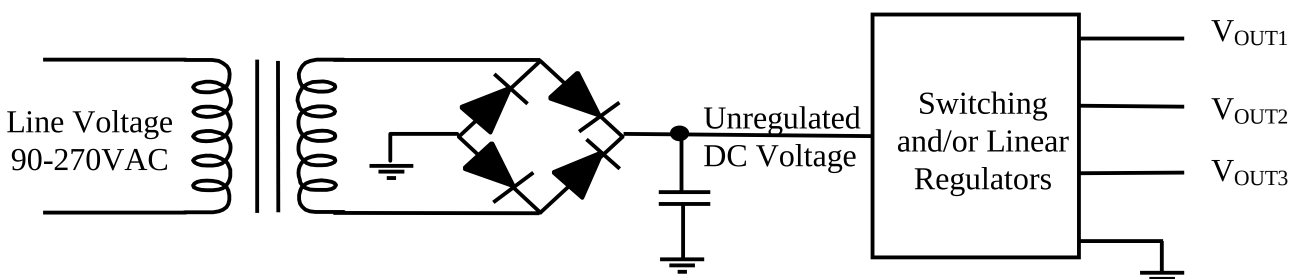


Figure 1 *Typical Distributed Power System*

Figure 2 shows a distributed power system that generates regulated 5V and 3.3V outputs. The unregulated DC voltage, generated from the AC line, varies between 12V and 25V and is converted to tightly regulated DC voltages using two Simple Switcher™ buck regulators. A flyback converter could have been used to perform this conversion, but it was not used because of the need for better output regulation. The two buck regulators are designed using the associated Simple Switcher design software, and their design specifications are as shown in *Table 1*.

Table 1:

Specifications	LM2596	LM2675
Switching Frequency	150kHz	260kHz
Input Voltage	12-25V	12-25V
Output Voltage	3.3V	5V
Output Power	10Watts	5Watts
Associated Software	SMS4.2.1	LM267X

As seen in *Figure 2*, the converters are using the same DC input source. With this simple connection, both output voltages are regulated to a tolerance of better than 5%. However, the noise performance will be poor and the converters will interfere or cross-talk with each other. In the above example, this interference can be observed in at least four different modes:

a) Figure 3 shows the output ripple voltage of the LM2675 and LM2596 buck regulators. Because the LM2596 is a 150 kHz buck regulator, a 150 kHz ripple is expected at its output. However, as seen in *Figure 2*, a 260 kHz ripple is also observed at the LM2596 output.

b) The frequency spectrum of the LM2596 output contains a 260 kHz frequency component (and its harmonics), as shown in *Figure 4*.

c) The switch voltage waveform (*Figure 5*) indicates instability on the edges. However, the converter is designed for a stable loop gain, using Simple Switcher software. This instability is caused only due to interaction between the converters.

d) When a transient is applied at one output, the effect of the transient is observed on the other output, as shown in *Figure 6*.

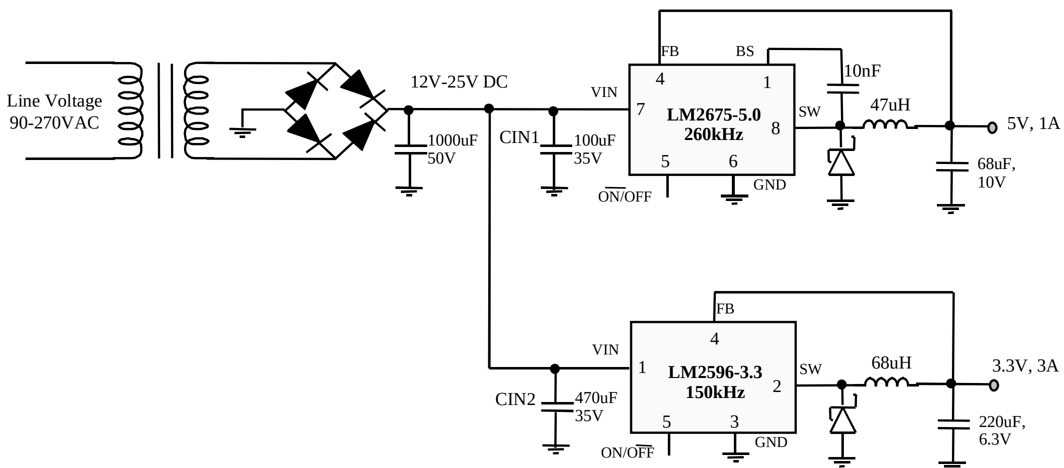
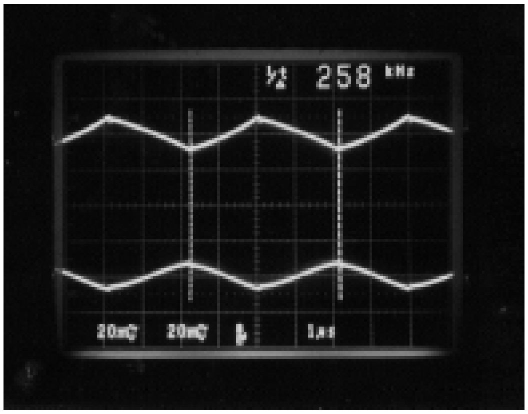


Figure 2: A distributed power system solution



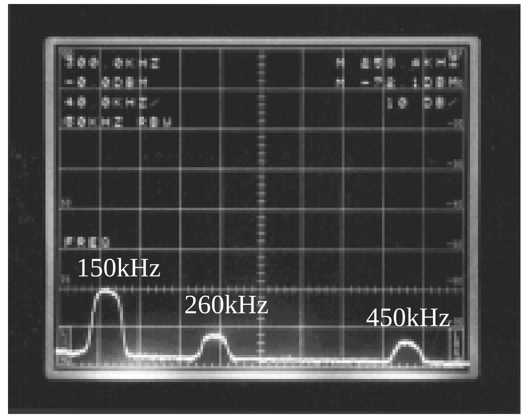
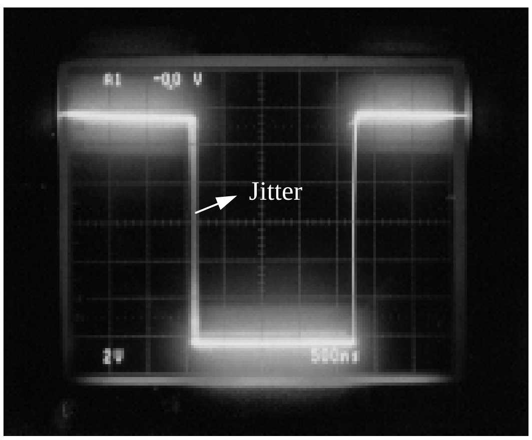


Figure 3- Top: LM2675 Output Ripple(260kHz, 1A) Bottom:LM2596 Output Ripple (150kHz, No-load) A 260 kHz ripple is observed on the LM2596 output

Figure 4: Frequency Spectrum of the LM2596 output(load current =0.5A on LM2596 and 1A on LM2675). *A 260kHz frequency component (and its associated harmonics)is observed.*



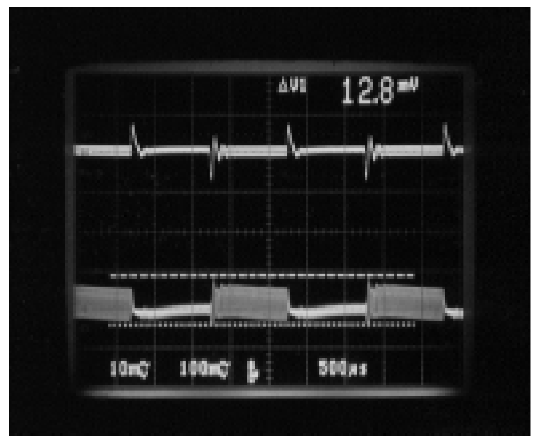


Figure 5: Instability is observed in the switch voltage waveform (pin 8 of LM2675) when a converter with different switching frequencies (LM2596) shares the Input line.

Figure 6: When a transient is applied on the LM2596 output, the effect of the transient is observed on LM2675 output.

This phenomenon is not unique to switching regulators, but is related to high frequency ripple rejection and transient response. If two linear regulators share the input line and a transient is applied on one output, then the effect of transient is observed on the other output. However, the interaction is less severe in linear regulators.

What causes the beat frequencies?

Figure 7 shows the closed-loop power supply ripple rejection (PSRR) of the LM2596 Simple Switchers under no load conditions. The closed-loop power supply ripple rejection (also known as audio-susceptibility) is a function of the loop gain for a voltage mode converter:

$$G_v = G_{vo}/(1+T) \qquad (1)$$

where:
T = Loop gain
G_{vo} = Open-loop PSRR
G_v = Closed-loop PSRR

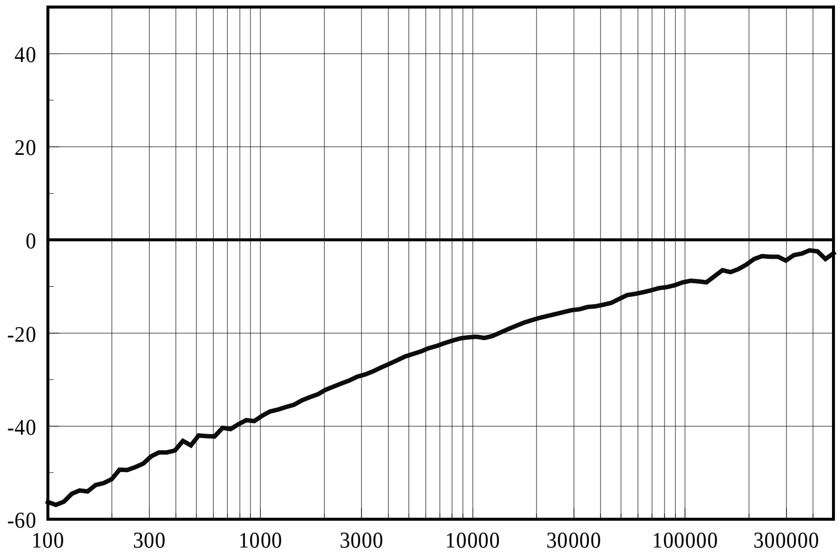


Figure 7: Audio-susceptibility or PSRR of the LM2596 switching regulator

In switching regulators, at very high frequencies near the switching frequencies, the loop gain is very low and the PSRR is poor. Any disturbance or noise at the input will appear at the output. The switching action of one converter creates a disturbance on the input line (*Figure 8*). Because the PSRR of other switching (or linear regulators) is very low at high frequencies, this disturbance will appear at the output of all other switchers and linear regulators connected to the input line. Also, the disturbance on the input line propagates to the circuit internal to the ICs. This introduces noise and instability in the circuit.

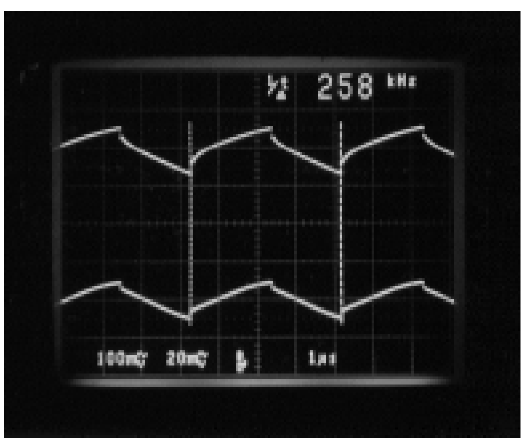


Figure 8: Bottom- A 260kHz disturbance appears on the input line(100mV/div)
Top-This disturbance is transmitted to the output of LM2596(20mV/div)

Reducing Cross Coupling

Two general approaches are used to reduce the cross-coupling interactions between different switching frequency regulators running from the same input power line. The easiest approach is to filter the undesired disturbance on the input line. For regulators with oscillators that can be controlled, synchronization of multiple regulators can eliminate the cross coupling effects.

Adding a filter minimizes cross coupling

Adding an inductor in the front end of each regulator can filter disturbances on the input power line, as shown in *Figure 9*. The inductor forms an LC filter with the regulator's input capacitor. As an example, if we wish to reject the 260kHz disturbance from the input to LM2596 by a factor of 100 (so that the 260kHz ripple seen on its output is minimized), then:

$$\frac{V_{in}}{V_f} = 100\text{, or}$$

$$20\log\left(\frac{V_{in}}{V_f}\right) = 40\text{dB}$$

The LC filter provides an attenuation of 40 dB per decade. Select the LC filter pole frequency, f_p, so that at least 40dB attenuation is obtained at 260kHz. Therefore:

$$f_p = \frac{1}{2\pi\sqrt{L_f C_{in2}}} = 26\text{kHz} \qquad (2)$$

Using Equation (2), C_{in2} and L_f can be calculated for the converter in *Figure 9*. *Figure 10* shows the reduction in 260 kHz disturbance on the input power line with the addition of the inductor. The output ripple voltage of the LM2596, frequency spectrum, switch voltage waveforms, and the transient response, are all improved by adding the filter inductance, as shown in *Figures 11, 12, 13, and 14*.

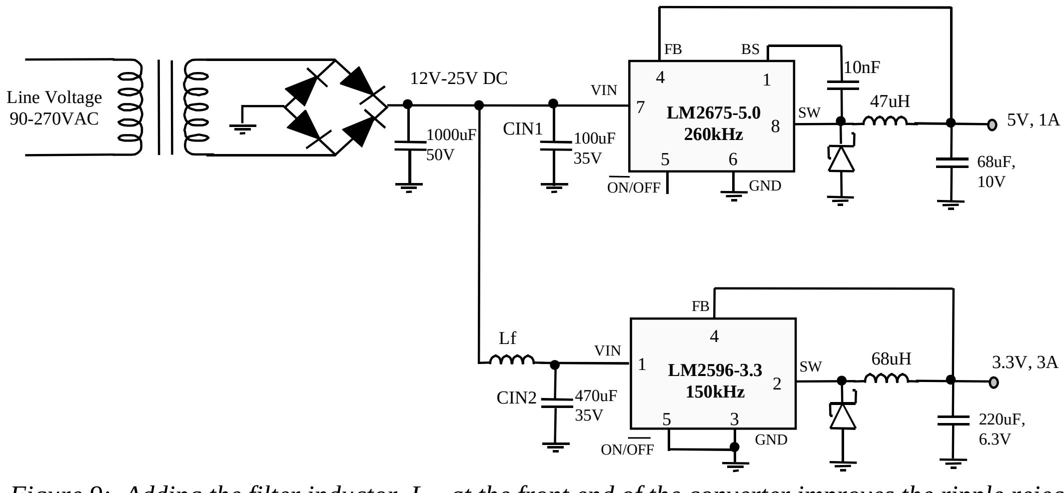


Figure 9: Adding the filter inductor, L_f, at the front end of the converter improves the ripple rejection at higher frequencies

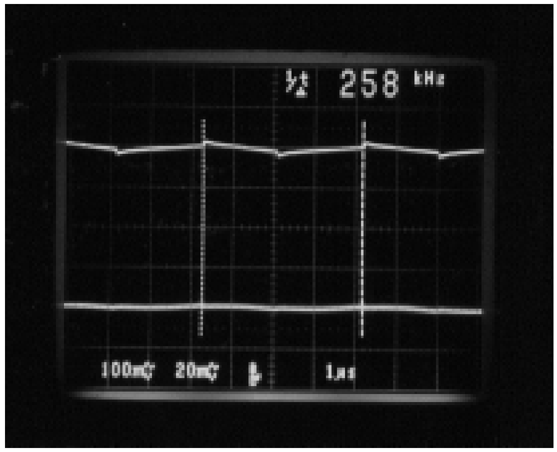


Figure 10: Disturbances on the input voltage being fed to LM2596, caused by LM2675, are filtered by the extra inductor

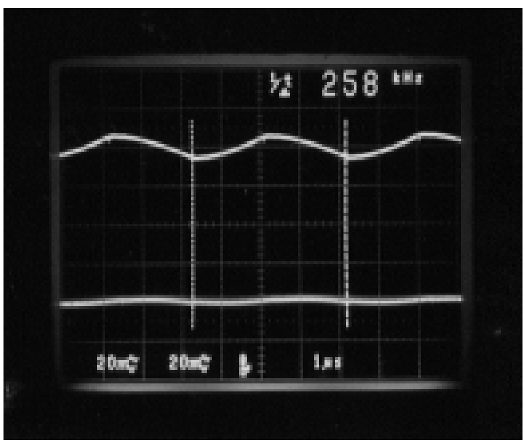


Figure 11- Top: LM2675 Output Ripple(260kHz, 1A) Bottom:LM2596 Output Ripple (150kHz,No-load) The 260 kHz ripple is attenuated at the output by the filter inductor.

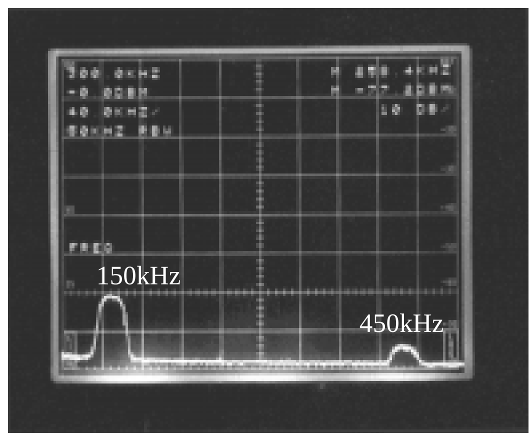


*Figure 12: Frequency Spectrum of the LM2596 output**.** The 260kHz frequency component (and its associated harmonics)are attenuated by the filter inductor.*

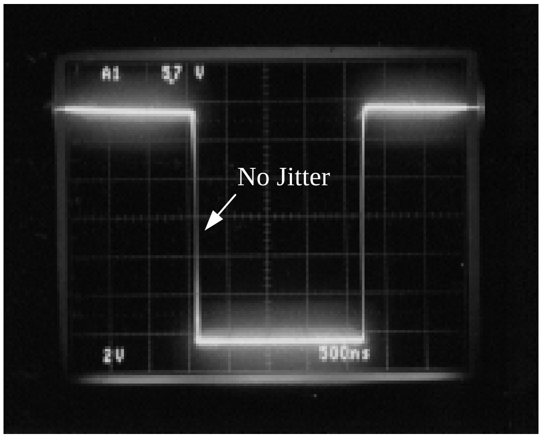


Figure 13 No jitter or instability is observed in the switch voltage waveform (with filter inductor)

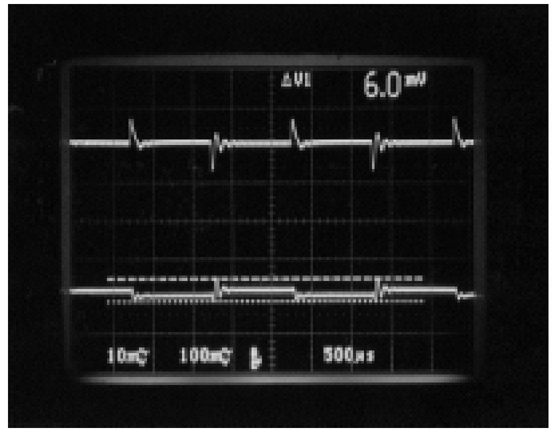


Figure 14 If a transient is applied to one output, the effect of the transient on the other output is reduced with the filter inductor.

Synchronization eliminates cross-coupling

As an alternative to filtering, synchronization can force the switching frequencies of two regulators to match that of an external source, such as another switching regulator or a system clock. It prevents similar (but not matching) switching frequencies from producing cross coupling. This also keeps the EMI generated within the system to a predictable set of frequencies. Both of these results make it easier to filter out switching noise in the system. As an example, in *Figure 15*, the LM2588 boost regulator has been synchronized to the LM2596 (150kHz) buck Simple Switcher to avoid cross coupling. The LM2586 (boost), LM2588 (boost), LM2671 (buck), and LM2672 (buck) Simple Switchers can all be synchronized.

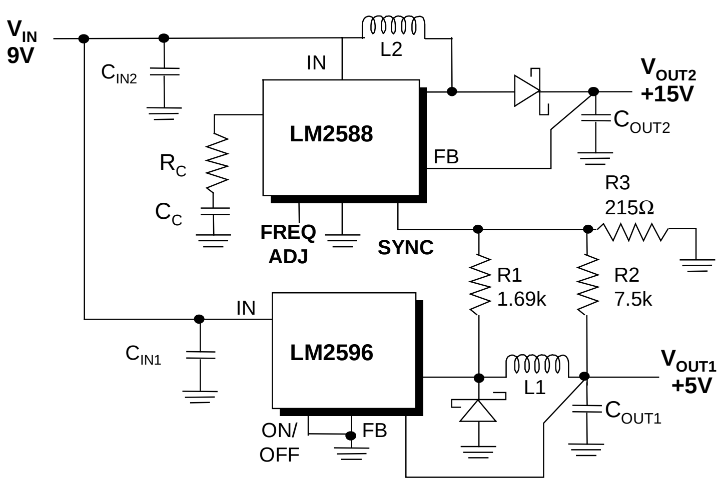


Figure 15 : Synchronizing LM2588 boost to LM2596 buck regulator to avoid beat frequencies

Acknowledgements:

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References:

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