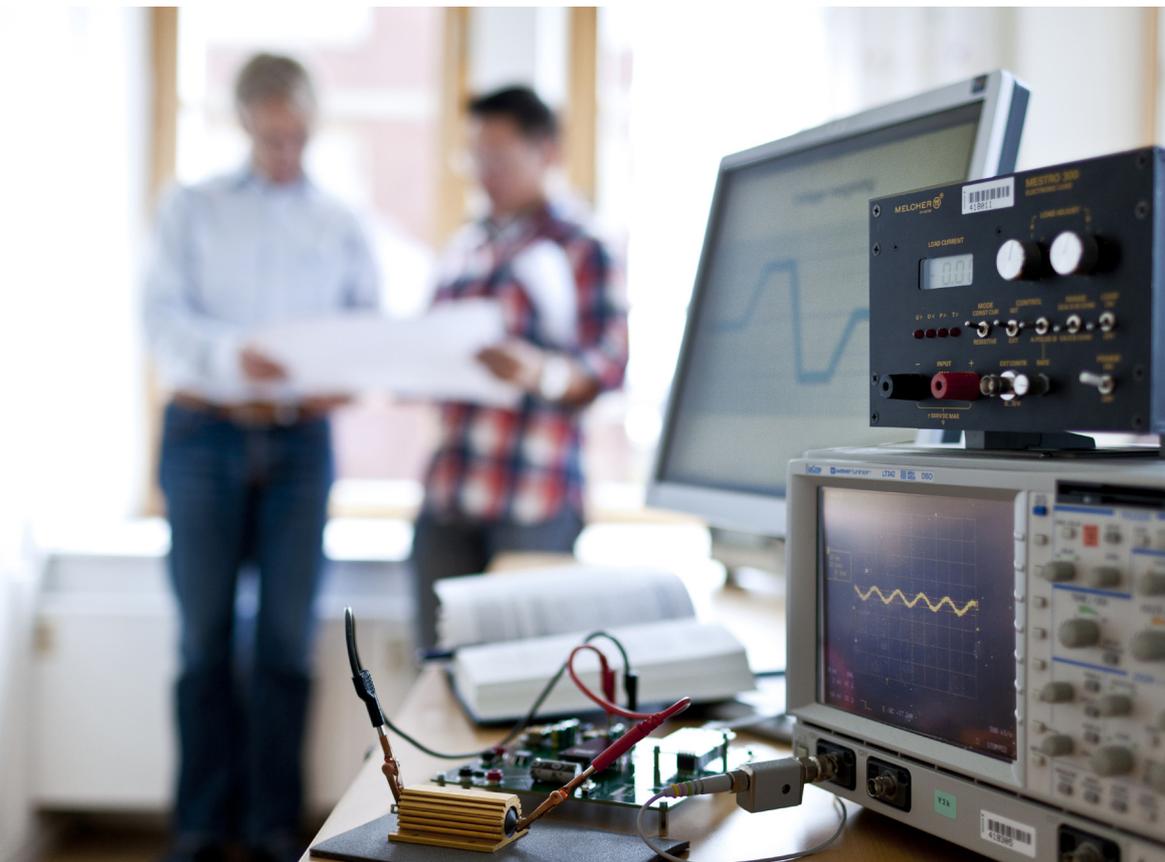


OUTPUT RIPPLE AND NOISE MEASUREMENT METHODS FOR ERICSSON POWER MODULES



Abstract

There is no industry-wide standard for measuring output ripple and noise in DC/DC converters. The methods and test setups vary from supplier to supplier, which sometimes can cause confusion. Ericsson uses methods that give meaningful and reproducible results to the user, but the test methods and assumptions used are not the same for all series of Ericsson products due to the wide range of power levels and end-use applications. The purpose of this design note is to summarize the methods most widely used in the industry and within Ericsson and to show how the test methodology can affect the output ripple and noise reading of a typical DC/DC converter.

Layout design practices for the test setup will be discussed so that pickup of external noise can be minimized. The use and design of low pass filters for the purpose of increasing the reproducibility and significance of noise measurements will be described, as will the usage of capacitance on the product output. An example will be shown that summarizes the effects of the different measurement techniques on a typical product.

Ripple and Noise

All switching power converters with a DC output voltage will contain some ripple and noise component on the output. The ripple and noise show up as an AC waveform that is superimposed on the DC output voltage. The amplitude of this AC component is typically on the order of from ten to a few hundred millivolts peak to peak. The ripple and noise are an artefact of the product's topology and the values and characteristics of its internal components.

Ripple is the more basic and predictable element. The frequency of the ripple waveform is always at the fundamental operating frequency of the product or at some multiple thereof depending upon the topology used. Thus a product operating at 100 kHz, for example, might have a ripple frequency of 100 kHz or 200 kHz. The ripple voltage waveform represents the charging and discharging of the output filter capacitance (both internal and external) as the product commutates through its operating cycle.

In a product with perfect components, the ripple would be the only element of the AC component on the output voltage. Since components are not perfect, however, there is another AC element that is referred to as noise. Noise occurs when current is switched internal to the product. Since all semiconductors and capacitors have some parasitic inductive element associated with their construction, packaging and interconnections, there is a transient voltage developed each time current is switched quickly. Since quick switching is desirable to maximize efficiency and current levels of tens to even hundreds of amps are involved, the resultant noise is noticeable even with extreme care in the design of the product's packaging and layout. Parasitic capacitance associated with the layout can couple this noise to other circuit elements. While much of the noise is attenuated within the product, there will still be some amount of it visible on the output. The noise typically shows up as high frequency spikes or ringing at the transition points on the ripple waveform. Thus, if a peak to peak measurement is made of the ripple and noise, the amplitude of the noise will generally be additive to the ripple voltage as shown in Figure 1.

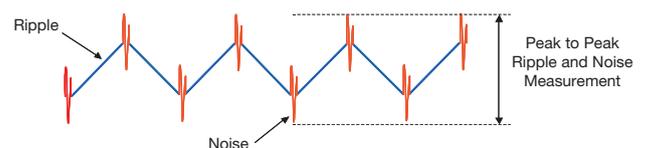


Figure 1. Ripple and noise

The ripple component is relatively robust and will only be slightly reduced by the addition of additional capacitance on the output. The noise component has a much lower energy content and can usually be successfully attenuated by using capacitance at the product's output and at the input to critical load components. This capacitance, in conjunction with the resistive and inductive elements of the distribution system, forms a low pass filter network. For example, it is a common design practice to use at least one 0.1 µF ceramic capacitor close to the output pins of the product to reduce the output noise.

Test Setup Design Considerations

The high frequency content of the noise waveform can present measurement problems unless care is taken in the design of the test setup and measurement procedure. Unless several setup variables are defined and adhered to, it will be difficult to achieve consistent reproducible results when measuring the noise and ripple of DC/DC converters.

The most accurate results are obtained when the measurement is taken as closely as possible to the output terminals of the product. This will minimize effects in the distribution system that may alter the ripple and noise waveform. Since the signal being measured is in the millivolt range and the measurement is made at a fairly high bandwidth, the measurement setup can be susceptible to picking up noise from external sources and distorting the measurement results. The best way to minimize this effect is to use very short and direct connections to the oscilloscope probe such that the total loop area in the signal and ground connections is as small as possible. One commonly used way to make this connection is to solder a probe socket to the PCB at the product output and then slip the probe tip into this socket. BNC connectors are also sometimes used for this purpose. You will get the best result when your test setup is more like the real board layout and impedance matches.

When making the ripple and noise measurement with external capacitors attached to the output remember that there can be fairly large amounts of ripple current flowing into these capacitors. This current flowing through the distribution resistance can cause AC voltage drops that affect the reading. Therefore, the most accurate reading is obtained when the oscilloscope connection point is located directly at the capacitors (0.1 µF).

The board layout and external capacitances that are used are also affecting the measurement result. The selection of the different components is also a critical. Different packages (inductance), values, appropriate rated voltage and temperature dependence must also be considered.

RC Filter Design and Performance

The decoupling capacitor network in conjunction with the distribution resistance and inductance forms a low pass filter for the DC/DC converter output in most applications. This filtering action reduces the output noise of the product.

THE OUTPUT NOISE AND RIPPLE OF DC/DC CONVERTERS ARE OFTEN SPECIFIED TO BE MEASURED WITH A LIMITED BANDWIDTH IN ORDER TO SIMULATE THIS CONDITION AND TO GIVE READINGS THAT ARE CONSISTENT WITH WHAT WILL BE SEEN IN THE ACTUAL END-USE SYSTEM.

The following summary of RC low pass filter design and performance is provided to show how such a filter could be configured for use in measuring ripple and noise. A single stage passive RC low pass filter is commonly used to limit the bandwidth when specifying and measuring the output noise of DC/DC converters. The filter consists of a series combination of a resistor and a capacitor with the filter output taken across the capacitor as shown in Figure 2. The cutoff frequency, f_c , of the low pass filter is defined by the following equation:

$$f_c = \frac{1}{2\pi RC}$$

Where f_c = frequency in Hertz
 R = resistance in Ohms
 C = capacitance in Farads

For example, we can design a filter with a cut off frequency of 5 MHz as follows. First, the resistor value can be arbitrarily selected as 2.2 Ω. Then the capacitor value can be determined by:

$$C = \frac{1}{2\pi R C f_c}$$

$$C = \frac{1}{2\pi \cdot 2.2 \cdot 5 \cdot 10^6}$$

$$C = 14.5 \cdot 10^{-9} \text{ F} \approx 15 \text{ nF}$$

The single stage low pass RC filter amplitude frequency response (gain vs. frequency) is given by the equation:

$$|G| = \frac{|U_{out}|}{|U_{in}|} = \frac{1}{\sqrt{1+(\omega \cdot RC)^2}}$$

Where $|G|$ = gain (gain will be 1 at DC)
 $\omega = 2\pi \cdot f_c$ = angular frequency
 R = resistance in Ohms
 C = capacitance in Farads
 f = frequency in Hertz

The response for the filter designed above is plotted in Figure 2. If this filter were to be used with a DC/DC converter with an operating frequency and ripple frequency of 100 kHz, note that the filter would not appreciably attenuate the ripple waveform. It would, however, attenuate the high frequency content of the output noise. This characteristic is desirable and is consistent with the behaviour of the DC distribution network in typical systems. Rather than using a discrete filter as shown here, another option is to use the filters built into many oscilloscopes. The most common implementation of an oscilloscope internal filter is to have a switch selectable option of full bandwidth or a 20 MHz filter.

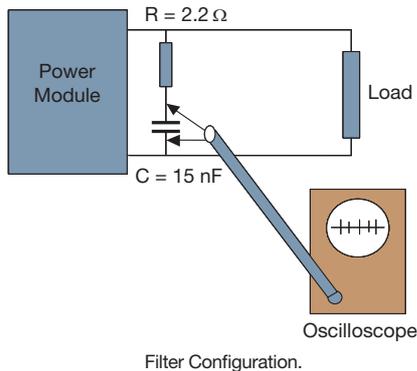


Figure 2a - RC Low pass filter configuration and test setup.

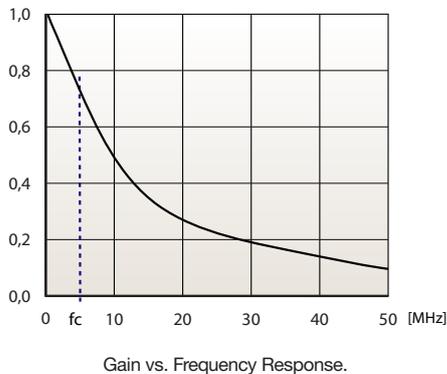


Figure 2b - RC Low pass filter configuration and test setup.

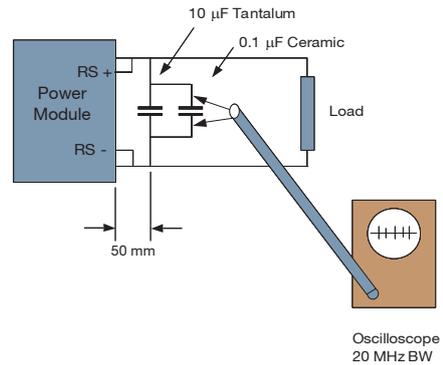


Figure 3 - Test setup for some Ericsson high power products.

Commonly used Test Methodologies

Although there are dozens of techniques used to specify and measure ripple and noise, some are more common than others. In this section we will summarize the most frequently used techniques within the high density power conversion industry and within Ericsson Power Modules.

20 MHz Filter - The most commonly used practice in the power conversion industry is to limit the measurement bandwidth with a low pass RC filter with a crossover frequency of 20 MHz. The 20 MHz value was probably first initiated because of the 20 MHz filter already built into many oscilloscopes. The filter can, however, be constructed from external components as shown in Figure 2 (with different R and C values) if desired. Ericsson uses this method to specify some series in its Point of Load Alliance (POLA) compatible non-isolated point of load converters. Examples include the PMF, PMG, PMH and PMJ.

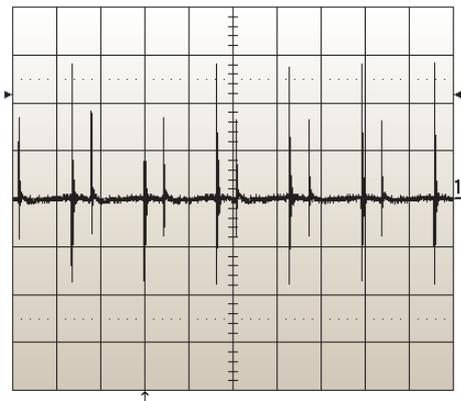
5 MHz Filter - The most commonly used practice within Ericsson Power Modules is to use a low pass RC filter with a crossover frequency of 5 MHz as depicted in Figure 2. The 5 MHz crossover frequency was selected to simulate the performance in the actual end-use systems where the distributed resistance and inductance imbedded in the distribution network in conjunction with the decoupling capacitors form a very effective low pass filter. Some families of Ericsson products that utilize this technique include the PKC, PKD, PKF, PKG and PKN.

Capacitive Filter, 20 MHz Bandwidth - Some types of Ericsson high power products are specified with a capacitive output filter configured as shown in Figure 3. The capacitance consists of a parallel combination of a 0.1 uF ceramic capacitor and a 10 uF tantalum capacitor with ESR=0.2-0.4 Ohms. The capacitors should be located at the oscilloscope probe tip and close to the output pins of the product. The measurement bandwidth is limited to 20 MHz by the low pass filter in the oscilloscope. Some families of products that utilize this technique include the PKB, PKJ and PKM.

Example of Measurement Results

To provide an example of how the different test methods described in this design note will affect the measurement results, the same DC/DC converter was used and its output ripple and noise measured with the various methodologies. The product used was a PKF 4110 B SI, which is an isolated 48 V input that provides an output of 4.5 A at 3.3 V.

As a “baseline” for the measurements, the product was first tested without any filter using the full available bandwidth of the oscilloscope which was 200 MHz. The ripple and noise measurement was 460 mV p-p as shown in Figure 4.



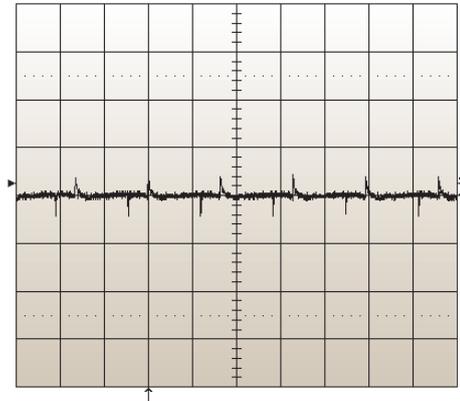
Ripple and Noise 460 mV p-p.
Vertical 100 mV/div Horizontal 2 ms/div

Figure 4 - Example without Filter (200 MHz bandwidth).

The next measurement was made with the commonly used industry practice of using the 20 MHz low pass filter internal to the oscilloscope. This method gave a result of 230 mV p-p as shown in Figure 5.

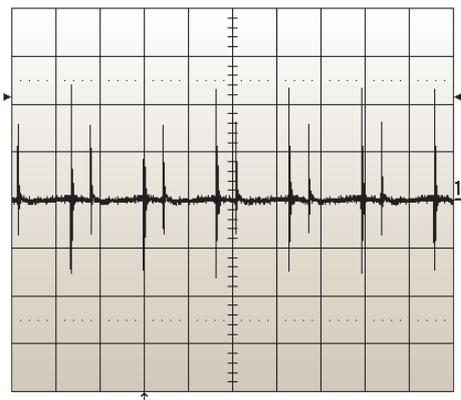
The 5 MHz discrete component low pass filter as often used by Ericsson and described in Figure 2 was tested next. This is the test method specified in the PKF datasheet. This method gave a result of 80 mV p-p as shown in Figure 6.

The last measurement was done using the paralleled capacitor output filter as described in Figure 3. This method gave a ripple and noise reading of 120 mV p-p as shown in Figure 7.



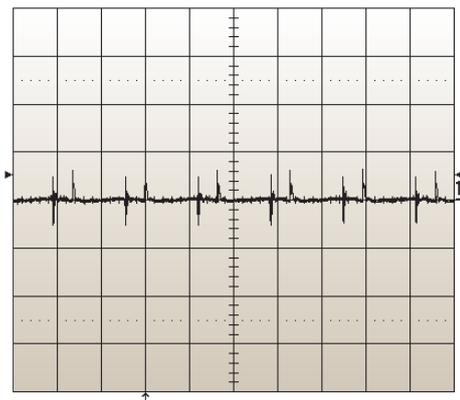
Ripple and Noise 80 mV p-p.
Vertical 100 mV/div Horizontal 2 ms/div

Figure 6 - Example with 5 MHz bandwidth.



Ripple and Noise 230 mV p-p.
Vertical 100 mV/div Horizontal 2 ms/div

Figure 5 - Example with 20 MHz bandwidth.



Ripple and Noise 120 mV p-p.
Vertical 100 mV/div Horizontal 2 ms/div

Figure 7 - Example with Capacitive Filter.

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Formed in the late seventies, Ericsson Power Modules is a division of Ericsson AB that primarily designs and manufactures isolated DC/DC converters and non-isolated voltage regulators such as point-of-load units ranging in output power from 1 W to 700 W. The products are aimed at (but not limited to) the new generation of ICT (information and communication technology) equipment where systems' architects are designing boards for optimized control and reduced power consumption.

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