
Low Leakage Medical power supplies.

Abstract: *There is a fine line between designing a power supply to meet low leakage requirements while at the same time ensuring compliance with international standards for Electro Magnetic Interference. This paper discusses the sources and quantifies this leakage current, and also details the impact of balancing this with the need to meet radiated and conducted emissions. It also discusses the limiting factors that your design needs to meet in order for it to be used in an N+1 redundant system.*

Background:

The IEC 60601-1:2005 (3rd edition) was published in December 2005. This replaced the previous version IEC 606011:1988+A1:1991+A2:1995 as the basic standard for medical electrical equipment, and it deals with the general requirements concerning basic safety and the essential performance. One of these key items is the maximum leakage current under normal and single fault conditions that can occur on the finished design. Leakage current is specified to ensure that direct contact with the medical equipment is highly unlikely to result in electrical shock. Leakage tests are designed to simulate a human body coming in contact with different parts of the equipment. The measured leakage current values are then compared with acceptable limits.

Where does this leakage current originate?

Leakage current is a direct function of the line-to-ground capacitance value. The larger the capacitance, the lower the impedance to Common Mode currents and the greater the Common Mode Disturbance rejection. Therefore, leakage current can also be thought of as a measure of filter performance. However, there is a maximum value placed on this leakage current in order to limit the magnitude of expected ground return currents. The line-to-ground capacitance (or Y-capacitors) provide a path for the Common Mode current to flow to the chassis. As long as the equipment is grounded, these currents will flow in the ground circuit and present no hazard. However, if the ground circuit is faulty, the earth connection may be established by the body of a person. If this should occur, the maximum leakage current specification limits the ground return current to a safe limit.

Quantifying this Leakage current:

With a given supply voltage and frequency, the leakage current depends solely on the capacitors C_{YL} (Live to Earth) and C_{YN} (Neutral to Earth). The total amount is given by the equation

$$I_{leak} = \omega C_Y V$$

For a filter with a C_Y of 2.2 nF (typical on a medical power supplies), an input voltage of 230 V at 50 Hz, and factoring in a tolerance of +/- 20% the expected leakage current can be calculated as:

$$\begin{aligned} &= 2 * 3.14 * 50 * (2.2 * 10^{-9} * 1.2) * 230 \\ &= 190 \mu A \end{aligned}$$

With the limit for a medical power supply being 300uA, such a supply will have say a typical measured leakage current of around 240 μA . The additional leakage current can be attributed to stray capacitance between the Live / Neutral lines and Ground, which will act in parallel to the capacitance of the Y caps. This stray capacitance can be responsible for approximately 50 uA of leakage current.

If we want to use two power supplies in parallel (say in an N+1 redundancy scheme), we must half the leakage current. We can do this by sufficiently reducing the Y-capacitance (since we cannot adjust the input voltage or frequency). It should also be remembered that the leakage current due to the stray capacitance will remain the same. If the Y-capacitors of 2.2 nF are replaced with Y-capacitors of 470 pF, and the calculations repeated, we get:

$$\begin{aligned} I_{leak} &= \omega C_Y V \\ &= 2 * 3.14 * 50 * (0.47 * 10^{-9} * 1.2) * 230 \\ &= 41 \mu A \end{aligned}$$

Add in the additional 50 μA from the stray capacitance and we would expect a leakage current of around 91 μA . Thus, two supplies used in parallel would have a combined leakage of around 180 μA at 230 V, less than the medical standard limit of 300 μA .

How this this have an impact on EMI ?

As well as being obliged to ensure that these electrical devices produce very little electromagnetic disturbances to their surroundings (emission), according to standards, manufacturers of electrical devices are also obliged to sufficiently protect their devices from electromagnetic disturbances (immunity). Both of these requirements are achieved through the use of an electrical filter, but additional filters mean more paths to earth, and so increased leakage currents, so you can see quickly where this is a tricky scenario to design around.

There are two forms of possible conducted disturbances, namely differential mode and common mode.

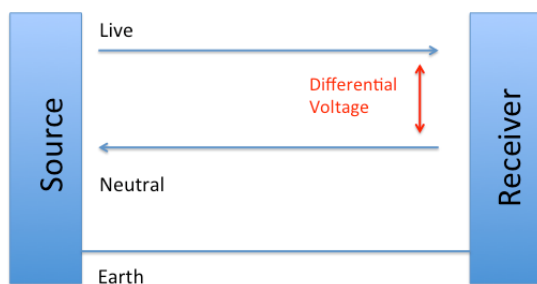


Figure 1: Differential Mode Disturbances

Differential mode disturbances flow via the live line to the interference receiver and via the neutral line back to the interference source. Differential mode disturbances can be quantified by measuring the voltage between the live and neutral conductors. Differential noise mainly occurs at relatively low frequencies (up to several hundred kHz). The use of an X-capacitor (between the live and neutral lines) can dampen differential mode disturbances between

live and neutral. It will do so acting as a short circuit for high frequency noise.

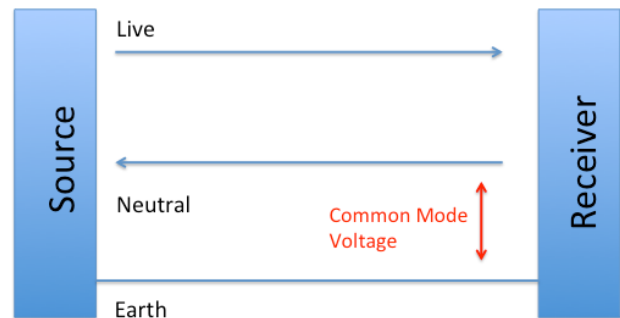


Figure 2: Common Mode Disturbances

Common Mode Disturbances flow via the live / neutral line to the interference receiver and via ground back to the source of interference. Common mode noise can be quantified by measuring the voltage between the live / neutral and earth. Common mode noise occurs mainly at high frequencies (1 MHz upwards).

A Y-capacitor can be used to dampen common mode noise between live / neutral and earth. For high frequency energy that comes simultaneously on both lines, the capacitors act as a short circuit to ground. The key point to note here is that the Y-capacitor capacitance must be limited in order to limit leakage current; the higher the capacitance, the greater the leakage current. Leakage current can be reduced by reducing the Y capacitor's value, but this has the unwanted knock on effect of increasing common mode noise.

How this this have an impact on the final design?

If we were to measure the conducted emissions on the AC inlet of two power supplies with the Y capacitors reduced only, we could expect to measure a fail. Table 1 below shows this on an actual power supply with these changes implemented. In this case the existing caapcitors of 1.5pF were replaced with 470pF capacitors respectively.

Frequency	Line1 dB μV		Line2 dB μV		Limit dB μV	
	QP	Avg.	QP	Avg.	QP	Avg.
150.57 kHz	80	73.8	-	-	79	66

Table 1: Conducted Emissions – Line 1 (Fail)

The low leakage power supply now fails Class A limits (EN55022) for QP and Average readings. If

it is to pass the Class A limits, we would need to improve the filtering of common mode noise without increasing the Y-capacitance which would increase the leakage current. An alternative to the Y-capacitor is to use a common mode choke. A Common-mode choke can be used as these are designed to pass differential currents while blocking common-mode currents. This type of coil is produced by winding both supply wires on one single ferrite core.

not be permitted to use the finished goods in the field.

Since magnetic flux flows inside the ferrite core, the common mode choke coils work as an inductor against common mode current. An ideal common-mode choke is perfectly transparent to every mode except the common mode. It offers no resistance to any differential or transmission line current, but for common mode current it looks like an open circuit.

Two common mode chokes were tested with the parallel power supply setup, with the following results:

Frequency	Line1 dBµV		Limit dBµV	
	QP	Avg.	QP	Avg.
150 kHz	69.4	62.7	79	66
284.1 kHz	57	52		
207 kHz	60	59.8		

Table 2: Conducted Emissions - Line 1 (Pass)

Frequency	Line2 dBµV		Limit dBµV	
	QP	Avg.	QP	Avg.
150 kHz	70.4	63.4	79	66
16.65 MHz	40.4	36		
207 kHz	61	60		

Table 3: Conducted Emissions – Line 2 (Pass)

Both tests now result in a pass for Class A EMC limits (EN55022) and medical rated leakage current.

In summary:

In summary, if you are designing a system which required the use of two power supplies, you must satisfy yourself that the supplies used have sufficiently low leakage currents, so their combined total will not exceed 300 uA. Power supply designers will need to go to great lengths in order to provide a solution that not only meets the leakage requirements but continues to meet Electro Magnetic Interference limits, or your end user will

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