THE GROUND RULES: EARTHING, CLASS, AND EMC

Simply grounding the output of a standard class II AC/DC switching power supply can create EMC problems. The solution is to use an external mains filter or to select a RECOM series that is specially designed for PELV applications with additional internal filtering.

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WHY GROUND?

Mains electricity is a hazardous voltage, so safeguards are needed against electric shock (Table 1). As current always takes the easiest path, earthing is one way to reduce the electric shock hazard by shunting any leakage or fault current back to the ground potential instead of through the relatively high impedance of the human body. The other way to safeguard against electric shock is to introduce sufficient insulation to block the flow of current to safe levels. Usually, for mains voltages, two separate means of insulation (double or reinforced insulation) are required so that if one insulation barrier fails, the remaining barrier(s) can still block the flow of current.

EFFECT OF ELECTRIC GROUND	CURRENT	ELECTRICAL SAFETY (HBSE) CLASS
Minimal Reaction	<0.5mA	ES1
Startle Reaction, but no Injury	up to 5mA	ES2
Muscles Contract, Unable to Let Go	up to 10mA	ES3
Heart Defibrillation, Internal Injury, Death	>10mA	

Table 1: Human body threshold currents (source: DC/DC BoK 6.1.2).

If a power supply is grounded or earthed, it will carry a standardized symbol to indicate the ground connection. There are three types of ground symbol because the function of the ground potentials are slightly different (figure 1):

Figure 1: Types of ground symbol.

Signal ground: The return path or zero voltage connection point within a circuit. This point need not be connected to the chassis or earth ground point, but it can be.

Chassis ground: A single connection to the metal chassis or enclosure. The function of the chassis ground is to collect any stray or induced voltages and return them to a ground potential (shielding function), but it can also be connected to the earth ground to prevent electric shock (grounding function). It is important that the chassis ground and earthing ground meet at a single connection point, otherwise current could flow through the chassis from one part of the circuit to another to form a ground loop. Ground loops can insert unwanted electrical noise into a circuit harming performance and adversely affecting the EMC (Electro-Magnetic Compatibility) immunity.

Earth ground: this is the Protective Earth (PE) connection that is wired back to the earth pins in the mains connector forming the safety low impedance path for any leakage or fault currents. Earth and Ground are used interchangeably in this White Paper.

WHAT IS THE POWER SUPPLY CLASS?

It is not always necessary to ground a power supply if it has sufficient insulation to avoid electric shock to anyone who touches it or uses a safe extra-low supply voltage (SELV). Confusingly, the class system is divided into Class I, II or III, or into Class 1 or Class 2, depending on the standards used:
The IEC (International Electrotechnical Commission) circuit classifications are:

- **Class I Equipment:** Systems which use protective earthing (e.g., a grounded metal enclosure or grounded output) and fault supply disconnection (fuse or circuit breaker) as one level of protection and thus require only basic insulation. No exposed hazardous voltages (earthed metal enclosure or non-conducting enclosure).

Figure 2a: Earth symbol.

- **Class II Equipment:** The use of double or reinforced insulation to eliminate the need for a grounded metal enclosure, no exposed hazardous voltages (non-conducting enclosure). No PE connection is required, but a filter ground connection may be used (functional earth rather than protective earth).

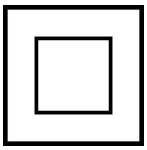

Figure 2b: Double insulated symbol.

Note: If an AC/DC power supply has a Filter Ground (FG) connection to meet the EMC regulations, it can still be classed as a Class II power supply if it does not need the ground connection for protection against electric shock.

- **Class III Equipment:** Powered from a SELV source and with no potential for generation of hazardous voltages internally, and therefore requiring only functional insulation. Functional earthing may be used, but a connection to PE is not permitted (no return path to ground via the power supply).

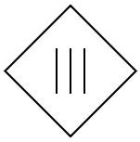

Figure 2c: Class III symbol.

The US-based NEC (National Electrical Code) classification also uses a similar "Class" system to describe the different levels of protection but uses Arabic numerals to describe the level of protection against excessive energy dissipation (fire hazard).

The NEC circuit classifications are:

- **Class 1 Circuits:** Power limited <1kVA and output voltage <30VAC
- **Class 2 Circuits:** Power limited <100VA, input voltage <600VAC and output voltage <42.5VAC
- **Class 3 Circuits:** Power limited <100VA, input voltage <600VAC and output voltage <100VAC; Additional protection against electric shock needed.

Thus, when someone talks about a "Class Two" power supply, it is important to determine if they are using the IEC or NEC definitions.

GROUNDING THE INPUT

A class I power supply that uses a protective earth connection for both safety and noise filtering is shown in Figure 3:

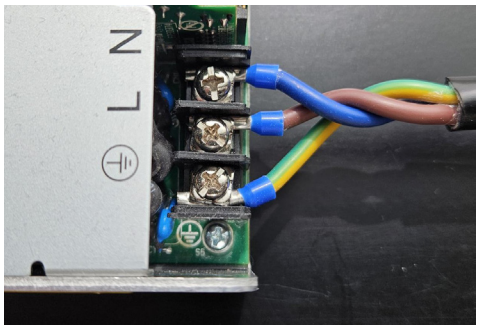

Figure 3: Mains input connection on a Class 1 power supply (RACM600-L). Next to the earth connection terminal is the case earthing point, also marked with the ground symbol.

Figure 4 shows a simplified block diagram of a typical AC/DC class I switching converter. The switching stage generates electrical noise (shown in red) that is conducted both back to the input and across the isolation transformer coupling capacitance to the output. Noise filtering paths (shown in blue) use C2, C3, C5, and C6 to channel the interference to low impedance ground. The capacitively coupled noise on the output is "shorted" back to the switcher via capacitor C4, thus closing the loop. C4 is placed across the isolation barrier so it must be rated for the isolation withstand voltage (typically 4kV) and be a Y-capacitor type. C1 is a mains-rated X-capacitor and C2, C3, C5, and C6 are all Y-capacitors. For an explanation of the difference between Y- and X-capacitors, refer to the RECOM AC/DC Book of Knowledge, Chapter 5.

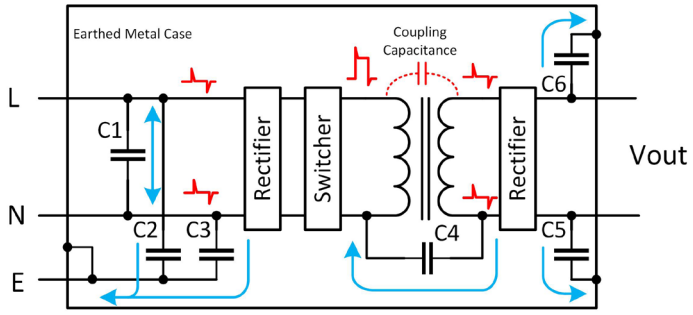

Figure 4: Class I power supply with noise filtering capacitors (schematic).

Class II power supplies that do not have an earth connection require additional input filtering to block the conducted noise (Figure 5). The components C1, L1, and C2 form a Pi-filter that effectively blocks conducted noise without the need for a ground connection. The insulated case means that a protective earth connection is also not needed for safety. C4 has the same function as in the previous example, but to be single-fault failure safe, the regulations require two Y-capacitors connected in series.

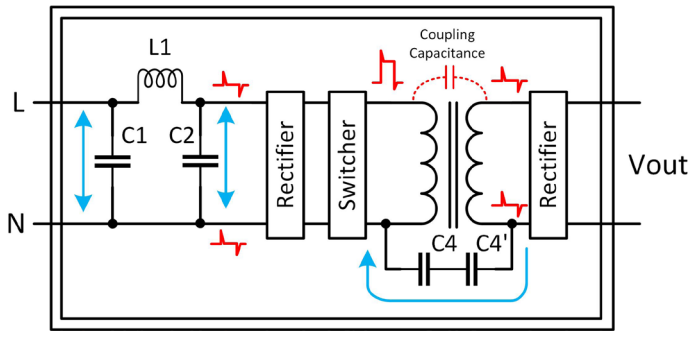

Figure 5: Class II power supply without an earth connection (schematic).

GROUNDING THE OUTPUT

In some Class II applications, the isolated floating output may be accidentally or deliberately connected to the ground potential. Although this does not cause any safety issues and may even be desirable to have a ground-referenced power supply for safety reasons (PELV applications), it can cause an EMC fail because the transformer coupled switching noise can now flow through the grounded output side as well as through C4 (Figure 6).

Earth and Neutral are connected at the main power supply input of a building, but also cable capacitances can cause capacitively-coupled noise loops between neutral and earth in the wiring. The leakage current flow is not high enough to cause an electrical shock hazard, but it can exceed the strict class B EMC limits.

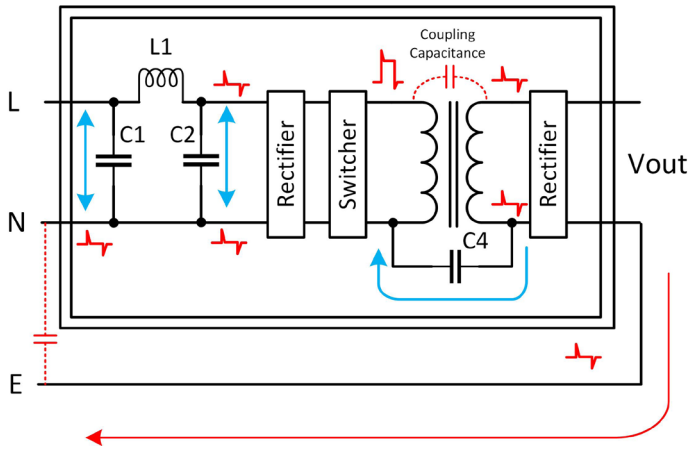

Figure 6: Ground-referenced outputs can create an external noise current loop.

The solution to this problem is to provide additional input filtering to block the noise interference as shown in Figures 7 and 8. The external common mode (CM) mains filter stops the noise interference from being coupled back through to the earthed output.

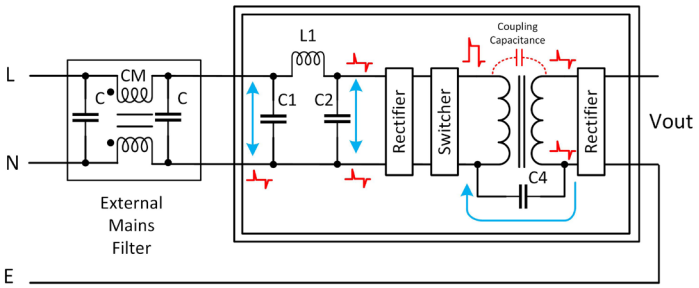

Figure 7: Ground-referenced output noise blocked by additional input filtering (schematic).

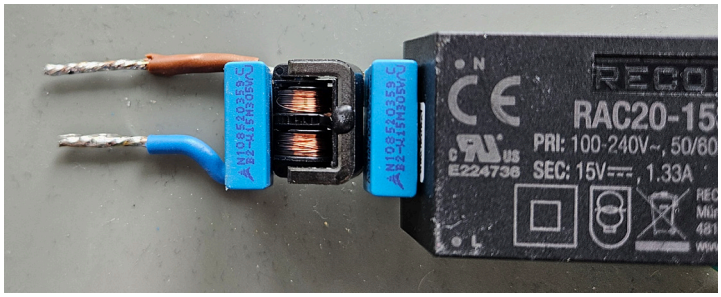

Figure 8: Ground-referenced output noise blocked by additional input filtering (test setup).

The following EMC spectra show the difference between a ground referenced output AC/DC converter with and without the external filter mains filter components (Figure 9):

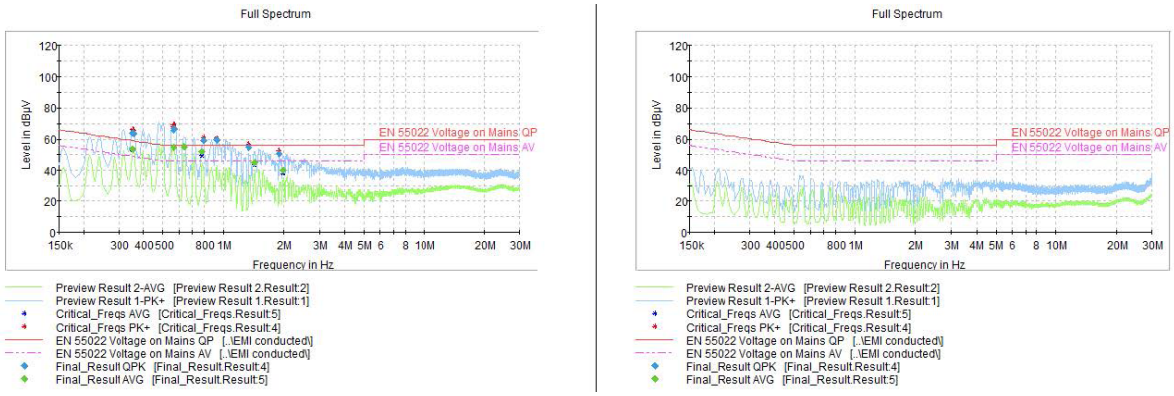

Figure 9: Comparison of ground-referenced output EMC test spectra without an external filter (left) and with the filter (right). Without the filter, the results exceed the EN55022 limits by more than -10dB. With the filter, the results are well under the limits.

Realizing that many customers would prefer an all-in-one solution, RECOM manufactures several PCB-mount Class II power supplies that include the additional mains input filtering internally so that the output can be ground-referenced without causing any EMC problems (Figure 10).

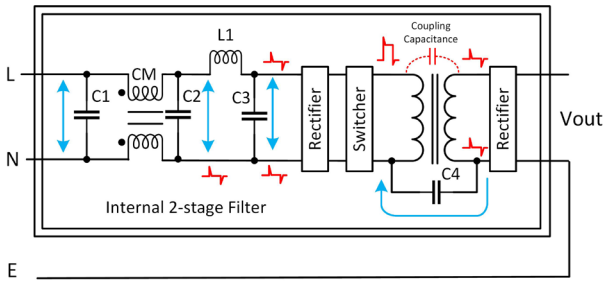

Figure 10: Ground-referenced class II power supply with two-stage internal filtering.

Adding internal filter components increases cost and makes the part larger, so they are only included in a select few series. A selection of RECOM AC/DC part numbers that can be PELV output grounded and still meet class B EMC limits are shown in Table 2 (class I power supplies can all be operated in PELV mode):

SERIES	POWER	VIN (AC)	CLASS, GRADE	PELV OPERATION	TYPE
RAC02E-K/277	2W	85-305	Class II	With ext. mains filter	PCB-Mount
RAC03-K	3W	85-264	Class II	With ext. mains filter	PCB-Mount
RAC03-K/SMT	3W	85-264	Class II	With ext. mains filter	SMT-Mount
RAC03-K/277	3W	85-305	Class II	With ext. mains filter	PCB-Mount
RAC04-K/277	4W	85-305	Class II	With ext. mains filter	PCB-Mount
RAC04NE-K/277	**4W**	**85-305**	**Class II**	**Built-in PELV filter**	**PCB-Mount**
RAC05E-K	5W	90-264	Class II	With ext. mains filter	PCB-Mount
RAC05E-K/277	5W	90-305	Class II	With ext. mains filter	PCB-Mount
RAC05-K/480	5W	85-528	Class II	With ext. mains filter	PCB-Mount
RACM06E-K/277	6W	89-305	Class II, Medical	With ext. mains filter	PCB-Mount
RAC10E-K/277	10W	90-305	Class II	With ext. mains filter	PCB-Mount
RACM15E-K	15W	80-275	Class II, Medical	With ext. mains filter	PCB/DIN-Mount
RAC15-K/480	15W	85-528	Class II	With ext. mains filter	PCB-Mount

SERIES	POWER	VIN (AC)	CLASS, GRADE	PELV OPERATION	TYPE
RACM16E-K/277	16W	90-305	Class II, Medical	With ext. mains filter	PCB-Mount
RAC20NE-K/277	**20W**	**90-305**	**Class II**	**Built-in PELV filter**	**PCB-Mount**
RAC25-K/480	25W	85-528	Class II	With ext. mains filter	PCB-Mount
RACM30-K/277	**30W**	**90-305**	**Class II, Medical**	**Built-in PELV filter**	**PCB/Chassis/DIN-Mount**
RACM40-K	**40W**	**80-264**	**Class II, Medical**	**Built-in PELV filter**	**PCB/Chassis-Mount**
RACM60-K	60W	80-264	Class II, Medical	With ext. mains filter	Chassis-Mount
RACM60-K/2x4"	**60W**	**80-265**	**Class II*, Medical**	**PELV Compatible**	**Chassis-Mount, *Functional Earth**
RACM90-K	90W	85-265	Class II, Medical	With ext. mains filter	Chassis-Mount
RACM130E-K	130W	85-264	Class II, Medical	With ext. mains filter	Chassis-Mount
RACM140-K	**140W**	**80-264**	**Class I, Medical**	**PELV Compatible**	**Chassis-Mount**
RACM150-G	**150W**	**90-264**	**Class I, Medical**	**PELV Compatible**	**Chassis-Mount**
RACM230-G	**230W**	**80-264**	**Class I, Medical**	**PELV Compatible**	**Chassis-Mount**
RACM550-G	**550W**	**80-264**	**Class I, Medical**	**PELV Compatible**	**Chassis-Mount**
RACM600-L	**600W**	**80-275**	**Class I, Medical**	**PELV Compatible**	**Chassis-Mount**
RACM1200-V	**1200W**	**80-264**	**Class I, Medical**	**PELV Compatible**	**Chassis-Mount**

Table 2: RECOM's PELV-compatible series

CONCLUSION

PELV (Protective Extra Low Voltage) applications that require an earth-referenced DC output are often specified in areas where a high level of electrical safety is required, for example, in hospitals, swimming pools or in areas where highly flammable materials are stored.

However, simply grounding the output of a standard class II AC/DC switching power supply can create EMC problems. The solution is to use an external mains filter or to select a RECOM series that is specially designed for PELV applications with additional internal filtering.

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