

The trouble with wall-warts

Tim Williams, Elmac Services

Introduction

Many small electronic products use external mains-to-DC power supplies, often known because of their appearance and location as “wall-warts”. These are usually bought in from a volume supplier and packaged with the product, and as such they must follow the same EMC compliance rules as the product does. Problems arise when the wall-wart meets its own EMC emissions limits but when tested in conjunction with the product, the combination does not. Whose fault is it, and what can be done?

Using external power supplies

Because many small products – particularly IT and consumer products – use low levels of power at DC (typically 12V) but need to be supplied at mains voltage, a large market has grown up for external DC switchmode power supplies which plug directly into the mains outlet (hence, “wall-wart”) and which supply power to the application unit via a short two-wire low voltage cable. The product manufacturer normally buys these in from an external supplier, often in the Far East, and has no control over the design of the supply itself. In particular, its EMC aspects are likely to be relegated to the requirement that the supply must simply carry the CE Mark – even though, since it is not placed on the market to the final end user by its own manufacturer, this requirement is strictly incorrect.

However, the wall-wart supplier will typically offer a product which does in fact meet at least the conducted emissions requirements of the IT standard EN 55022, and this might appear to be enough for the product manufacturer who will package it with their own unit – let’s for the sake of argument in the rest of this article, call this a LAN hub, but the principle is the same whatever the product. It is sometimes assumed that, because the LAN hub does not directly connect to the mains supply, it doesn’t need testing for mains conducted emissions or immunity if the supply itself already complies. This is a fallacy, as we can see from inspection of the system equivalent circuit. The supplier of a system – in this case, the LAN hub and its mains power supply – must ensure that the whole system complies when it is used in a typical configuration, and the connection of a DC load to the output of the wall-wart may change its emissions profile, as well as adding its own emissions coupled back down the DC power lead.

But this isn’t the only problem. EN 55022 includes requirements for conducted emissions tests on telecom ports. While these aren’t yet mandatory under the EMC Directive, many manufacturers are applying the tests now to make sure they do not get caught out when the compliance regime changes to make them so. And in doing so, they are bumping again into the problem of conducted emissions generated by the wall-wart power supply. To understand the mechanism, we must delve more deeply into the equivalent circuit.

The conducted emissions equivalent circuit

The equivalent circuit of the conducted emissions test, both for mains port and telecom port emissions, can be drawn as shown in Figure 1. For the sake of this discussion, disturbances generated within the LAN hub itself are ignored.

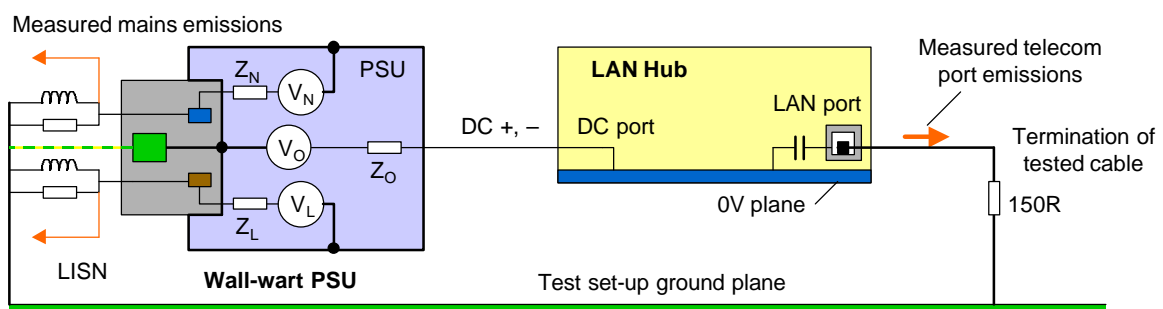


Figure 1

The interference is generated within the wall-wart PSU due to its switching power supply and is represented by V_N and V_L , feeding the live and neutral mains connections, and V_O , feeding the output

connection. Each has a source impedance Z_L , Z_N or Z_O , and each is referred to the enclosure and thence to the earth pin of the power supply, which is connected through the LISN to the ground reference plane of the test. These impedances are likely to be predominantly capacitive and affected by layout aspects and transformer construction of the power supply. (If the enclosure is entirely plastic then the capacitive interconnections become more complicated, but do not vanish.)

It is vital to appreciate that the components at the output of the wall-wart form the *common mode* circuit; that is, neither the DC link voltage nor the LAN output signals are of any interest to us and are not shown, only the entire cable, considered as a whole, is shown. It doesn't actually matter whether or not the LAN hub itself is powered up and operating for this circuit and its effects to be valid.

In the above circuit the output noise voltage V_O is referred to the earth pin. As shown, there would be no feedthrough of the output noise to the mains L and N connections, which would see only V_N and V_L . But what happens if the power supply is safety Class 2, i.e. has no connection to earth so that the green-and-yellow wire in Figure 1 is missing? V_O can then only be referred to the case of the unit, to which V_N and V_L are also referred. This means that V_O will be added to the measurement of both V_L and V_N , but its level will depend on the ratio of the various impedances in the power supply circuit (Z_O , Z_L , Z_N and the LISN impedance) as well as the impedance of whatever the output is connected to. In the circuit this is determined by the connection of the LAN hub's signal port. Clearly then, mains emissions in this case will be affected by the test set-up at the output of the wall-wart.

The effect of impedances

To clarify this a bit, let's re-draw the impedances in the circuit when the earth is removed (Figure 2).

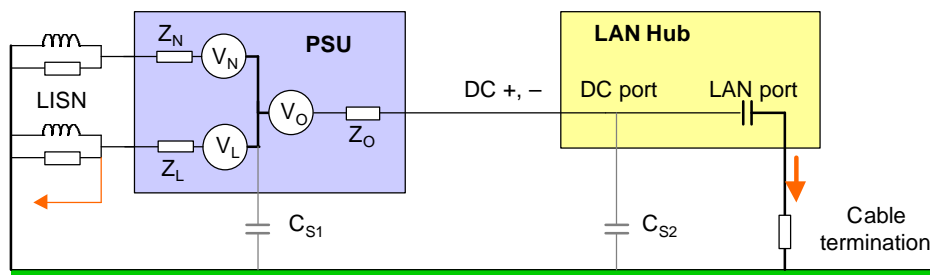


Figure 2

If there were no output connection, V_O would be irrelevant, and the levels measured at live and neutral would be entirely determined by V_L , V_N , their source impedances and the LISN impedance. But with the LAN hub connected, V_O is added to each of V_N and V_L from a source impedance determined at low frequency by the series combination of Z_O , the LAN port output impedance and the cable termination impedance. From this you can see that if the LAN cable termination is a high impedance (say, a short unscreened cable to a laptop) the effect of adding V_O will be negligible; but if it is low, such as a desktop PC fed via a screened cable, V_O will be significant. So it would be quite reasonable for two different but equally valid test set-ups to produce markedly different results.

The situation is complicated at high frequencies by the presence of stray capacitances C_{S1} and C_{S2} , and also by the inductive impedance of the DC power cable and the signal cable. These can often combine with other strays into a series resonant circuit that gives a characteristic hump in switchmode emissions around 10-25MHz, but usually they are less significant below, say, 1MHz.

Telecom port emissions

The previous discussion has concerned mains conducted emissions, but Figure 2 shows that similar issues apply to telecom port emissions, i.e. those measured in common mode on the LAN cable. Although some such emissions will be generated within the LAN hub, particularly the common mode component of the LAN data, there will also be a significant component that is passed directly through the LAN hub from the wall-wart. Here, the worst case will be if the reference for V_O is in fact directly connected to earth. This allows the maximum current developed by V_O to flow through Z_O and out through the terminated LAN cable. Even so, there may not be much difference if the earth is removed, since the parallel combination of L and N impedances at the LISN is a mere 25 ohms, and Z_L and Z_N may not be much

higher. On the other hand, even if V_O is negligible, the mains sources V_L and V_N will also contribute to levels at the telecom port if the earth is removed.

Precautions for mitigation

Because all these emissions are propagated from the wall-wart to the LAN hub in common mode, any differential mode fixes such as capacitive filtering at the DC supply input of the LAN hub will be utterly useless. Indeed, this is a simple diagnostic technique: put a big capacitor, say $1\mu\text{F}$, across + and – at the input to the LAN hub and check to see if it makes any difference. Assuming it doesn't, and if you have confirmed that the emissions frequency spectrum implicates the wall-wart, this is conclusive evidence of the coupling path.

In this case, screening of the LAN hub or providing a metal chassis or improving its PCB layout will also all be useless, since the interference is being passed directly from DC input to LAN output.

The first solution that will work is to put a common mode choke right at the DC input to the LAN hub. The effect of this can be seen in Figure 3.

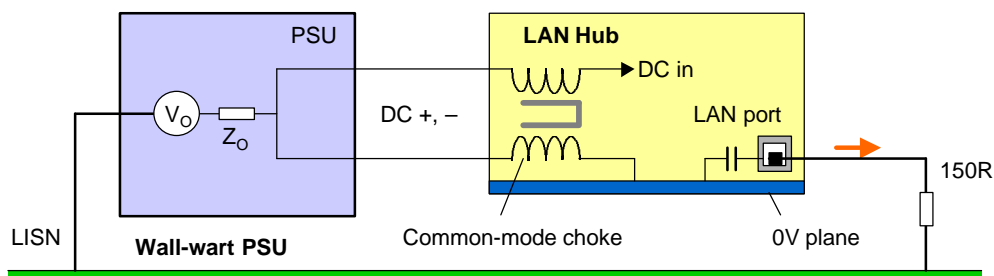


Figure 3

The choke increases the impedance in series with Z_O . This will reduce the disturbance currents flowing through the LAN cable in direct proportion to the difference in impedances with and without the choke. Thus if the dominant impedances without the choke are $(Z_O + 150)$ ohms, and you need a 6dB improvement in emissions, the CM choke must also have an impedance of $(Z_O + 150)$ ohms at the appropriate frequency. This works well if Z_O is relatively low and the frequencies are high; there are many small surface-mount CM chokes for DC inputs that can give well over 1kohm impedance. It also has the benefit of reducing the effect of any common mode emission sources within the LAN hub. If the frequency is down towards 150kHz though, and Z_O is already high (implying that the wall-wart is acting more like a common mode current source), then you will need a potentially very large CM choke to have enough effect.

The next "solution" that will work is to reduce the impedance of the LAN hub itself to the ground plane. If it were to have an earth point, then this would be directly connected to the ground plane and the majority of the power supply emissions would pass into the plane rather than through the LAN port. But how many such devices have an intentional earth connection?

You may, though, have the option of making additional connections to other ports. If these have a low impedance connection to the LAN hub's 0V plane, and also a low impedance termination to the ground plane (or at least stabilised to 150 ohms, as with the LAN port) then they will also pass a proportion of the power supply emission currents to the plane (Figure 4). The proportion will be directly related to the ratio of impedances at the various ports; if the impedance of one additional connected port is the same as that of the measured LAN port, then a reduction in the LAN port emissions of 6dB can be expected.

The requirement of CISPR 22 (EN 55022) is that the set-up should maximise emissions, but this is contingent on having cable positions "in a test arrangement that is representative of typical installation practice". The standard also requires that "Interface cables/loads/devices shall be connected to at least one of each type of interface port of the EUT, and where practical, each cable shall be terminated in a device typical of actual usage." So it is entirely possible to be consistent with the standard with a set-up which uses more than one cable and in fact reduces the emissions at a telecom port. You should, of course, use the same practical set-up for the mains conducted emissions test and it is possible that this would increase these levels, since you are reducing the common mode impedance from the LAN hub to the ground plane with reference to Figure 2.

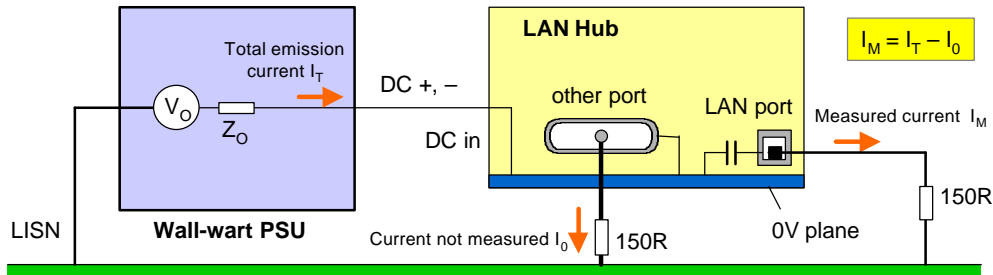


Figure 4

Lastly, the best way of dealing with the whole problem is to specify the emissions of the wall-wart supply properly. Instead of leaving it to the wholly unsatisfactory and uncontrolled requirement that the wall-wart be CE Marked, place explicit specifications on both the input and output emissions levels. It will generally be sufficient to quote EN 55022 Class B levels for the mains conducted emissions, with the output terminated in a DC load equivalent to its maximum rated power and at the same time a common mode impedance of 150 ohms to the ground plane. The crucial extra requirement is that the DC output common mode voltage and/or current is also specified to EN 55022 Class B telecom port emission levels, under the same conditions. If the supplier can be contractually persuaded to meet these limits, then you have good confidence that any emission failures are due to your own product, not the wall-wart.

Conclusions

If you are in the business of specifying and procuring wall-wart switchmode power supplies, you need to be prepared to ensure that they do not contribute to emissions non-compliance of your overall product when the two are used together. Emission levels may be exceeded simply by the interaction of the two units and their external cables.

Examining the common mode equivalent circuit for conducted emissions shows how this can come about, and also gives pointers to how the effects can be mitigated. In general, the most effective mitigation technique is to ensure that the emissions from the external power supply are properly controlled in the first place.

Originally published in EMC Journal No. 58 May 2005

This paper can be freely downloaded from www.elmac.co.uk