NOISE SUPPRESSION

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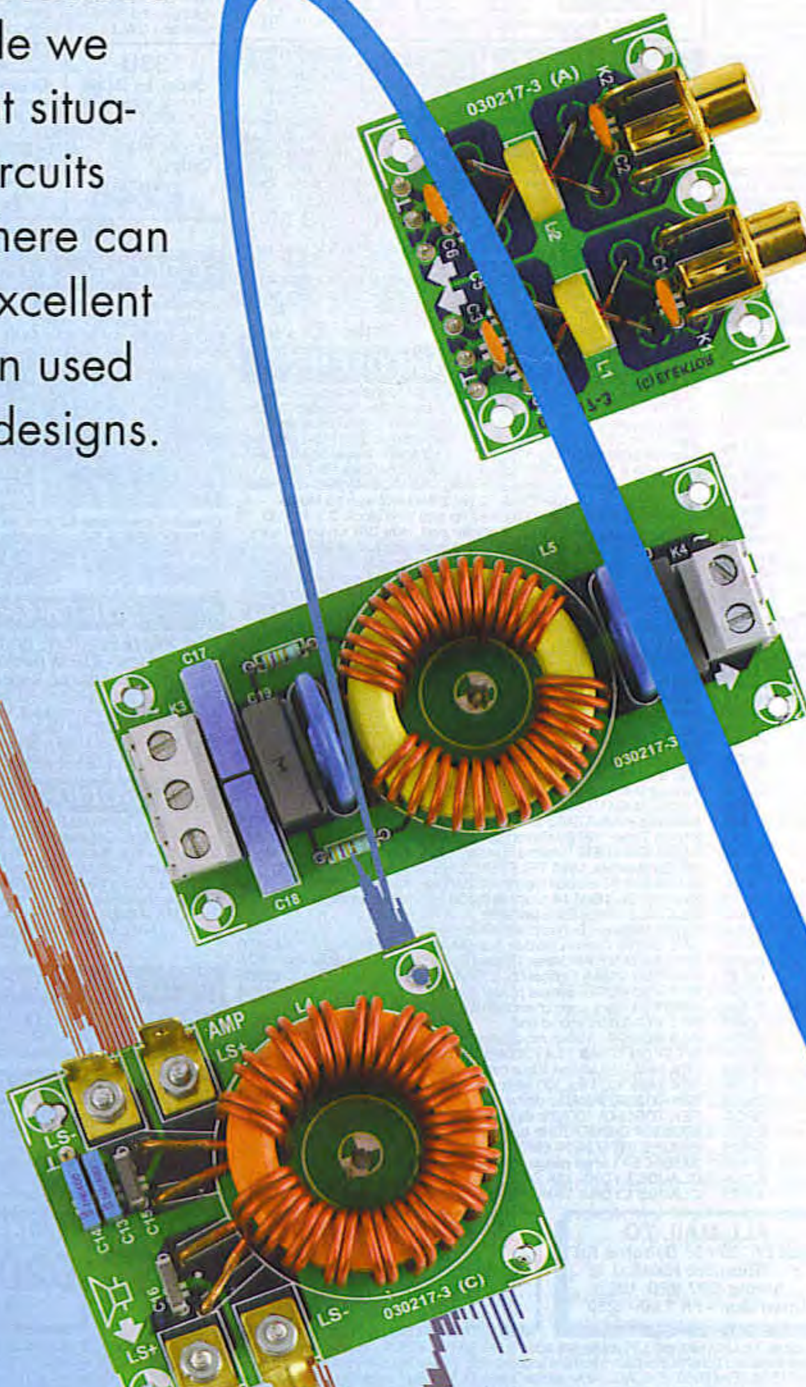
In the three-part article for the ClariTy 2 x 300-W final amplifier, the various input and output filters were not described. In this article we remedy that situation. The circuits described here can also give excellent results when used with other designs.



FILTERS For ClariTy and other final amps

Extremely high currents at relatively high frequencies are present in amplifiers such as our ClariTy design (*Elektor Electronics* June, September, October 2004). In such situations it is recommended to take measures to suppress interference signals (electromagnetic interference, or EMI for short). This can be done by using additional filters for all connections to the outside world. For an amplifier, three different types of filters are necessary. They are respectively used for the loudspeaker connections, the signal inputs and the 230-V mains connection.

For the inputs and the loudspeaker connections, it is common practice to filter only the interference currents shared by the two conductors (signal and ground), which is called 'common-mode suppression'. This causes the least possible effect on the audio spectrum. At the inputs to the 2 × 300-W amplifier, for example, it is clear that only common-mode interference can be present. This is because an analogue gain stage is present at the input of the TA3030 amplifier IC, and there is also no question of interference arising directly from the signal source.

Another factor is that here the loudspeaker outputs drive loads having very low impedance, which means large currents can occur. However, the filters already present on the circuit board of the ClariTy amplifier suppress only the PWM signal. Such a signal is actually a purely differential-mode interference signal.

In the case of this amplifier, common-mode interference primarily arises from the amplifier as a whole. This interference can thus be found on all of its connections. That means that separate filters for suppressing common-mode interference must also be used for the loudspeakers in order to reduce EMI.

As a PWM amplifier also loads its power source with a 'nasty' signal, it's a good idea to use a combination of common-mode and differential-mode suppression for the mains filter. This can be implemented relatively easily by winding the filter coil in a special manner.

Toroidal cores are used for all of the filters described here. This minimises inductive coupling to the surroundings. Another advantage of using toroidal cores is that they make it possible to wind inductors that only generate an inductance for common-mode signals. By now it should thus be clear that inductors for mains filters generally have to be would differently than inductors for loudspeaker filters.

Input filter

Let's start at the beginning: the input. In practice, it's clear from measurements made using an Audio Precision analyser that a sturdy input filter can provide significant benefits. Without such a filter, the measurements made on the ClariTy amplifier were instable and in fact unusable.

The input filter (**Figure 1**) thus provides common-mode isolation between the signal source and the amplifier. In addition, capacitors for differential-mode suppression are included as a precaution. We prefer not to use ceramic capacitors in the signal path for audio applications, but in this case they are present in parallel with the output of the preamplifier for audio signals. If the preamplifier has low output impedance, the effect on the sound quality will be negligible. The two channels are kept fully apart on the circuit board, so the entire signal path between the preamplifier and the final amplifier remains separate for the two channels. The two grounds must be connected together at a single point at the analogue power supply neutral potential. In the case of our amplifier, this point is thus on the amplifier board. The filter also prevents ground loops from arising.

The inductor uses a very small toroidal core with dimensions of 10 × 4 mm. It has two windings, each just a bit more than a single turn. In practice, this proves to be more than adequate (for our application). Two short (but sufficiently long) lengths of 0.5-mm diameter enamelled copper wire (ECW) are passed through the centre of the small toroidal core and wound together around the core (bifilar) in a single loop. The other ends thus emerge on the opposite side of the core. This yields a self-inductance of twice 14 µH and a leakage inductance of less than 100 nH. The leakage inductance is the virtual inductor that contributes to the differential-mode effect of the filter. Incidentally, it's difficult to measure the leakage inductance.

From the value of 14 µH, it's apparent that each winding behaves as though it had nearly two turns. This can be seen from the fact that according to the data sheet, the value of the A_L factor for this toroidal core is 3470 nH. You can calculate this for yourself using the formula $L = N^2 \times A_L$ (where N is the number of turns).

Just as for the filters described later on, a printed circuit board has been designed for this filter. The inductor should be fitted vertically on the circuit board, and its leads must be pulled tight and soldered to the circuit board under tension. This avoids the need for any additional fastening. The component overlay (**Figure 2**) and photo (**Figure 1**) clearly show what is intended. Cinch sockets can also be fitted to the circuit board. The board should be fixed firmly in place using the five mounting holes.

The connections marked with the 'output' arrows and ground symbols must be connected to the amplifier inputs using good-quality screened audio cable. The pin between these connections must be connected to the enclosure via the shortest possible path. This can be done by fitting an M3 washer with soldering lugs to one of the fastening screws.

In the dimensioning of the capacitors, the primary consideration was the

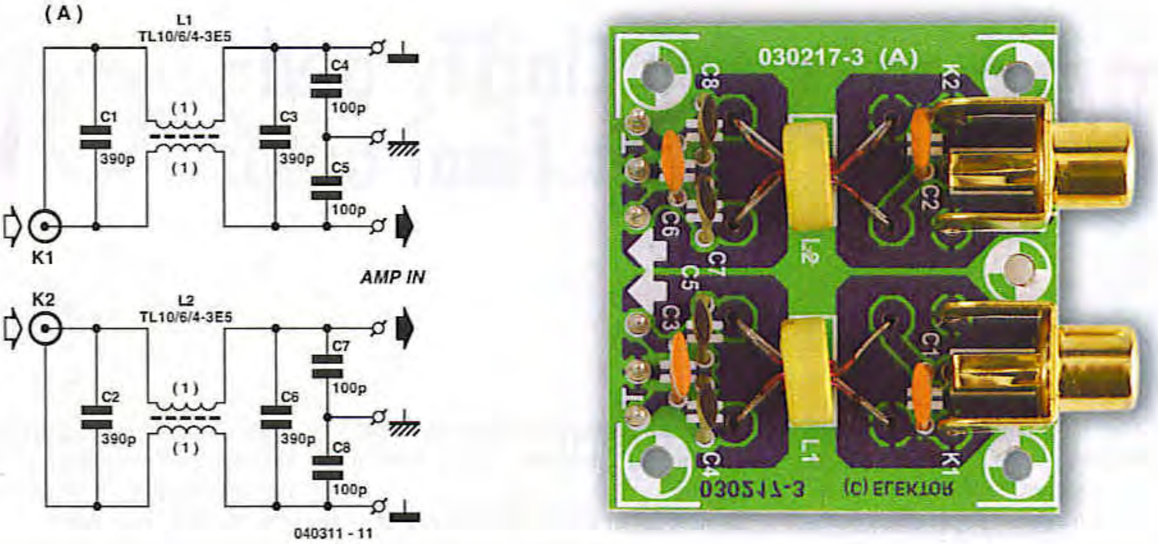


Figure 1. The input filter suppresses both common-mode and differential-mode signals. Pay particular attention to how the inductors must be wound and placed. Copper track layouts from our website.

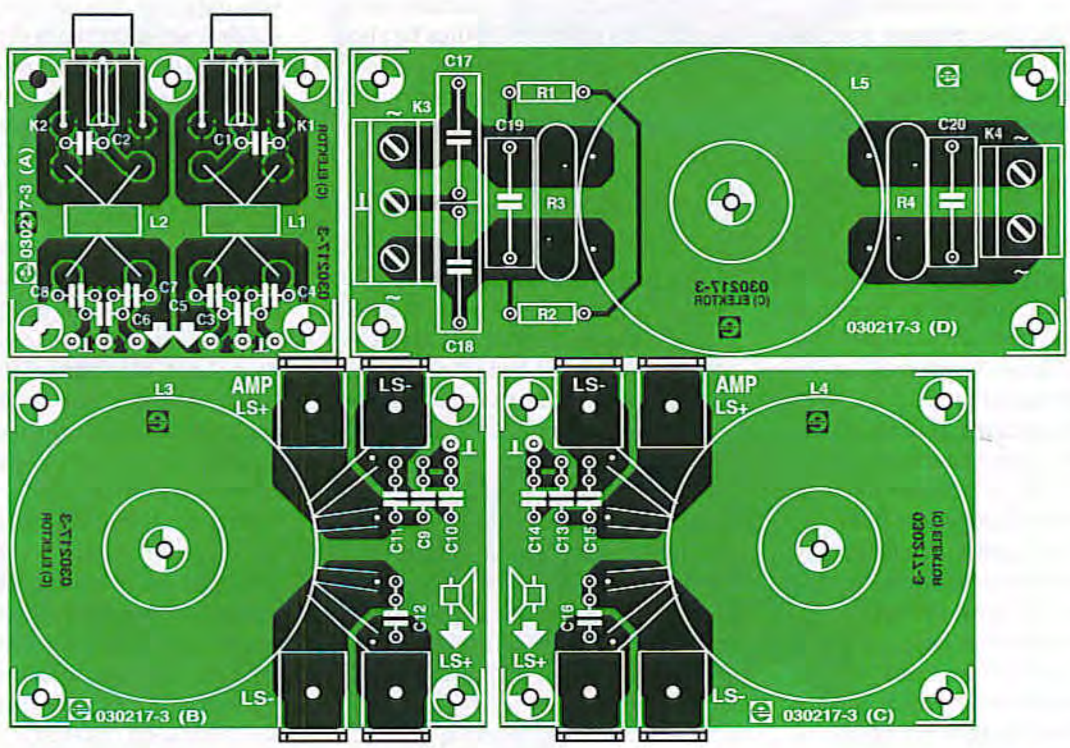


Figure 2. A single printed circuit board has been designed for all of the filters. The portions for the loudspeaker filters are laid out as mirror images of each other.

Components list

Resistors:

R1,R2 = 470kΩ
R3,R4 = Varistor 275V (Epcos SIOV-S20K275, Farnell # 580-284)

Capacitors:

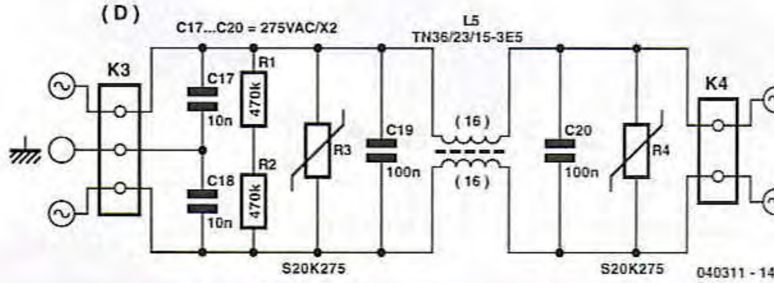
C1,C2,C3,C6 = 390pF
C4,C5,C7,C8 = 100pF
C9,C10,C13,C14 = 1nF 400V, lead pitch 5mm or 7.5 mm
C11,C12,C15,C16 = 10nF 400V, lead pitch 5mm or 7.5 mm
C17,C18 = 10nF 275 V_{AC}, Class X2, lead pitch 15mm
C19,C20 = 100nF 275 V_{AC}, Class X2, lead pitch 15mm

Inductors:

L1,L2 = 2 x 1 turn (bifilar) 0.5mm dia. (SWG26) enamelled coppper wire on Ferroxcube core TL10/6/4-3E5 (Farnell # 305-6960)
L3,L4 = 2 x 18 turns (bifilar) 1.5mm dia. (SWG16) enamelled coppper wire on Ferroxcube core TX36/23/15-3E25 (Farnell # 305-7021)
L5 = 2 x 16 turns 1.5mm dia. (SWG16) enamelled coppper wire on core TN36/23/15-3E5 (Farnell # 305-7010)

Miscellaneous:

K1,K2 = PCB mount cinch socket (T-709G from Monacor/Monarch)
K3 = 3-way PCB terminal block, lead pitch 7.5mm
K4 = 2- way PCB terminal block, lead pitch 7.5mm
8 x spade terminal (fast-on), PCB mount, 3mm screw mounting
PCB, order code **030217-1** (see Readers Services)



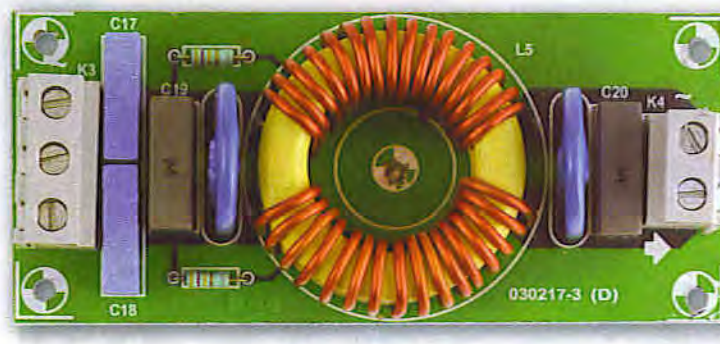


Figure 3. The mains filter is a quite conventional design, and like the input filter it suppresses both common-mode and differential-mode signals. For safety, the two inductor windings must be separated as far as possible.

capacitive load on the preamplifier. With this filter, it is only 880 pF (C1 + C3 + C5).

Mains filter

The mains inlet naturally amounts to a second input. Here we chose a conventional design (**Figure 3**). We used the largest possible core here (in terms of availability), which results in a large load capacity as well as high inductance. For mains filters, the inductance normally decreases as the load impedance increases (for the same dimensions). By using a large core (36 mm outside diameter) with 1.5-mm diameter wire wound in only a singly layer (which increases the maximum permissible current), we obtained a filter that can easily handle loads as high as 1000 VA.

The inductor has two identical windings, which are well coupled but separate. The separation is important due to the mains voltage connected between the two windings. For superior coupling, we selected 3E5 core material. It has very high permeability; the A_L factor for this core is no less than 11,400 nH.

The two windings are wound tightly on the core. This takes a certain amount of strength, since they are wound using 1.5-mm copper wire and a gap of at least 3 mm must remain between the opposing windings (for Class 1 insulation). If you can't manage this, just reduce each winding by one turn. Note that the two windings must be as nearly possible identical. This prevents premature saturation of the core.

With 16 turns per winding, you will have two windings with a self-inductance of somewhat more than 3 mH ±30 % (which is also the self-inductance of the inductor for common-mode signals) and a leakage inductance of around 15 µH.

The filter also contains two robust varistors that provide additional protection against sporadic mains disturbances (transients), although they don't protect against common-mode transients.

R1 and R2 ensure that the capacitors are quickly discharged if no mains voltage is present (and after it's disconnected). This prevents dangerous voltages from remaining present on the mains connector. For safety, use plastic stand-off bushes for mounting the circuit board in order to maintain adequate clearance between the circuit board tracks and protruding connections on the copper side and the metal parts of the enclosure. For a Class-1 device, a separation of 3 mm is in principle sufficient, but 6 mm is recommended.

As the inductor is attached to the circuit board quite securely by its four leads, additional mechanical fastening is not required. For anyone who nevertheless considers mechanical fastening necessary, a hole is provided in the circuit board in the middle of the inductor. Be sure to use only plastic parts for any such fastening, in order to avoid affecting the inductance of the coils. The layout of the printed circuit board is shown in **Figure 3**.

Capacitors C19 and C20 form part of the differential-mode suppression network, but given the low impedance of the power supply and mains network, they have less effect than C17 and C18, which provide common-mode suppression. These two capacitors are configured in parallel for common-mode signals, so they constitute a 20-nF capacitor that forms an LC filter in combination with the self-inductance of L5.

The impedance of the amplifier for common-mode signals primarily depends on the parasitic capacitance between the primary and secondary windings of the supply transformer (as well as the impedance of the wiring inside the enclosure), and it is reasonably high. This means that the self-inductance of the inductor is primarily responsible for filtering common-mode signals.

The values of C17 and C18 cannot easily be increased, since they also generate leakage currents to ground when the filter is connected to the mains voltage (via one of the two capacitors, depending on which one is connected to the live mains lead).

The ground rail of the filter is connected to the enclosure together with the ground connection of the mains inlet connector.

Speaker filter

In contrast to the mains filter, the inductors for the loudspeaker filters (**Figure 4**) are would bifilar (see **Figure 5**). Consequently you have to wind

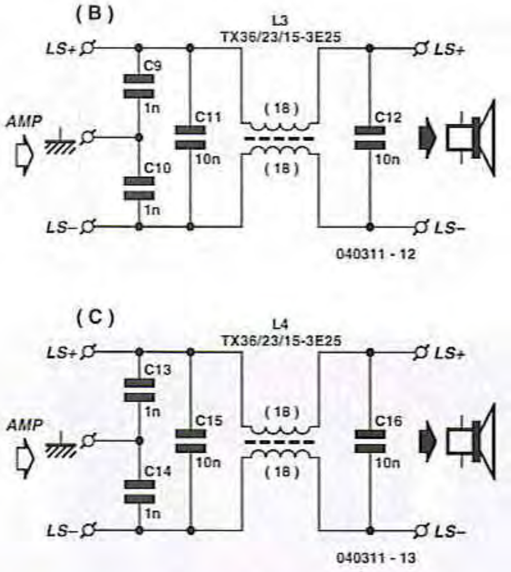


Figure 4. The output filter for the loudspeaker signals is specifically intended to provide common-mode suppression.

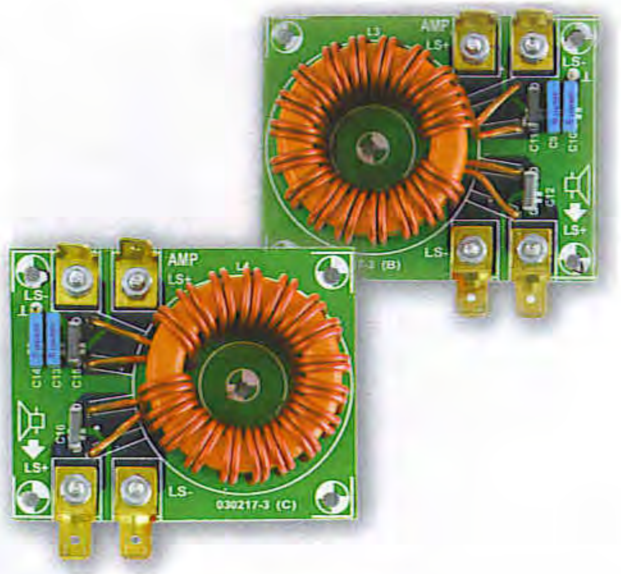


Figure 5. The inductors are wound bifilar.

two lengths of 1.5-mm copper wire on the core at the same time, which takes even more strength.

Bifilar winding ensures excellent coupling between the two windings and causes the leakage inductance to be very small. You have to bear in mind that peak currents of around 20 A can flow through the wires of the inductor. If the windings are not identical, the inductor will saturate and the filter will be ineffective.

Naturally, using these filters slightly increases the output impedance of the amplifier. Flat tab connectors are used for the connections, due to the potentially high currents. This also makes it possible to connect leads directly to the circuit board using M3 solder lugs (spade terminals). This helps avoid a certain amount of contact resistance. Another possibility is to solder the leads directly to the copper side.

Here we selected 3E25 core material. It has somewhat lower permeability than 3E5 material, but it can be used over a wider frequency range and is less prone to saturation (although that isn't so important if the inductor is wound properly). The selected core has the same dimensions as the one used in the mains filter.

As no special insulation between the two windings is necessary here (although the copper wires must naturally have a heavy enamel coating), it's easily possible to add two more turns. The two 18-turn windings of 1.5-mm enamelled copper wire yield an inductor with a self-inductance of approximately 2×2.4 mH ± 25 % and a leakage inductance of only 2 µH.

Be sure to leave the windings leads long enough to allow them to be properly fitted to the circuit board. This will require a bit of 'cut and try'. The inductor is held reasonably firmly on the board by its four leads, but we recommend using a small sheet of plastic and plastic screw to secure it to the circuit board. These filters should be placed as close as possible to the amplifier outputs.

Next a few remarks about the capacitors. C1, C12, C15 and C16 are actually intended to filter out RF interference (in differential mode); they do not have any effect on common-mode signals. However, they are connected in parallel with the output of the amplifier, so they have intentionally been kept rather small in order to keep their effect as small as possible. They increase the filter capacitance by just less than 10 %.

There are also capacitors in the filter that do provide common-mode suppression: C9, C10, C13 and C14. They are effectively in series for differential-mode signals, so they can practically be ignored for such signals. For common-mode signals, by contrast, they are effectively in parallel and provide a capacitance of 2 nF. The junction of C9/C10 and C13/C14 must be connected to the enclosure.

If you use our printed circuit board design, be sure to pay attention to the polarisation of the filters for two-channel applications, since they are opposite to each other. For stereo use, swapping the phases of the outputs wouldn't be obvious, but if the amplifier is used in bridge mode, it is essential ensure that the phasing is correct. For this reason, the circuit boards for the two channels are designed as mirror images of each other, so equivalent connections are close together and on the same side of the board.

Speaker cables

Finally, we mustn't forget the cabling. Generally speaking, cables make excellent aerials, with a common-mode impedance of approximately 150 Ω. Particularly with the pulse-width modulated signals coming from our amplifier, the cables can be blamed for a significant portion of the interference radiated to the surroundings.

The simplest way to counter this is to keep the distance between the amplifier and the loudspeakers as short as possible. Another possibility is to slide a pair of substantial ferrite cores over the cables (at the amplifier end), which can increase the common-mode impedance by a factor of as much as several hundred. Another option is to run the loudspeaker cables inside metal screens connected to the amplifier enclosure.

Ferrite cores of various sizes can also be fitted to the other cables (mains cable and input signal cables).

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