Step up transformers

Summary
The step up transformer is a simple and effective way to amplify the cartridge's signal adding very low noise and distortion; a close look to its details explains the mechanism behind a good and a bad match and the effect of the load on the secondary winding. Cartridge's and transformer's electrical characteristics play a key role and can generate an ultrasonic resonance or a response damped at high frequencies, an accurate tuning of the resistor at the output of the transformer can smooth this irregularity. Eventually, fine-tuning by ear will allow the listener to select the best match according to her/his personal preferences.

The electrical model of the cartridge and step up

A moving coil cartridge can be modelled as voltage generator with an internal resistance $R_{cartridge}$, ranging from a few ohms to several tens, and an inductance $L_{cartridge}$, from few μH to 100μH and more. Typically, lower output cartridges have smaller coils and hence lower resistance and inductance. The transformer is more complex and more parameters must be included in the model:

L_p – inductance of the primary winding, 0.1H to 2H typically
L_s – inductance of the secondary winding, the ratio of L_{ess}/L_p equals the square of transformer ratio
R_{pw} – resistance of primary winding, a few ohms
R_{sw} – resistance of secondary winding, several hundreds of ohms
L_{ss} – stray inductance of the secondary winding, in the range of 10mH
C_{ss} – stray capacitance of the secondary winding, a few hundreds pF
C_{pss} – primary to secondary stray capacitance, a few hundreds pF
N_p – number of turns of primary winding
N_s – number of turns of secondary winding

For the sake of simplicity parasitic capacitance and leakeage inductance of primary winding are omitted. Figure 1 shows the electrical model of the cartdrige and a 1:10 step up transformer with typical values for the C, L and R parameters. The loading resistor R_{load} is assumed to be the standard 47k found in most preamplifier.

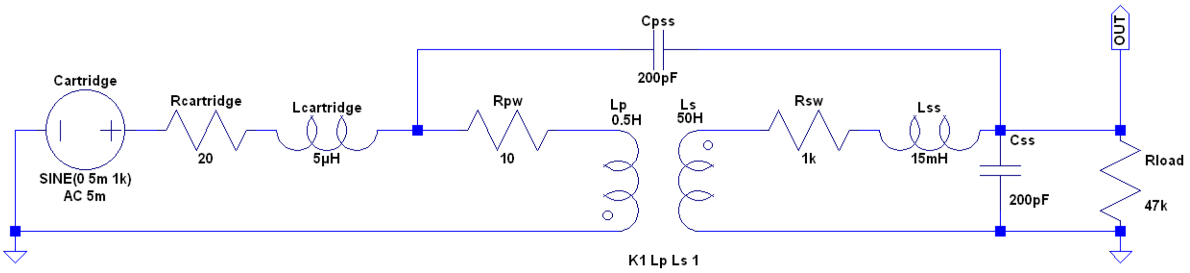


Fig. 1 Cartridge electrical model on the left, transformer model in the middle and loading resistor Rload on the right. 'K1 L_p L_s 1' is the spice command that simulates a perfect magnetic coupling of primary to secondary.

The influence of cartridge parameters

As anticipated, the stray inductance and capacitance of the cartridge will generate a peak in the frequency response. In our model a +3dB resonance appears at 55kHz, well above the 20kHz limit but its effects can be starting from 10kHz and generate a +0.75dB deviation at 20kHz.

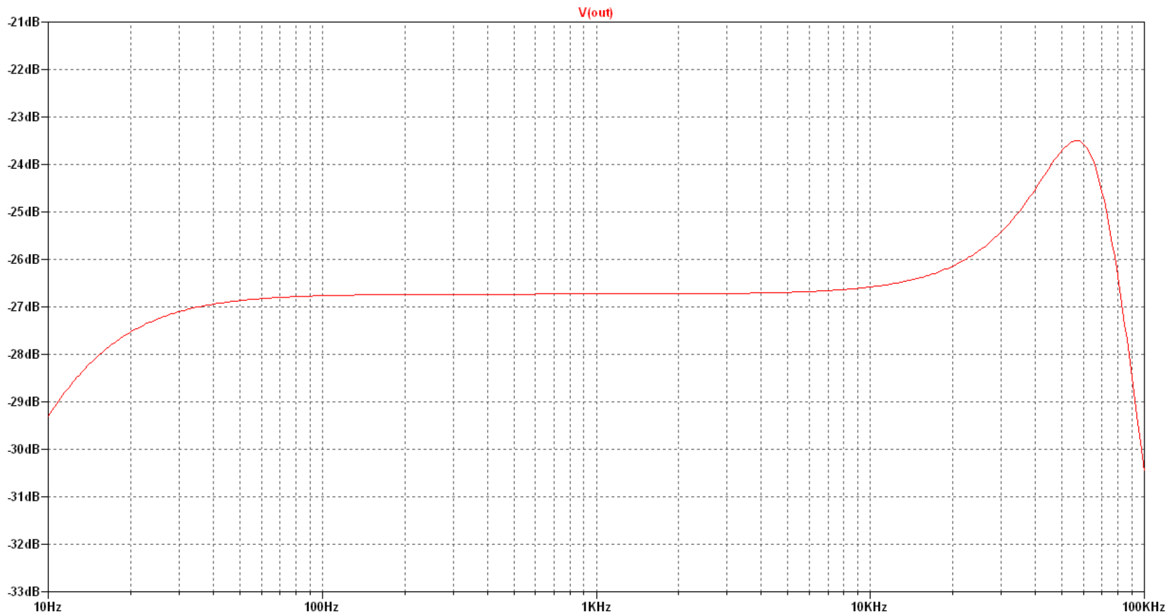


Fig. 2 A resonance of the cartridge-step up appears at 55kHz.

$R_{cartridge}$ and $L_{cartridge}$ will have an influence upon the resonance: a large R cartridge will exhibit a small resonance but high frequency response will be impaired for higher values; a larger inductance will move the peak towards the 20kHz limit affecting the audio band.

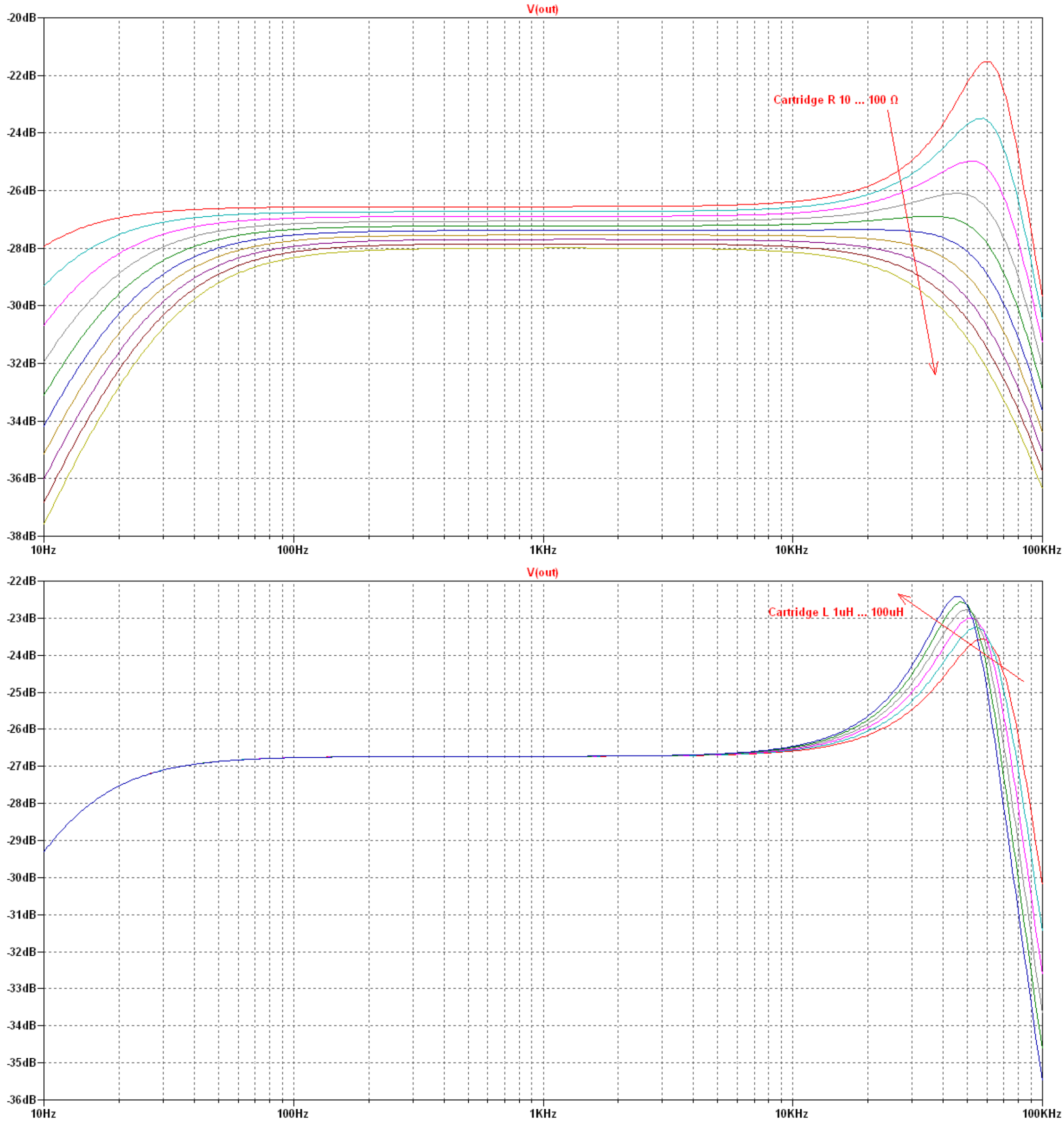


Fig. 3 and 4 Effect of cartridge parameters on the frequency response of the combined system. In figure 3, the low frequency response is impaired for higher $R_{cartridge}$ that would require higher L_p for a proper match.

Tuning the load at the secondary winding

R_{load} will appear at the cartridge reduced by the square of the transformer ratio $(N_p/N_s)^2$ so the 47k R_{load}, reflected by the 1:10 step up, looks like a 470Ω at the primary. A 20k will be stepped down to 200Ω and so on. A lower load will reduce the peak but a too small load will affect high frequencies as the transformer will not work in its best condition. The optimal load depends on the specific cartridge and step up. A flat frequency response might not correspond to the preferred sound and listener is encorauged to tune R_{load} according to her/his taste and sensibility.

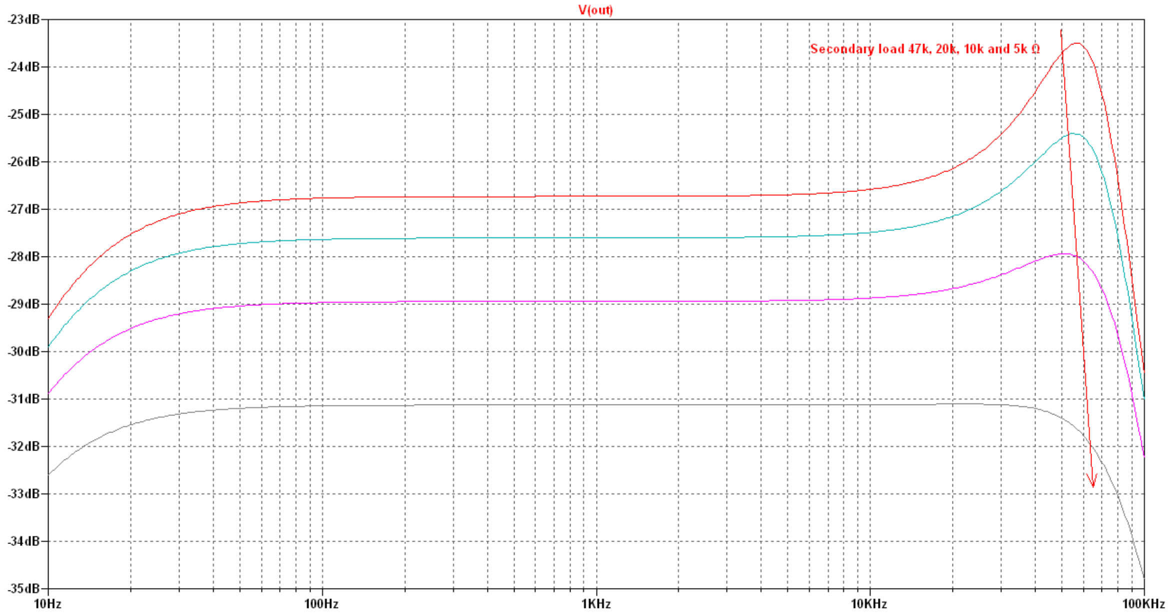
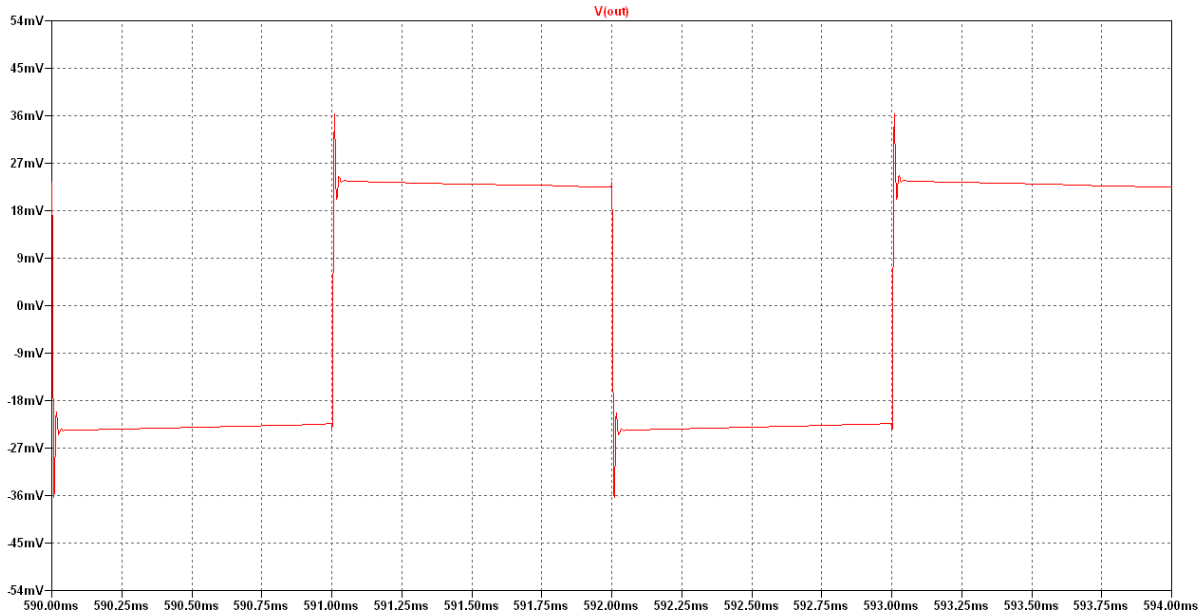


Fig. 5 Effect of reduced load on the cartridge-step up frequency response.

In figure 5, you will also notice as lower R_{load} will diminish the available signal due to the insertion loss, this can somehow confuse the listener as the phenomenon might be interpreted as a loss in dynamics. Figure 6 and 7 show the effects of R_{load} during a square test: the lower R dampens the resonance and the ripple at the rising and falling edges.



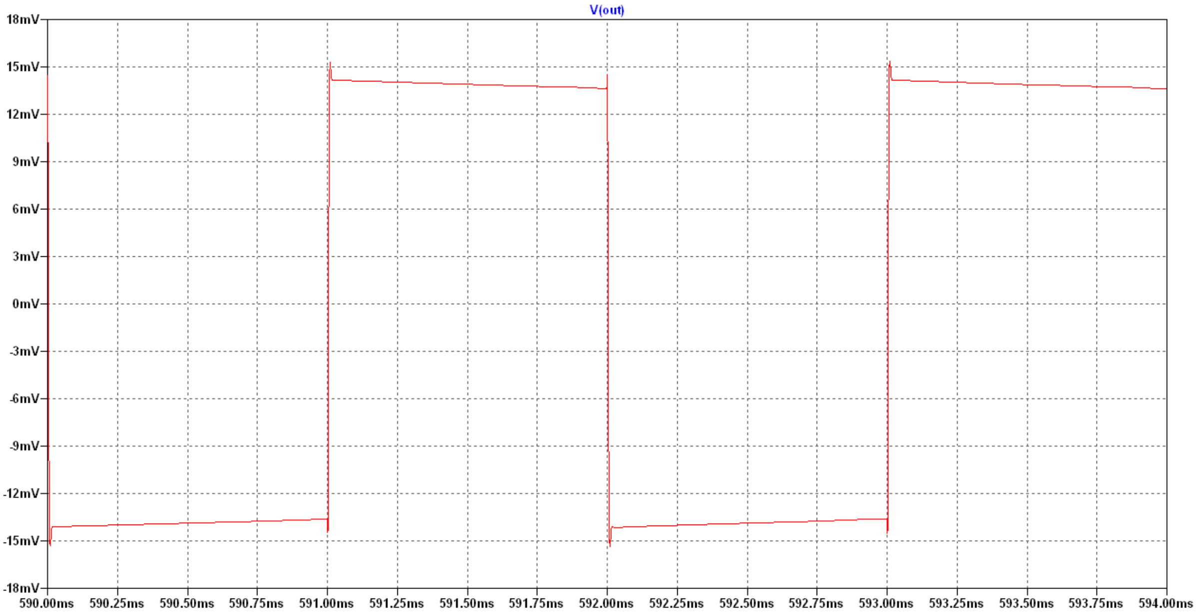


Fig. 6 and 7. 1kHz square wave response for a 47kΩ (upper fig) and 5kΩ (lower fig) R_{load}: the undamped resonance with 47kΩ generates a higher ripple.

The best step up transformer

A good transformer must have reasonably low stray C and L and a sufficiently high primary inductance L_p for an extended flat bandwidith.

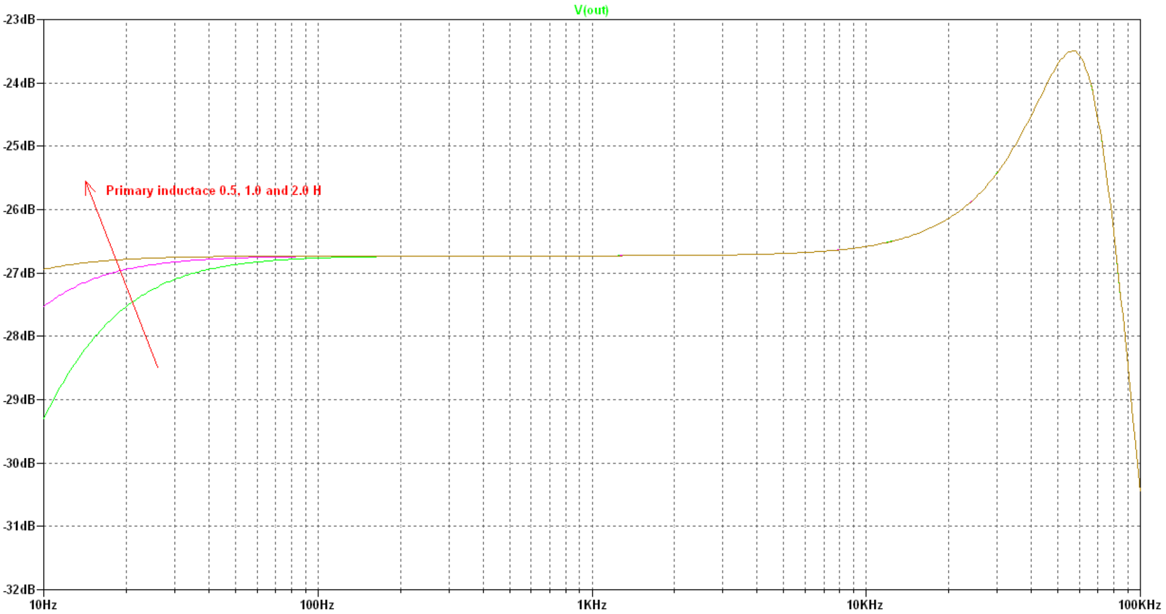
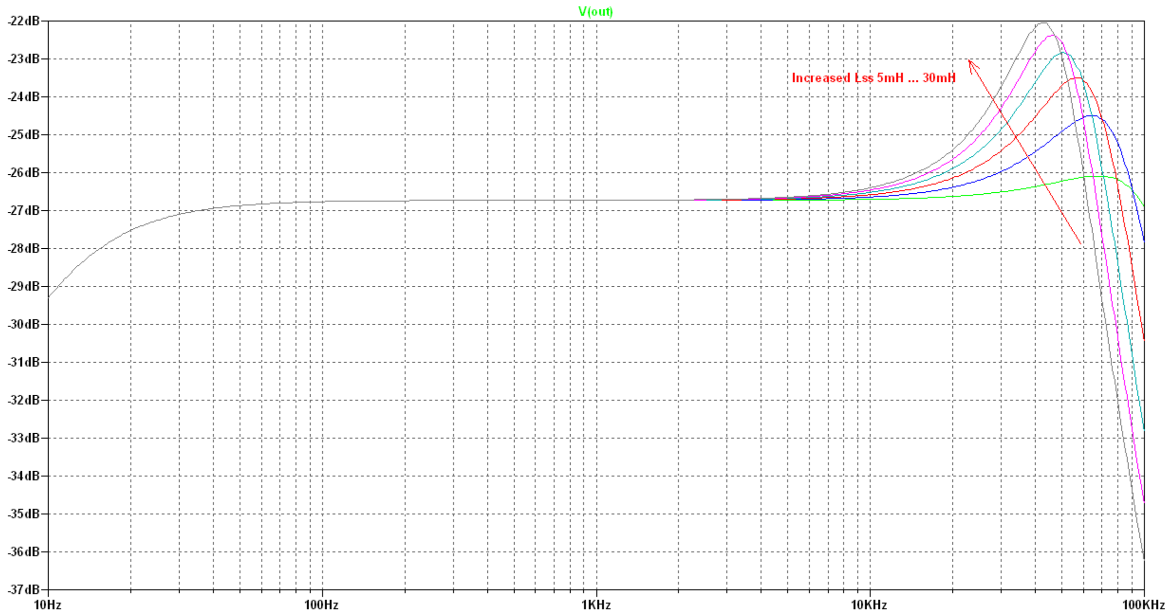
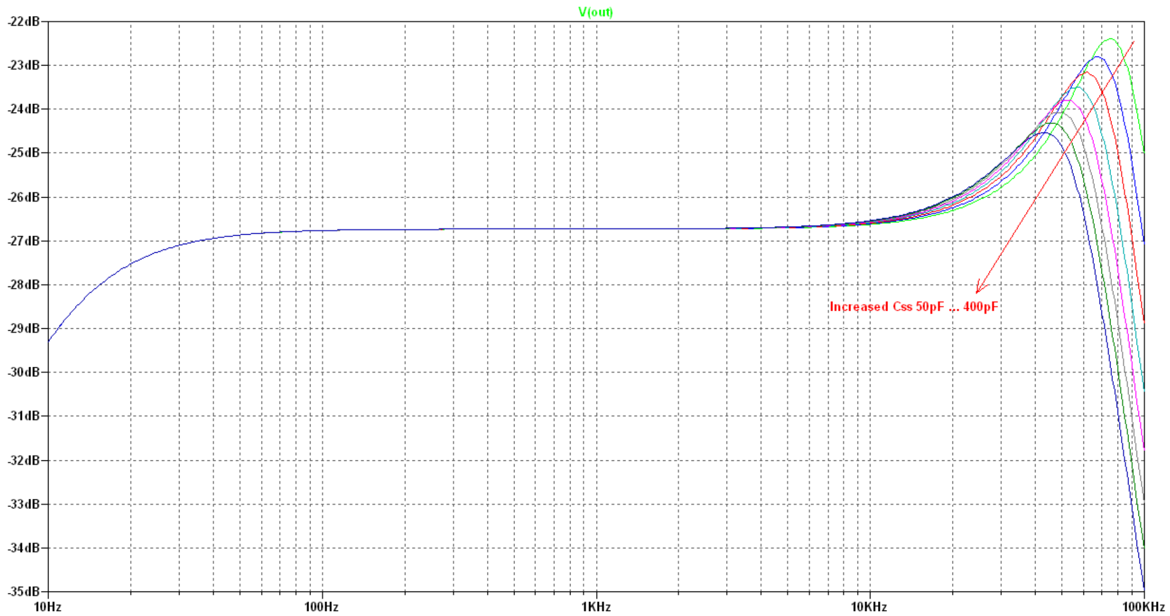


Fig. 8 Higher L_p extends into deeper bass the transformer's bandwidth.

A higher L_p is required to properly load high R cartridges, see also figure 3, and this should be the very first parameter to check when selecting a step-up. At low frequency *f* the transformer behaves as the parallel of the reflected R_{load} and of the primary reactance $2\pi f L_p$; in this example at 20Hz we have 470Ω in parallel with 62Ω for an equivalent resistance of 55Ω substantially higher then the 20Ω cartridge.

The effect of C_{ss}, L_{ss} and C_{ssp} is similar: higher stray capacitance and inductance will move the resonance closer to the audio band affecting the response from 10kHz onwards and making the tuning of R_{load} even more critical. Leakage inductance is proportional to the N^2 while special winding tecniques are employed to reduce parasitic capacitanc: a good transformer is the result of years of experience and experimentations.





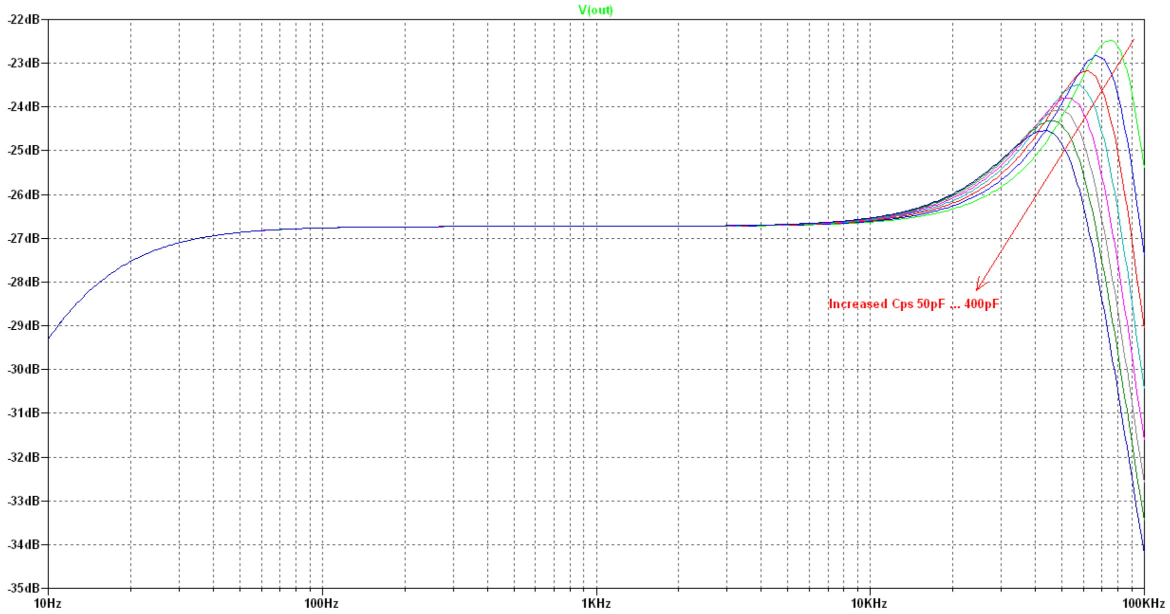


Fig. 9, 10 and 11 Effect of stray C and L on cartridge-step up frequency response.

The core of the transformer matters

Primary inductance is proportional to the square of turns N_p, to the cross section of the core, to the magnetic path and to the permeability of the core material; the designer has to determine the best balance of core size and number of turns to assure the transformer will operate with low distortion and extended frequency range. Unfortunately, increasing the number of turns will also increase the flux density bringing the core closer to the saturation at low frequencies. On the other hand, a bigger core will have a larger cross section and a longer magnetic path but will also determine an increase of stray capacitance.

Gianluca Sperti

Audio*dinamica* co-founder and product development

info@audiodinamica.com