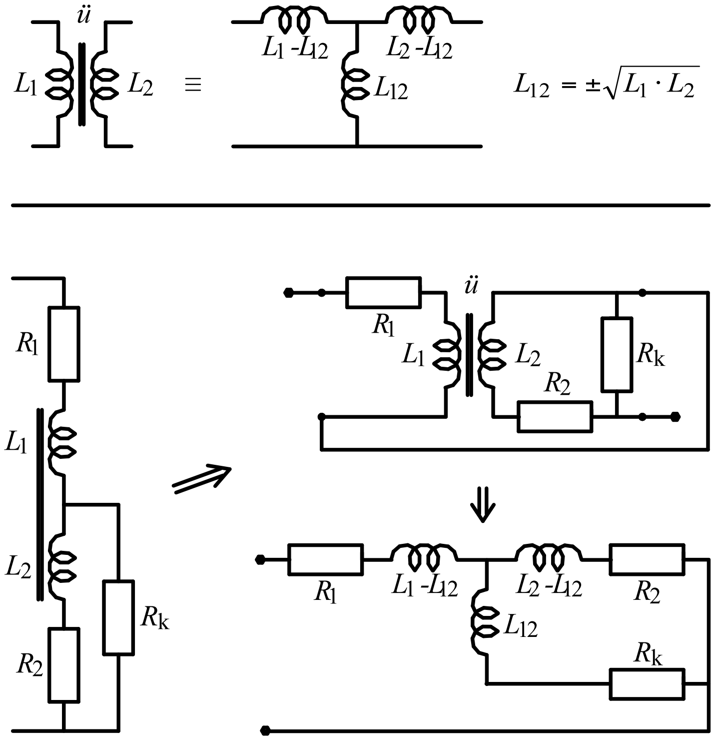
5.14 Pickups with shorts in the coil-winding

The coil of a magnetic pickup is made of very thin copper wire carrying an even thinner layer of varnish for insulation. The insulation resistance of the varnish would still be sufficiently high with a thickness as small as 4 µm, but to keep the insulation layer undamaged is somewhat of a challenge. This was especially true in the old days when the magnet wire was often directly wound onto the magnet rods and it could happen that the insulating layer was abraded and shorts were introduced. Moreover, some of the insulating varnishes used back then became brittle over the decades and came loose from the copper. It is also conceivable that already the application of the varnish sometimes was sub-par or even faulty. Last, if the quality control was done merely using an ohmmeter with a tolerance of 20% [Duchossoir, Strat], much room remains for undetected shorted turns in the coils.

How does the transfer behavior of a pickup change it one or several windings are shorted out? If indeed merely *a single* winding is shorted, the effects are negligible, but in case a wire establishes contact to the next whole layer of the winding (or even the layer beyond that) we would be confronted with a possibly substantial defect. It shows some naïveté if a pickup manufacturer still writes in the year 2011 that it's ok if a few hundred of 8000 turns of a pickup are shorted out: indeed a few percent change in the DC resistance may be insignificant, but the pickup operation is based on AC. And with AC a short in the winding brings with it a resistive load and therefore a treble-loss.

It is purposeful to interpret a partially shorted inductance as a transformer (**Fig. 5.14.1**). Of the *N* turns of the winding, *n* are shorted; they *N-n* non-shorted turns form the primary inductance L_1, while the remaining (shorted) *n* turns form the secondary inductance L_2.



$$R = R_1 + R_2;\quad R_2 = R \cdot n/N;$$

$$L_2 = L \cdot (n/N)^2;$$

$$L_1 = L \cdot (1 - n/N)^2;$$

$$L_{12} = -\sqrt{L_1 \cdot L_2}\ :$$

$R_k = 0$ yields an input impedance $\underline{Z}$ of:

$$\underline{Z} = \frac{R_1 R_2 + p(R_1 L_2 + R_2 L_1)}{R_2 + pL_1}$$

Fig. 5.14.1: T-equivalent circuit diagram of the transformer with hard coupling (top); ECD with short in the winding (bottom)

The copper-resistance (DC-resistance) of the full winding is R. R_1 belongs to the primary winding and R_2 to the secondary winding. The resistance occurring between two turns (the short resistance) is R_k. For a perfect short, R_k will be zero, but in the general model we will assume an arbitrary value. A hard-coupled transformer without flux leakage can be described by its T-equivalent-circuit-diagram, with L_{12} being the **mutual inductance**. The latter is positive for a concordant coupling, and negative for a inverse coupling. Interpreting the shorted inductance as transformer leads to a inverse coupling: L_{12} is negative.

From the ECD shown in Fig. 5.14.1 we can calculate the pickup impedance $\underline{Z}$. For an ideal short ($R_k = 0$) it may be simplified to the given formula. The DC-situation ($f = 0$) yields $\underline{Z} = R_1$; however, towards high frequencies ($f \to \infty$), $\underline{Z}$ does not remain inductive but converges to a real final value. With a further simplification (for $n << N$) we get $R \cdot N/n$ for this final high-frequency end value. If e.g. 4% of a pickup winding is shorted, the end-value is 25 x R (i.e. 25 x 6 kΩ = 150 kΩ for a typical Strat pickup). This only seems like a sufficiently high resistance – for a capacitive load, the effect is substantial and the resonance emphasis drops strongly (**Fig. 5.14.2**). As a consequence of the reduced Q-factor (compare to Chapter 5.9.3) the resonance emphasis of the transfer function goes down, as well. This is depicted in **Fig. 5.14.3** with a Stratocaster pickup serving for the example. A short across 2 layers of winding is approximately equal to n = 280; the corresponding loss in brilliance is not negligible anymore.

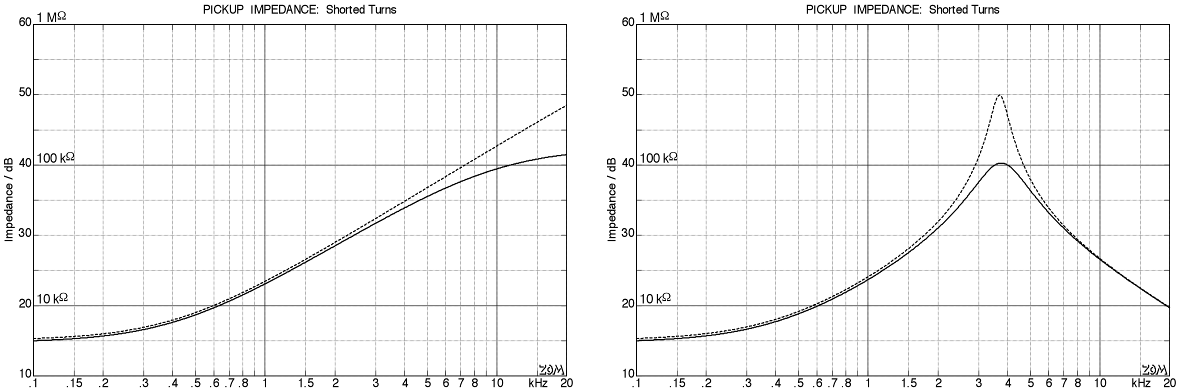


Fig. 5.14.2: Short in the winding. Left: without parallel capacitance; right: with parallel capacitance (850 pF). Stratocaster-Pickup: R = 5700 Ω, L = 2.2 H, N = 7600, n = 280. Without (----) and with (——) short.

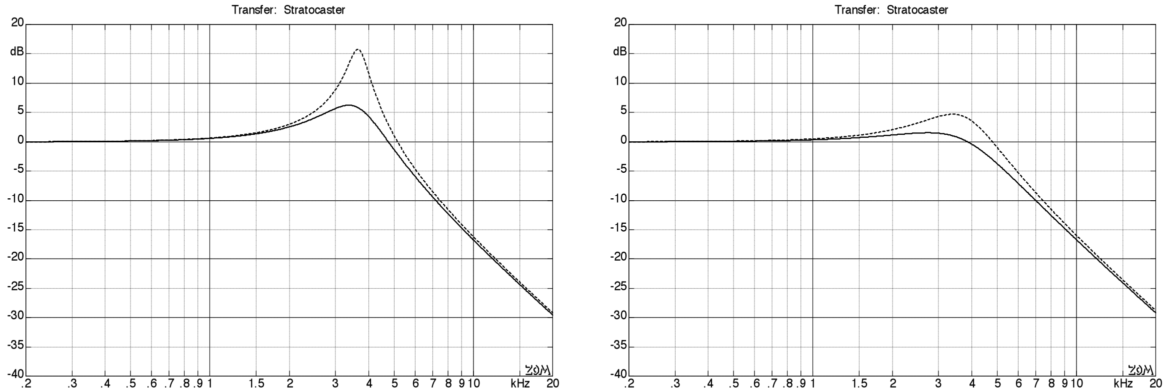


Fig. 5.14.3: Without (----) and with (——) short in the winding, data as in Fig. 5.14.2. Left: pickup with purely capacitive load (850 pF), right: 110 kΩ load resistance added (potentiometers + amp).

So. More than 160 pages about magnetic pickups – quite a heavy load. To conclude, let's bring in a goodie for those who persevered (no, not that Thorben-guy, he was not available – and he's had it, anyway). But we have Mr. **Chris Kinman**, well-known pickup manufacturer. He had some news for his followers published on his website around Christmas in 2010 which we may look into here:

Chris K. was repairing two '64 Strat pickups both of which had succumbed to broken coil wiring. For one of the two, the fracture had occurred right on the outside of the pickup; so that one is dealt with easily but the other's gonna be a lot of work: it has to be rewound entirely. Some original wire (i.e. the real Voodoo-stuff) was brought in, the rewinding done … however the two pickups sounded differently. That remained the case even after the magnets had been re-magnetized. Writes Chris: *"This experiment exploded the myth that aged magnets were the reason for this massive difference in sound. Another well known pickup manufacturer claims weaker magnets are the reason that old pickups sound sweet, but I can not confirm that claim when I deliberately degauss magnets."* Well, he's right on target: magnets do not age (he could have read up on that in Chapter 4, by the way). That **vintage sound** must still have some reason, though, and here it comes: *"It turns out that Formvar insulation is not age stable, it's an unsophisticated old technology coating that degrades over time, unlike modern Polyurethane coatings which seem to go on forever. ... So there you have conclusive scientific proof for aging of old Fender pickups, Formvar wire degrades in time. It definitely is not due to aging of magnets."* The "scientific proof" then uncharitably hides behind an impedance plot which indicates at the resonance frequency (3,2 kHz) a maximum value of merely 41.25 kΩ[♣], but even given this there are still differences between the two pickups: the *"1964 original Strat pickup that has aged excessively"* indeed shows only 36 kOhm at the most. Approximately, that is – since the 4,46 kΩ per scale-division chosen by Chris K. makes it difficult to interpolate. Anyway, the older the pickup, the smaller the Q-factor will get because the aging insulating varnish encourages shorts in the winding. With the decreasing Q the *"ice-pick brittleness"* goes away and the aged sound (***less treble***) is in reach. That sound is – according to Chris K. – simply due to shorts in the coil winding. Conclusion: anybody who would like to play a 1954 Strat but would rather invest money in old Aston Martins does not really have a problem. Just buy a new Strat, turn down the "Tone" control a bit: voila – aged sound. However: it is now psychologically prohibitive to ever again read music "trade journals" because there the investor may find the statement that the old Strats have an unequalled brilliant sound (***more treble***).

Good advice? You are very welcome. As a return service, someone could pay a visit to Chris Kinman and show him how correct impedance measurements are done. Having said that, he actually deserves much credit because he does make the effort and takes some decent instrumentation to the pickups. Many manufacturer seem not to do even that …

[♣] With a purely capacitive load, that should be (without the potentiometers) about 300 kΩ sein, and with the pots still about 88 kΩ.