5.4 The magnetic field of the pickup

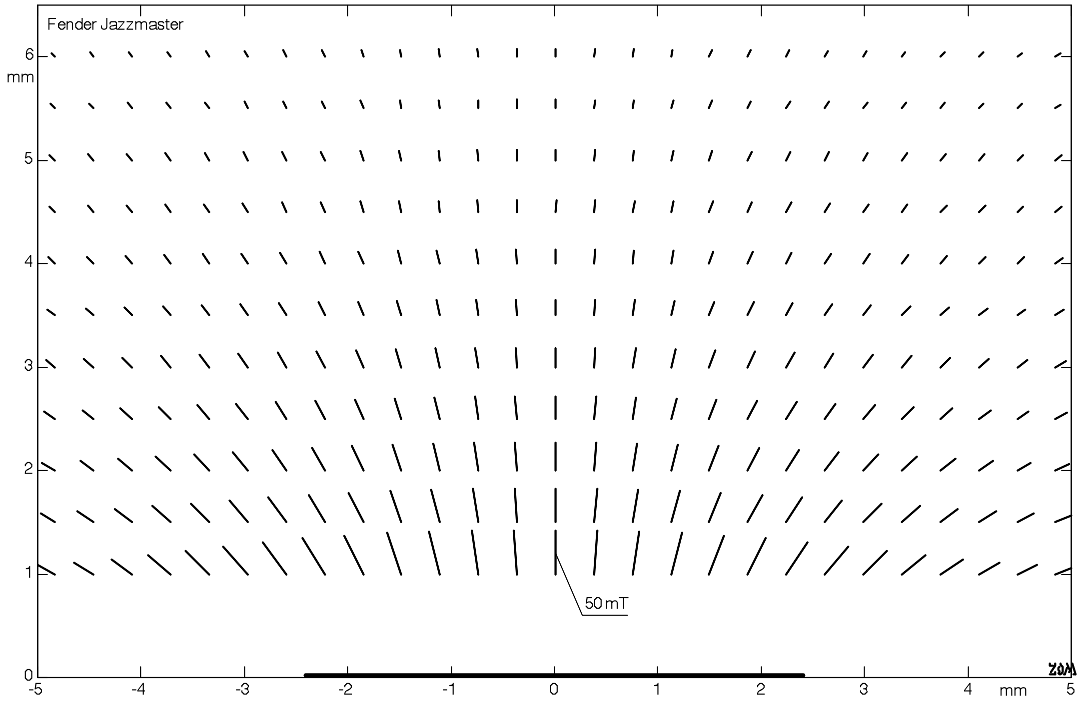
5.4.1 Static magnetic field without string

The vibrating string causes a change in the magnetic flux; this change induces an electric voltage in the pickup coil. The terminology of systems theory describes change as a dynamic (i.e. time-dependent) process superimposed onto a static magnetic field. The alternating flux is rather small and reaches merely about 1% of the static part of the field even for strong excitation of the string.

The source of the magnetic field is a permanent magnet installed under the string in the pickup housing. For a typical Fender pickup (for example the one in the Stratocaster) the end surface of the axially magnetized cylindrical magnet is positioned a few millimeters from the strings. For the Gibson P-90 a bar magnet is mounted underneath the pickup coil; for better field focus ferromagnetic screws penetrate the coil surface and guide the magnetic flux to the string. It is of interest to measure the strength of the static magnetic field since the efficiency of the mechano-electric transduction depends on it: without magnetic field there is no induced voltage i.e. the stronger the magnetic field the louder the pickup, although the correspondences are not quite that simple, after all. Besides the absolute strength of the magnetic field, its distribution in space is of importance as well. Moreover the static magnetic field exerts attraction forces towards the string which influence the vibration behavior − for this reason particularly strong magnets are not generally desirable.

To measure the static magnetic field, a Hall probe (after Edwin Hall) is suitable. This is a small semiconductor plate in which an electric voltage dependent on the magnetic field is generated. The effective measurement surface is about 0.4 mm in diameter. For the measurements described in the following, such a Hall probe was moved along a straight line by a spindle drive. At the same time the field-proportional electrical voltage was recorded. The direction of the advance was either in parallel to the string axis or perpendicular to it. With a parallel shift of the Hall probe an area could be sampled.

In contrast to the sound pressure measurements favored in acoustics, the magnetic flux density is not a scalar but a **vector** in space. The electromagnetic field is a vector field, each point of which in space is associated with three-dimensional field values. The Hall probe , however, reacts merely to the flux density component which is parallel to its surface vector. For a complete description of the field it would be necessary to use three orthogonally oriented Hall probes. Simultaneous operation of the three sensors results in a mutual interference, sequential operation is problematic due to the limited accuracy of the positioning in space. To make the overall measurement effort not too excessive, it was the **axial component** which was recorded. What is meant here is not the axis of the string but the axis of the cylindrical magnets or the pole-pieces; in other words the Hall probe is oriented in parallel to the fretboard of the guitar and samples the magnetic field component perpendicular to the fretboard. In the vicinity of the magnetic poles a flux density of between 10 and 100 mT is found while larger distances result in a very steep decrease of B. Figure 5.4.1 gives an impression of the field pattern above the pole area. Of course, it needs always to be considered that a pickup without string is without purpose. The field pattern with string is more important, however this is also much more difficult to determine.



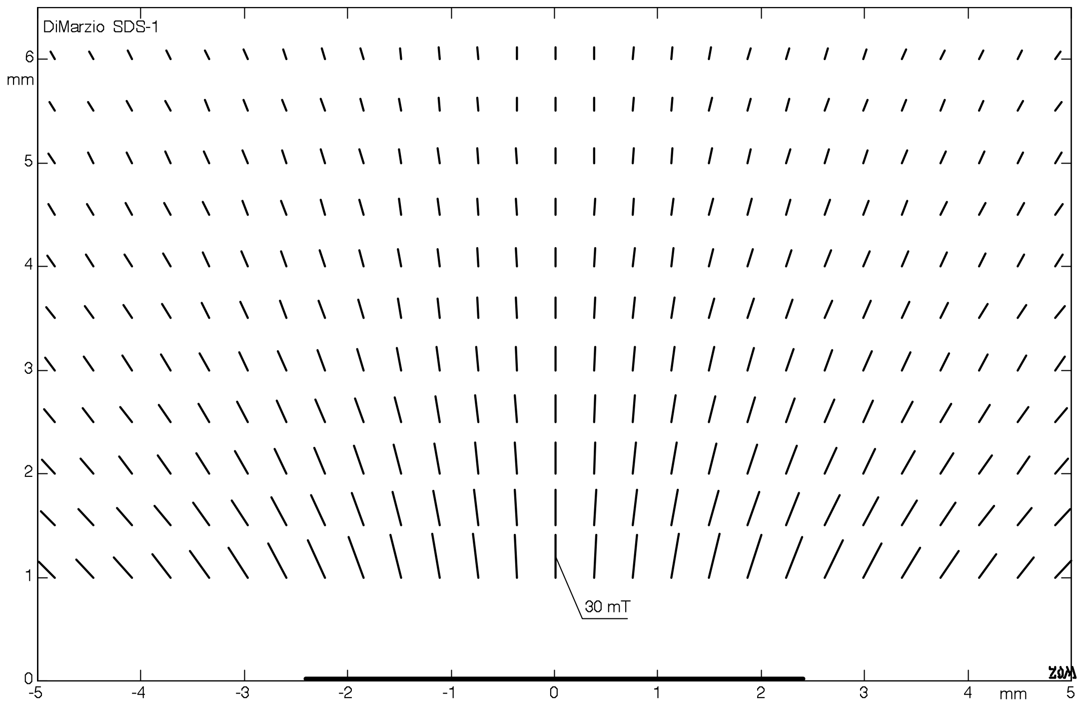


Fig. 5.4.1: Field vectors above a magnetic pole without string in the filed (measured results). For the Jazzmaster pickup (top) the field diverges more strongly than for the SDS-1 (bottom). Length and direction of the individual lines represent strength and direction of the magnetic flux density; the coordinates (given in millimeters) refer to the middle of the pole-plates (shown as thick line on the lower border of the figure. For this representation the abscissa- and ordinate-components of the *B*-vector were measured at distances of d = 1:0,5:6 mm to the magnetic pole.

In Fig. 5.4.1, the individual lines of the dashed line field represent – with their length and direction – the pattern of the field. Since the medium the field propagates in is air, both the B- and the H-Patterns can be determined: $\vec{B} = \mu_0 \vec{H}$. The magnetic field is a **vortex-field**: its flux lines (field lines) are closed lines without start- or end-point. Nevertheless, a presentation as a **point-source-field** is customary, as well, although this is a rather rough simplification. For the point-source approximation, the magnetic flux is thought of as originating from a point-source which is located within the interior of the cylindrical magnet on its axle. A first-order approximation for the distance of this point to the to the front face is the radius of the cylinder. Outbound from this source the magnetic field diverges equally in all direction. The surface area of a sphere concentric with the source point increases with the square of the radius, and thus the radially oriented flux-density will decrease with the square ($B \sim 1/r^2$). **Fig. 5.4.2** shows the measured results for the flux density at the magnet axis m; for this, the Hall probe was moving axially away from the pole-piece.

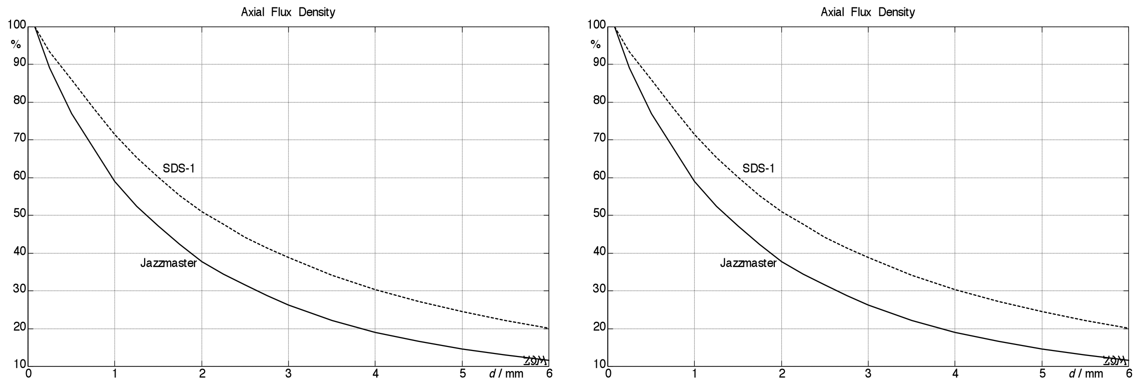


Fig. 5.4.2: Axial Flux-Density in absolute (left) and relative (right) representation,
d = distance to the pole-plate

The field of the Jazzmaster pickup is, in absolute terms, larger than that of the SDS-1 but does decrease faster. If this decrease happens according to a power law, it should show up as a straight line in double-logarithmic coordinates. **Fig. 5.4.3** shows $\log(B/B_0)$ over $\log[(d+\Delta)/d_0]$; the abscissa, however, is scaled for d and not for $d+\Delta$. B_0 and d_0 are reference values for the logarithms (such that they are without a dimension). $+\ \Delta$ is the depth of the magnetic source: it amounts to $\Delta = 4.7$ mm for the SDS-1, and for the Jazzmaster-pickup it is $\Delta = 3$ mm.

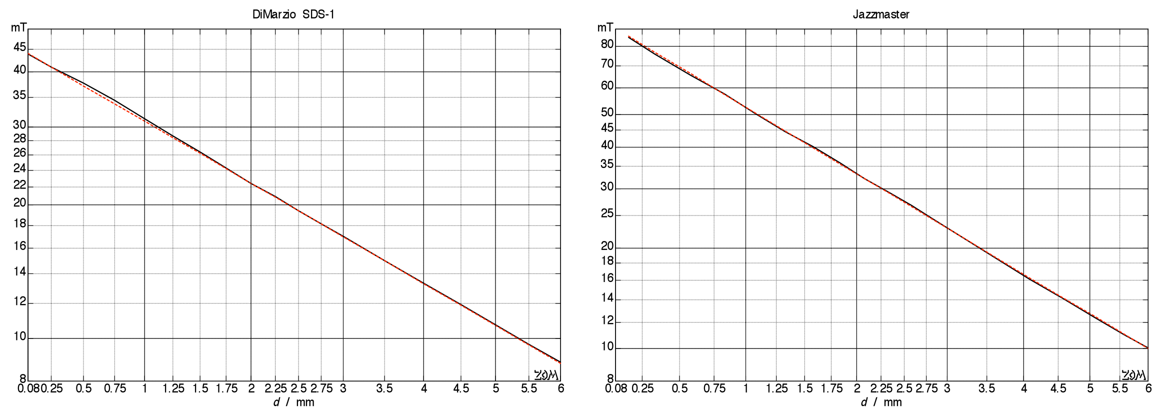


Fig 5.4.3: as shown in Fig. 5.4.2, but here in double-logarithmic scaling (measured ——, $1/r^2$-dep. -----).

The measured data shown in Fig. 5.4.3 are located almost perfectly on the given straight lines which approximates the $1/r^2$-dependence rather well. We still need to consider that only data along the magnet axis are depicted; in contrast Fig. 5.4.1 lends itself to show that the elongations of the field vectors do not met in a *single* source-point, after all. Here, the point-source-approximation reaches its limit of validity.

For the **humbucker** *both* magnet poles are positioned close to the strings; this results in a dipole field (**Fig. 5.4.4**). Directly in front of the pole plate (slug or screw) we obtain a rotationally symmetric field similar to Fig. 5.4.1, with a dependency on distance as given in **Fig. 5.4.1**. In the area between the pole plates (middle of the figure) the superposition of the anti-phasic fields results in a compensation of the vertical field component such that the magnetic flux runs horizontally i.e. parallel to the strings.

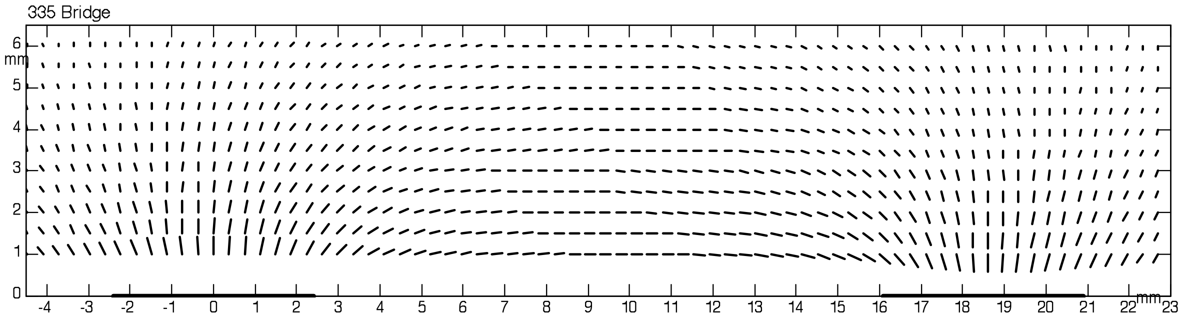


Fig. 5.4.4: Dipole-field of a humbucker (Gibson ES 335). The screw (right pole) is the south pole. No string.

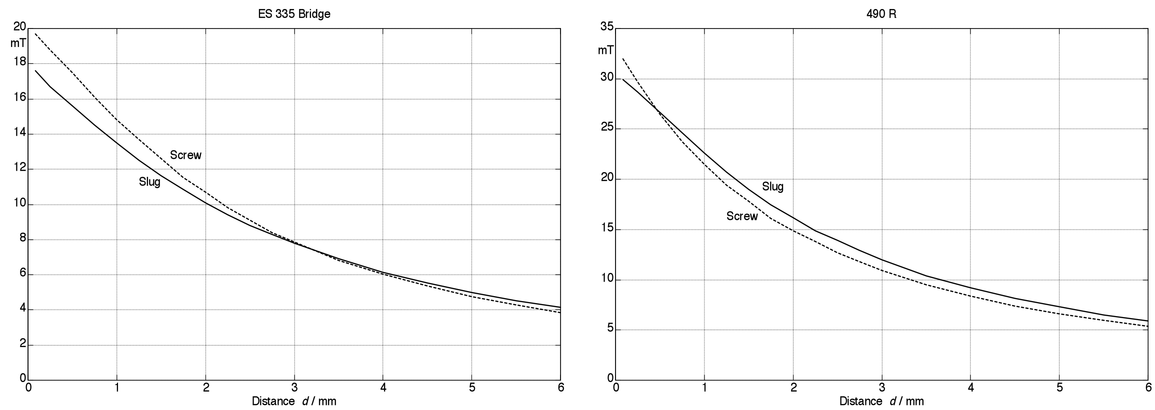
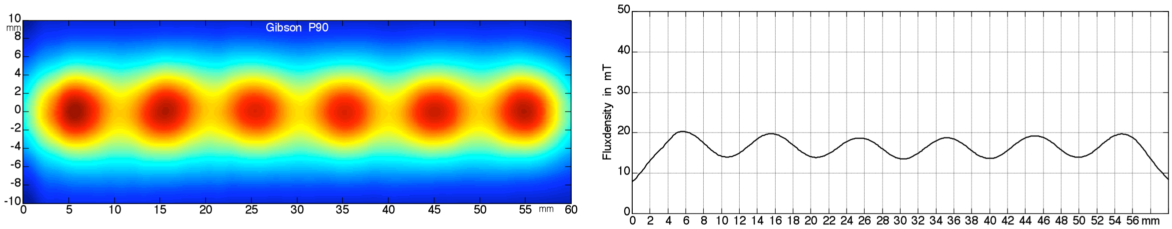


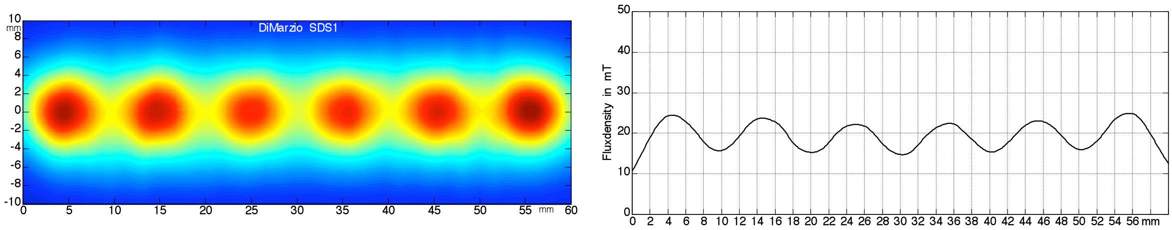
Fig. 5.4.5: magnitude of the vertical field, measured on the axis of the magnet.
The distance-dependency corresponds well to a $1/r^2$-Funktion well.
ES335: Δ_{Slug} = 5,1 mm, Δ_{Screw} = 4,0 mm. 490R: Δ_{Slug} = 4,1 mm, Δ_{Screw} = 4,0 mm

Magnetic fields are vector fields; a complete characterization of the *B*-field would require a special representation of all three *B*-coordinates which is impossible to accomplish with two-dimensional figures. In order to still get an impression of the filed distribution, colored flux-diagrams are shown in the following. The axial component of the *B*-vector (corresponding to the vertical component in Fig. 5.4.1) was measured with a Hall probe at a distance of 2 mm from the pole plate. It was then recorded using color-coding. For single coil pickups the areas of small flux density are shown in blue; in contrast, the same color blue characterizes areas of high negative flux density.

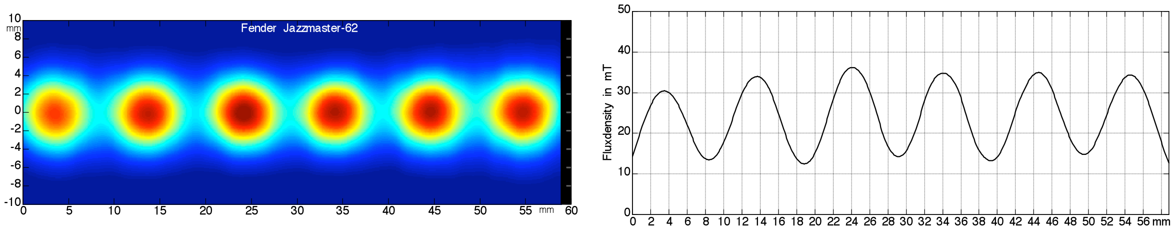
a) Axial magnetic flux density for singlecoil pickups:



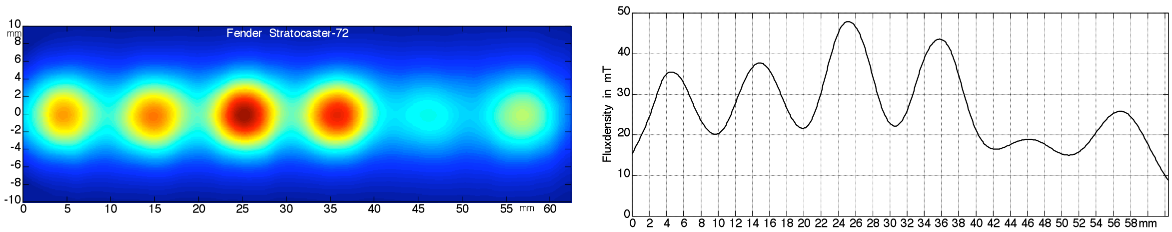
Gibson P-90, bar magnet + pole-pieces (screws)



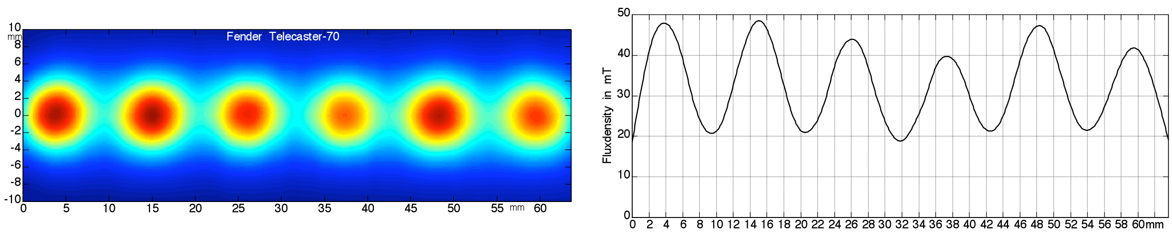
DiMarzio SDS-1, bar magnet + pole-pieces (screws)



Fender Jazzmaster, cylindrical bar magnets

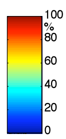


Fender Stratocaster, cylindrical magnets of varying lengths

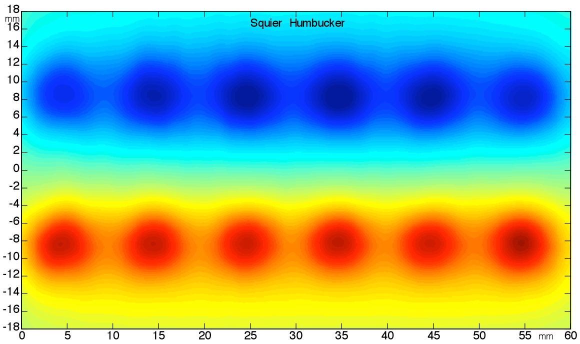


Fender Telecaster (bridge), cylindrical magnets + metal plate

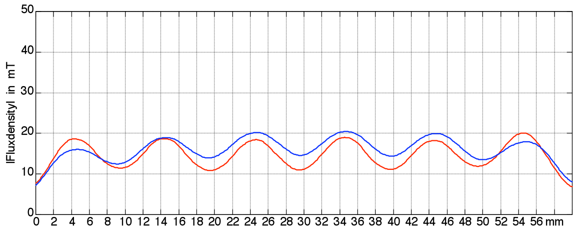
Fig. 5.4.6: The column on the left shows the distribution of standardized axial flux density in the plane of the strings. The color-scaling is as given by the color bar on the lower right
The right-hand column depicts the absolute axial flux densities 2 mm above the pole plates. d = 2mm.

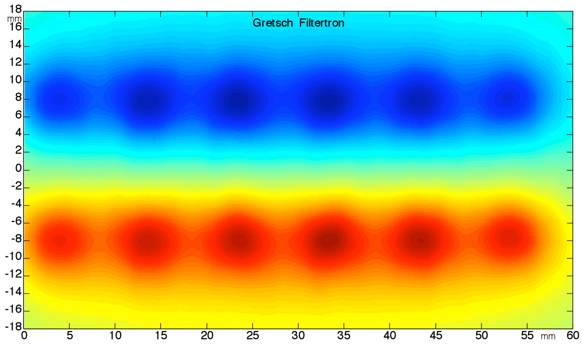


b) Axial magnetic flux density for humbucking pickups:

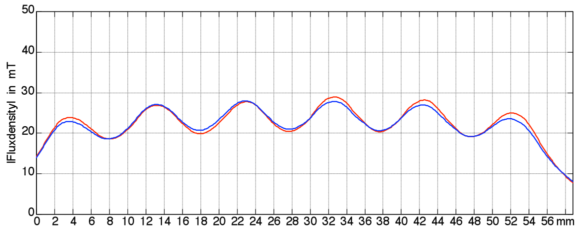


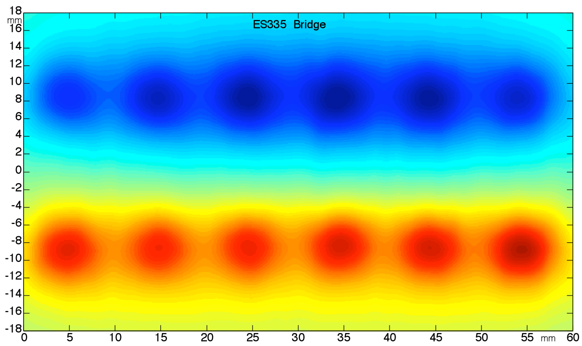
Squier Humbucker
bar magnet, 6 (pole-) screws, 6 pole pins (slugs)



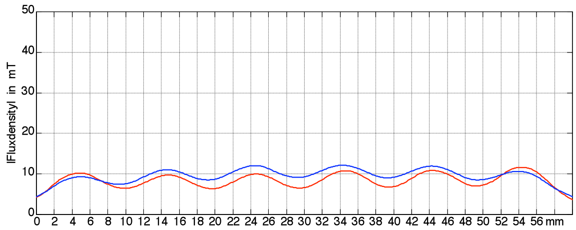


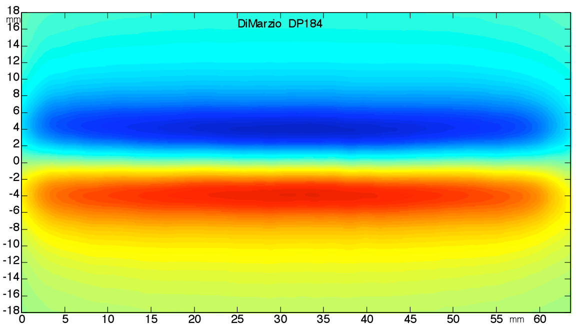
Gretsch Filtertron
bar magnet, 12 pole-screws





Gibson ES335 (square window),
bar magnet, 6 (pole-) screws, 6 pole pins (slugs)





DiMarzio DP184
bar magnet, 2 (pole-) blades

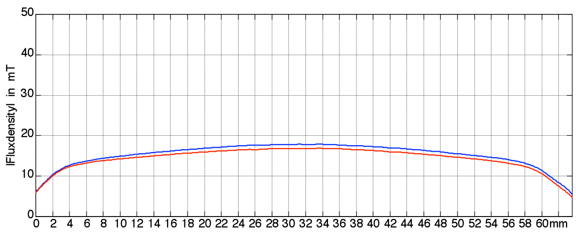
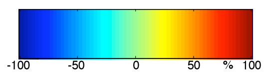


Fig. 5.4.7: Standardized axial flux density (left-hand column), magnitude of the absolute flux density (to the right); bipolar color scaling (color bar lower right); d = 2mm



Figs. 5.4.6 and 5.4.7 show the axial component of the static magnetic flux (measurement without string), i.e. the flux running perpendicular to the guitar top. The figure could create the impression that the Jazzmaster Pickup generates a more focused field than the P-90. However, the contrary is the case: a (locally) quick decrease of the axial component points to a strongly diverging field. For the Jazzmaster pickup (Fig. 5.4.1), the vertical (= axial) field component at 2 mm distance decreases quickly with horizontal movement of the measuring point because the direction of the field changes strongly.

Still, one should not attribute too much significance to the geometry of the magnetic field. As soon as a steel string is introduced in front of the pole-pieces the static magnetic flux changes, and as the string starts to vibrate, again entirely new field shapes result (Ch. 5,4,3). Actually, measurements of the static magnetic field are only undertaken to obtain hints as to the magnet(s), and even there merely a rough classification is advised: very strong (50 – 60 mT), strong (40 – 50 mT), medium (30 – 40 mT), weak (20 – 30 mT) and very weak (< 20 mT), with all measurements taken at a distance of 2 mm. Sure, the class borders given here are a subjective choice – if one so desires, 5-mT-intervals may also be used. Much finer steps are not purposeful, though: the measurement results depend rather strongly on the measurement position, after all, adjustment screws may be twisted, the measuring distance may be defined differently in case of tilted magnets of bent carrier plates, the 6 magnets of a pickup may result in different flux densities – with all these imponderables it is only possible to arrive at a **mean value** to the best of ones knowledge.

In the following **table** the static field measurements are listed – each taken at a distance of 2 mm above the pole plate (i.e. the slug, screw and blade, respectively). Data were collected using a Hall probe (Bell Technologies Inc., Model 5060, Gauss/Tesla Meter). The measurement error is specified by the manufacturer to ± 4%, which is adequately precise because the errors caused by inaccuracies of the sensor-positioning are – as a rule – bigger. Thus it is not sensible in the framework of the results presented here to judge e.g. the Duncan APTL-1 with its 36 mT as “stronger” relative to the Jazzmaster pickup (33 mT).

Pickup	§)	
Fender Telecaster Texas special (Bridge)		
Fender Telecaster-70 (Bridge)		
Fender Stratocaster (USA Standard, Middle)		
Rickenbacker (Toaster-Pickup)		
Fender Noiseless Stratocaster (Neck)		
Fender Stratocaster (USA Standard, Neck)		
Fender Stratocaster (USA Standard, Bridge)		
Fender Stratocaster-72		
Fender Jaguar (Neck)		
Fender Telecaster-73 (Bridge)		
Duncan SSL-1 (Strat-Type)		
Duncan APTL-1 (Telecaster-Type Bridge)		
Fender Jazzmaster-62 (Neck)		
Fender Jazzmaster-62 (Bridge)		
Schaller		
Fender Vintage Telecaster (Bridge)		
"Telecaster"-Fake (Bridge)		
DiMarzio DP172 (Tele-Type Neck)		with cover
Rockinger Strat (bar magnet)		
Fender Stratocaster (bar magnet)		
DiMarzio SDS-1		
Duncan APTR-1 (Telecaster-Type Neck)		with cover
Fender Vintage Telecaster (Neck)		with cover
Lace-Sensor gold		
Gibson P90		
"Telecaster"-Fake (Neck)		with cover
Rockinger P90		
Ibanez Blazer (Strat-Type Type)		
Gretsch HiLoTron		
Gretsch Filtertron		
DiMarzio DP107 Megadrive		
Joe Barden (Strat-Type, Bridge)		
DiMarzio DP184		
Gibson Tony Iommi		with cover
Squier Humbucker		without cover
Gibson Burstbucker Neck		with cover
Gibson Burstbucker Bridge		with cover
Gibson 490R		without cover
Gibson ES 335 (Neck, 1968)		without cover
Gibson 57 classic		with cover
Gibson ES 335 (Bridge, 1968)		without cover

Table: static pickup magnetic field without strings. + = north pole; measured at 2 mm distance (orientation values – the measurement precision is mere moderate).

§) the actual numbers are reserved for the printed version of this publication