# Continuously Adjustable Passive Shims


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**<u>Introduction:</u>** Traditional passive and active shims have complementary properties. Passives can create strong fields and operate without requiring power and dissipating heat, but their correction fields are fixed once they are constructed and installed. Actives provide continuous adjustability in situ, but their fields are weak. In many applications, the passive shims are intended to correct the majority of the field errors due to magnet imperfections and perhaps due to the probe structure. The actives are utilized for fine corrections of these errors, and to account for variations due to temperature changes, differences between samples, etc. We have developed an approach [1] to passive shimming in dipole magnets that allows the shims to have full, continuous adjustability, without removing the shims from the magnet.

**<u>Methods</u>** The new approach is possible because the passive shim structures that generate harmonic correction fields come in pairs, for example X and Y, YZ and YZ, XY and $X^2$-$Y^2$. The members of each pair are identical in structure and differ only in orientation (Fig. 1). To achieve adjustability, we build both members of a given pair using full-strength magnetic material, such a magnetic ink, and then manipulate the orientations of the pair members to achieve any value of the total correction field produced by the pair's members. For example, any linear field in the X-Y plane may be produced by reorienting the "X" and "Y" shim elements. We have demonstrated the viability of this method by building shims for a 0.5 T magnet and mounting them so that they may be rotated around a fixed axis without removing them from the magnet. The fields produced by the shims were mapped using a computer-positioned NMR probe.

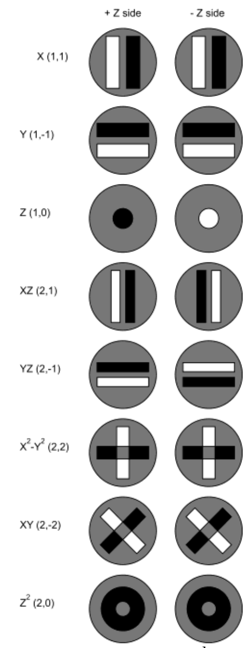


Fig. 1: 1st and 2nd order passive shim structures.

**<u>Results and discussion:</u>** Data demonstrate that, for each pair of harmonic fields, it is possible to produce any desired strength and orientation of the total correction field, up to the maximum field produced by the passive shim structures. We also demonstrate design control of the produced shim field by calculating orientations needed to produce particular results, for example, the spiral of Archimedes in the X-Y plane shown in Fig. 2. We have also used the adjustable shims to correct the magnet used for this work.

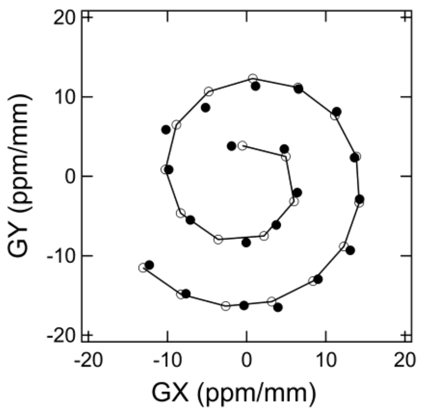


Fig. 2: Calculation and production of desired passive shim fields.

**<u>Conclusion:</u>** For applications using dipole magnets, we have demonstrated that it is possible to endow strong passive shims with the adjustability usually associated with active shims. The key is to construct passive shims that produce harmonic fields and then manipulate them in pairs by adjusting their orientations. It is possible to make the adjustments in situ, without removing the shims from the magnet. The method also allows the mass production of passive shims (as is currently possible with active shims), with the shims later being adjusted for the idiosyncrasies of individual magnets.


**<u>References:</u>** [1] McDowell, *J. Magn. Reson*. **296,** 143 (2018).