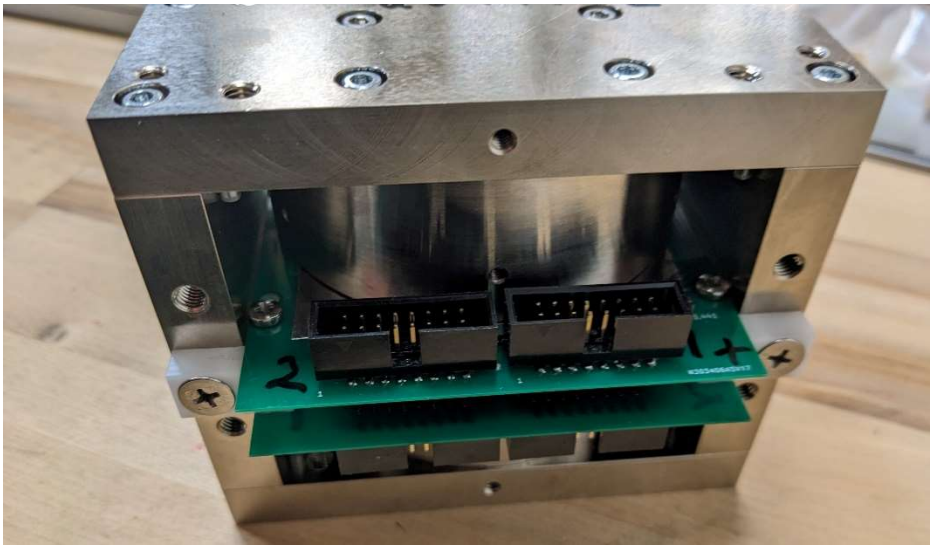
0.6 T ETH-Zürich magnet

SABR PN 105490
NuevoMR, LLC
Albuquerque, NM 87106



This 0.6 T permanent magnet was built for ETH-Zürich for use in moderately high resolution NMR system development. It has been passively shimmed using magnetic ink, and has fourth-order active shims. It is capable of achieving a largely Lorentzian NMR line with FWHM of better than 0.1 ppm on a sample contained in a 5 mm NMR tube.

Resonance Frequency: 25.05 MHz (21° C)

Clear Gap: 10 mm x 70 mm

Permanent magnet material: temperature compensated SmCo (10-30 ppm/°C)

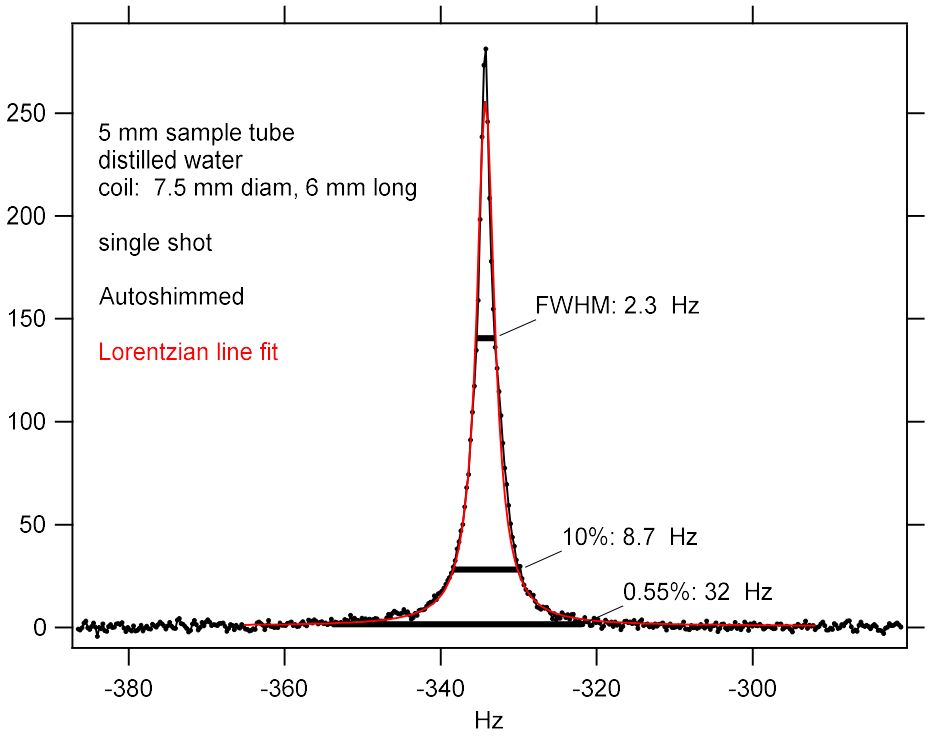
Passive shims: mechanical tilt, alignment, and Rose ring height adjusted at SABR, magnetic ink shimming carried out at NuevoMR

Active shims: 32-channel matrix shim, covering spherical harmonic fields of order 1-4 (fourth order field $XY(X^2-Y^2)$ is not created)

This magnet contains patented technology: US 9285441 covering the passive shimming with ink, and US 10739428 covering the active shim design

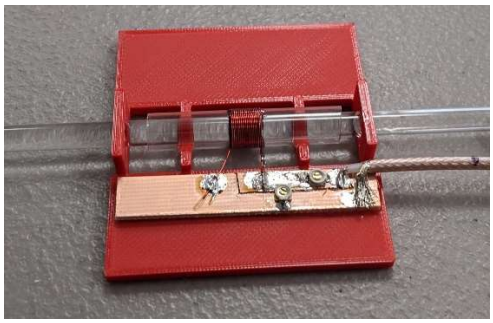
Demonstration data

To confirm that the magnet and shimming system can meet the expected specification, we constructed a rudimentary probe for 5mm NMR tubes. Using a semi-automated shim process based on work by Carl Michal, a line width with FWHM < 0.1 ppm was achieved:



The line is almost Lorentzian. Although all 23 shims were utilized, the total current draw from the positive and negative supply rails was minimal (<0.2 A each).

The probe used was assembled from 3D printed parts and a simple hand-modified copper clad board, and is shown below. It accepts a 5 mm NMR tube.

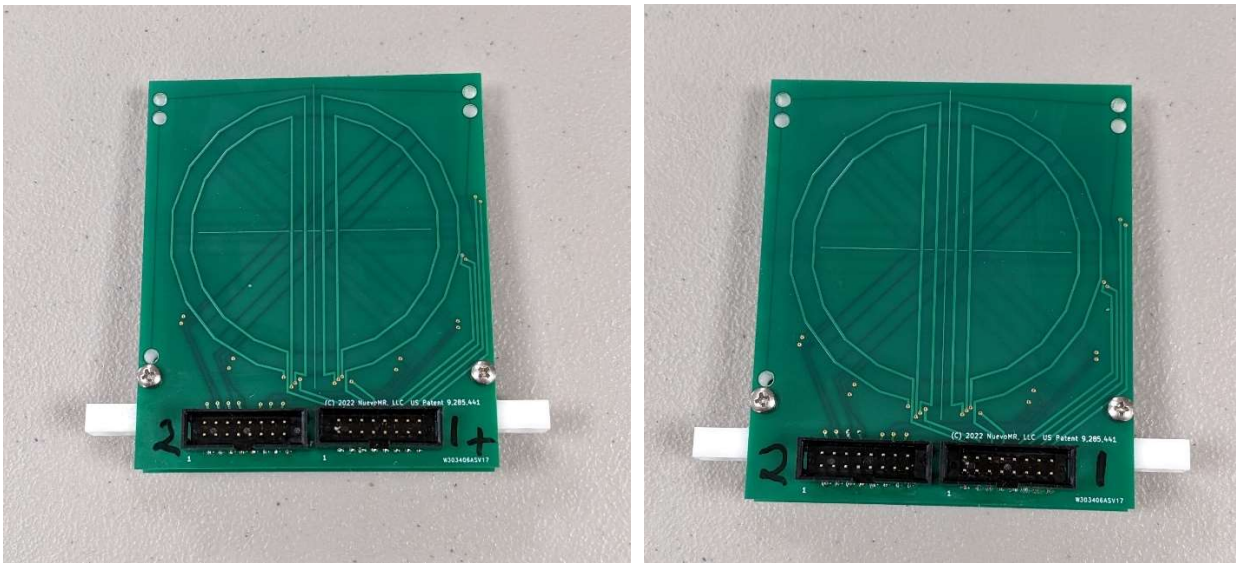


The coil is 18 turns on a 7.5 mm plastic coil form, 6 mm long. We expect that we are seeing NMR signal from a volume about 8 mm long. This would be a bit more than 100 µL. The magnet was shimmed over a 6 mm diameter sphere (also > 100 µL), and a sample with that geometry should have an even narrower NMR line.

Using the active shims

The magnet is supplied with active shims but not the shim driver. The shims are of a unique design consisting of straight paths across the pole faces. By supplying 32 independent currents, first through fourth order shim fields can be produced. The resistance of each of the current paths is about 0.2 Ω.

The active shims, without the passive shim layer installed, are show below with the top side (+Z in the magnet) shown on the left and the bottom side (-Z) on the right. These shims come installed in the magnet and should not be removed. The shims are held in place on support rails machined from Delrin. The NMR probe (not supplied) to be used will need to be installed inside this shim structure. In order to maximize the clear space inside the probe structure, the Delrin pieces were kept quite small. Therefore, the shim structure is not particularly robust; care should be exercised when installing NMR probes.

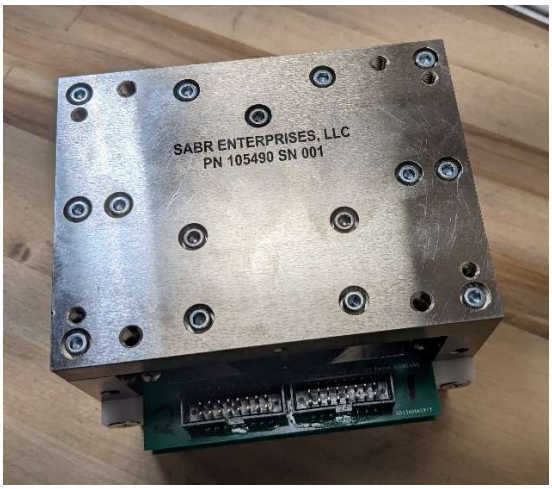


It is important to properly identify the two connectors on each of the shim panels in order to supply the correct current to the correct wires. The topside (+Z) shim pictured above on the left shows connector #1 on the right and #2 on the left. The bottom side (-Z) shim pictured on the right seems the same, but the picture shows the structure in an upside-down orientation. When installed in the magnet, the topside shim connectors are arranged with connector #1 on the right, while the bottom side shim will have connector #1 on the left (and pointing down).

The active shim matrix specifies vectors of 32 current values for wires #0 through #31. Wires #0-8 are on connector J1 on the top. Wires #9-15 are on connector J2 on the top. Wires #16-23 are on connector J1 on the bottom. Wires #24-31 are on connector J2 on the bottom. The matrix is included below and also given in an EXCEL spreadsheet

The user will need to implement the matrix in software that can control a 32-channel current supply. The impedance of each of the current paths on the PCB is about 0.2 Ω. The cabling between the PCBs and the power supply will add to this impedance.

There are markings on the magnet to help identify the top and bottom side. The top side is the +Z side; in other words, the magnetic field points in the direction of the +Z side.



The SABR markings end up on the bottom of the magnet when mounted “right-side up.” The definition of X and Y are marked on the top. The topside (+Z) active shim PCB also has a + sign.

<u>The shim matrix</u> (Also supplied in an EXCEL spreadsheet)

			Shim:		Z	X	Y	Z2	XZ	YZ	X2-Y2	XY														
			Harmonic term:		(1,0)	(1,1)	(1,-1)	(2,0)	(2,1)	(2,-1)	(2,2)	(2,-2)	(3,0)	(3,1)	(3,-1)	(3,2)	(3,-2)	(3,3)	(3,-3)	(4,0)	(4,1)	(4,-1)	(4,2)	(4,-2)	(4,3)	(4,-3)	(4,4)
		Measured P-P strength (ϕ6mm):			45 ppm	86 ppm	84 ppm	36 ppm	24 ppm	23 ppm	12 ppm	11 ppm	32 ppm	7 ppm	7 ppm	8 ppm	8 ppm	2.6 ppm	2.7 ppm	7.4 ppm	4.7 ppm	6.2 ppm	3.5 ppm	3.1 ppm	3.1 ppm	3.6 ppm	2.8 ppm
Board	Channel	IDC Connector	IDC pin	Wire #	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)	I(mA)
0	0	J1-Top (+Z)	1	0	-60.55	-43.36	6.08	-96.88	63.55	0.47	100.00	-6.91	96.87	100.00	0.98	7.89	20.77	-97.60	-4.65	99.71	97.87	-3.24	-73.09	14.45	-99.71	11.85	25.23
0	1	J1-Top (+Z)	2	1	18.97	-100.00	-1.59	-25.09	-94.39	0.63	23.58	3.40	-87.02	-28.99	-0.63	79.59	-3.17	75.33	6.72	-43.71	60.87	-6.74	30.80	4.78	-64.98	-13.46	-95.73
0	2	J1-Top (+Z)	3	2	17.64	-100.00	-1.59	22.84	-94.39	0.63	-23.58	-3.39	84.59	-29.00	-0.70	-62.30	1.82	75.20	7.14	41.23	65.29	-5.85	-45.29	-0.60	-65.04	-12.99	92.87
0	3	J1-Top (+Z)	4	3	63.37	-43.36	6.08	97.39	63.55	0.47	-100.00	6.91	-96.35	100.00	1.76	-6.68	-17.27	-97.52	-4.82	-100.00	97.94	3.56	89.69	23.33	-93.42	11.39	-2.32
0	4	J1-Top (+Z)	5	4	-99.95	-5.79	-44.08	-99.55	-6.29	51.24	-100.00	6.91	100.00	-1.39	99.71	-23.66	-19.28	-6.21	89.88	98.73	-11.06	88.75	58.72	-10.36	-29.98	-99.56	16.37
0	5	J1-Top (+Z)	6	5	-55.79	1.41	-100.00	-23.41	-14.16	-100.00	-23.58	-3.40	-81.67	0.18	-26.68	-100.00	1.99	-8.60	-92.72	-46.23	0.24	84.71	-43.67	-5.17	11.71	-81.63	-97.86
0	6	J1-Top (+Z)	7	6	-57.12	1.41	-100.00	24.99	-14.16	-100.00	23.58	3.40	89.82	0.19	-26.67	42.01	-3.00	-8.55	-92.99	38.85	4.33	83.99	34.96	-5.60	11.63	-81.38	90.45
0	7	J1-Top (+Z)	8	7	23.97	-5.79	-44.08	94.32	-6.29	51.24	100.00	-6.90	-93.28	-1.39	100.00	-18.12	18.76	-6.09	90.16	-98.49	-10.03	96.75	-100.00	-6.90	-23.65	-100.00	-11.19
1	0	J2-Top (+Z)	1	8	-59.40	-27.48	34.36	-99.13	43.96	-40.68	-6.92	-99.99	95.84	70.02	-68.86	2.62	-99.84	65.07	14.59	90.71	66.87	-85.63	-17.66	58.83	59.98	-78.75	-20.34
1	1	J2-Top (+Z)	2	9	-23.42	-73.96	66.36	-23.44	-73.25	56.59	3.40	-23.55	-84.87	-20.41	19.00	-13.84	-75.94	-57.97	-80.51	-45.21	54.45	-47.22	3.81	-45.51	59.28	-48.82	92.79
1	2	J2-Top (+Z)	3	10	-24.75	-73.96	66.36	26.23	-73.25	56.59	-3.40	23.56	86.92	-20.42	19.05	-15.08	76.15	-57.90	-80.45	41.88	50.07	-47.19	-1.05	34.12	59.21	-48.63	-96.04
1	3	J2-Top (+Z)	4	11	64.52	-27.48	34.36	95.19	43.96	-40.68	6.91	100.00	-97.52	70.03	-69.58	0.73	96.97	65.17	4.93	-89.46	66.33	-100.00	-26.65	-100.00	66.42	-79.23	7.78
1	4	J2-Top (+Z)	5	12	-77.52	-34.97	-26.46	-96.52	42.73	38.54	6.91	99.99	98.15	68.59	70.67	-5.31	97.37	73.93	-11.40	92.40	84.34	88.48	7.97	-88.40	64.84	62.58	-23.95
1	5	J2-Top (+Z)	6	13	5.59	-68.69	-70.46	-24.79	-69.92	-64.23	-3.40	23.55	-85.64	-19.58	-18.99	1.97	76.89	-45.85	72.14	-39.70	52.50	55.83	6.06	38.43	45.49	66.34	97.99
1	6	J2-Top (+Z)	7	14	4.26	-68.69	-70.46	24.94	-69.92	-64.23	3.40	-23.56	86.01	-19.58	-18.99	3.33	-75.20	-45.99	71.93	47.36	48.37	55.25	4.97	-36.68	45.42	66.87	-90.69
1	7	J2-Top (+Z)	8	15	46.40	-34.97	-26.46	99.36	42.73	38.54	-6.91	-99.99	-95.28	68.59	70.33	-12.45	-99.44	74.02	-14.66	-90.87	83.76	88.62	-1.08	69.31	71.25	62.16	4.18
2	0	J1-Bottom (-Z)	1	16	-60.99	-43.88	6.01	97.67	-63.90	-0.77	-100.00	6.91	96.48	97.96	-0.26	7.60	17.16	-99.95	-10.13	-90.26	-100.00	-8.14	68.09	-3.19	93.69	-16.98	-23.63
2	1	J1-Bottom (-Z)	2	17	19.12	-99.83	-1.57	25.53	100.00	4.32	-23.58	-3.40	-86.94	-28.32	-1.33	79.68	-1.99	76.03	12.36	45.16	-66.22	3.73	-35.26	11.06	66.78	-0.71	99.76
2	2	J1-Bottom (-Z)	3	18	17.78	-99.83	-1.57	-23.62	100.00	4.32	23.58	3.40	84.59	-28.33	-0.74	-62.20	3.01	76.07	10.43	-39.81	-64.94	-1.01	43.31	11.02	66.68	-0.17	-88.69
2	3	J1-Bottom (-Z)	4	19	62.93	-43.88	6.01	-97.70	-63.90	-0.77	100.00	-6.90	-96.83	97.96	0.04	-6.97	-20.88	-100.00	-9.40	95.41	-96.78	0.93	-85.95	-17.04	100.00	-17.42	4.07
2	4	J1-Bottom (-Z)	5	20	-100.00	5.93	41.11	94.47	-6.29	51.24	100.00	-6.91	99.81	1.46	-99.06	-23.70	-18.60	6.32	-96.34	-94.44	-8.21	95.22	-93.14	-9.74	-9.10	-94.88	-15.19
2	5	J1-Bottom (-Z)	6	21	-55.78	-3.23	95.51	25.80	-14.16	-100.00	23.58	3.40	-81.71	-0.92	25.47	-99.99	1.77	7.89	6.03	41.12	4.33	79.67	37.48	0.82	8.53	-83.08	91.93
2	6	J1-Bottom (-Z)	7	22	-57.11	-3.23	95.51	-23.42	-14.16	-100.00	-23.58	-3.39	89.94	-0.92	26.01	42.03	-3.22	7.91	5.45	-44.50	5.96	78.05	-37.87	-4.50	8.40	-82.89	-96.75
2	7	J1-Bottom (-Z)	8	23	23.92	5.93	41.11	-100.00	-6.29	51.24	-100.00	6.90	-93.37	1.46	-98.95	-18.16	19.44	6.21	-100.00	95.89	-5.71	94.29	70.37	-9.32	-2.78	-95.36	12.50
3	0	J2-Bottom (-Z)	1	24	-59.55	-35.67	-25.83	94.75	-46.15	-41.56	-6.91	-100.00	96.10	70.08	72.17	5.17	100.00	75.86	-72.61	-97.03	-80.45	-86.18	-2.78	78.62	-85.99	-55.84	19.93
3	1	J2-Bottom (-Z)	2	25	-23.37	-70.87	-71.89	24.74	64.21	59.20	3.40	-23.55	-84.94	-20.58	-19.13	-15.12	75.16	-46.88	-21.72	39.89	-45.59	-57.24	1.25	-47.71	-41.46	-58.01	-100.00
3	2	J2-Bottom (-Z)	3	26	-24.70	-70.87	-71.89	-24.07	64.21	59.20	-3.40	23.56	86.81	-20.57	-19.68	-13.75	-76.93	-46.98	-20.41	-46.90	-47.20	-54.12	-0.99	32.60	-41.48	-57.59	88.72
3	3	J2-Bottom (-Z)	4	27	64.37	-35.67	-25.83	-98.14	-46.15	-41.56	6.91	99.99	-97.27	70.08	72.03	-1.96	-96.82	75.77	-74.69	93.52	-82.75	-83.43	6.63	-73.57	-79.64	-56.31	-8.07
3	4	J2-Bottom (-Z)	5	28	-77.61	-26.02	33.79	99.71	-47.38	37.67	6.91	99.99	98.59	71.42	-68.86	-7.97	-97.37	66.73	83.73	-99.20	-67.18	99.08	17.42	-71.40	-51.24	78.94	21.90
3	5	J2-Bottom (-Z)	6	29	5.62	-72.03	67.77	22.71	67.54	-61.63	-3.40	23.55	-85.77	-20.37	20.10	3.27	-75.89	-58.14	7.13	42.52	-51.67	53.31	-2.92	31.14	-60.26	59.60	-96.48
3	6	J2-Bottom (-Z)	7	30	4.29	-72.03	67.77	-25.82	67.54	-61.63	3.40	-23.56	85.84	-20.37	19.51	2.05	76.21	-57.99	8.47	-44.31	-53.09	56.51	-0.64	-42.98	-60.23	59.92	92.09
3	7	J2-Bottom (-Z)	8	31	46.31	-26.02	33.79	-95.90	-47.38	37.67	-6.91	-100.00	-94.80	71.42	-69.13	-9.85	99.44	58.36	71.04	94.66	-80.05	77.63	6.87	88.79	-63.68	57.31	-18.83