EDGES MEMO #384

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

February 2, 2022

Telephone: 617-715-5533

To: EDGES Group

From: Alan E.E. Rogers

Subject: Further optimization of wire grid ground plane

Wire grid ground planes have been studied in memos 298, 308 and 378. A "meandering wire grid" ground plane was used in the EDGES-3 deployment described in memo 310.A comparison of wire grid ground planes of different sizes and wire spacing are compared with solid ground planes in memo 378. The solid metal ground planes are assumed to be equivalent to welded mesh ground planes which are studied in memos 316, 328 and 350 because the loss due to leakage through the mesh with 5 cm spacing is less than 0.1 % and resistive loss is also under 0.1% if galvanized as studied in memos 179, 258, 315 and 316. The wire grid parameters included are in the list in table 1

parameter	Range studied	comments
Length in the direction of antenna E-field	5 - 30m	square, rectangular and 45 degree
Length perpendicular to antenna E-field	5 - 30m	can be obtained and spacing away
Wire spacing	3.125 – 25 cm	from antenna increased to save wire
Meandering		whether wire in continuous or cut
Wire size/diameter	14 – 18 awg	1.042 – 1.628 mm in diameter
Change of wire spacing with distance	1 – 2 or more	change of 2 as in memo 310
Use of shorted annular-ring SAR	1 – 4 rings	use of outer shorted squares of wire
Height off the ground or soil for test only	0-25 cm	> 1 cm degrades performance
Overall shape	square or rectangle	Also square rotated by 45 degrees

Table 1. Wire grid ground plane parameters

Estimates of loss were made in memo 298 are repeated here for different wire gauges and for smaller sizes which then can be extended to larger sizes by increasing the spacing with increased distance from the center line of the antenna E-field in order to save wire.

The loss estimates in table 2 are derived using FEKO which uses the Green's function (GF) method to account for the soil which has limited accuracy and some "glitches" which make it difficult to access the smoothness of the loss variation with frequency. However the loss at the 2% level typically has little contribution to the beam chromaticity based on comparisons using the "reflection method" in FEKO. See memos 258, 277 and 315.

Wire gauge awg	Diam mm	Size m	spacing cm	loss
18	1.024	5x5	12.5	5.6%
18		5x5	6.25	3.3%
18		10x10	6.25	2.1%
18		10x10	3.125	1.4%
14	1.628	10x10	6.25	1.9%
14		30x30	6.25 100	1.1%
18		30x30	6.25 100	1.6%
18		30x30	3.125 250	0.7%

Table 2. Loss dependence at 76 MHz on wire gauge and spacing

Since 30x30m wire grid with uniform wire spacing of 6.25 cm would take 960 pegs and 14.4 km of wire there is a strong motivation to examine ways of reducing these numbers. Figures 1 and 2 show the use of adding wire squares or meandering wires with 1 meter spacing beyond a 10x10m meandering ground plane with constant of 6.25 cm. The motivation for squares comes from the use of shorted annular-ring (SAR) used in some planar GPS and GNSS antennas. FEKO simulations of these 2 cases show lower chromaticity for the continuation of the meandering with wide spacing while in both cases the ground loss is about the same. A variation of the spacing of the meandering is also examined. Meandering results in slightly better chromaticity than cutting each wire to remove the connections between adjacent wires.

Wire gauge	Inner size	Overall size	Initial spacing	Final spacing	Av rms mK	rms 1	rms 2	loss	comments
18		10x10	6.25	6.25	199	97	50	2.0%	Az = 0 deg
18	10x10	30x30	6.25	1000	191	53	29	2.0%	Added squares
18	10x10	30x30	6.25	1000	119	74	28	1.7%	Added meander
18		30x30	6.25	250	109	85	33	0.8%	Continuous spacing
solid	20m	diam	circle		330	81	13	0.2%	Az = 60 deg
solid	20m	diam	circle		314	112	40	0.2%	Az = 0 deg
mesh	30x30	perf			89	64	4	0.2%	Az = 60 deg
mesh	30x30	perf			81	55	7	0.2%	Az = 0 deg
18	10x10	square	rotated 45 deg	3.1 cm	154	76	1	1.6%	Az = 60 deg
18	10x10	square	rotated 45 deg	to 6.28	154	50	10	1.6%	Az = 0 deg
18	15x15	square	rotated 45 deg	3.1 cm	182	63	8	1.6%	Az = 60 deg
18	15x15	square	rotated 45 deg	to 7.8	182	42	18	1.6%	Az = 0 deg
18	20x20	square	rotated 45 deg	3.1 cm	214	60	1	1.0%	Az = 60 deg
18	20x20	square	rotated 45 deg	to 9.5	220	120	36	1.0%	Az = 0 deg

solid	20x20	square	rotated 45 deg		175	50	9	0.1%	Az = 60 deg
solid	20x20	square	rotated 45 deg		179	119	28	0.1%	Az = 0 deg
18	30x30	square	6.25	250	102	56	6	0.8%	Az = 60 deg
18	30x30	square	6.25	250	110	85	34	0.8%	Az = 0 deg
18	30x30	square	3.125		112	63	7	1%	Az = 60 deg
18	30x30	square	3.125		139	111	47	1%	Az = 0 deg
18	20x10	rectangle	3.125		184	90	18	1.3%	Az = 60 deg
18	20x10	rectangle	3.125		184	68	13	1.3%	Az = 0 deg
18	10x5	rectangle	3.125		216	108	67	3.0%	Az = 60 deg
18	10x5	rectangle	3.125		166	57	26	3.0%	Az = 0 deg

Table 3. Effect of wire spacing on average rms over 1 hour blocks of GHA at latitude 69 degrees and rms before and after fitting the Nature absorption with 5-terms removed from 55 – 97 MHz

When testing square ground planes it was noticed that when the square in rotated by 45 degrees to the antenna electric field vector as shown in Figure 3 the chromaticity is reduced because with this orientation the edges smear the phases of the reflections like in the 30x30 “perforated” ground plane in memo 204. It is noted that the square ground plane shows a large range of performance vs azimuth angle which requires a closer examination as the orientation cannot be easily changed without removing the pegs and wire and reinstalling the pegs and using a new supply of wire.

parameters	change	Avrms mK	rms1	rms2	comments
30x30m_meav6_2p5_t2_1e-3_18a_0cm	1e-2 – 1e-3	69	64	4	Az = 60 deg
“	“	73	65	8	Az = 0 deg
20x10m_mea1_mspac4_1e-2_18a_0cm_rock2	rock 0 - 2	65	55	5	Az = 60 deg
“	“	76	70	6	Az = 0 deg
20x10m_mea1_mspac4_1e-2_18a_0cm	1e-2 – 1e-3	75	59	8	Az = 60 deg
“	“	74	61	7	Az = 0 deg

Table 4. Effects of a change in soil conductivity and layer of rock below

The chromaticity with 5-physical terms removed is examined for various cases

Wire gauge	Inner size	Init grid spacing	Soil S/m	diel	Av rms mK	rms 1	rms 2	loss	comments
18	20x10	3.125cm	1e-2	3.5	184	90	18	1.4%	Az = 60 deg
18	20x10	“	1e-2	3.5	184	69	14	1.4%	Az = 0 deg
18	20x10	“	1e-3	3.5	204	94	22	1.5%	Az = 60 deg
18	20x10	“	1e-3	3.5	204	72	14	1.5%	Az = 0 deg

18	20x10	"	1e-2	rock2	194	83	16	1.5%	Az = 60 deg
18	20x10	"	1e-2	rock2	196	76	11	1.5%	Az = 0 deg
18	10x20	"	1e-2	3.5	197	68	13	1.2%	Az = 60 deg
18	10x20	"	1e-2	3.5	195	74	50	1.2%	Az = 0 deg
18	15x15	"	1e-2	3.5	206	70	14	1.0%	Az = 60 deg
18	15x15	"	1e-2	3.5	227	72	12	1.0%	Az = 0 deg

Table 5. Effects of the different soil conductivity and rock layer below for 20x10m and 10x20m rectangular wire grid ground plane.

size	nspac	awg	wire spacings	#pegs	Wire len m	loss	chromaticity
15x15	4	18	3.125 6.25 12.5 25	562	4215	1.0%	227
15x15	8	18	3.125 gradual	588	2589	1.6%	181
30x16	Oregon	18	6.25 12.5	320	4800	1.7%	146
30x15	4	18	3.125 6.25 12.4 25	562	8430	1.7%	146
30x30	4	18	3.125 6.25 12.5 25	754	11310	0.7%	139
30x30	4	18	6.25 12.5 25	378	5670	1.6%	133
30x30	4	14	6.25 12.5 25	378	5670	1.4%	135
30x15	4	18	6.25 12.5 25	282	4230	1.8%	133
30x15	4	14	6.25 12.5 25	282	4230	1.6%	135
15-45x15	4	18	6.25 12.5 25	282	4308	1.8%	116

Table 6. The number of pegs and wire lengths needed for a few selected cases

The last entry in table 6 in which the wire length is varied from 15 to 45m to form 4 perforations on each end shown in Figure 6. The chromaticity is slightly better but the layout of pegs in more complex.

Based on consideration of wire size and length of wire needed the best choice is 30x15m with about 4.23 km of 18 awg which is close to the design used in Oregon with a more gradual change in spacing from 6.25 to 12.25 at 2m to 25.0 at 6m from antenna using 282 pegs.

In overall summary of ground planes this study combined with previous studies show:

1] The antenna should be as electrically small as possible without compromise of the S11 magnitude
2] The antenna should have the small delay in the S11
3] The antenna should be horizontally polarized to minimize reflections from the edges of the ground plane
4] A square ground plane has a lower chromaticity than a circular ground plane of the same area
5] A ground plane with perforated edges has lower chromaticity but is not practical with a wire grid
6] The ground plane needs to be level to within 1 degree and flat to within 5cm peak deviation

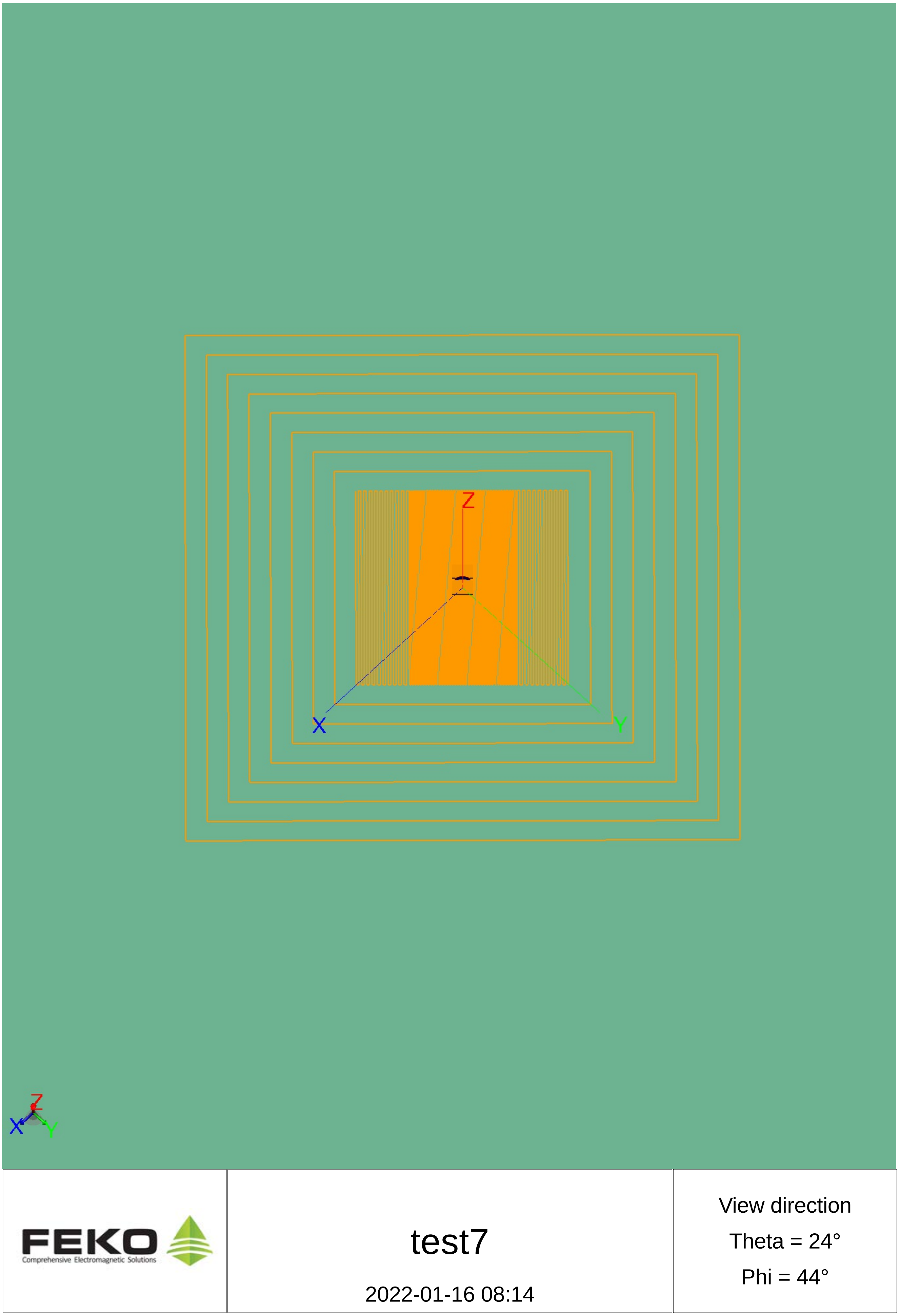

Figure 1. 10x10m wire grid with wire squares with 1m spacing to extend to 30x30m the first case in table 3.

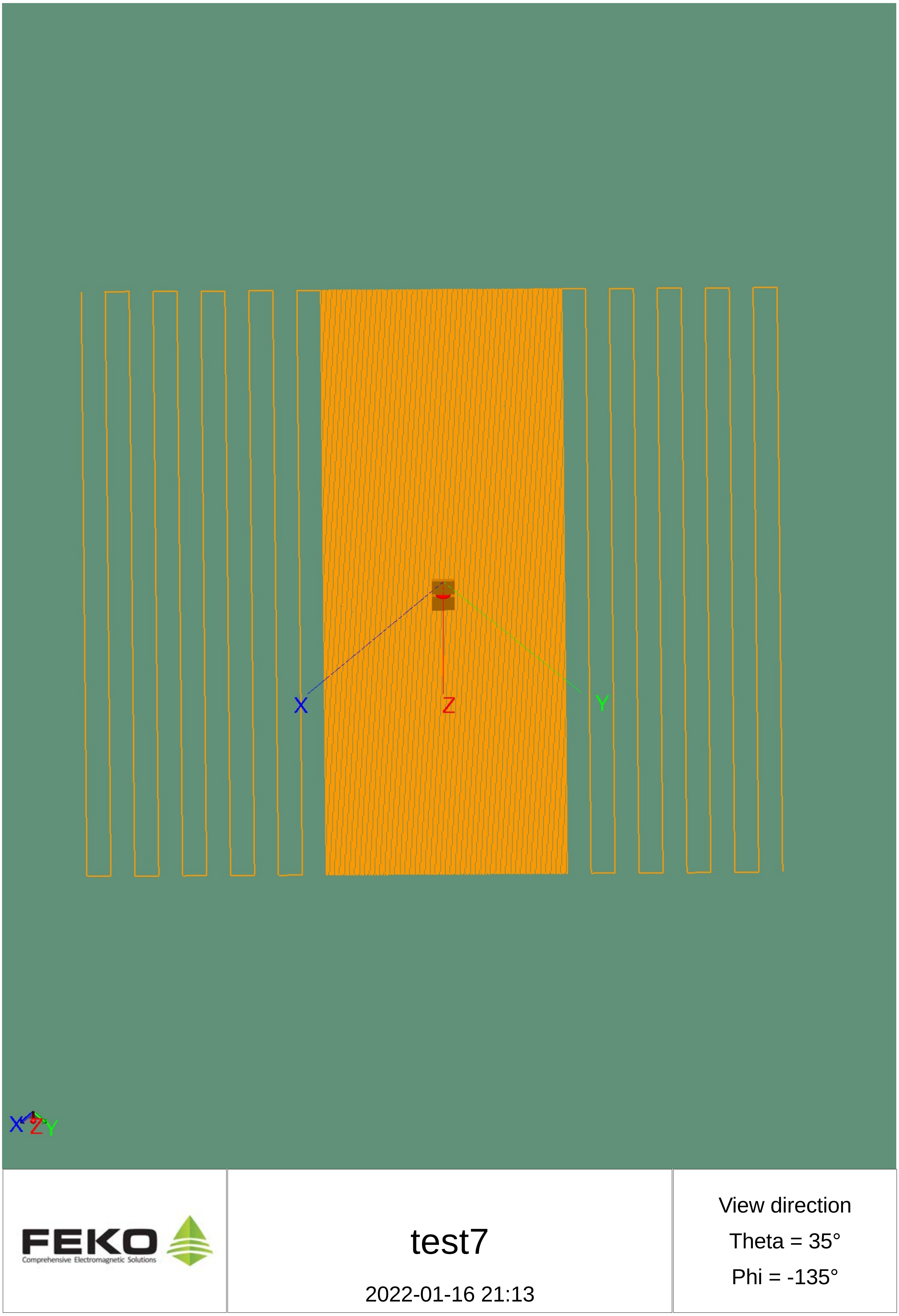

Figure 2. 10x10m wire grid with meandering wire with 1m spacing to extend to 30x30m the second case case in table 3.

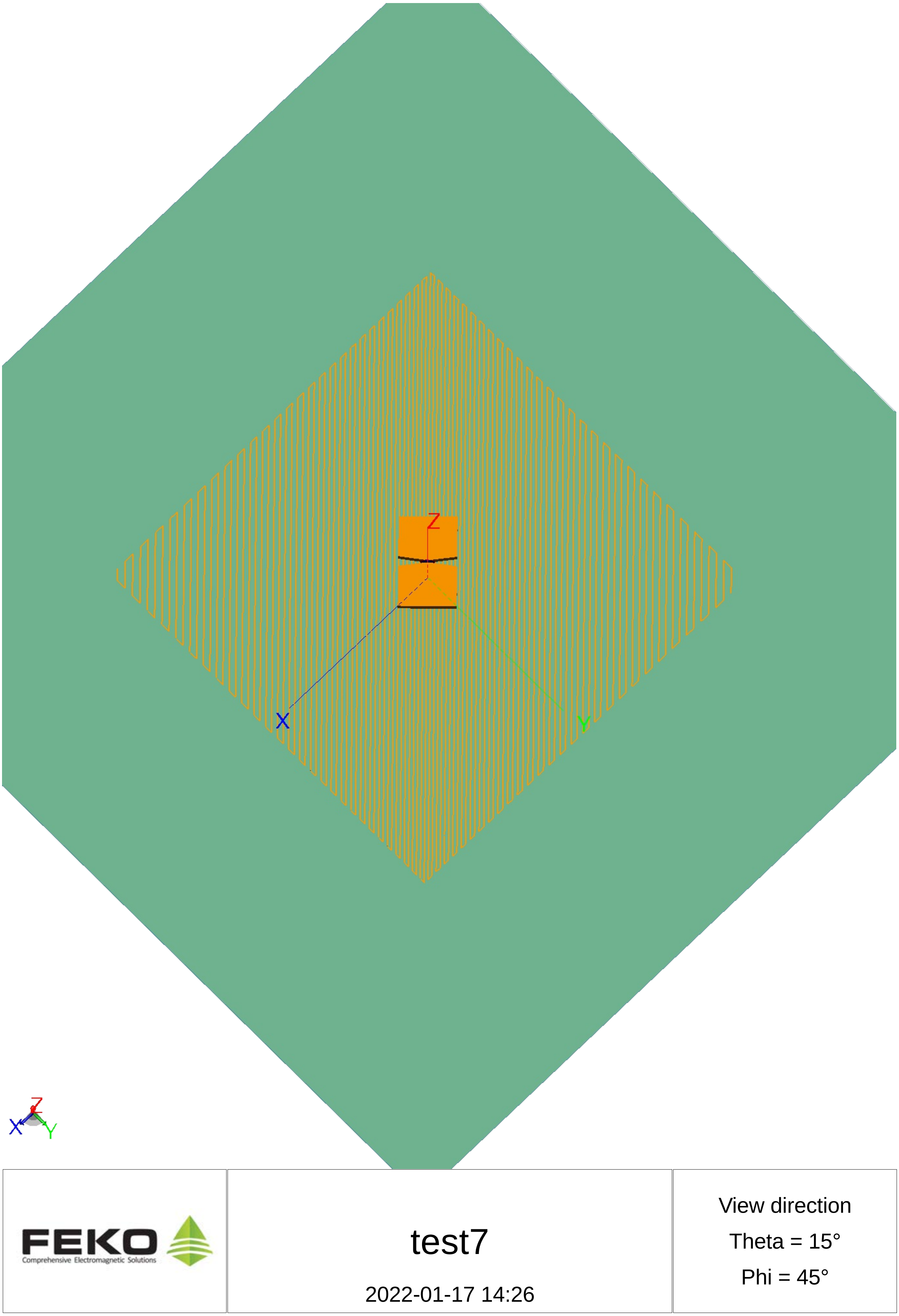

Figure 3. 10x10m square meandering wire grid orientated 45 degrees to the antenna

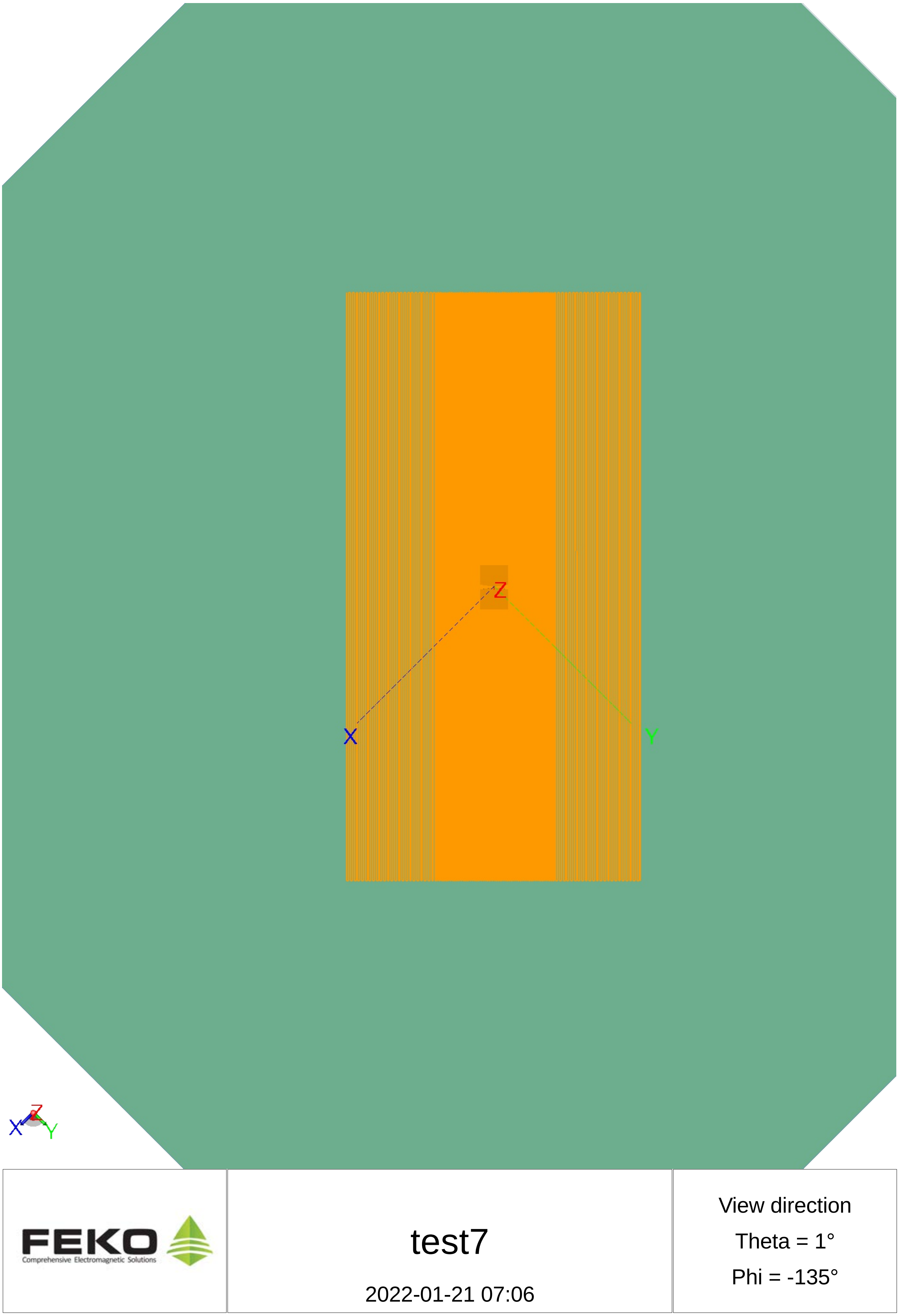

Figure 4. 20x10m rectangular meandering wire grid with change in spacing

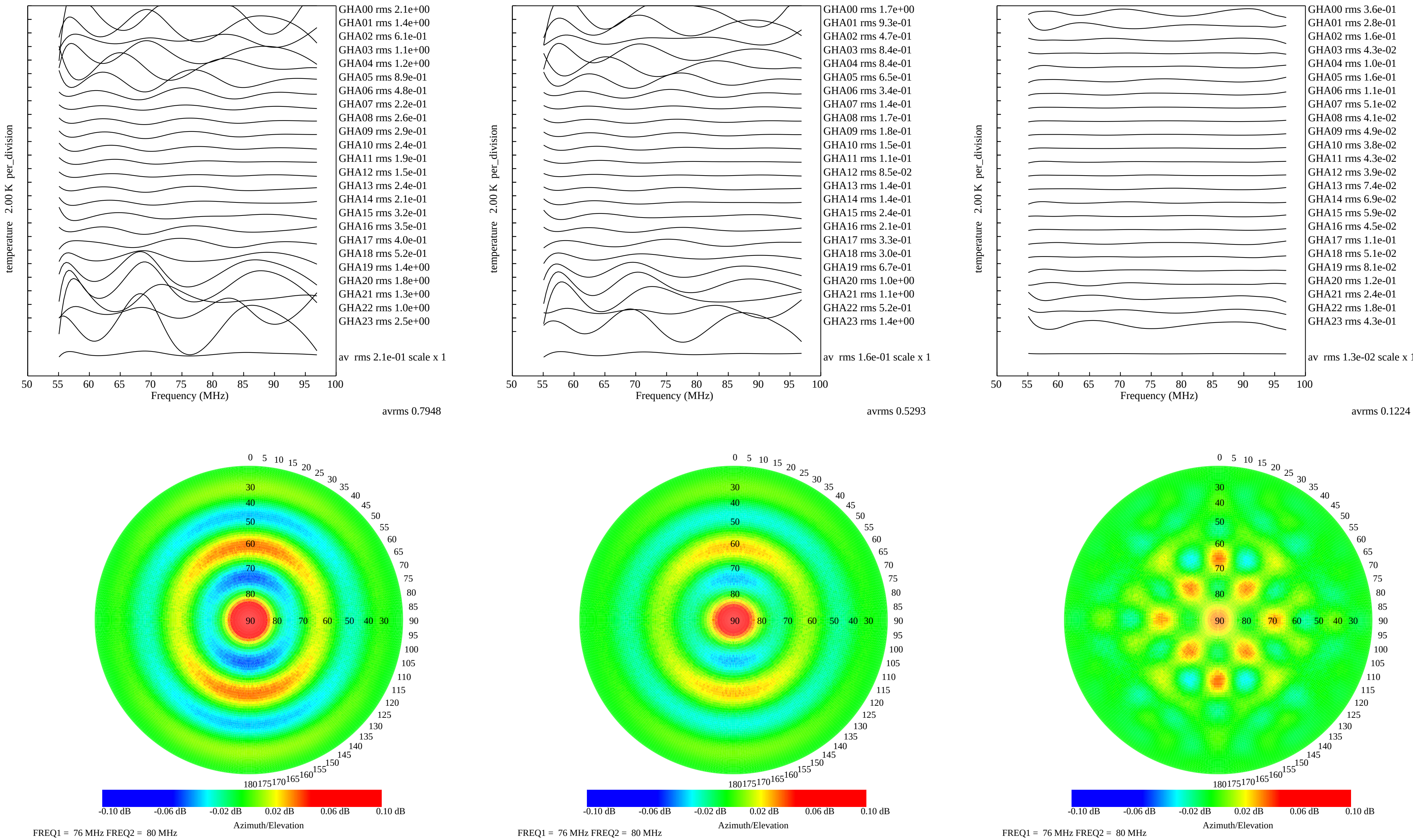

Figure 5. The chromaticity (5 terms removed) of the 20m diameter circular ground plane in space on the left and on soil 3.5 1e-2 S/m in the middle and 30x30m EDGES-3 mesh ground plane on the right. In this case the chromaticity is for the latitude of -26.7 degrees of the MRO

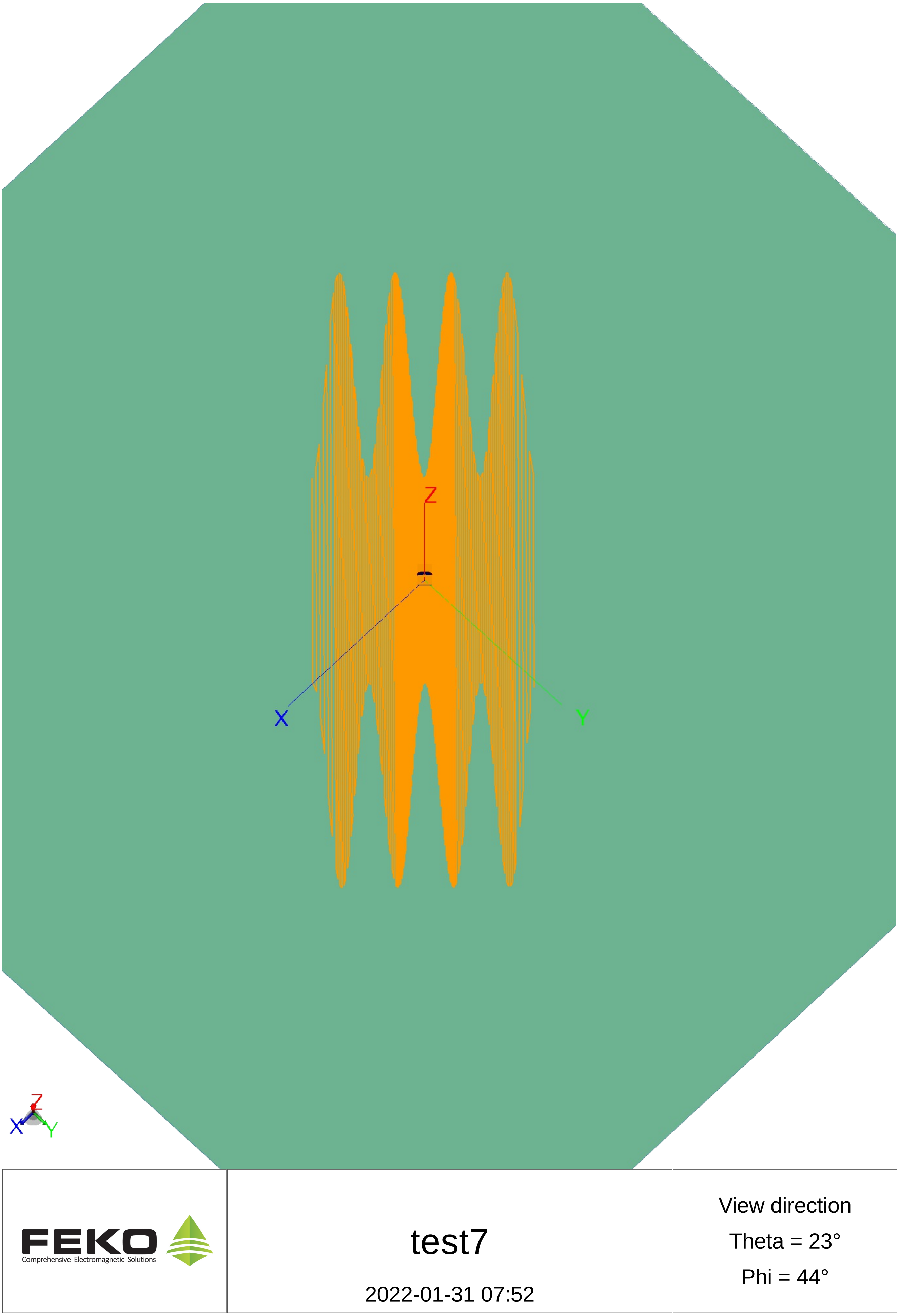

Figure 6. The 15x15m to 45x15m meandering wire grid layout used for the last