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# A novel grey wolf optimizer and its applications in 5G frequency selection surface design



**Key words:** Grey wolf optimizer; Fifth-generation wireless communication system (5G); Frequency selection surface; Shape optimization

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# Motivation

1. While the fifth-generation wireless communication system (5G) technology brings convenience, it also faces the new electromagnetic compatibility problems. It is difficult for traditional electromagnetic shielding methods to meet the requirements of 5G equipment.
2. Electromagnetic metamaterial frequency selection surface (FSS) has great potential to solve new electromagnetic compatibility problems.
3. Intelligent optimization algorithm can help solve the problems of FSS structure design and optimization.

# Main idea

1. Improving the initial distribution, increasing the randomness, and enhancing the local search are effective for accelerating the convergence and avoiding local optima.

2. A novel FSS shape optimization method is designed, which uses the node coordinates of the unit structure as design variables.

3. The combination of self-adaptive grey wolf optimizer (SAGWO) and the new FSS optimization model can obtain the FSS that has good electromagnetic interference shielding and high angular stability.

# Method

1. An SAGWO is proposed which consists mainly of three improvement strategies.

2. The novel FSS shape optimization method uses the node coordinates of the unit structure as design variables. SAGWO and the novel model are used to design an optimized FSS.

# Method (Cont'd)

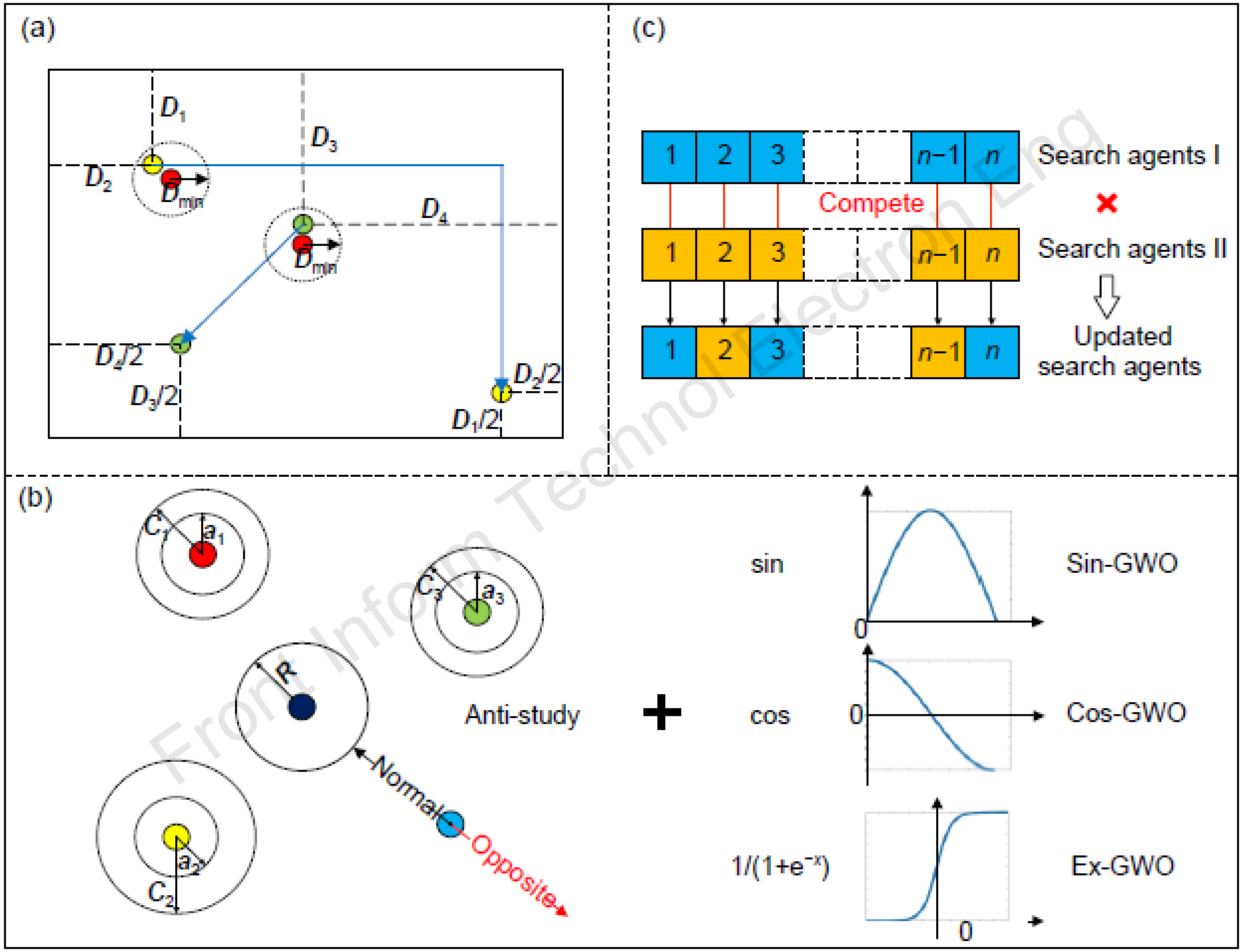



**Fig. 2 Three improvement strategies for SAGWO: (a) improvement of the initial distribution strategy; (b) improvement of the randomness strategy; (c) improvement of the local search strategy**

# Method (Cont'd)

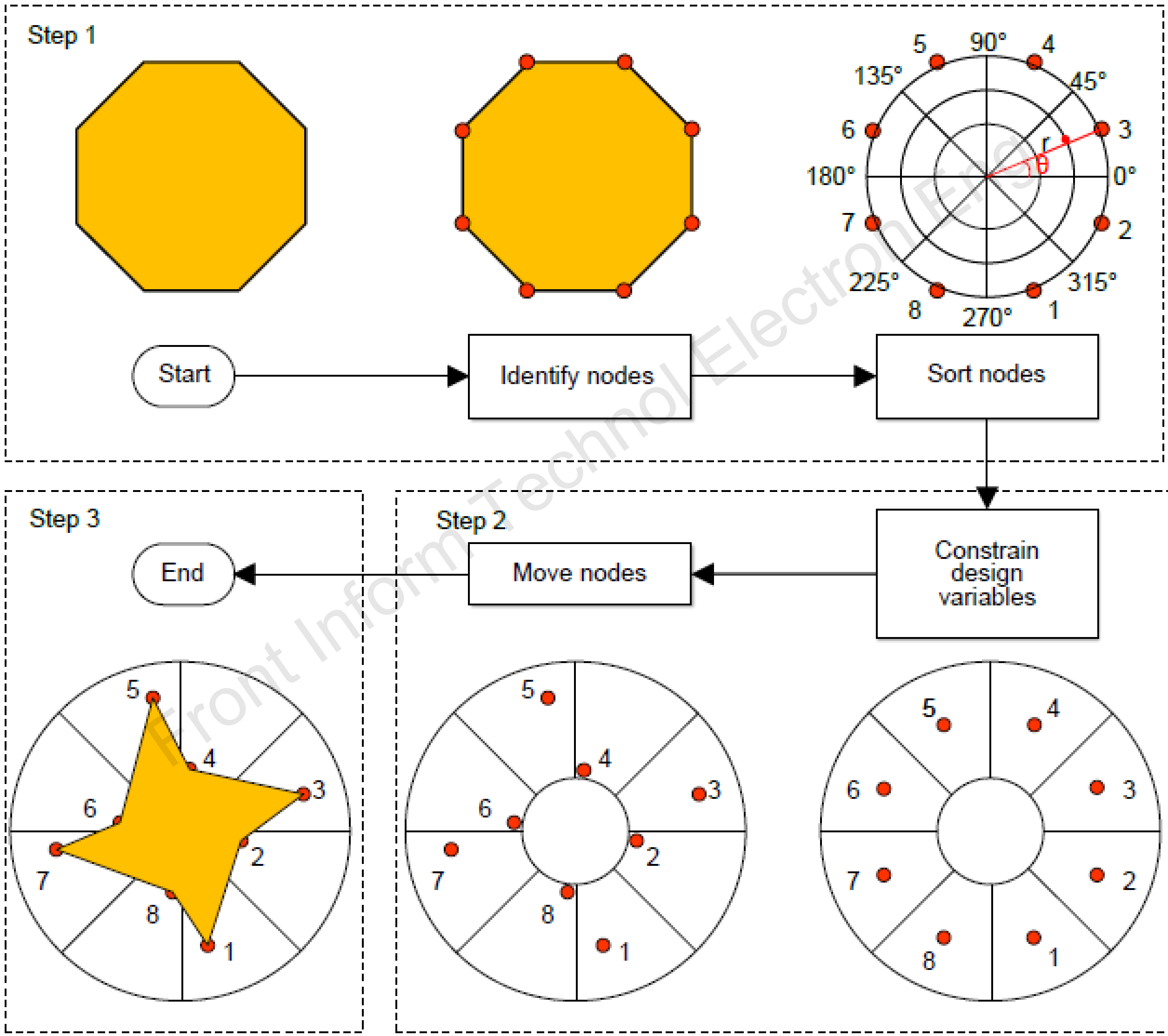



Fig. 4 Illustration of the eight-node FSS unit modeling method

# Major results

**Table 1 Wilcoxon sign rank test on the solutions obtained by different algorithms for benchmarks in Tables S2–S4 ($\alpha$=0.05)**

| Case | Sin-GWO vs. Cos-GWO | | | Sin-GWO vs. Ex-GWO | | | Cos-GWO vs. Ex-GWO | | |
|---|---|---|---|---|---|---|---|---|---|
| | $R^+$ | $R^-$ | $p$-value | $R^+$ | $R^-$ | $p$-value | $R^+$ | $R^-$ | $p$-value |
| $f_1$ | 181 | 284 | 2.77E-01= | 0 | 465 | 3.02E-11− | 11 | 454 | 2.87E-10− |
| $f_2$ | 152 | 313 | 1.62E-01= | 62 | 403 | 8.20E-07− | 49 | 416 | 1.29E-06− |
| $f_3$ | 209 | 256 | 8.53E-01= | 0 | 465 | 3.02E-11− | 0 | 465 | 3.02E-11− |
| $f_4$ | 151 | 314 | 2.90E-01= | 0 | 465 | 3.02E-11− | 0 | 465 | 3.02E-11− |
| $f_5$ | 227.5 | 237.5 | 9.51E-01= | 217.5 | 247.5 | 3.29E-01= | 236.5 | 228.5 | 3.49E-01= |
| $f_6$ | 279 | 186 | 2.58E-01= | 278 | 187 | 6.79E-01= | 227 | 238 | 7.34E-01= |
| $f_7$ | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= |
| $f_8$ | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= |
| $f_9$ | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= |
| $f_{10}$ | 337 | 128 | 1.17E-01= | 247 | 218 | 3.85E-02− | 269 | 196 | 3.29E-01= |
| $f_{11}$ | 200 | 265 | 5.59E-01= | 209 | 256 | 6.60E-01= | 256.5 | 208.5 | 9.02E-01= |
| $f_{12}$ | 252.5 | 212.5 | 2.70E-01= | 279.5 | 185.5 | 6.90E-01= | 206 | 259 | 5.79E-01= |
| $f_{13}$ | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= | 232.5 | 232.5 | 1.00E+00= |
| $f_{14}$ | 213.5 | 251.5 | 4.72E-01= | 225 | 240 | 1.00E+00= | 232.5 | 232.5 | 5.67E-01= |
| $f_{15}$ | 190 | 275 | 6.88E-01= | 220.5 | 244.5 | 5.31E-01= | 226 | 239 | 8.92E-01= |
| +/=/− | 0/15/0 | | | 0/10/5 | | | 0/11/4 | | |

# Major results (Cont'd)

Table 3 Wilcoxon sign rank test of the solutions obtained by different algorithms for benchmarks in Tables S5–S7 ($\alpha$=0.05)

| Case | SAGWO vs. PSO | | | SAGWO vs. GA | | | SAGWO vs. GWO | | |
|---|---|---|---|---|---|---|---|---|---|
| | $R^+$ | $R^-$ | *p*-value | $R^+$ | $R^-$ | *p*-value | $R^+$ | $R^-$ | *p*-value |
| $f_1$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ |
| $f_2$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ |
| $f_3$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.01E-11+ |
| $f_4$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ |
| $f_5$ | 253 | 212 | 5.62E-01= | 259 | 206 | 1.84E-01= | 8 | 457 | 2.98E-11– |
| $f_6$ | 273 | 192 | 4.29E-01= | 406 | 59 | 8.58E-06+ | 318 | 147 | 7.73E-01= |
| $f_7$ | 465 | 0 | 1.21E-12+ | 465 | 0 | 1.21E-12+ | 436.5 | 28.5 | 1.07E-11+ |
| $f_8$ | 465 | 0 | 1.21E-12+ | 465 | 0 | 1.19E-12+ | 465 | 0 | 5.11E-13+ |
| $f_9$ | 465 | 0 | 1.18E-12+ | 465 | 0 | 1.21E-12+ | 272.5 | 192.5 | 2.16E-02+ |
| $f_{10}$ | 0 | 465 | 3.01E-11– | 89 | 376 | 9.81E-08– | 0 | 465 | 3.01E-11– |
| $f_{11}$ | 167.5 | 297.5 | 1.76E-02– | 310.5 | 154.5 | 1.21E-01= | 260 | 205 | 1.46E-01= |
| $f_{12}$ | 465 | 0 | 4.17E-10+ | 455 | 10 | 3.29E-11+ | 237 | 228 | 8.42E-01= |
| $f_{13}$ | 232.5 | 232.5 | 1.00E+00= | 244.5 | 220.5 | 3.34E-01= | 232.5 | 232.5 | 1.00E+00= |
| $f_{14}$ | 232 | 233 | 2.53E-01= | 311 | 154 | 8.79E-02= | 184 | 281 | 7.01E-01= |
| $f_{15}$ | 51 | 414 | 2.76E-06– | 338 | 127 | 9.54E-04+ | 20 | 445 | 1.27E-09– |
| +/=/– | 8/4/3 | | | 10/4/1 | | | 7/5/3 | | |

# Major results (Cont'd)

Table 4 Wilcoxon sign rank test of the solutions obtained by the two improved GWOs for benchmarks in Tables S8–S10 ($\alpha$=0.05)

| Case | SAGWO vs. SOGWO | | | SAGWO vs. IGWO | | |
|---|---|---|---|---|---|---|
| | $R^+$ | $R^-$ | $p$-value | $R^+$ | $R^-$ | $p$-value |
| $f_1$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ |
| $f_2$ | 465 | 0 | 3.01E-11+ | 465 | 0 | 3.02E-11+ |
| $f_3$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ |
| $f_4$ | 465 | 0 | 3.02E-11+ | 465 | 0 | 3.02E-11+ |
| $f_5$ | 465 | 0 | 2.46E-11+ | 0 | 465 | 2.46E-11– |
| $f_6$ | 245 | 220 | 6.95E-01= | 267 | 198 | 8.88E-01= |
| $f_7$ | 465 | 0 | 1.21E-12+ | 465 | 0 | 1.21E-12+ |
| $f_8$ | 465 | 0 | 1.21E-12+ | 465 | 0 | 7.11E-13+ |
| $f_9$ | 465 | 0 | 1.21E-12+ | 283 | 182 | 5.58E-03= |
| $f_{10}$ | 35 | 430 | 1.14E-04– | 0 | 465 | 3.01E-11– |
| $f_{11}$ | 321 | 144 | 3.95E-03+ | 152 | 313 | 1.52E-01= |
| $f_{12}$ | 228 | 237 | 6.41E-01= | 97 | 368 | 5.13E-03= |
| $f_{13}$ | 465 | 0 | 1.21E-12+ | 232.5 | 232.5 | 1.00E+00= |
| $f_{14}$ | 0 | 465 | 1.41E-11– | 0 | 465 | 9.81E-12– |
| $f_{15}$ | 10 | 455 | 2.26E-10– | 0 | 465 | 4.58E-12– |
| +/=/– | 9/2/3 | | | 6/5/4 | | |

# Major results (Cont’d)

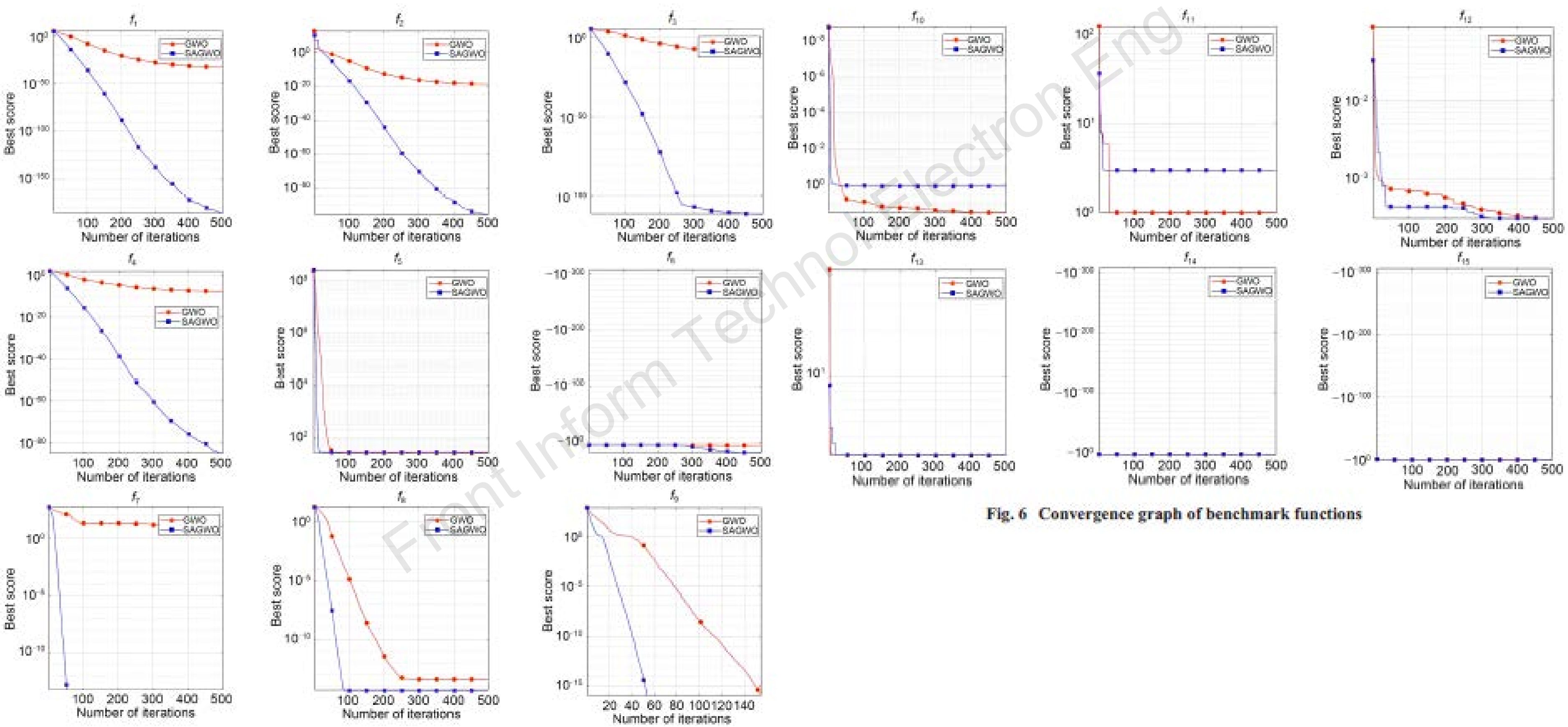



**Fig. 6 Convergence graph of benchmark functions**

# Major results (Cont’d)

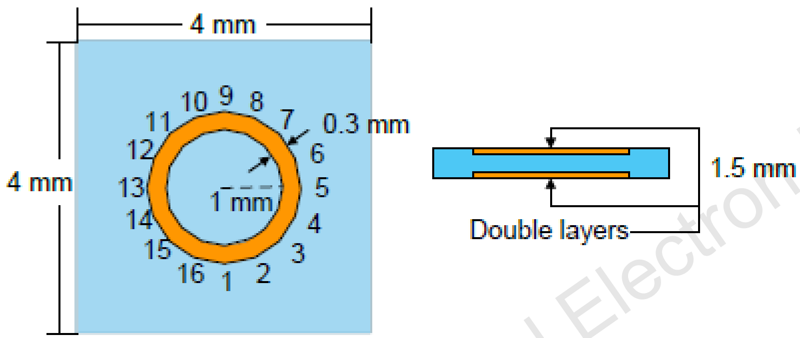



Fig. 7 Design domain of ring units

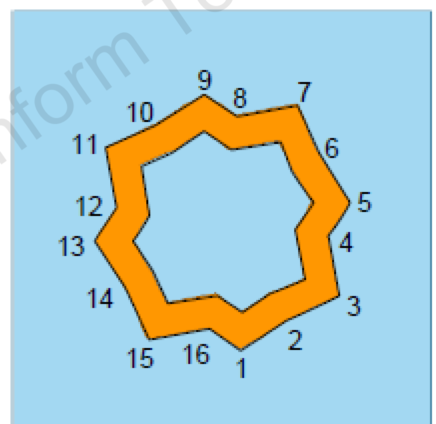



Fig. 8 Shape optimization results of ring units

# Major results (Cont’d)

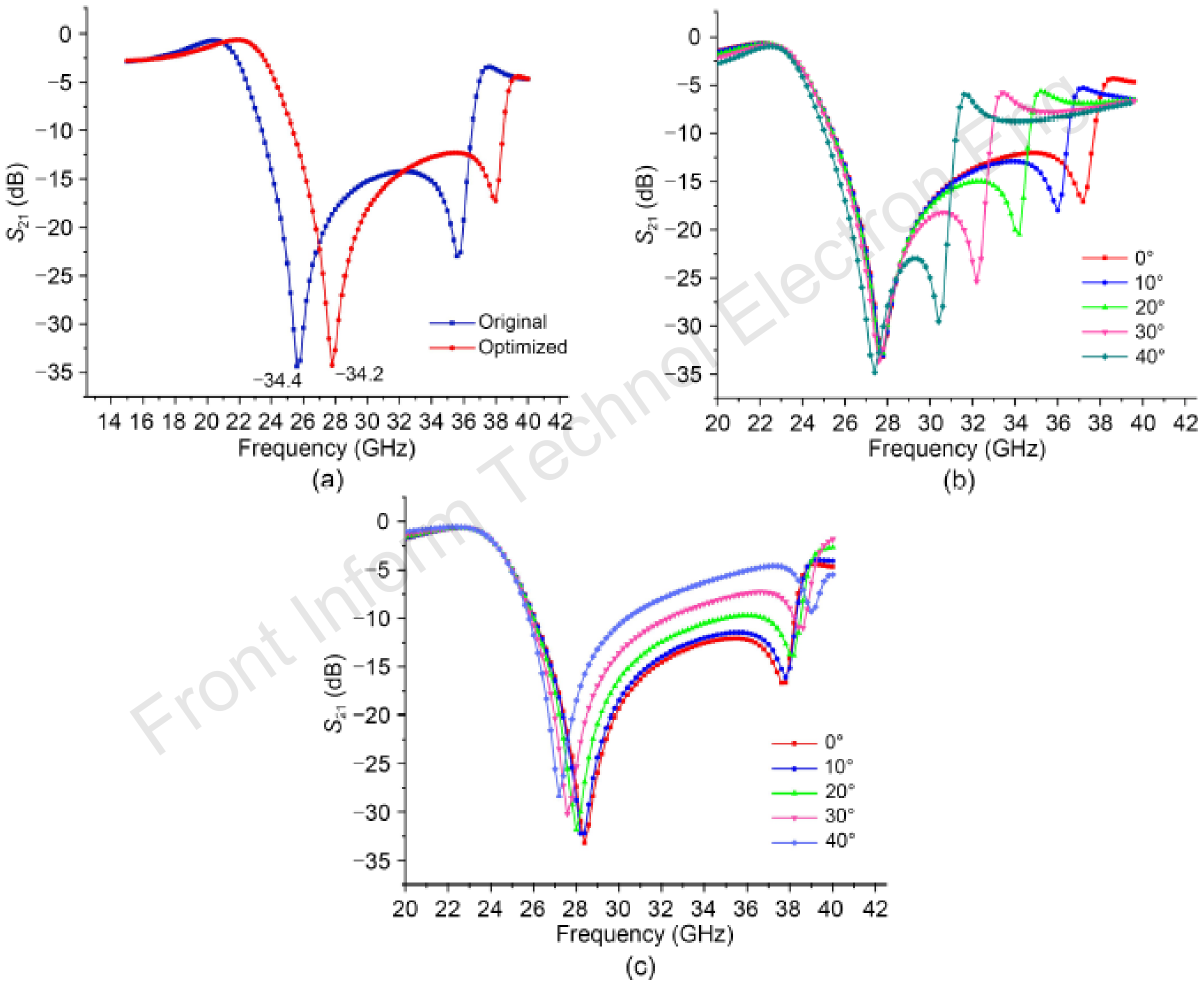




**Fig. 9 Simulation results $S_{21}$ of the ring unit: (a) original and optimized results; (b) with different incident angles in TE mode; (c) with different incident angles in TM mode**

# Major results (Cont'd)

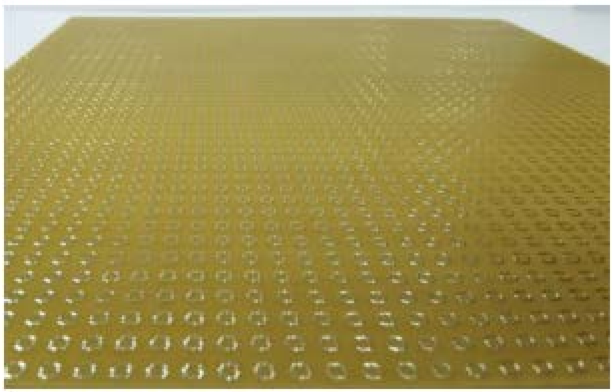
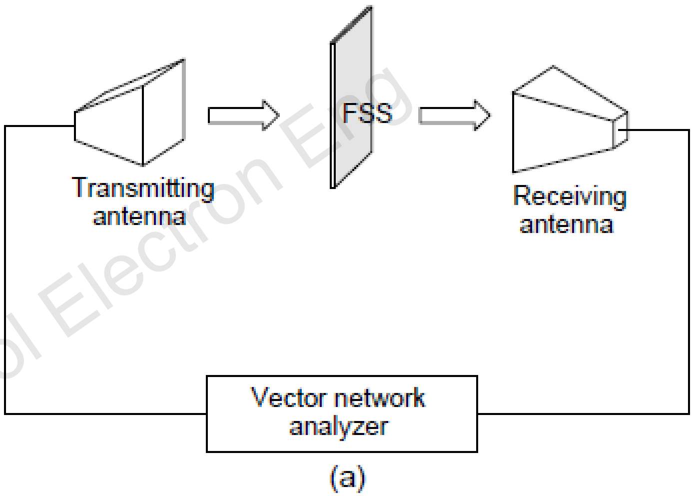
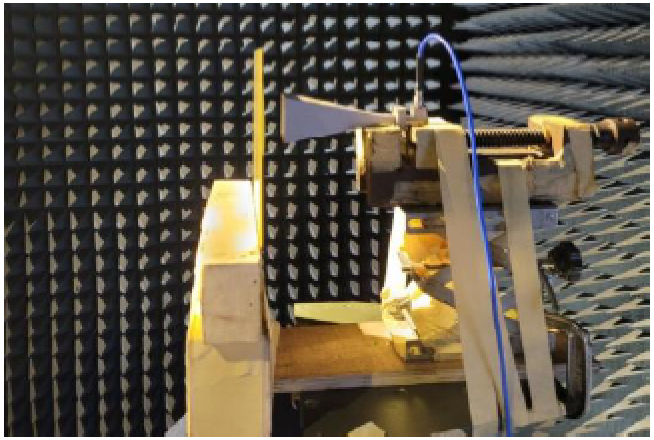


Fig. 10 FSS sample




(a)



(b)

Fig. 11 FSS measurement: (a) free-space method; (b) test instruments

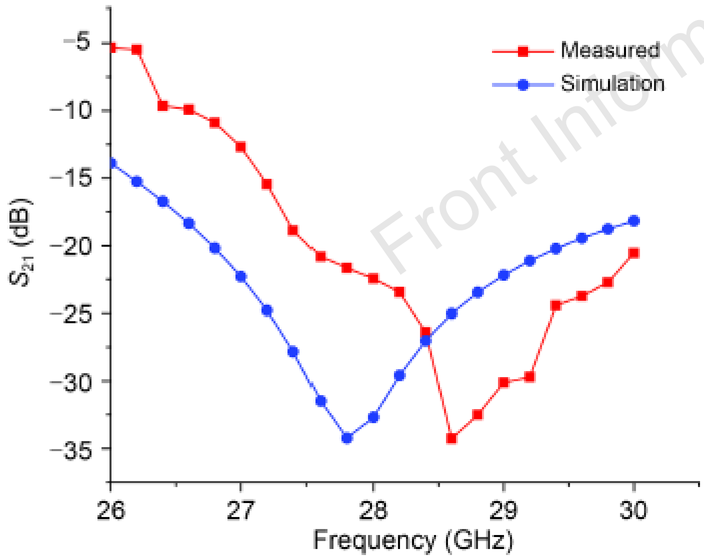



Fig. 12 Measured and simulation $S_{21}$ of the ring unit

# Conclusions

1. A novel SAGWO for the design of a 5G FSS has been proposed which uses three randomness strategies to accelerate the convergence and effectively avoid local optima.

2. SAGWO and the new FSS optimization model can automatically obtain the shape of the FSS unit with electromagnetic interference shielding capability.

Yingjun WANG is an associate professor of the South China University of Technology. He received his PhD degree from Huazhong University of Science and Technology, in 2013. From 2013 to 2015, he served as a postdoctoral fellow at the University of California, USA. From 2015 to 2016, he served as a postdoctoral fellow at the McGill University, Canada. His research interests include CAD/CAE, isogeometric analysis, structural optimization, and high-performance computing.

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