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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)

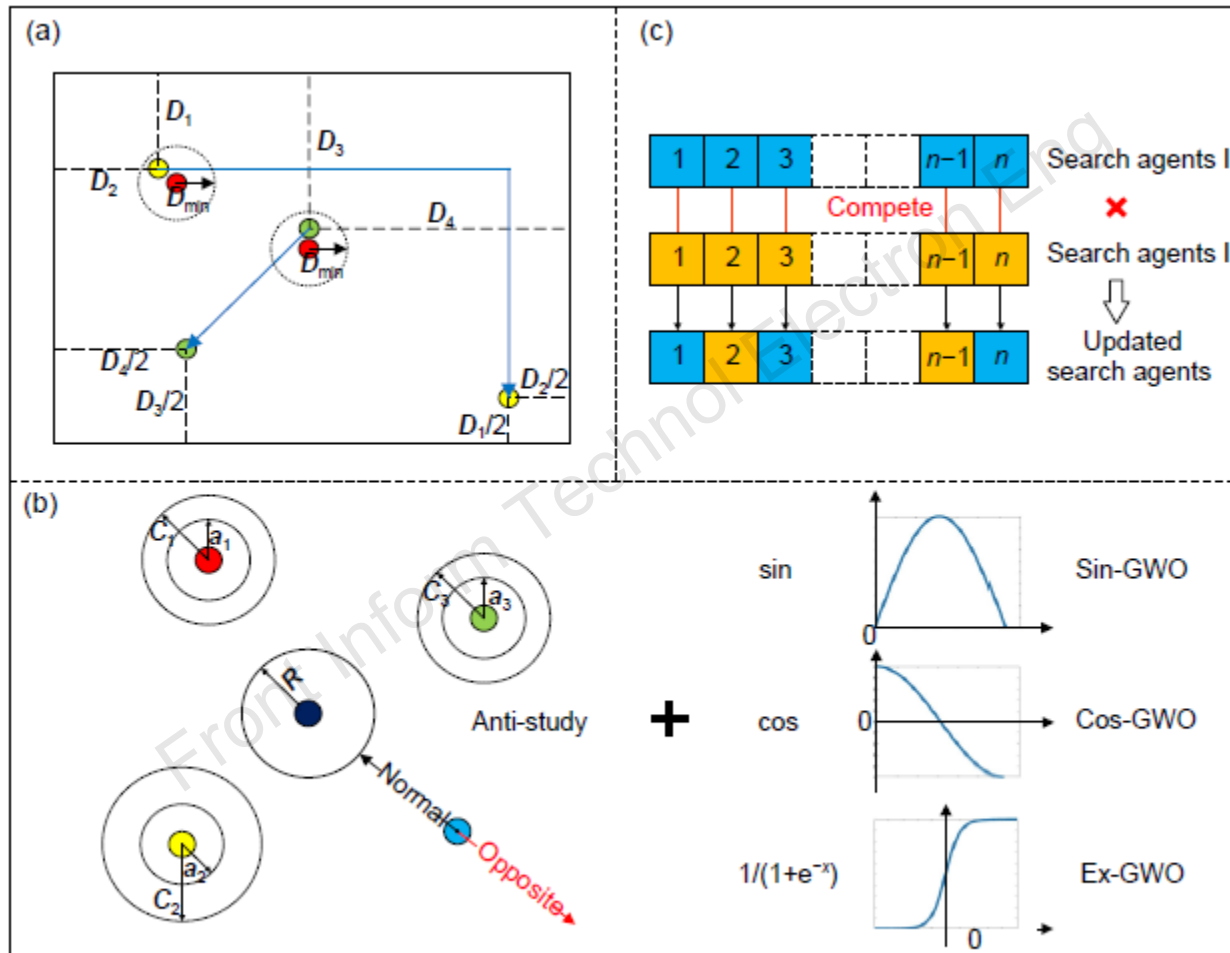


Fig. 2 Three improvement strategies for SAGWO: (a) improvement of the initial distribution strategy; (b) improvement of the randomness strategy; (c) improvement of the local search strategy

Method (Cont'd)

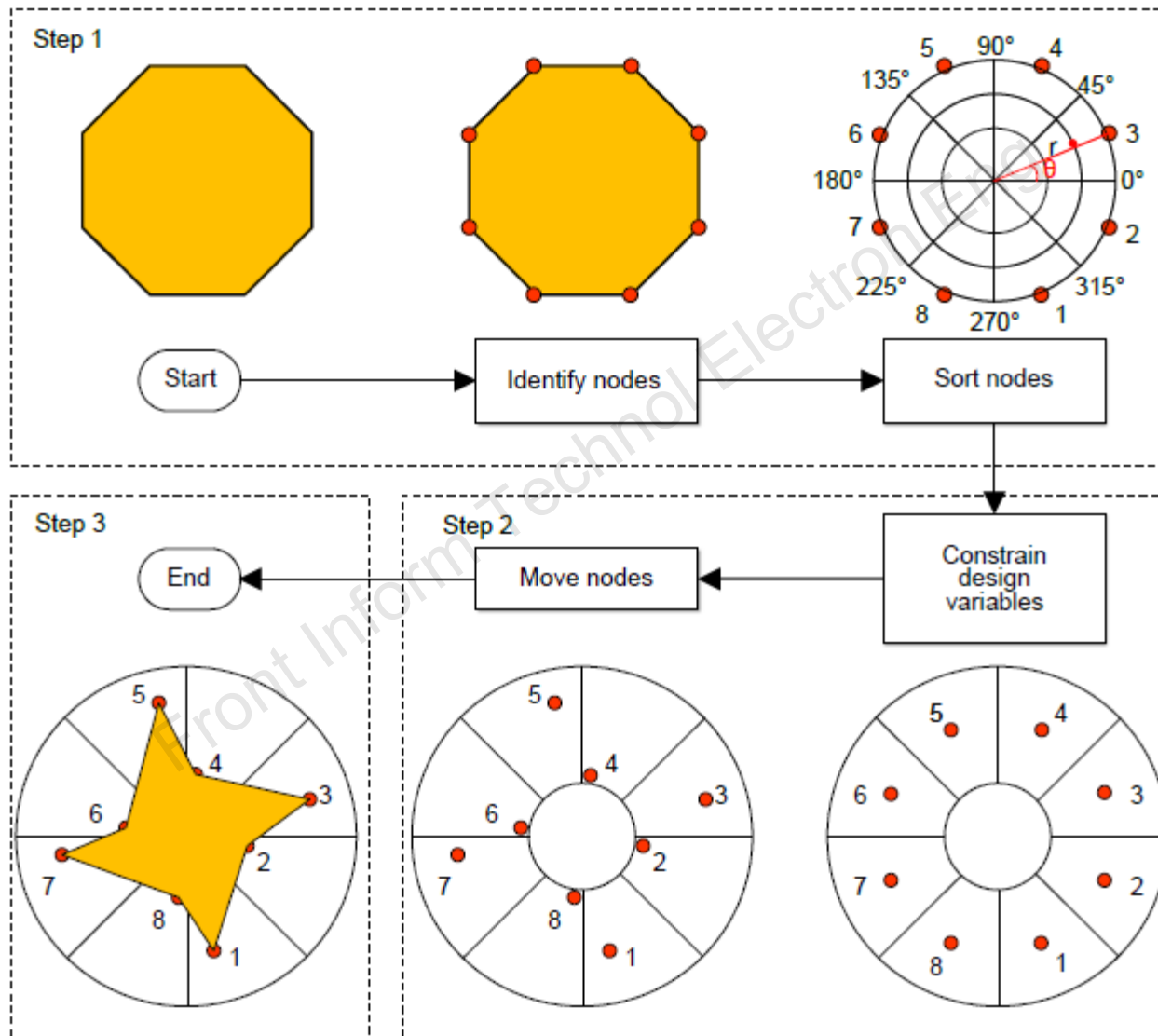


Fig. 4 Illustration of the eight-node FSS unit modeling method

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)

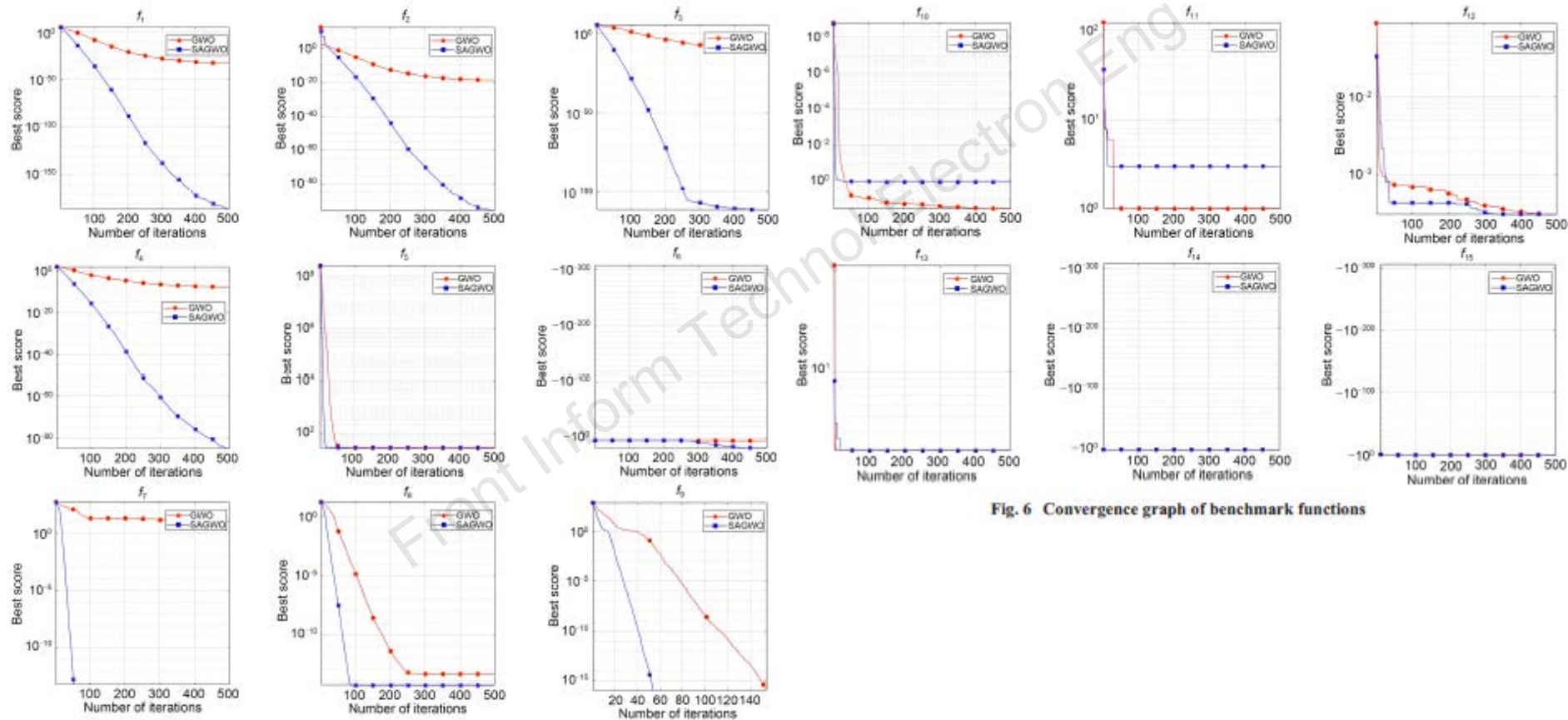


Fig. 6 Convergence graph of benchmark functions

Major results (Cont'd)

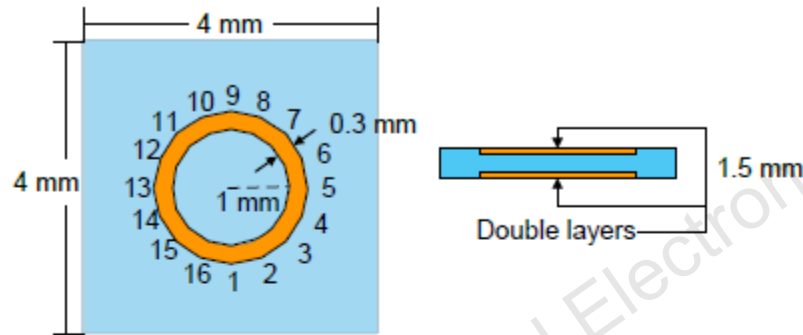


Fig. 7 Design domain of ring units

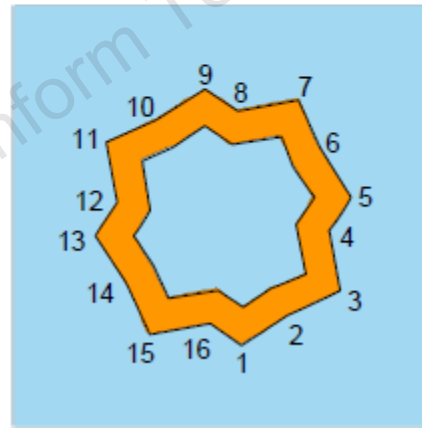


Fig. 8 Shape optimization results of ring units

Major results (Cont'd)

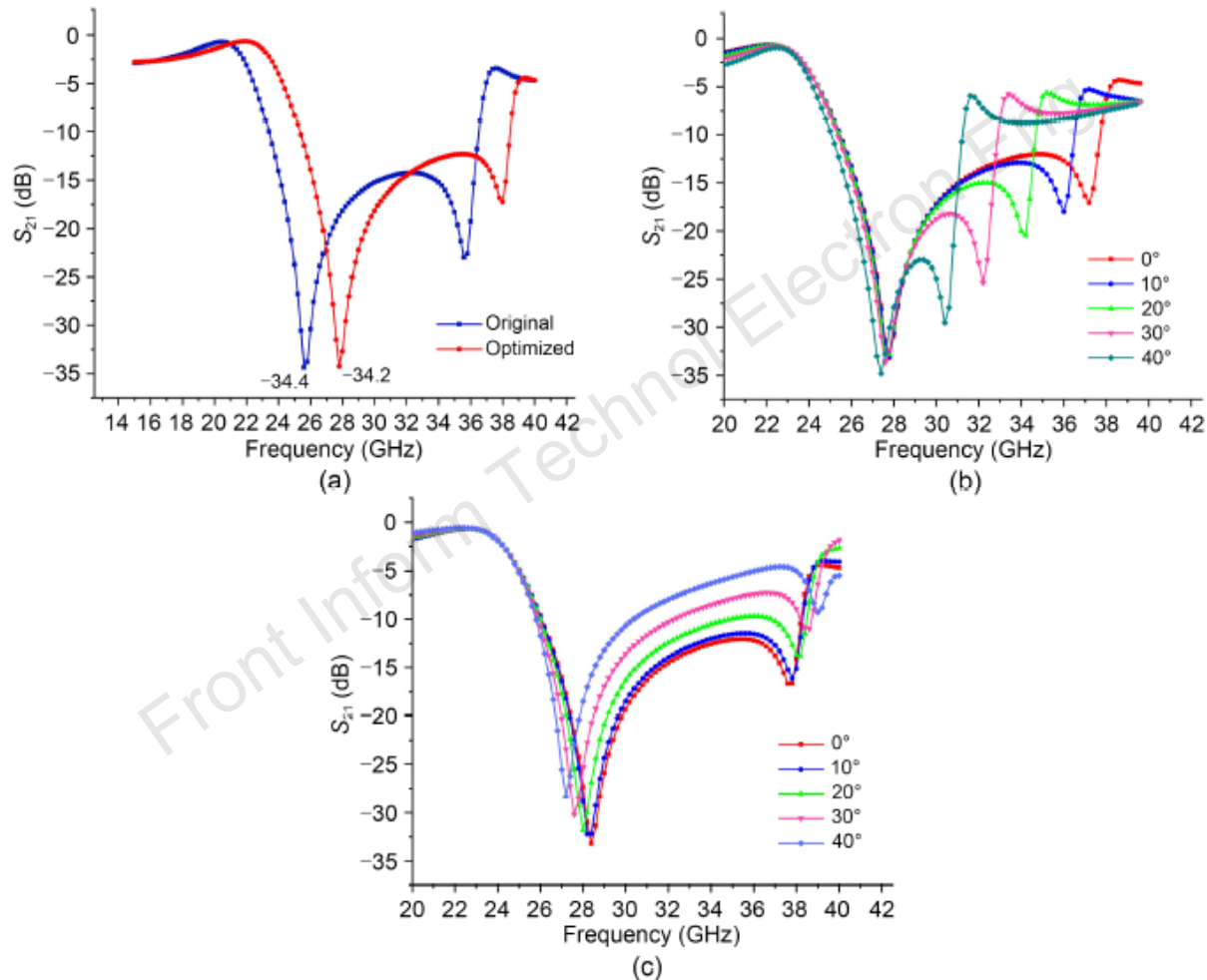


Fig. 9 Simulation results S_{21} of the ring unit: (a) original and optimized results; (b) with different incident angles in TE mode; (c) with different incident angles in TM mode

Major results (Cont'd)

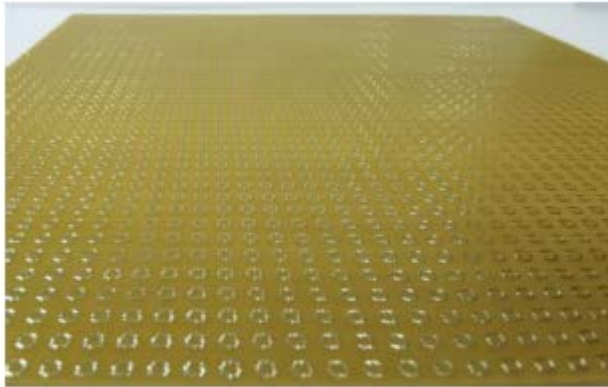


Fig. 10 FSS sample

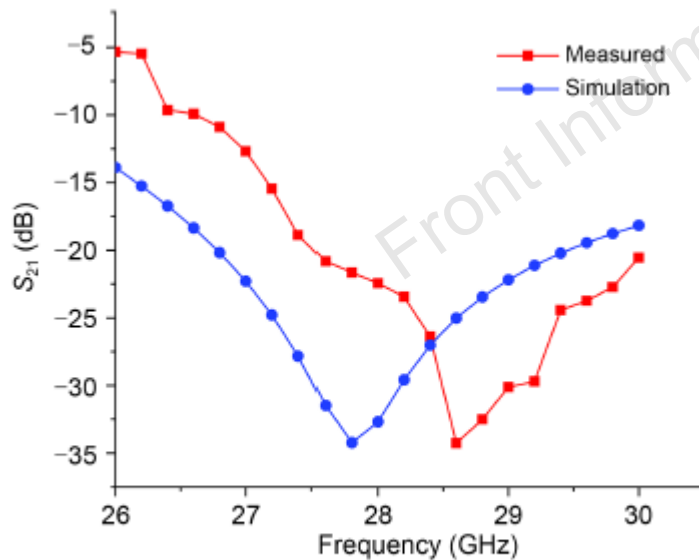
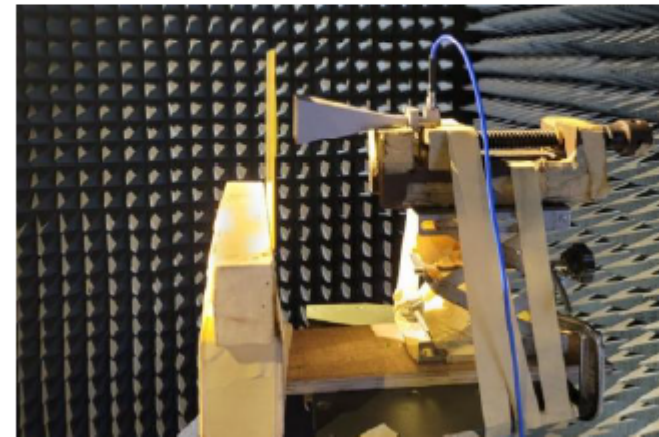
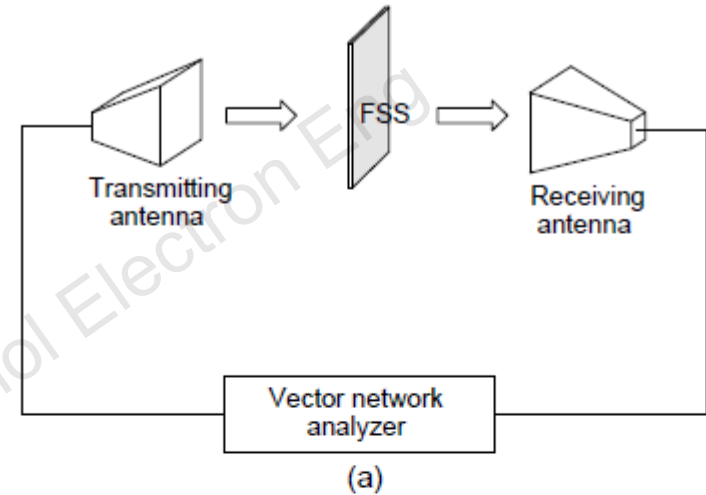


Fig. 12 Measured and simulation S_{21} of the ring unit



(b)

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

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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