Tables

Table I A comparative study among negative permittivity, permeability, and refractive index regions of the proposed MTM unit cell, 2×2, and 4×4 MTM array structures.

Effective parameters	Structure	Frequency range (GHz)	Bandwidth (GHz)	Application bands
Permittivity	Unit cell	1.4–3.9	2.5	S, C, X, Ku
		6.8–7.6	0.8	
		10.1–10.4	0.3	
		12.2–13.8	1.6	
	2×2 array	1.6–4.2	2.6	S, C, X, Ku
		7–8	1	
		10.2–10.8	0.6	
		12.2–13.4	1.2	
	4×4 array	3.2–4.6	1.4	S, C, X, Ku
		6.7–7.6	0.9	
		10.1–11	0.9	
		12.7–13.5	0.5	
Permeability	Unit cell	3.6–3.9	0.2	S, C, X, Ku
		6.8–8	1.2	
		10.1–10.4	0.3	
		13.4–13.7	0.3	
	2×2 array	3.2–4.8	0.3	S, C, X, Ku
		6.3–7.5	0.4	
		9.5–10.6	1.1	
		13–13.8	0.8	
	4×4 array	3.4–4.1	0.7	S, C, X, Ku
		6.6–8	1.3	
		9.5–11.3	1.7	
		12.8–13.8	1	
Refractive Index	Unit cell	3.7–3.9	0.2	S, C, X, Ku
		6.8–7.1	0.3	
		10.11–10.4	0.29	
		13.4–13.7	0.3	
	2×2 array	3.5–3.8	0.3	S, C, X, Ku
		7–7.3	0.3	
		10.1–10.8	0.7	
		13–13.4	0.4	
	4×4 array	3.7–3.9	0.2	S, C, X, Ku
		6.8–7.3	0.5	
		10.3–10.8	0.5	
		12.9-13.4	0.5	

Table II Comparison of the proposed MTM unit cell with other literature.

Reference	Shape of NRI unit cell	Covered NRI frequency band	Resonant frequency	Application frequency band	Size of unit cell (mm^2)	Effective medium ratio, λ_0/p	Publication year
[10]	Double G	4-4.95 & 5-5.57	2.7, 5.6	C	12×12	9.25	2015
[15]	ELC and loop resonator	1.95-2.13, 2.30-2.41, & 4.63-4.87	2.03, 2.36, 4.81	L, S	8×8	18.47	2016
[16]	C	4.906-10.632 & 10.884-13.348	3.36, 8.574, 11.57	C, X, Ku	12×12	7.4	2017
[17]	Crossed S	13.4-18.6	14	Ku	5.2×5.2	4.12	2016
[18]	H	8.31-15.43 & 17.43-18	1.63, 10.93	X, Ku	12×12	15.33	2018
[19]	Modified H	7.615-8.46, 8.755-9.36, & 10.68-15	6.8, 10.8, 12.5	C, X, Ku	7.92×7.92	5.57	2018
[20]	Bare H	7.37-7.66, 8.47-10.12, 10.39-10.57, & 11.26-11.33	4.29, 9.93	C, X	20×20	3.49	2014
[21]	Z	3.482-7.096, 7.876-10.047, & 11.594-14	7.32, 11.84	C, X, Ku	10×10	4.09	2016
[22]	Hexagonal	3.36-3.52, 5.34-5.52, 5.63-8.69, 9.71-10.55, & 11.84-13.90	1.64, 3.6, 7.23, 10.225	S, C, X, Ku	10×9.8	18.2	2018
Proposed design	Combination of square and triangular resonators	3.7–3.9, 6.8–7.1, 10.11–10.4, & 13.4-13.7	3.66, 6.66, 9.8, 12.58	S, C, X, Ku	6×6	13.8	------

Table III Performance comparison of the proposed transformer oil sensor with other MTM based transformer oil sensors.

References	Configuration of MTM	Resonance frequency (GHz)	Permittivity for clean & dark oil	Frequency range (GHz)	Resonance frequency shift (MHz)	Publication year
[24]	Square ring resonators	—	2.7 & 2.8	8–12	70	2019
[25]	Labyrinth Resonator	4.62	2.7 & 2.9	4–5	40	2019
[26]	Omega shaped resonator	1.9	2.74 & 2.87	1–8	63	2020
[27]	Omega shaped resonator	9.85	2.7 & 2.9	8.5–10.5	77	2020
This work	Combination of square and triangular resonators	9.54	2.7 & 2.8	8–12	80	—

Table IV Comparison of the proposed methanol sensor with other MTM based methanol sensors.

References	Configuration of MTM	Resonance frequency (GHz)	Concentration of methanol	Permittivity	Frequency range (GHz)	Resonance frequency shift, (MHz)	Publication year
[23]	Chiral	9.26	10%–90%	62–50, 12–7	8–12	270	2018
[24]	Square ring resonators	—	20–100%	55–40, 11–7	8–12	210	2019
[25]	Labyrinth Resonator	4.62	0–40%	75-73, 45–39	4–5	60	2018
[26]	Omega shaped resonator	1.9	0–40%	78-76, 55–53	2.5–3	230	2020
[28]	SRR	4.62	10–95%	77.5–55	4–6	20	2017
This work	Combination of square and triangular resonators	9.54	0–100%	65–10	8–12	500	—

Table V Performance evaluation of the proposed ethanol sensor with other MTM based ethanol sensors.

References	Configuration	Resonance	Concentration		Frequency	Resonance	Publication

	of MTM	frequency (GHz)	of ethanol	Permittivity	range (GHz)	frequency shift (MHz)	year
[25]	Labyrinth Resonator	4.62	0–40%	75–73, 45–39	4–5	100	2018
[26]	Omega shaped resonator	1.9	0–40%	77–76, 51–50	2.5–3	250	2020
[28]	SRR	4.62	10–95%	70–11, 21–11	4–6	50	2017
This work	Combination of square and triangular resonators	9.54	0–100%	65–6	8–12	340	—

Table VI Performance evaluation of the proposed acetone sensor with other MTM based acetone sensors.

References	Configuration of MTM	Resonance frequency (GHz)	Concentration of acetone	Permittivity	Frequency range (GHz)	Resonance frequency shift (MHz)	Publication year
[28]	SRR	4.62	10%–30%	72–68, 60–52	4–6	40	2017
[30]	S-shaped resonator and circular ring resonator	9.5	10–90%	62–50, 26–21	8–12	220	2020
This work	Combination of square and triangular resonators	9.54	0–100%	65–20	8–12	370	—

Table VII Performance evaluation of the proposed pressure sensor with other MTM based pressure sensors.

References	Configuration of MTM	Thickness change of sensor layer (mm)	Operating band	Frequency range (GHz)	Resonance frequency shift (MHz)	Publication year
[31]	SRR	2–0.4	X	12.1–11	1100	2013
[32]	MTM absorber	2–0.5	X	10.25–10.1	150	2017
This work	Combination of square and triangular resonators	2–0.5	S	3.34–3.93	590	—
			C	6–6.6	600	
			X	9.9–9.10	800	
				11.5–10.98	610	