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RF MEMS Switches for Reconfigurable Microstrip Patch Antennas

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Abstract

In this paper, we have designed a reconfigurable micro strip patch antenna by using RF MEMS. Primarily we have analyzed the performance of different shunt capacitive RF MEMS switches and eventually we have incorporated the switch on reconfigurable micro strip patch antenna. The performance indices analysis is done in simulation level using FEM tool by extracting different parameters like pull-in voltage, insertion and isolation losses. In the process of performance analysis we have analyzed the role of material and micromechanical structure on improving the pull-in voltage. Eventually we have proposed a RF micro electro mechanical systems switch with improved performance, the switch offering an actuation voltage of 4.5 V, insertion losses of -0.55 dB, isolation losses of-51 dB. Two identical RF MEMS switches are placed on the reconfigurable antenna, based on the switching the antenna is resonating in different frequency bands. The designed antenna is switching between X-band, K-band and Ka-band applications.

Keywords: RF MEMS switches, reconfigurable antenna, FEM tool, material analysis, micro structure analysis.

I. INTRODUCTION

MEMS is the trending technology with great potential which offers high reliability and linearity. RF switches are very needy devices in future high frequency communication applications. Now micro electro mechanical systems technology based RF switches are offering best performance when compared with solid state technology based RF switches. Not only RF switches, micro electro mechanical systems technology proved its ability in the design of filters, varactors which are essential devices in communication applications [1-3].

The high frequency communication applications need reconfigurable antenna elements which is capable to switch from one frequency band to another frequency band. To design such a reconfigurable antenna elements we can use high reliability offering RF MEMS switches. The primary challenges of MEMS technology in the design of RF switches using electrostatic actuation are offering low actuation voltage, maintaining good radio frequency properties, low upstate capacitance and high downstate capacitance. X-band, K-band and Ka-band frequency ranges are 8-12 GHz, 18-26.5GHz and 26.5 - 40 GHz respectively, which have some potential millimeter wave range applications like vehicle speed detection, satellite communication, satellite television, radar astronomical observation and microwave communication[3-5].

Earlier so many researchers proposed different RF MEMS switch with different verities of material and actuation techniques [6]. RF micro electro mechanical systems switches can be configured different actuation techniques, i.e., piezoelectric, magneto static, electro thermal and electrostatic. The thin film material section, i.e., substrate, dielectric and membrane material is one of the RF electro mechanical systems technology switch performance deciding factor [7]. By considering potential applications in X, K and Ka-band, in this paper we have presented an performance analysis based design of reconfigurable microstrip patch antenna using shunt capacitive RF MEMS switches with electrostatic actuation for k-band applications[8-9].

This paper is organized as follows: in section II, we have presented RF MEMS switches literature survey. Section III reported the performance analysis of shunt capacitive RF MEMS switches. Performance improved RF MEMS switch for K-band applications is discussed in section IV. Reconfigurable micrpstrip patch antenna using RF MEMS switches is discussed in section V and the paper is concluded in section VI.

II. RELATED WORK

RF MEMS switches is the potential research area, so many researchers are advance the research on RF MEMS switches. But because of the requirements of future communication applications still there are few research challenges like low actuation voltage, high isolation, low insertion losses and high switching speed.

In paper [10], the authors planned shunt capacitive RF MEMS switch with SiO_2 as a dielectric material. The switch actuation voltage is 5.5 V, insertion losses of -0.62 dB & isolation losses of -52 dB.

In paper [11], the authors proposed a antenna expending RF micro electro mechanical systems switches. Overall two switches are incorporated for reconfigurability with four switching modes i.e., for S1(OFF) and S2(OFF) at 8.6 GHz & 12.5 GHz, if S1- ON & S2-OFF the operating frequency is 9 GHz & 12.4 GHz, if S1- OFF & S2-ON the operating frequency is 9 GHz & 12.4 GHz, and if S1- ON & S2-ON the operating frequency is 4.5, 9 and 12.3 GHz.

In paper [12], the authors discussed the design aspects of the antenna with RF micro electro mechanical systems switches. The frequency range is up to 40 GHz. Especially the antenna is designed for K-band applications. Two shunt capacitive RF micro electro mechanical systems switches are used for the antenna design.

III. RF MEMS SWITCH

The in general mass (m) of the micromechanica arrangement can be calculate with m=ρ*l*w*t. Spring constant for the serpentine flexure with material young's modulus (E), the spring constant can be uttered as,

$$\frac{1}{K} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4} \tag{1}$$

Where,

$$K_{(1,2,3,4)} = \frac{Ewt^3}{l^3}$$

The switching time is the main performance indices which will determine the switch presentation, the switching time can be invent with the assist of resonant frequency. From the gratis stiff study the resonant frequency can be term as,

$$\omega = \sqrt{\frac{K}{m}}$$

$$f_r = \frac{1}{2\pi}\sqrt{\frac{K}{m}} \tag{2}$$

The electrostatically actuated RF MEMS switch performance primarily depends on the pull-in voltage, it can be expressed as,

$$V_{pull-in} = \sqrt{\frac{8kg^3}{27A\varepsilon_0}} \tag{3}$$

Compared to series DC contact switches, shunt capacitive RF MEMS switches offer best performance at high frequency applications. The shunt capacitive RF MEMS switch upstate capacitance (C_{up}) and downstate capacitance (C_{down})can be expressed as,

$$C_{up} = \frac{\varepsilon_0 A}{g + \frac{t_d}{\varepsilon_r}} \tag{4}$$

$$C_{down} = \frac{\varepsilon_0 \varepsilon_r A}{t_d} \tag{5}$$

The switch performance primarily depends on the micro mechanical structure incorporated. Previously there are so many popular structures are proposed by different researchers, here we have taken clamped-clamped structure and serpentine structure for performance analysis. Gold material with E of 70 GPa, and density (ρ) of 19300 Kg/m^3. The thickness of the structure is taken as 1 µm.

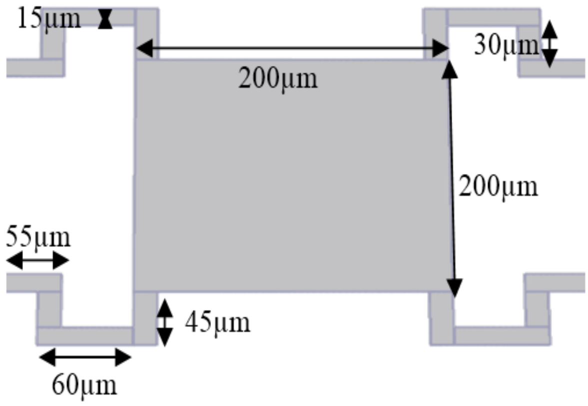

Figure 1. Structural analysis, serpentine flexure with uniform meanders.

The micro mechanical structure is designed with gold metal and actuated electrostatically. The structure with serpentine flexure requires an actuation voltage of 5V for one micro meter displacement.

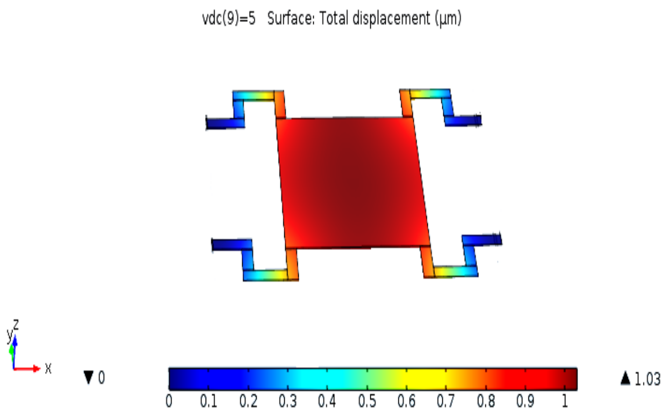

Figure 2. Electrostatic actuation, serpentine structure.

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Because of the perforation the micromechanical structures displacement is increased an amount of 0.04 µm. And it is clear that compared to the clamped-clamped flexure serpentine flexure is offering low actuation voltage. So, further analysis id done on the serpentine structure.

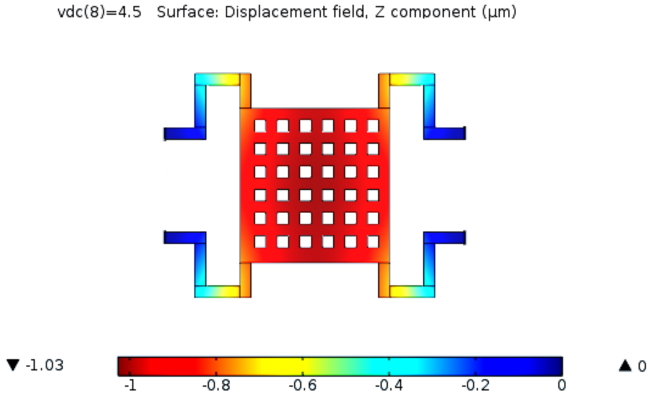


Figure 3. Electrostatic actuation of serpentine flexure.

After observing the electrostatic actuation, it is clear that compared to uniform meanders, the non uniform meander serpentine structure is offering a low actuation voltage. The structure is offering a displacement of 1 µm for 4.5V. The above analysis is performed by considering the gold (Au) as the membrane material.

The shunt capacitive RF micro electro mechanical systems switch performance depends on the capacitance offered by the switch when membrane in up and down state. Here we have performed the capacitance analysis by choosing AlN as a dielectric material. The thickness of the dielectric material is 0.05µm and the relative permittivity is 8.8.

The micromechanical structures most of the parameters are extracted, which helps in the process of structure validation and the theory and simulated results are compared for better support. Finally it is clear that, the serpentine with non uniform meander is helping to reduce the voltage, and AlN as a dielectric material the switch is offering good upstate and downstate capacitances. Perforation to the membrane helps to reduce the actuation voltage.

Table 1. Shunt capacitive RF micro electro mechanical systems switch dimensions and materials.

Parameter	Material	Dimension (µm) (l x w x t)
Substrate	Si	400 x 400 x 800
Insulator	Silicon Dioxide	400 x 400 x 1
CPW	Au	100 x 80 x 100
Dielectric	Aluminum Nitrite (ε_r=8.8)	220 x 80 x 0.05

If the applied voltage is below the pull-in voltage the micro mechanical beam is in upstate, the input RF signal is completely permitted to the RF_out, so it present low insertion loss of -0.55 dB at 23 GHz.

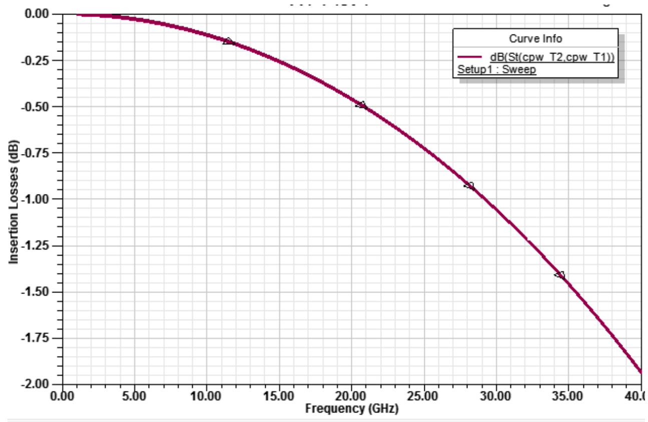


Figure 4. Insertion Losses (dB)

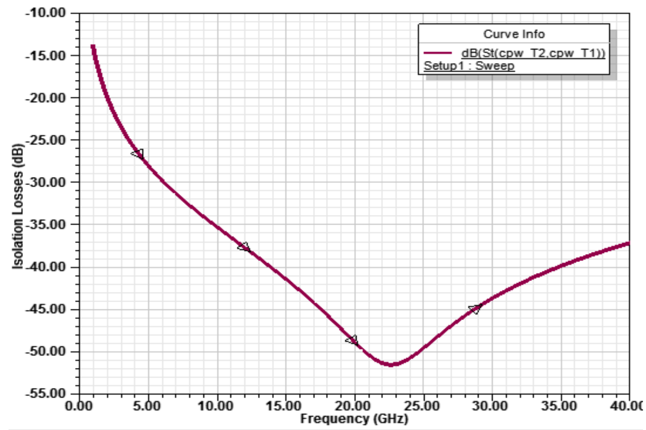
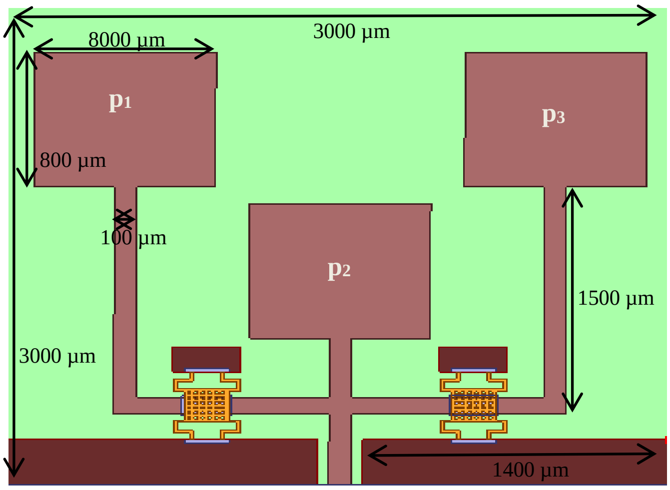


Figure 5. Isolation Losses (dB)

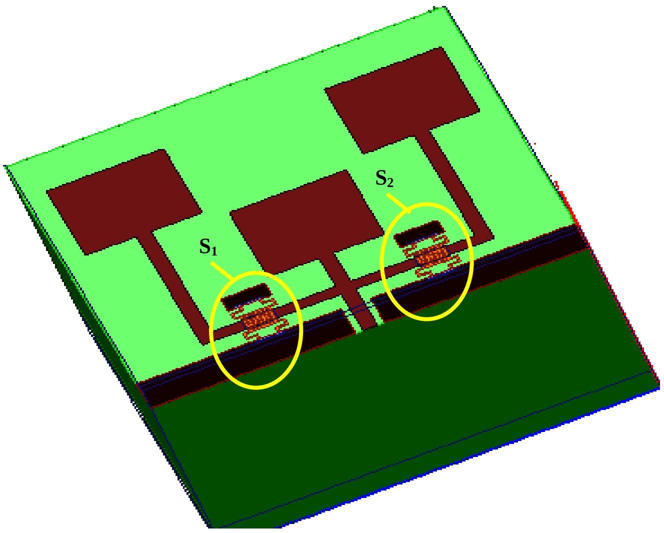
Eventually we have extracted the most of the performance deciding parameters of the RF MEMS switch and try to compare the theoretical and simulated values. Here the simulated results are very close to the theoretical values. The roof mass of the serpentine structure is 827 x 10^{-12} Kg, because of the serpentine with non uniform meanders the structure is offering low spring constant of 1.93 N/m. The Eigen frequency (or) natural frequency (or) resonant frequency is 7.745 KHz.

IV. RECONFIGURABLE ANTENNA

In this section, we have discussed about the design of reconfigurable microstrip patch antenna using performance improved shunt capacitive RF MEMS switches discussed in section IV.



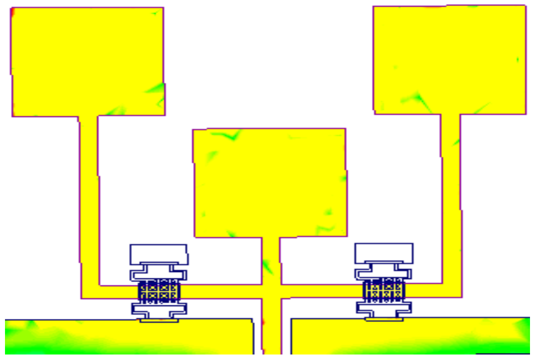
(a)



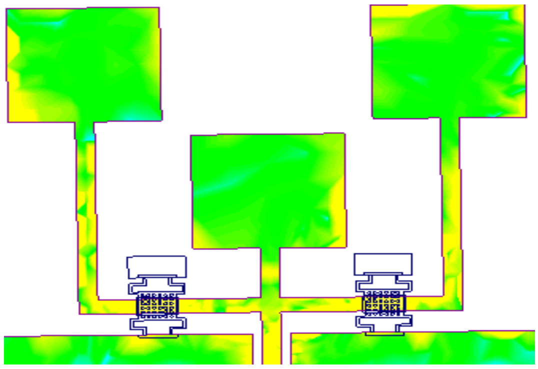
(b)

Figure 6. Reconfigurable microstrip patch antenna using RF micro electro mechanical systems switches, (a) top view, (b) side view.

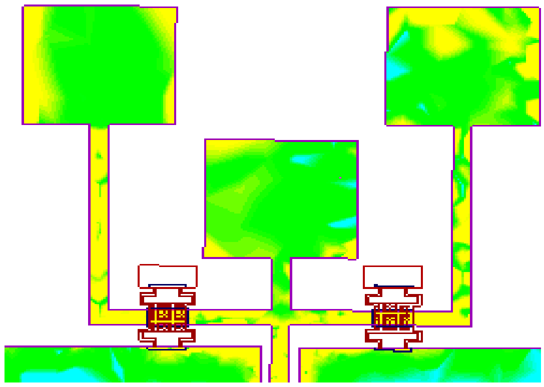
Three uniform size of 800 µm x 800 µm square type microstrip patch antennas (P_1, P_2 & P_3) are connected CPW feed line through two identical RF micro electro mechanical systems switches (S_1 & S_2) as shown in Figure 3. The antenna is micro machined on 3000 µm x 3000 µm size high resistance offering silicon substrate. 50µm/100µm/50µm are the G/S/G values of the CPW feeding line. SiO_2 thin film of 1 µm thickness is used as a insulating layer on the top of the silicon substrate. AlN is used as a dielectric material for the both the RF MEMS switches. Gold (Au) is used to micro machine the serpentine membrane with perforation of 1 µm thickness.



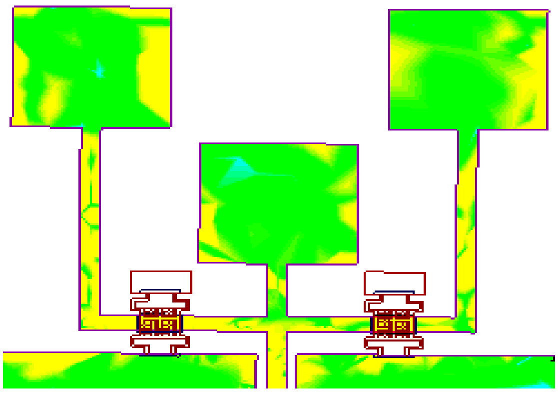
(a)



(b)



(c)



(d)

Figure 7. Current distribution of reconfigurable antenna under different switching conditions, (a)S_1-OFF & S_2- OFF,(b) S_1-ON & S_2- ON,(c) S_1-ON & S_2- OFF,(d) S_1-OFF & S_2- ON.

Table 2. Comparison our work on reconfigurable microstrip patch antenna using RF MEMS switches with literature

Parameter		Reference [11]	Reference [12]	Present work
Shunt capacitive RF MEMS switches	Number of switches	2	2	2
	Type	SPST	SPST	SPST
	Substrate	silicon	silicon	silicon
	Dielectric material	---	Si_3N_4	SiO_2
	Membrane material (thickness)	---	Gold (1 µm)	Gold (0.5 µm)
	Perforation	no	yes	yes
Reconfigur-able antenna	Working Band	4.5-12.5	Up 40 GHz	Up to 40 GHz
	Number of modes Mode, operating frequency and application	4	4	4
		S1- OFF & S2-OFF 8.6 GHz & 12.5 GHz	S1- OFF & S2-OFF 16.4 GHz & 21 GHz	S1- OFF & S2-ON, 12 GHz & 25-37 GHz
		S1- ON & S2-OFF 9 GHz & 12.4 GHz	S1- ON & S2-ON 14.2 GHz & 16.8 GHz	S1- ON & S2-OFF, 27- 40 GHz
		S1- OFF & S2-ON 9 GHz & 12.4 GHz	S1- OFF & S2-ON 16.5 GHz & 21 GHz	S1- OFF & S2-OFF, 10 GHz
		S1- ON & S2-ON 4.5 GHz, 9 GHz & 12.3 GHz	S1- ON & S2-OFF 14.5 GHz & 19 GHz	S1- ON & S2-ON, 22 GHz & 33 GHz

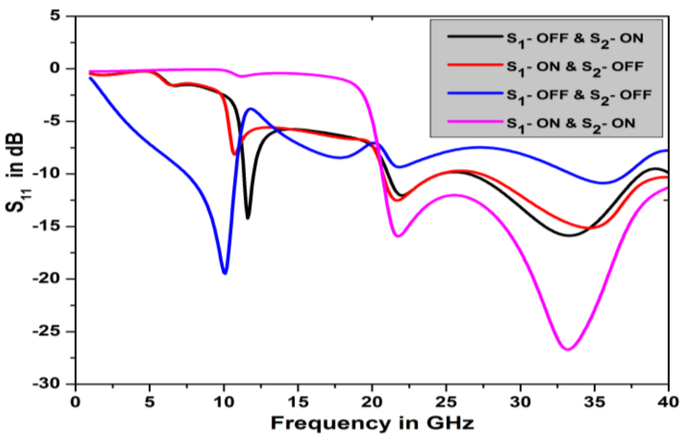


Figure 8. S_{11} under different switching conditions.

The reconfigurable antenna designed in this section has two RF MEMS switches (S_1 & S_2) with four operating modes. In mode-1, S_1 is OFF and S_2 is ON and the antenna is resonating at 12 GHz and 25-37 GHz. In mode-2, S_1 is ON and S_2 is OFF and the antenna resonating frequency is shifted to 27- 40 GHz. In mode-3, S_1 is OFF and S_2 is OFF the resonating frequency is 10 GHz. In mode-4, the S_1 is ON and S_2 is ON the resonating frequency is 22 GHz & 33 GHz. The designed antenna is preferable for X-band and Ka-band applications.

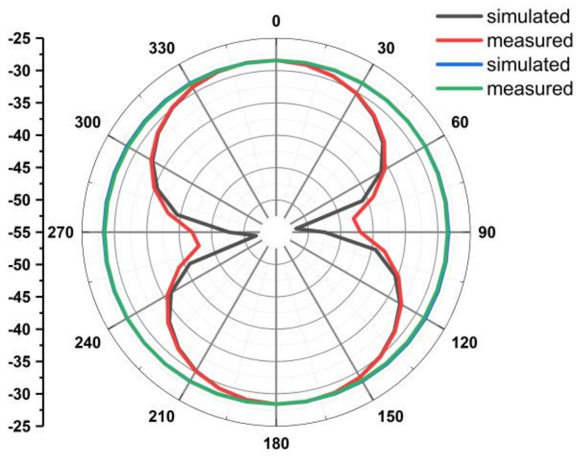


Figure 9. Radiation characteristics at GHz.

The radiation characteristics of the proposed antenna are demonstrated in the Figure 9.The project radiation patterns are verified in both E-plane as well as H-plane it is noted that at E-plane the antenna gets dipole type of pattern and at H-plane the pattern is omnidirectional pattern. The radiation characteristics is verified, and good correlation can be seen in simulated and measured characteristics.

V. CONCLUSION

In this paper, initially we have designed RF MEMS switches for reconfigurable microstrip patch antenna. Overall we have analyzed two micromechanical flexures i.e., fixed-fixed and serpentine flexure. The roof mass of the serpentine structure is 827 x 10^{-12} Kg, because of the serpentine structure with non uniform meanders the structure is offering low spring constant of 1.93 N/m. The Eigen frequency (or) natural frequency (or) resonant frequency is 7.745 KHz. The upstate capacitance (C_{up}) is 151.1 fF and the downstate capacitance (C_{down}) of the switch is 20.8 pF. The proposed switch is offering a low insertion loss of -0.55 dB and high isolation of -51dB at 23 GHz. So, the switch offers best performance in k-band applications. Eventual, we have designed RF MEMS switches based reconfigurable microstrip patch antenna with four modes of operation. In mode-1, S_1 is OFF and S_2 is ON and the antenna is resonating at 12 GHz and 25-37 GHz. In mode-2, S_1 is ON and S_2 is OFF and the antenna resonating frequency is shifted to 27- 40 GHz. In mode-3, S_1 is OFF and S_2 is OFF the resonating frequency is 10 GHz. In mode-4, the S_1 is ON and S_2 is ON the resonating frequency is 22 GHz & 33 GHz. The designed antenna is preferable for X-band and Ka-band applications.

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