Power Scalability Modeling of Reconfigurable Intelligent Surfaces for THz Applications

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***Abstract*—In this paper, an attempt is made to model the total power requirements of a full scale Reflective Intelligent Surface (RIS) with switches(microfluidics based and CMOS based) operating at 140 GHz frequencies. First, we modeled the static powers associated with FPGA boards and its control boards of RIS and then estimated the dynamic power requirements associated with RIS based on different unit cell elements configurations and then the combined total power values for various configurations with 1-bit, 2-bit, and 3-bit (binary switching states) are presented.**

Keywords*—Reconfigurable intelligent surfaces, power scalability, liquid metal switch, THz frequency.

I. INTRODUCTION

In recent years, Reconfigurable Intelligent Surfaces (RIS) appeared as a promising technology for GHz & THz frequency applications by smartly tuning the EM waves using various switching technologies [1-4] such as PIN diode, varactor diode, RF switch, Liquid Metal, BiCMOS, memristors, microfluidics etc. This leads to a great attention among researchers in understanding and modeling the practical power consumption requirements of RIS and its associated hardware for various switching technologies in evaluating its energy efficiency performance and cost associated for fabrication and its maintenance. In [5-6], an attempt is made in modeling power scalability of small size (16x16) RIS operating at 3.5 GHz frequency with three different switches. A novel beam steering technique using active artificial magnetic conductors was reported [7] for modern wireless applications. In this paper, we present power scalability analysis of microfluidics based and CMOS based RIS operating at 140 THz frequency, and we discuss in detail about the steps that we followed in obtaining static & dynamic power consumption values.

II. SCALABILITY ANALYSIS

In this section, we present detailed steps that we followed in calculation of RIS power scalability analysis for microfluidics based and CMOS based RIS which is operating at 140 GHz frequency. We describe two possible cases: case-1(outdoor scenario) with RIS unit cells of 118 x 118 and case-2 (indoor scenario) with RIS unit cells of 24 x 24, in both cases we presented the total static power, total dynamic power and total power values for RIS with 1-bit, 2-bit and 3-bit for $\phi=0°$, $\theta=45°$ and $\phi=45°$, $\theta=-45°$. For both cases, we have assumed, period of unit cells is 0.5 λ_0 and a commercially available FPGA board[5] as master for RIS control board (Fig. 1) that consumes very low power of 1.5 W and for LM RIS for its drivers board (Fig.1) we have assumed another low power FPGA [6] board that can control about 75 RF switches with voltage 12V and current 20 mA which gives drive circuit power of 240 mW and for CMOS based switch case power of 0.2 micro watt [9] is assumed.

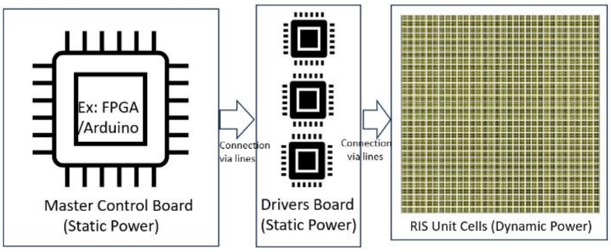

Fig.1 Pictorial view of overall RIS hardware.

In order to calculate total drive board power we have used the following equations (1-2) [5-6] and used notation as follows N_c: total no of electronic components, N_g: number of RIS unit cells that are in the same group with the same control signal, and N_s: number of control signals generated by a single drive circuit.

$$P_{total\_drive\_board} = N_{drive\_boards} * P_{drive\_board} \tag{1}$$

$$N_{drive\_boards} = \left(\frac{Nc}{Ng*Ns}\right) \tag{2}$$

Case-1: Outdoor scenario #118 x 118 unit cells at 140 GHz

(a) Total Static Power Calculation: For microfluidics based RIS with unit cells 118 x 118 we get Nc = 13,924 (1-bit), 27,848 (2-bits), 41,772 (3-bits), Ng = 1, Ns = 75, $N_{driveboards}$ = 186 (1-bit), 372 (2-bits), 557 (3-bits). In the calculation of total static power, we have added master FPGA board power (P =1.5 W) and total drivers circuit power values ($P_{totaldrive}$) that gave us $P_{totalstatic}$ and presented in the below table.1

(b) Total dynamic Power ($P_{dynamic}$) Calculation: For calculating the total dynamic power, first we have generated Weight (W) matrix for the desired pointing angles using (3) in MATLAB for RIS sizes of 24 x 24, and 118x118 and then we generated phase angles of each complex value followed by rounding to 360° and then converted into binary bits based on quantization levels w.r.t 1-bit, 2-bits and 3-bits respectively.

From the binary converted matrix, we have counted total number of ones and zeros and then multiplied the value with power value of RF switch for ON and OFF conditions.

$$W = e^{-jk(dx\ n\ sin\theta\ cos\phi + dy\ m\ sin\theta\ sin\phi)} \quad (3)$$

Where, d_x and d_y are period of unit cells, N & M are no of unit cells in x-and y-directions and θ,ϕ are steering angles, n ranges from 0 to N-1, m ranges from 0 to M-1.

In our calculations w.r.t microfluidic-based switch, we have assumed power to ON the switch is 0.001 mW [8] and 0 W to OFF the switch. The microfluidic-based switch in [8] consumes very low power by using electrical modulation of surface tension to actuate fluid. In general power consumption of microfluidic-based switches are very much dependent on actuation method and specific switch structure and therefore might be significant higher than the reported value in [8].The detailed calculations for 1-bit, 2-bit and 3-bit (switching states) with various θ, ϕ steering angles are presented in table.1. Finally, the addition of P_{static} and $P_{dynamic}$ gives the total power required for a RIS.

TABLE 1. CASE -1 (# UNIT CELLS : 118 X 118)

	Microfluidics-based Switch		
	P_{static}	***$P_{dynamic}$***	***Total P***
1-bit (ϕ=0°, θ=45°)	46.14W	0.007080W	46.147080W
1-bit (ϕ=45°, θ=-45°)		0.006987W	46.146987W
2-bit (ϕ=0°, θ=45°)	90.78W	0.017582W	90.797582W
2-bit (ϕ=45°, θ=-45°)		0.017304W	90.797304W
3-bit (ϕ=0°, θ=45°)	135.18W	0.021122W	135.201122W
3-bit (ϕ=45°, θ=-45°)		0.025881W	135.205881W
	CMOS Based Switch		
1-bit (ϕ=0°, θ=45°)	46.14W	0.001416W	46.141416W
1-bit (ϕ=45°, θ=-45°)		0.001397W	46.141397W
2-bit (ϕ=0°, θ=45°)	90.78W	0.003516W	90.783516W
2-bit (ϕ=45°, θ=-45°)		0.003461W	90.783461W
3-bit (ϕ=0°, θ=45°)	135.18W	0.004224W	135.184224W
3-bit (ϕ=45°, θ=-45°)		0.005176W	135.185176W

TABLE 2. CASE -2 (# UNIT CELLS : 24 X 24)

	Microfluidics-based Switch		
	P_{static}	***$P_{dynamic}$***	***Total P***
1-bit (ϕ=0°, θ=45°)	3.42W	0.000312W	3.420312W
1-bit (ϕ=45°, θ=-45°)		0.000308W	3.420308W
2-bit (ϕ=0°, θ=45°)	5.34W	0.000744W	5.340744W
2-bit (ϕ=45°, θ=-45°)		0.000782W	5.340782W
3-bit (ϕ=0°, θ=45°)	7.26W	0.000888W	7.260888W
3-bit (ϕ=45°, θ=-45°)		0.001108W	7.261108W
	CMOS Based Switch		
1-bit (ϕ=0°, θ=45°)	3.42W	0.000062W	3.420062W
1-bit (ϕ=45°, θ=-45°)		0.000062W	3.420062W
2-bit (ϕ=0°, θ=45°)	5.34W	0.000149W	5.340149W
2-bit (ϕ=45°, θ=-45°)		0.000156W	5.340156W
3-bit (ϕ=0°, θ=45°)	7.26W	0.000178W	7.260178W
3-bit (ϕ=45°, θ=-45°)		0.000222W	7.260222W

Case-2: Indoor scenario #unit cells 24 x 24 at 140 GHz

Total static power and dynamic power calculation, for a RIS with unit cells 24 x 24, are done similar to previous case-1, we have obtained values for microfluidic-based RIS as given here Nc = 576 (1-bit), Nc = 1152 (2-bit), Nc = 1728 (3-bit), Ng = 1, Ns = 75, $N_{driveboards}$ = 8(1-bit), 16 (2-bits), 24 (3-bits). Similar to case-1, we have also calculated the total dynamic power values and presented in table.2.

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III. CONCLUSIONS

A scalability approach to estimate the total power requirements of a large size RIS with microfluidic-based and CMOS based switching technology operating at 140 THz frequencies for 1-bit, 2-bit and 3-bits is presented. First, we calculated the static powers associated with FPGA and control boards of RIS and then estimated the dynamic power requirements associated with RIS unit cells and finally combined the both the powers that gives the total RIS power values. In this approach, we have considered various critical factors such as RIS size, no of control lines and bit resolutions. One major observation is total static power values are very high than dynamic power so there is a great research scope in low-power hardware circuity to meet overall energy efficiency requirements.

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