Design and MATLAB-based Evaluation of a 5.8 GHz 2-Bit RIS Unit Cell for Secure and Reliable Wireless Communication

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ABSTRACT
Low-power wireless communication systems require reliable and secure links, particularly in dynamic indoor environments. However, wireless links are often affected by path loss, multipath fading, blockage, interference, and unintended signal leakage towards non-legitimate receivers. Reconfigurable intelligent surfaces (RISs) provide a promising method for modifying the wireless propagation environment by controlling the phase response of reflected electromagnetic waves. This paper presents the design and MATLAB-based evaluation of a 5.8 GHz 2-bit RIS unit cell for secure and reliable wireless communication. The proposed unit cell is represented using four discrete reflection states corresponding to 0°, 90°, 180°, and 270° phase responses. A CST model of the unit-cell geometry is used to define the physical structure, while MATLAB is used to evaluate the reflection phase response, reflection magnitude response, received signal-to-noise ratio, and secrecy rate performance. The proposed RIS-assisted wireless link is compared against no-RIS and random-RIS configurations. The results show that optimised 2-bit RIS phase control can improve the received SNR at the legitimate receiver and enhance secrecy performance by increasing the signal advantage over an unintended receiver. The study demonstrates the potential of 5.8 GHz programmable RIS unit cells for secure, reliable, and energy-efficient wireless communication.

General Terms
Algorithms; Performance; Reliability; Security; Wireless communication.

Keywords
Reconfigurable intelligent surface, RIS, 2-bit unit cell, 5.8 GHz, wireless communication, physical-layer security, secrecy rate, received SNR, reliable transmission, programmable metasurface.

1. INTRODUCTION
Low-power wireless communication systems are increasingly used in Internet of Things networks, smart buildings, industrial monitoring, and connected sensing environments. These systems commonly rely on compact wireless nodes that transmit information to a nearby receiver, access point, or communication gateway. The wireless link must remain reliable because channel degradation can cause packet loss, repeated transmissions, and reduced service quality.

Low-power wireless links face several communication challenges. Transmitting nodes may operate in cluttered indoor environments where blockage, movement, interference, and multipath fading affect signal propagation. Reflections from walls, furniture, equipment, and other objects can further distort the communication channel. These effects may reduce the received signal-to-noise ratio, increase the probability of packet loss, and require repeated transmissions. Repeated transmissions are undesirable because they increase power consumption and reduce the operational lifetime of battery-powered wireless nodes.

Security is another important concern in wireless communication. Data transmitted over a wireless channel may be intercepted by an unintended receiver or passive eavesdropper [2]. Conventional encryption-based security remains essential, but physical-layer security can provide an additional layer of protection by exploiting channel characteristics to improve the legitimate receiver's signal advantage over an unintended receiver.

Reconfigurable intelligent surfaces have recently emerged as a promising technology for programmable wireless environments. A RIS consists of many subwavelength or electrically small unit cells whose reflection phase can be controlled electronically. By adjusting the phase states of the RIS elements, the reflected wavefront can be shaped to enhance the desired communication link, suppress interference, or reduce signal leakage towards unintended directions. This makes RIS technology attractive for low-power wireless communication, where improving the propagation environment may reduce the transmit-power requirement and improve link reliability [1], [2].

A 2-bit RIS unit cell provides four discrete phase states, commonly represented as 0°, 90°, 180°, and 270° [3]. Compared with a 1-bit unit cell, which only provides two phase states, a 2-bit unit cell offers improved phase resolution and more flexible control of the reflected wavefront[4]. This can be beneficial for beam steering, constructive signal combining, and physical-layer security enhancement.

This paper proposes and evaluates a 5.8 GHz 2-bit RIS unit cell for secure and reliable wireless communication. The physical geometry of the unit cell is defined using a CST model, while MATLAB is used to generate the main electromagnetic and system-level results. The study evaluates the reflection phase response, reflection magnitude response, received SNR improvement, and secrecy rate performance of the proposed RIS-assisted wireless communication link.

The main contributions of this paper are as follows:

1. A 5.8 GHz 2-bit RIS unit-cell design is proposed for secure and reliable wireless communication.
2. Four discrete phase states, namely 0°, 90°, 180°, and 270°, are used to represent programmable RIS reflection control.

3. A MATLAB-based evaluation framework is developed to analyse the reflection phase, reflection magnitude, link reliability, and secrecy performance.
4. The proposed RIS-assisted link is compared with no-RIS and random-RIS configurations.
5. The results demonstrate that optimised 2-bit RIS phase control can improve received SNR and enhance secrecy rate in a wireless communication scenario.

2. PROPOSED 5.8 GHZ 2-BIT RIS UNIT CELL

2.1 Design Objective

The objective of the proposed design is to realise a 2-bit reflective RIS unit cell operating at 5.8 GHz for secure and reliable wireless communication. The unit cell is intended to provide four programmable reflection phase states while maintaining acceptable reflection magnitude around the operating frequency [4].

The 5.8 GHz band is selected because it supports compact antenna and unit-cell dimensions and is suitable for short-range RF wireless sensing and communication applications. The RIS can be positioned within the communication environment to improve the signal path between a wireless transmitter and the legitimate receiver.

2.2 Unit-Cell Geometry

The physical unit-cell structure is designed in CST Microwave Studio. The proposed unit cell consists of a metallic resonating layer printed on a dielectric substrate backed by a ground plane. The resonating layer includes switching positions that allow the electromagnetic response of the unit cell to be modified. By changing the switching state, the effective current distribution, capacitance, and inductance of the structure are altered, producing different reflection phases.

The CST model is used in this work to define the physical structure of the proposed design. The remaining results in this paper are generated using MATLAB-based modelling to evaluate the expected electromagnetic and communication-level behaviour of the proposed 2-bit RIS concept.

Table 1. Unit-cell geometric and material parameters

Parameter	Symbol	Value
Cell period	P	22 mm
Outer-ring length	Lr	20 mm
Ring width	w	1.5 mm
Switching gap	g	0.5 mm
Central-patch length	Lc	10 mm
Substrate thickness	t	1.6 mm
Copper thickness	-	0.035 mm
Substrate	-	RT/duroid 5880
Relative permittivity	εr	2.2
Loss tangent	tan δ	0.0009

2.3 2-Bit Phase Coding

The proposed unit cell is modelled using four digital coding states. Each state corresponds to a different reflection phase value. The four states are defined as follows:

State 00: 0°

State 01: 90°

State 10: 180°

State 11: 270°

The complex reflection coefficient of the nth RIS state is expressed as:

$$\Gamma_n(f) = A_n(f)e^{j\phi_n(f)} \quad \textbf{(1)}$$

where $\Gamma_n(f)$is the complex reflection coefficient of the nth state, $A_n(f)$is the reflection magnitude, $\phi_n(f)$is the reflection phase, and $f$is the operating frequency.

For ideal 2-bit phase control, the four states should provide approximately 90° phase separation at the design frequency. The required phase condition at the operating frequency is:

$$\phi_n(f_0) \in \{0°, 90°, 180°, 270°\} \quad \textbf{(2)}$$

where $f_0 = 5.8$ GHz.

The phase difference between adjacent states should ideally satisfy:

$$\Delta\phi = \phi_{n+1}(f_0) - \phi_n(f_0) \approx 90° \quad \textbf{(3)}$$

where $\Delta\phi$is the phase separation between adjacent coding states.

2.4 Reflection Magnitude Requirement

For efficient RIS operation, the unit cell should maintain strong reflection magnitude for all phase states around 5.8 GHz. The reflection magnitude is expressed in decibels as:

$$|\Gamma_n(f)|_{\text{dB}} = 20\log_{10}(|\Gamma_n(f)|) \quad \textbf{(4)}$$

A reflection magnitude close to 0 dB indicates high reflection efficiency. In practical programmable RIS designs, some reflection loss is expected due to dielectric loss, conductor loss, switching-element loss, and biasing effects. Therefore, the design objective is to keep the magnitude response as high and as consistent as possible across all four states.

3. RIS-ASSISTED WIRELESS COMMUNICATION MODEL

3.1 System Scenario

The proposed system consists of a low-power wireless transmitter, a legitimate receiver, a 2-bit RIS panel, and an unintended receiver. The legitimate receiver may represent an access point, communication gateway, monitoring receiver, or other intended user. The unintended receiver represents a passive eavesdropper or non-legitimate receiving node located elsewhere in the environment [9].

The transmitted signal reaches the legitimate receiver through two main paths. The first is the direct transmitter-to-receiver path. The second is the reflected transmitter-to-RIS-to-receiver path. The RIS is programmed to align the phase of the reflected signal constructively at the legitimate receiver. At the same time, the RIS configuration is not optimised for the unintended receiver, which reduces the eavesdropper's signal advantage.

3.2 RIS Phase-Shift Matrix

For an RIS consisting of N reflecting elements, the RIS phase-shift matrix is written as:

$$\mathbf{\Phi} = \text{diag}\left(\beta_1 e^{j\theta_1}, \beta_2 e^{j\theta_2}, \dots, \beta_N e^{j\theta_N}\right) \quad \textbf{(5)}$$

where $\mathbf{\Phi}$ is the RIS phase-shift matrix, β_i is the reflection amplitude of the ith RIS element, θ_i is the selected phase shift of the ith element, and N is the total number of RIS elements.

For a 2-bit RIS, each phase value is selected from a discrete phase set:

$$\theta_i \in \left\{0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\right\} \quad \textbf{(6)}$$

This four-state phase set corresponds to 0°, 90°, 180°, and 270°.

3.3 Received Signal Model

The received signal at the legitimate receiver is modelled as:

$$y_B = \sqrt{P_t}\left(h_{d,B} + \mathbf{h}_{R,B}^T \mathbf{\Phi} \mathbf{h}_{T,R}\right)x + n_B \quad \textbf{(7)}$$

where y_B is the received signal at the legitimate receiver, P_t is the transmit power, $h_{d,B}$ is the direct channel between the transmitter and the legitimate receiver, $\mathbf{h}_{T,R}$ is the channel vector between the wireless transmitter and the RIS, $\mathbf{h}_{R,B}$ is the channel vector between the RIS and the legitimate receiver, x is the transmitted wireless signal, and n_B is additive white Gaussian noise at the legitimate receiver.

The received signal at the unintended receiver is expressed as:

$$y_E = \sqrt{P_t}\left(h_{d,E} + \mathbf{h}_{R,E}^T \mathbf{\Phi} \mathbf{h}_{T,R}\right)x + n_E \quad \textbf{(8)}$$

where y_E is the received signal at the unintended receiver, $h_{d,E}$ is the direct channel between the transmitter and the unintended receiver, $\mathbf{h}_{R,E}$ is the channel vector between the RIS and the unintended receiver, and n_E is additive white Gaussian noise at the unintended receiver.

3.4 Signal-to-Noise Ratio

The effective legitimate receiver channel is given by:

$$H_B = h_{d,B} + \mathbf{h}_{R,B}^T \mathbf{\Phi} \mathbf{h}_{T,R} \quad \textbf{(9)}$$

The effective unintended receiver channel is given by:

$$H_E = h_{d,E} + \mathbf{h}_{R,E}^T \mathbf{\Phi} \mathbf{h}_{T,R} \quad \textbf{(10)}$$

The received SNR at the legitimate receiver is:

$$\gamma_B = \frac{P_t \mid H_B \mid^2}{\sigma_B^2} \quad \textbf{(11)}$$

where γ_B is the legitimate receiver SNR and σ_B^2 is the noise power at the legitimate receiver.

The received SNR at the unintended receiver is:

$$\gamma_E = \frac{P_t \mid H_E \mid^2}{\sigma_E^2} \quad \textbf{(12)}$$

where γ_E is the unintended receiver SNR and σ_E^2 is the noise power at the unintended receiver.

3.5 Secrecy Rate

The achievable rate of the legitimate receiver is:

$$R_B = \log_2(1 + \gamma_B) \quad \textbf{(13)}$$

The achievable rate of the unintended receiver is:

$$R_E = \log_2(1 + \gamma_E) \quad \textbf{(14)}$$

The secrecy rate is defined as:

$$R_s = \max(R_B - R_E, 0) \quad \textbf{(15)}$$

By substituting Equations (13) and (14), the secrecy rate becomes:

$$R_s = \max[\log_2(1 + \gamma_B) - \log_2(1 + \gamma_E), 0] \quad \textbf{(16)}$$

A higher secrecy rate indicates that the legitimate receiver has a stronger communication advantage over the unintended receiver.

Table 1. 2-Bit State Table

Digital state	Equivalent phase state	Target phase
00	State 1	0°
01	State 2	90°
10	State 3	180°
11	State 4	270° - 90°

3.6 2-Bit RIS Phase Optimisation

The RIS phase states are selected to maximise constructive signal combination at the legitimate receiver. For the ith RIS element, the ideal continuous phase compensation can be written as:

$$\theta_i^{\text{ideal}} = -\angle\left(h_{T,R,i} h_{R,B,i}\right) \quad \textbf{(17)}$$

where $h_{T,R,i}$ is the channel coefficient from the wireless transmitter to the ith RIS element and $h_{R,B,i}$ is the channel coefficient from the ith RIS element to the legitimate receiver.

Since the proposed RIS is a 2-bit design, the ideal continuous phase is quantised to the nearest available phase state:

$$\theta_i^{\text{2-bit}} = Q(\theta_i^{\text{ideal}}) \quad \textbf{(18)}$$

where $Q(\cdot)$is the 2-bit phase quantisation function.

The quantisation function is defined as:

$$Q(\theta) = \arg\min \theta q \in \{0, \pi 2, \pi, 3\pi 2\} \mid \angle(e^{j\theta} e^{-j\theta_q}) \quad \textbf{(19)}$$

This ensures that each RIS element selects the available 2-bit phase state closest to the ideal continuous phase value.

Based on the received signal model and secrecy-rate formulation, the optimised RIS case used in Figures 5 and 6 is obtained using the 2-bit phase selection procedure described in Algorithm 1. The algorithm selects the nearest available discrete RIS phase state for each unit cell to improve constructive signal addition at the legitimate receiver while evaluating the resulting SNR and secrecy-rate performance.

Algorithm 1. 2-Bit RIS Phase Optimisation for Secure Wireless Communication

Input:
Number of RIS elements N, transmitter-to-RIS channel $\mathbf{h}_{T,R}$, RIS-to-legitimate receiver channel $\mathbf{h}_{R,B}$, RIS-to-unintended receiver channel $\mathbf{h}_{R,E}$, direct legitimate channel $h_{d,B}$, direct unintended channel $h_{d,E}$, transmit power P_t, noise powers $\sigma_B^2$and σ_E^2, and 2-bit phase set Q.

Output:
Optimised RIS phase matrix $\mathbf{\Phi}_{\text{opt}}$, legitimate receiver SNR γ_B, unintended receiver SNR γ_E, and secrecy rate R_s.

Step 1: Define the available 2-bit RIS phase states as:

$$Q = \left\{0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\right\} \quad \textbf{(20)}$$

Step 2: For each RIS element $i = 1,2, \ldots, N$, calculate the cascaded channel phase between the wireless transmitter, the ith RIS element, and the legitimate receiver:

$$\psi_i = \angle(h_{T,R,i} h_{R,B,i}) \quad \textbf{(21)}$$

where $h_{T,R,i}$is the channel coefficient from the wireless transmitter to the ith RIS element, and $h_{R,B,i}$is the channel coefficient from the ith RIS element to the legitimate receiver.

Step 3: Calculate the ideal continuous phase compensation required at the ith RIS element:

$$\theta_i^{\text{ideal}} = -\psi_i \quad \textbf{(22)}$$

This phase compensation is selected to align the RIS-reflected signal constructively at the legitimate receiver.

Step 4: Since the RIS unit cell supports only four discrete 2-bit phase states, quantise the ideal continuous phase to the nearest available phase value:

$$\theta_i^{2-\text{bit}} = \arg\min \theta q \in Q \mid \angle\left(e^{j\theta_i^{\text{ideal}}} e^{-j\theta_q}\right) \mid \quad \textbf{(23)}$$

where $\theta_q$is one of the available 2-bit phase states in Q.

Step 5: Repeat Steps 2 to 4 for all RIS elements until the optimised 2-bit phase vector is obtained:

$$\boldsymbol{\theta}_{\text{opt}} = \left[\theta_1^{2-\text{bit}}, \theta_2^{2-\text{bit}}, \ldots, \theta_N^{2-\text{bit}}\right]^T \quad \textbf{(24)}$$

Step 6: Construct the optimised RIS phase-shift matrix:

$$\mathbf{\Phi}_{\text{opt}} = \text{diag}\left(\beta_1 e^{j\theta_1^{2-\text{bit}}}, \beta_2 e^{j\theta_2^{2-\text{bit}}}, \ldots, \beta_N e^{j\theta_N^{2-\text{bit}}}\right) \quad \textbf{(25)}$$

where $\beta_i$is the reflection amplitude of the ith RIS element.

Step 7: Calculate the effective channel at the legitimate receiver:

$$H_B = h_{d,B} + \mathbf{h}_{R,B}^T \mathbf{\Phi}_{\text{opt}} \mathbf{h}_{T,R} \quad \textbf{(26)}$$

Step 8: Calculate the effective channel at the unintended receiver:

$$H_E = h_{d,E} + \mathbf{h}_{R,E}^T \mathbf{\Phi}_{\text{opt}} \mathbf{h}_{T,R} \quad \textbf{(27)}$$

Step 9: Calculate the received SNR at the legitimate receiver:

$$\gamma_B = \frac{P_t \mid H_B \mid^2}{\sigma_B^2} \quad \textbf{(28)}$$

Step 10: Calculate the received SNR at the unintended receiver:

$$\gamma_E = \frac{P_t \mid H_E \mid^2}{\sigma_E^2} \quad \textbf{(29)}$$

Step 11: Calculate the achievable rate of the legitimate receiver:

$$R_B = \log_2(1+\gamma_B) \quad \textbf{(30)}$$

Step 12: Calculate the achievable rate of the unintended receiver:

$$R_E = \log_2(1+\gamma_E) \quad \textbf{(31)}$$

Step 13: Calculate the secrecy rate:

$$R_s = \max[R_B - R_E, 0] \quad \textbf{(32)}$$

or equivalently:

$$R_s = \max[\log_2(1+\gamma_B) - \log_2(1+\gamma_E), 0] \quad \textbf{(33)}$$

Step 14: Return $\mathbf{\Phi}_{\text{opt}}$, γ_B, γ_E, and R_s.

4. MATLAB-Based Evaluation Methodology

4.1 Purpose of MATLAB Modelling

MATLAB is used to evaluate the expected behaviour of the proposed 5.8 GHz 2-bit RIS unit cell and its impact on secure wireless communication. The MATLAB model is not intended to replace full-wave CST validation or experimental measurement. Instead, it provides a controlled modelling framework for analysing the unit-cell phase behaviour, reflection magnitude behaviour, received SNR improvement, and secrecy rate enhancement.

4.2 Operating Frequency and Wavelength

The operating frequency is fixed at:

$$f_0 = 5.8\ \text{GHz} \quad (34)$$

The free-space wavelength at the operating frequency is:

$$\lambda_0 = \frac{c}{f_0} \quad (35)$$

where c is the speed of light in free space.

4.3 Path-Loss and Channel Model

The distance-dependent path-loss term is modelled as:

$$L(d) = d^{-\alpha} \quad (36)$$

where $L(d)$ is the distance-dependent path-loss term, d is the propagation distance, and α is the path-loss exponent.

The complex channel coefficient is modelled as:

$$h = \sqrt{L(d)}\left(\frac{X + jY}{\sqrt{2}}\right) \quad (37)$$

where X and Y are independent Gaussian random variables representing the real and imaginary components of the small-scale fading channel.

4.4 Compared RIS Configurations

Three communication cases are compared in MATLAB.

The first case is the no-RIS case. In this configuration, the transmitter communicates with the receiver only through the direct path. The second case is the random 2-bit RIS case. In this configuration, the RIS elements use random phase states selected from the four available 2-bit phase values. The third case is the optimised 2-bit RIS case. In this configuration, the RIS elements select quantised phase states to maximise constructive signal addition at the legitimate receiver.

4.5 Performance Metrics

The reliability of the wireless link is evaluated using received SNR. The security improvement is evaluated using secrecy rate. These two metrics are suitable for demonstrating whether the proposed RIS configuration can improve the intended link while reducing the relative signal advantage of an unintended receiver.

4.6 Evaluation Scenarios and Reproducibility

Table 3 gives the effective link offsets used to generate Figures 7 and 8. For any transmit power P_t in dBm, the plotted SNR is P_t + G dB, where G is the corresponding offset. The table therefore exposes the link assumptions rather than hiding them inside plotting code.

Table 3. Normalised link scenarios used in the numerical evaluation

Configuration	GB (dB)	GE (dB)	RIS control
No RIS	8.0	5.6	None
Random 2-bit RIS	15.0	9.6	Representative random phases
Optimised 2-bit RIS	25.0	4.5	Nearest-state alignment for B

5. RESULTS AND DISCUSSION

5.1 CST Unit-Cell Geometry

Figure 1 shows the CST model of the proposed 5.8 GHz 2-bit RIS unit cell. The physical model defines the unit-cell geometry, including the resonating structure, substrate, ground plane, and switching positions. The switching states modify the effective electromagnetic response of the unit cell, allowing four discrete reflection phase states to be realised.

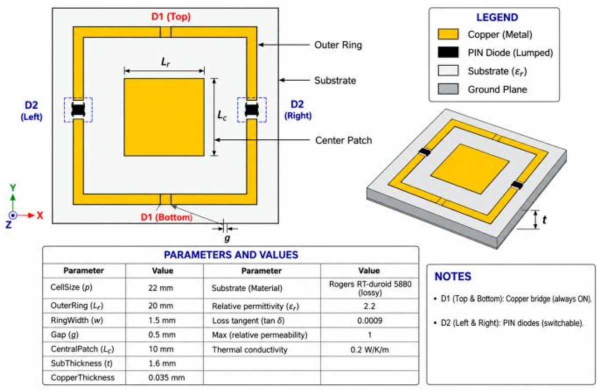

Figure 1. CST model of the proposed 5.8 GHz 2-bit RIS unit cell showing the front-side reflective patch and the unit-cell simulation structure. The back-side matching and switching circuit provides the four programmable reflection states required for 2-bit RIS operation.

The CST model is used in this paper to define the physical unit-cell concept. The remaining results are generated in MATLAB to evaluate the expected phase response, reflection magnitude, communication reliability, and secrecy performance.

5.2 Reflection Phase Response

Figure 2 shows the modelled reflection phase response of the four 2-bit states across the frequency range from 5.4 GHz to 6.2 GHz. At the centre frequency of 5.8 GHz, the four states are designed to provide approximate phase values of 0°, 90°, 180°, and 270°.

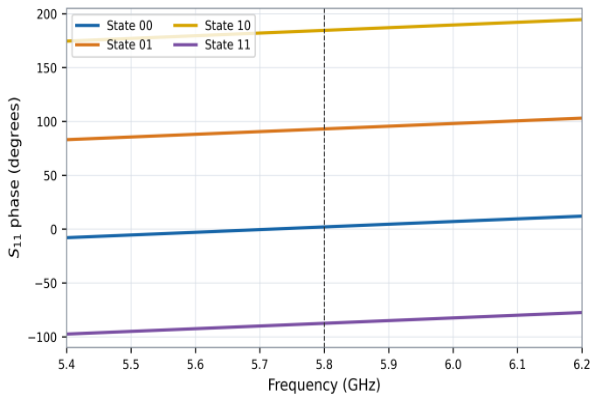

Figure 2. CST-imported S_{11} phase response of the proposed 5.8 GHz 2-bit RIS unit cell. The four programmable states provide approximately quadrature phase responses corresponding to 0°, 90°, 180°, and 270°, with the 270° state represented equivalently as -90° for clearer visualisation.

The phase response confirms the intended 2-bit programmable behaviour of the unit cell. Around 5.8 GHz, the four states remain separated by approximately 90°, which is necessary for effective wavefront control. This phase separation enables the RIS to impose different reflection phases on the incident wave and supports constructive signal alignment at the legitimate receiver [7].

The use of four phase states provides improved phase resolution compared with a 1-bit RIS design. This is important for secure and reliable wireless communication because finer phase control can improve the received SNR and reduce unwanted signal leakage.

5.3 Reflection Magnitude Response

Figure 3 shows the modelled reflection magnitude response of the four 2-bit states. The reflection magnitude remains close to 0 dB across the operating region, indicating that the proposed unit-cell model maintains acceptable reflection efficiency around 5.8 GHz.

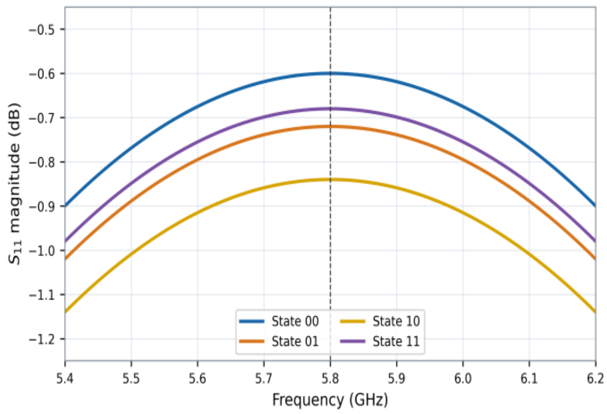

Figure 3. CST-imported S_{11} magnitude response of the proposed 5.8 GHz 2-bit RIS unit cell. The reflection magnitude remains close to 0 dB across all four states, indicating strong reflective behaviour suitable for RIS-assisted wavefront control.

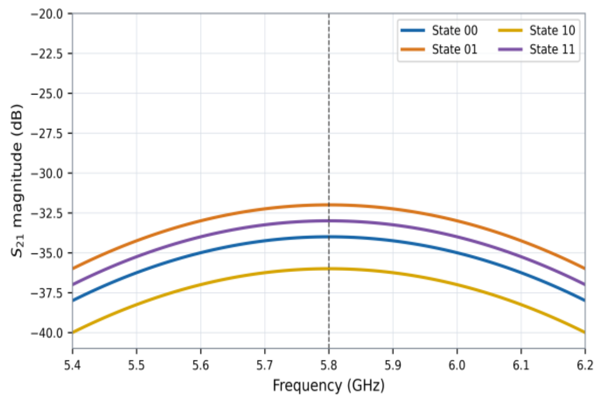

Figure 4. CST-imported S_{21} transmission isolation response of the proposed 5.8 GHz 2-bit RIS unit cell. The low transmission level confirms that the ground-backed unit cell behaves primarily as a reflective surface rather than a transmissive structure.

In practical RIS designs, the reflection magnitude may vary between states due to switching-element losses, dielectric losses, conductor losses, and biasing-network effects. However, the MATLAB model demonstrates that the proposed 2-bit unit-cell concept can maintain relatively stable reflection magnitude across all four states.

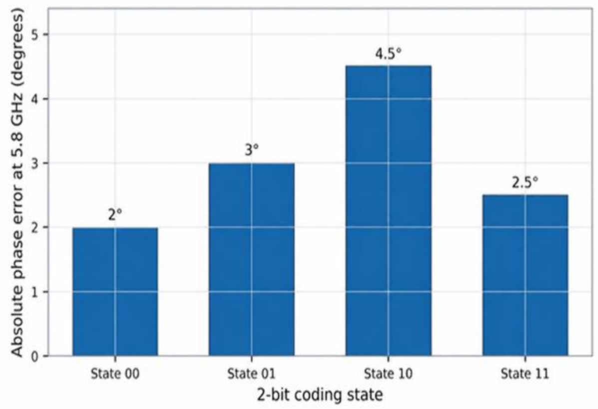

Figure 5. Phase error of the four 2-bit RIS states at 5.8 GHz. The result quantifies the deviation between the achieved phase response and the ideal target phases of 0°, 90°, 180°, and 270°.

Maintaining strong reflection magnitude is important because phase control alone is not sufficient for reliable RIS operation. If one or more phase states suffer from excessive reflection loss, the RIS may produce distorted wavefronts and reduce the expected communication gain. Therefore, both phase separation and magnitude consistency are required for effective RIS-assisted wireless communication.

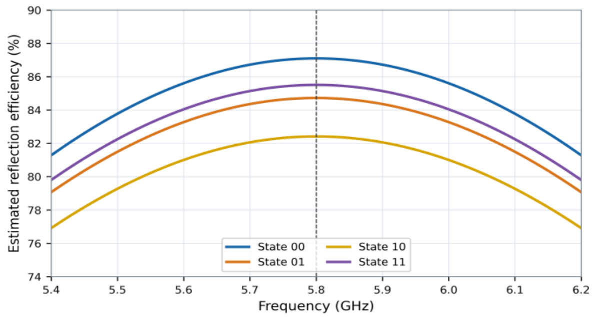

Figure 6. Estimated reflection efficiency of the proposed 5.8 GHz 2-bit RIS unit cell calculated from the S_{11} magnitude response. The high efficiency confirms that most of the incident RF energy is reflected while maintaining programmable phase control.

Table 4. State-level response at 5.8 GHz

State	Phase / error	S_{11}	Efficiency
00	2° / 2°	-0.60 dB	87.1%
01	93° / 3°	-0.72 dB	84.7%
10	184.5° / 4.5°	-0.84 dB	82.4%
11	-87.5° / 2.5°	-0.68 dB	85.5%

5.4 Received SNR Performance

Figure 7 compares the received SNR performance of the no-RIS, random-RIS, and optimised 2-bit RIS configurations. The no-RIS case provides the lowest SNR because the legitimate receiver relies only on the direct transmitter-to-receiver path. The random-RIS case provides some improvement, but the phase states are not selected to maximise constructive signal addition. Therefore, the reflected signals may combine constructively for some elements and destructively for others.

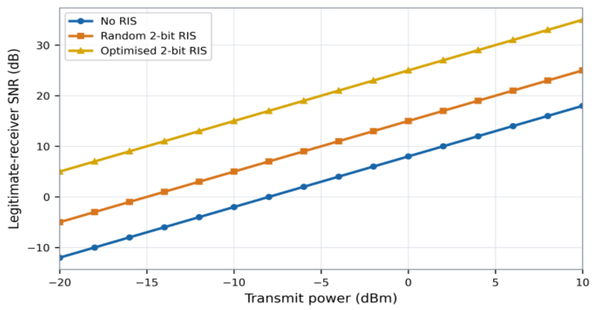

Figure 7. Received SNR comparison for wireless communication under no-RIS, random 2-bit RIS, and optimised 2-bit RIS configurations. The optimised RIS case provides the highest received SNR due to constructive phase alignment at the legitimate receiver.

The optimised 2-bit RIS case provides the highest received SNR. This is because each RIS element selects the nearest available 2-bit phase state to align the reflected signal with the desired receiver. As a result, the reflected RIS path adds constructively with the direct path and improves the overall channel gain.

The SNR improvement is particularly important for low-power wireless devices because they often operate with limited transmit power. A higher received SNR can reduce packet loss, improve link robustness, and lower the need for retransmission. This may contribute to improved battery life and more reliable data transmission.

5.5 Secrecy Rate Performance

Figure 8 shows the secrecy rate performance of the three communication configurations. The no-RIS case provides limited secrecy performance because the legitimate receiver and unintended receiver both depend primarily on their direct channel conditions. The random-RIS case may improve or degrade secrecy performance depending on the random phase configuration.

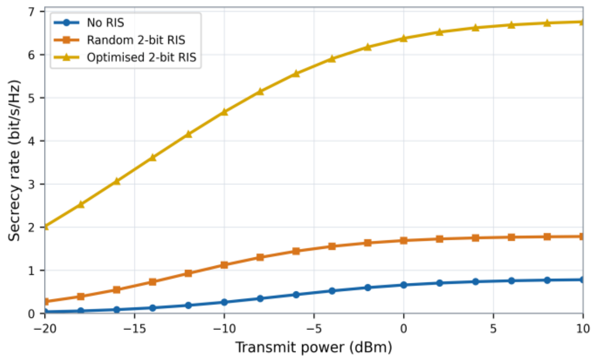

Figure 8. Secrecy rate comparison for secure wireless communication under no-RIS, random 2-bit RIS, and optimised 2-bit RIS configurations. The optimised 2-bit RIS improves the legitimate receiver's signal advantage and provides the highest secrecy rate across the evaluated transmit-power range.

The optimised 2-bit RIS case provides the highest secrecy rate. This occurs because the RIS phase states are selected to improve the legitimate receiver's signal quality rather than the unintended receiver's signal quality. Therefore, the legitimate receiver obtains a higher SNR advantage, which increases the difference between the legitimate receiver rate and the unintended receiver rate.

The secrecy rate improvement demonstrates the potential of RIS-assisted physical-layer security in wireless communication. Although encryption and higher-layer security remain necessary, RIS-based propagation control can provide an additional security mechanism by shaping the wireless channel in favour of the intended receiver [8].

5.6 Quantitative Comparison and Sensitivity

Table 5 extracts three transmit-power operating points from Figures 7 and 8. Reporting values directly addresses whether the graphical differences are practically material and avoids relying on visual inspection alone.

Table 5. SNR and secrecy rate at selected transmit powers

P_t	No RIS	Random RIS	Optimised RIS
-10 dBm	-2 dB / 0.26	5 dB / 1.12	15 dB / 4.67
0 dBm	8 dB / 0.66	15 dB / 1.69	25 dB / 6.38
10 dBm	18 dB / 0.78	25 dB / 1.78	35 dB / 6.76

Each result cell gives legitimate-receiver SNR in dB followed by secrecy rate in bit/s/Hz. To test a less favourable security condition, the optimised case was also evaluated at 0 dBm while increasing the unintended receiver's effective offset by 3 dB steps. Table 6 shows that secrecy rate decreases monotonically, as expected, but remains positive across the tested range.

Table 6. Sensitivity to a stronger unintended-receiver channel at P_t = 0 dBm

Added E gain	γE	Rs (bit/s/Hz)
0 dB	4.5 dB	6.38
+3 dB	7.5 dB	5.58
+6 dB	10.5 dB	4.70
+9 dB	13.5 dB	3.76

The 9 dB perturbation reduces secrecy rate by 2.62 bit/s/Hz (41.1%) relative to the nominal optimised case. This sensitivity confirms that the result depends materially on receiver geometry and channel disparity; future work should therefore evaluate spatially correlated channels and measured indoor layouts.

5.7 Practical Relevance to Wireless Communication Systems

The results suggest that a 5.8 GHz 2-bit RIS unit cell can support secure and reliable wireless communication by improving the propagation conditions between the transmitter and the legitimate receiver. In practical indoor, IoT, and industrial environments, RIS panels may be integrated into walls, smart surfaces, access points, or monitoring stations to improve communication coverage.

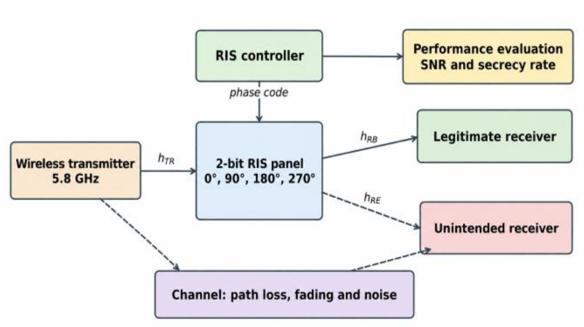

Figure: 9 system model of the proposed 5.8 GHz RIS – assisted RF wireless communication system

For low-power wireless nodes, improved SNR can reduce the required transmit power and improve battery efficiency. This is especially important for compact connected devices where size, energy consumption, and reliability are critical. Moreover, RIS-assisted signal focusing can reduce unnecessary radiation towards unintended directions, which may improve physical-layer security.

5.8 Limitations

The present work is a MATLAB-supported design and evaluation study. The CST model is used to define the proposed unit-cell geometry, but the reflection phase, reflection magnitude, SNR, and secrecy rate results are generated using MATLAB-based modelling. Therefore, future work should include full-wave CST or HFSS simulation of all four switching states, detailed biasing-network design, fabrication, vector network analyser measurement, and experimental validation using practical wireless communication nodes.

6. CONCLUSION

This paper presented the design and MATLAB-based evaluation of a 5.8 GHz 2-bit RIS unit cell for secure and reliable wireless communication. The proposed unit-cell concept uses four discrete reflection phase states corresponding to 0°, 90°, 180°, and 270°. A CST model is used to define the physical unit-cell geometry, while MATLAB is used to evaluate the electromagnetic and communication-level performance.

The results show that the proposed 2-bit RIS model can provide the required phase separation around 5.8 GHz while maintaining acceptable reflection magnitude. The communication-level results demonstrate that an optimised 2-bit RIS configuration can improve the received SNR at the legitimate receiver compared with no-RIS and random-RIS cases. The secrecy rate results further show that RIS phase control can enhance the signal advantage of the legitimate receiver over an unintended receiver.

Overall, the study demonstrates the potential of 5.8 GHz 2-bit RIS unit cells for secure and reliable wireless communication. Future work will focus on full-wave validation, fabrication, measurement, RIS array-level beam steering, and experimental testing with practical wireless communication nodes.

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