

ETSI GR RIS 004 V1.1.1 (2025-03)



Reconfigurable Intelligent Surfaces (RIS); Implementation and Practical Considerations

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Reconfigurable Intelligent Surfaces (RIS).

Modal verbs terminology

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1 Scope

The present document identifies Reconfigurable Intelligent Surfaces (RIS) relevant use cases with corresponding general Key-Performance-Indicators (KPIs), deployment scenarios operational requirements for each identified use case. KPIs and operational requirements will include system/link performance, spectrum, co-existence and security.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- [i.1] ETSI GR RIS 001: "Reconfigurable Intelligent Surfaces (RIS); Use Cases, Deployment Scenarios and Requirements".
- [i.2] ETSI GR RIS 002: "Reconfigurable Intelligent Surfaces (RIS); Technological challenges, architecture and impact on standardization".
- [i.3] ETSI GR RIS 003: "Reconfigurable Intelligent Surfaces (RIS); Communication Models, Channel Models, Channel Estimation and Evaluation Methodology".
- [i.4] George C. Alexandropoulos, et. all: "[RIS-Enabled Smart Wireless Environments: Deployment Scenarios, Network Architecture, Bandwidth and Area of Influence](#)", submitted to EURASIP Journal.
- [i.5] [Directive 2014/53/EU](#) of the European Parliament and of the Council of 16 April 2014.
- [i.6] A. Haskou, and H. Khaleghi: "On the effect of RIS phase quantization on communications system performances", 2023 International Wireless Communications and Mobile Computing (IWCMC), Marrakesh, Morocco, pp. 1406-1411, 2023.
- [i.7] ETSI TS 138 101-1: "5G; NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone (3GPP TS 38.101-1 Release 17)".
- [i.8] A. Tishchenko, A. Ali, A. Araghi, P. Botham, F. Burton and M. Khalily: "Autonomous Reconfigurable Intelligent Surface based on Highly-Efficient Solar Cells," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, pp. 1-5, 2023.
- [i.9] A. Haskou and H. Khaleghi: "An Efficient and Easy-to-Implement Method for SLL Reduction in RIS-Aided Systems". TechRxiv, 31-August-2023.
- [i.10] H. Taghvaei et al.: "Scalability Analysis of Programmable Metasurfaces for Beam Steering", in IEEE Access, vol. 8, pp. 105320-105334, 2020.
- [i.11] Fangzhou Wang, and A. Lee Swindlehurst: "Applications of Absorptive Reconfigurable Intelligent Surfaces in Interference Mitigation and Physical Layer Security", 2023.

- [i.12] S. Zeng et al.: "Intelligent Omni-Surfaces: Reflection-Refraction Circuit Model, Full-Dimensional Beamforming, and System Implementation", in IEEE Transactions on Communications, vol. 70, no. 11, pp. 7711-7727, November. 2022.
- [i.13] Recommendation ITU-R SM.329: "Unwanted emissions in the spurious domain".
- [i.14] ETSI GR RIS 006: "Reconfigurable Intelligent Surfaces (RIS); Multi-functional Reconfigurable Intelligent Surfaces (RIS): Modelling, Optimisation, and Operation".
- [i.15] R. Liu, J. Dou, P. Li, J. Wu and Y. Cui: "Simulation and Field Trial Results of Reconfigurable Intelligent Surfaces in 5G Networks", in IEEE Access, vol. 10, pp. 122786-122795, 2022.
- [i.16] M. Rossanese, P. Mursia, A. Garcia-Saavedra, V. Sciancalepore, A. Asadi, and X. Costa-Perez: "Design and validation of scalable reconfigurable intelligent surfaces", Computer Networks, vol. 241, no.110208, 2024.
- [i.17] H. Rajabalipanah, K. Rouhi, A. Abdolali, S. Iqbal, L. Zhang and S. Liu: "Real-time terahertz meta-cryptography using polarization-multiplexed graphene-based computer-generated holograms", in Nanophotonics, vol. 9, no. 9, pp. 2861-2877, 2020.
- [i.18] J. B. Gros, V. Popov, M. A. Odit, V. Lenets, G. Lerosey: "A Reconfigurable Intelligent Surface at mmWave Based on a Binary Phase Tunable Metasurface", IEEE Open Journal of the Communications Society, vol. 2, pp. 1055–1064, May 2021.
- [i.19] ETSI GR RIS 007: "Reconfigurable Intelligent Surfaces (RIS); Near-field Channel Modeling and Mechanics".
- [i.20] C.-L. Liao, Y.-H. Lin, I. Lin, and C.-F. Yang: "Performance Evaluation of RU and RIS Based on OTA Mode Near Field and Bistatic Measurement Systems", Antenna Measurement Techniques Association Symposium (AMTA), October 2023.
- [i.21] T.-H. Lee and W. D. Burnside: "Compact Range Reflector Edge Treatment Impact on Antenna and Scattering Measurements", IEEE Trans. Antennas Propagat., vol. 45, no. 1, pp. 57-65, January 1997.
- [i.22] Kitayama D, Hama Y, Goto K, Miyachi K, Motegi T, Kagaya O.: "Transparent dynamic metasurface for a visually unaffected reconfigurable intelligent surface: controlling transmission/reflection and making a window into an RF lens", in Opt. Express, 29(18):29292-29307, 2021.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms given in ETSI GR RIS 001 [i.1], in ETSI GR RIS 002 [i.2] and ETSI GR RIS 003 [i.3] apply.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

FPGA	Field Programmable Gate Array
KPI	Key Performance Index
RIS	Reconfigurable Intelligent Surfaces

4 General hardware aspects of RIS

4.0 Unit-cell principle of operation

The number of states of a unit-cell may be represented by a number of bits used based on the RIS implementation. RIS, when built using locally switchable elements, can be described as a bit or state matrix and digitally controlled through reconfigurable devices such as Field-Programmable Gate Arrays (FPGAs). Consequently, discretizing the electromagnetic characteristics of the unit-cell (amplitude and phase) realizes simple wave manipulation with straightforward tunability.

4.1 Quantized Phase Shifts

An ideal RIS unit cell is supposed to provide continuous phase shift values with infinite resolutions. However, in real-world implementations, the resolutions of phase shifters/diodes/varactors are generally limited, resulting in quantized phase shifts and degraded beamforming performances. The degradation of beamforming gains with different phase quantization, imperfection, and RIS implementation constraints need to be thoroughly investigated. Figure 4.1.1-1 and Figure 4.1.1-2 show the beamforming gain of RIS when a RIS aims to re-radiate the incident signals into different steering directions for different number of RIS elements respectively. With 1-bit quantization, the beamforming gain is generally about 3-4 dB less than the scenario with ideal phase shift control, which does not change significantly with the number of elements on the RIS panel. The beamforming gain loss caused by phase quantization can only be minimized in some certain re-radiating directions (e.g. when the re-radiation is subject to Snell's law), and such re-radiating directions correspond to peaks in Figure 4.1.1-1 and Figure 4.1.1-2.

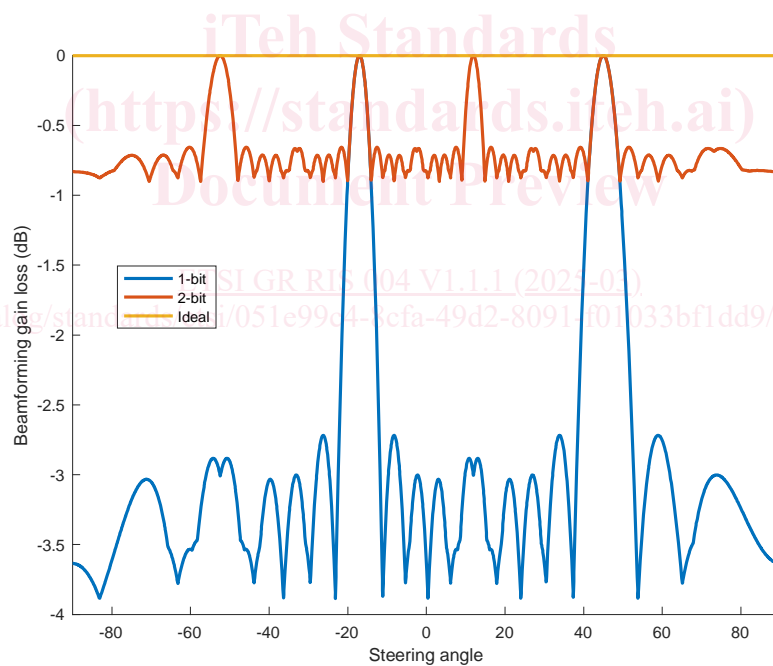
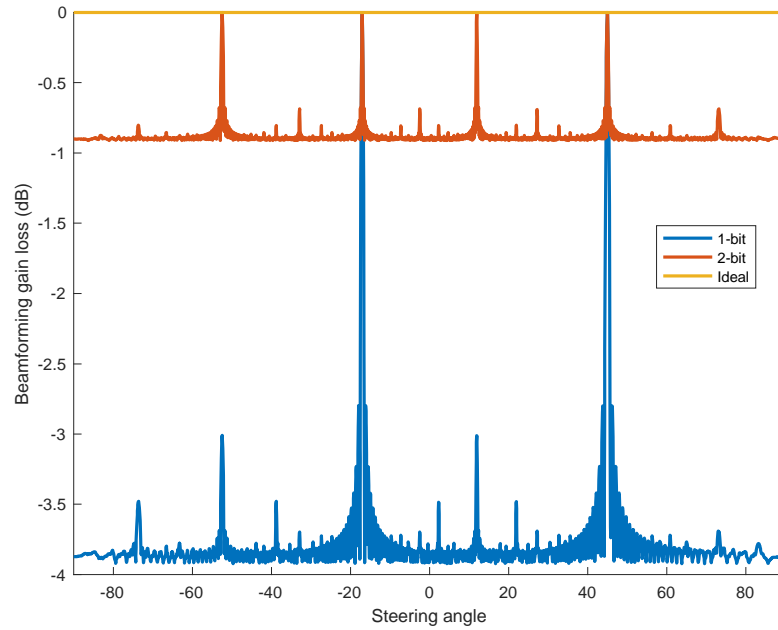


Figure 4.1.1-1: 10 × 10 RIS beamforming gain for varying steering angle obtained by using different phase shift control resolutions



NOTE: The incident angle is assumed to be -45 degrees in both examples. The yellow curve represents phase shift control with infinite resolution. Blue and red curves represent phase shift controls with 1-bit and 2-bit quantization, respectively.

Figure 4.1.1-2: 100 × 100 RIS beamforming gain for varying steering angle obtained by using different phase shift control resolutions

An RIS unit cell can also provide phase shift values quantized with multiple bits. The function can be realized by using phase shifters with higher resolution or multiple diodes in the same RIS unit. Figure 4.1.1-1 and Figure 4.1.1-2 show the beamforming gain of RIS with 2-bit quantization, and the beamforming gain loss is generally less than 1 dB. Therefore, the resolution of 2-bit quantization might be sufficient for RIS fabrication.

In some scenarios, the total number of control bits can be a constraint of RIS fabrication, which implies that the RIS can be larger with low phase resolution per unit. Although the gain improvement of 2-bit quantization over 1-bit quantization is around 3 dB, using 1-bit quantization leads to double RIS elements, which can provide around 6 dB gain. Therefore, with constraints on the total control bits, multi-bit quantization may not be an optimal solution for RIS fabrication. Generally, the requirement in terms of phase quantization can be determined depending on use-cases, deployment scenarios, accuracy requirements, etc. Therefore, in certain cases, a finer phase quantization, while in other cases coarser phase quantization may be needed.

Assuming an RIS with a large number of elements N , using far-field approximations, it can be shown that in absence of a direct Tx-Rx path, using i -bit phase quantization leads to a uniform phase quantization error $\Psi_{m,n} \sim U\left(-\frac{\pi}{2^i}, \frac{\pi}{2^i}\right)$. Then, the relative received signal level, i.e. the ratio between the received signal with phase quantization and the received signal without phase quantization, is given by [i.9]:

$$S_{relative} = \frac{E_{\Psi_{m,n}}(s_{rxq})}{s_{rx}} = \text{sinc}\left(\frac{\pi}{2^i}\right)$$

where s_{rxq} is the received signal using phase quantization, s_{rx} is the received signal without phase quantization and $\Psi_{m,n}$ is the difference between the optimal phase and the quantized phase.

Figure 4.1.1-3 shows the effect of the phase quantization on the relative received power (calculated as $P_{relative} = 20 \log(S_{relative})$). As it can be seen, using 1-bit and 2-bit quantization lead to around 3,9 dB and 0,9 dB loss in the received power.

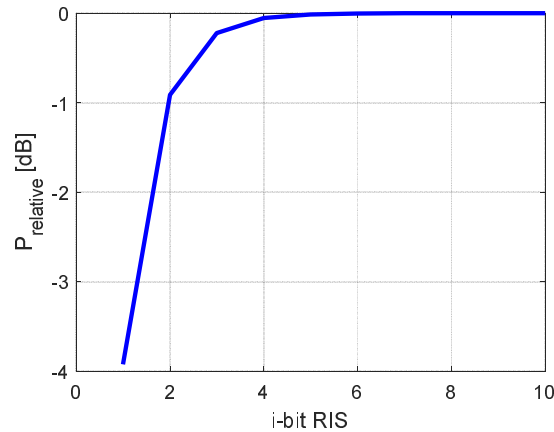


Figure 4.1.1-3: Effect of the quantization step on relative received power

In the case there is also a direct Tx-Rx path, the relative received signal is given by:

$$S_{relative} = \frac{\frac{\sqrt{G_d}}{d_d} + \frac{N\sqrt{G}\lambda}{4\pi d_{tx}d_{rx}} \text{sinc}\left(\frac{\pi}{2l}\right)}{\frac{\sqrt{G_d}}{d_d} + \frac{N\sqrt{G}\lambda}{4\pi d_{tx}d_{rx}}}$$

where λ is the free-space wavelength; d_{tx} , d_{rx} are respectively the distance from the RIS central element to Tx and Rx; G represents the overall gain between Tx and Rx through RIS; d_d is the direct distance between Tx and Rx and G_d is the overall direct path gain.

As it can be seen, in this case, the relative received signal is highly dependant on the direct path gain and distance, and it is always higher than the case without direct path. Indeed, in the case where the direct path is the dominant one, i.e.

$\frac{\sqrt{G_d}}{d_d} \gg \frac{N\sqrt{G}\lambda}{4\pi d_{tx}d_{rx}}$, this equation reduces to $S_{relative} \approx 1$. And in the case where the indirect path is the dominant one, i.e. $\frac{N\sqrt{G}\lambda}{4\pi d_{tx}d_{rx}} \gg \frac{\sqrt{G_d}}{d_d}$, this equation reduces to $S_{relative} \approx \text{sinc}\left(\frac{\pi}{2l}\right)$. This means that, for example, in the case of a 1-bit RIS the relative loss in the received power can vary from 0 dB to 3,9 dB depending on the RIS position (relative to Tx and Rx).

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4.2 Metasurface designs

RISs are composed of certain arrangement controllable resonators (unit-cells). These unit-cells can be implemented based on the deployment scenarios and requirements. For instance, in the Frequency Range 1 (FR1) regime they are typically metallic patches stacked on top of a dielectric. If the unit-cells are in the scale of subwavelength, they will form a composite called metasurface. The subwavelength granularity of these unit-cells confers metasurfaces with exceptional control of EM waves, that can even realize some unnatural EM properties such as negative permittivity (ϵ_r) or permeability (μ_r). With this feature, EM characteristics of impinging waves can be engineered.

One of the many challenges posed by this approach concerns the design and development of metasurfaces. This task is largely hindered by the unique combination of resource constraints and communication requirements of this new networking scenario, which prevents the use of conventional techniques and requires radically new solutions instead. The performance of RIS metasurface depends on the size of the unit-cells, the number of unit-cell states, and its overall size. On the other hand, there are costs and energy overheads associated with the fabrication and operation of metasurfaces that also scale with the aforementioned factors. Hence, to build an RIS capable of satisfying a set of application-specific requirements with the minimum cost, it becomes necessary to quantify the main scaling trends and trade-offs of the underlying metasurface design.

4.3 Switching element

RIS reconfiguration can be achieved through element inclusion (PIN diodes, varactors, etc.) within unit-cells. The tuning factor can be applied to unit-cells individually and to select the unit-cell state (each unit-cell can acquire different state from a selective number of states N_s). The tuning factor can be used for frequency tuning or function adjustment.

Realization of reconfigurable metasurfaces requires a network of wires or vias to convey the command signal from the control unit (i.e. RIS controller) to the surface.

The intensity and phase of reflecting EM waves are controlled by the variation of impedance Z_m in the unit cells through the switching element inclusion (PIN diodes, varactors, etc.). The conductive layer of the RIS can be described as a penetrable equivalent impedance surface \mathbf{Z} , which relates the tangential electric field \mathbf{E}_t to the discontinuity of the average tangential magnetic field \mathbf{H}_t across the conductive layer. The incident EM plane wave is characterized in terms of transverse wavenumber k_{y0} and the periodicity of RIS elements along the impedance profile d :

$$Z(y) = \sum_m Z_m e^{-j\frac{2\pi m}{d}y}$$

Then, the Floquet waves expansion of the currents induced in the equivalent impedance boundary in the $\hat{\mathbf{y}}$ direction can be expressed as:

$$I(y)\hat{\mathbf{y}} = \hat{\mathbf{z}} \times \mathbf{H}_t = \sum_n I_n e^{-jk_{yn}y}\hat{\mathbf{y}}$$

where the Floquet wavenumbers are defined as $k_{yn} = k_{y0} + \frac{2\pi}{d_z}n$,

m is a constant denoting the number of unit cells, and n represents individual reflecting coefficients for propagating diffracting harmonics of index $n = 0, \mp 1, \mp 2, \dots$. The sum of n -induced currents on the equivalent impedance boundary provides the accurate description of RIS, with the dispersion characteristics given in terms of frequency dispersion diagrams showing the transverse wavenumber as a function of the propagation direction for different frequencies. This relationship is illustrated in Figure 4.3-1.

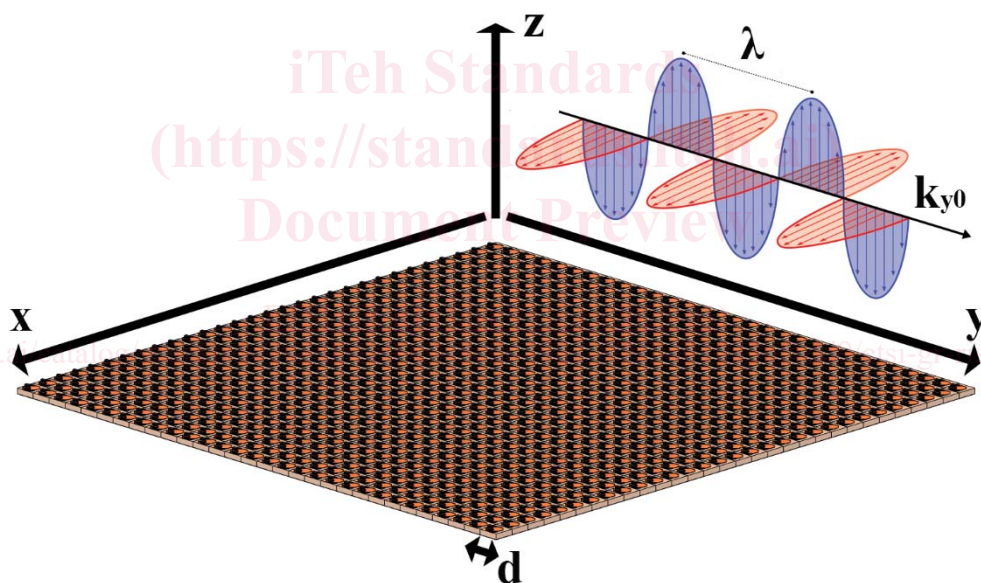


Figure 4.3-1: RIS modeled as an impedance boundary characterized by a transverse wavenumber k_{y0}

RIS can be realized by using various phase switching methods, where each method has its own advantages and disadvantages as summarized in Table 5.3.1-1 of ETSI GR RIS 002 [i.2]. As outlined in the table, the selection of the switching element is typically based on the following:

- Frequency of operation
- Switching speed
- Power consumption
- Insertion loss
- Size
- Cost

Out of the items outlined, only varactor diodes and liquid crystals can provide continuous phase switching as a function of the applied voltage that is typically regulated with Digital to Analogue Converters (DACs). This method of control is called "Analogue" because any phase value can be realized on such RIS. Other phase switching methods such as PIN diodes can only represent the value of 0 or 1, and this method is called "1-bit Digital", because only the pre-defined phase values can be realized on such RIS. However, if one unit cell features several switching elements, an "N-bit Digital" switching method can be realized, where N corresponds to the amount of switching elements within the unit cell. The design process of multi-bit digital RISs becomes progressively more complex with the amount of added switching elements. Additionally, this increases the number of control signals from the RIS controller.

The switching speed of unit cell elements needs to be fast enough to realize Time Division Duplexing (TDD) framework for operation in multi-user environments, which is described in clause 7.2.1 of ETSI GR RIS 002 [i.2]. For varactor diodes, PIN diodes and FETs it is typically in the region of nanoseconds, but the switching speed of liquid crystals and MEMS switches is in the region of milliseconds.

Although varactor diodes have negligible power consumption across the diode itself (< 1 mW), their application in analogue mode requires the use of DACs and operational amplifiers, which increases the overall power consumption of such RIS. Multiple unit cells can share the same control channel on an analogue RIS, for example in a diagonal RIS each column can be driven by a single DAC channel. However, this restricts beam steering to a single plane.

In case of a digital RIS, PIN diodes have higher power consumption across the diode itself (~ 5 mW) but can be driven directly from the microcontroller with CMOS logic. Digital RIS can also be implemented with multiple varactor diodes on the same unit cell that are switching between two or more voltage levels, but it requires the addition of voltage boosters and increases complexity of the unit cell design.

Most base stations are equipped with orthogonal and dual-polarized antenna arrays and most mobile user terminals are integrated with impurely polarized internal antennas. Hence, the unit cells of a RIS array should be designed with dual-polarization functionality in order to control any incoming EM wave with a random polarization successfully. The described scenarios below illustrate two RIS examples for the single- and dual-polarization RIS configurations, respectively. As shown in Figure 4.3-2, when the RIS design is specific to supporting merely one polarization orientation, only the polarized incident signals fit for the designed polarization are able to enhance the beamforming gain, whereas those whose polarization is orthogonal to the designed one cannot see any EM-field reconfigurability. By contrast, if a dual-polarized RIS is deployed instead, as shown in Figure 4.3-3, it will gain considerable advantage such that the orthogonally polarized signals simultaneously showcase an improvement in focusing the reflected waves on an aimed direction. This holds effective too when the EM-fields rotate by some inclination angle, which is further set forth in Figure 4.3-4 and Figure 4.3-5. Suppose that the radio wave groups propagate towards a unipolarised RIS at an incident angle of either 45 degrees or -45 degrees in Figure 4.3-3, both the radio wave groups of orthogonal polarizations sustain a roughly 3 dB polarization mismatch loss as compared to a dual-polarized RIS in Figure 4.3-5.

To support dual-polarized unit cell design for a RIS, it may need to integrate more than one phase switching elements for phase control of the incoming orthogonally polarized EM waves. On the other hand, this may increase the overall power consumption and the complexity of control signalling and circuit designs.

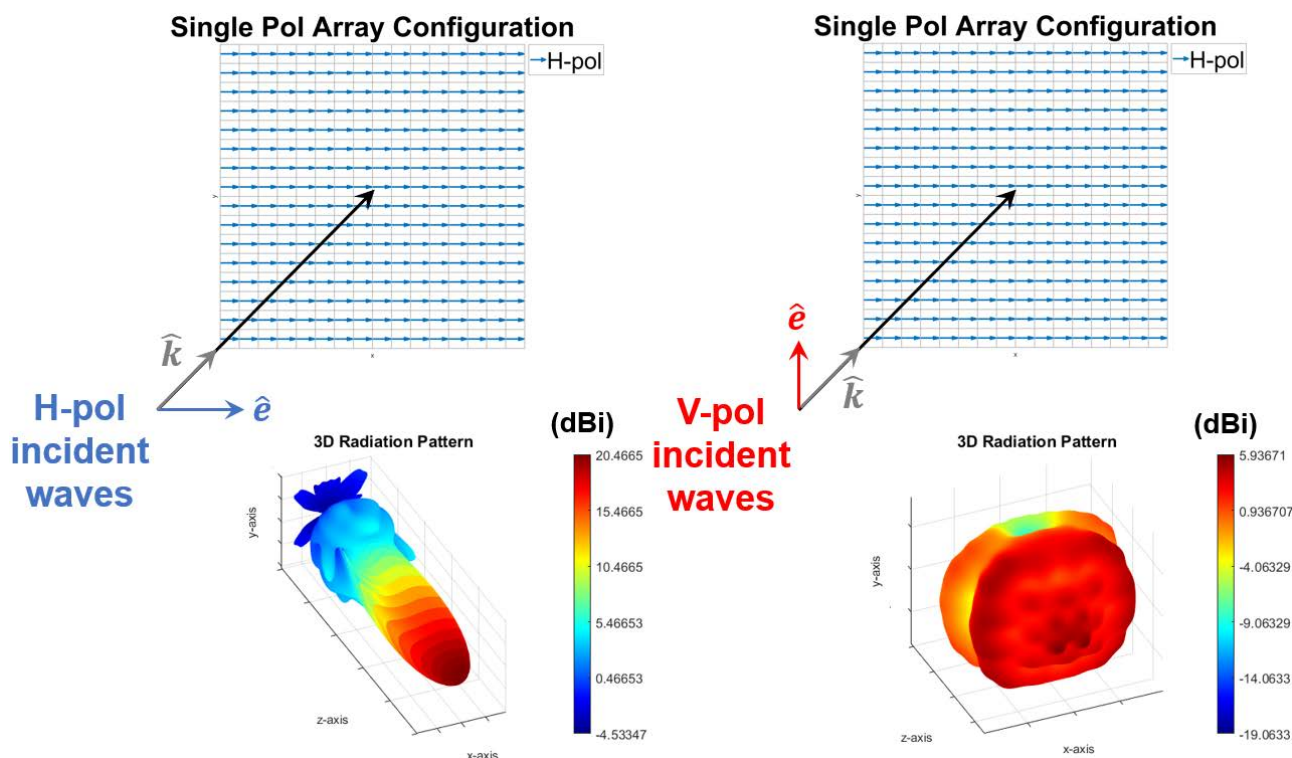


Figure 4.3-2: Scenarios of orthogonally polarized EM waves impinging on a RIS which only support specific polarization control and their corresponding radiation characteristics

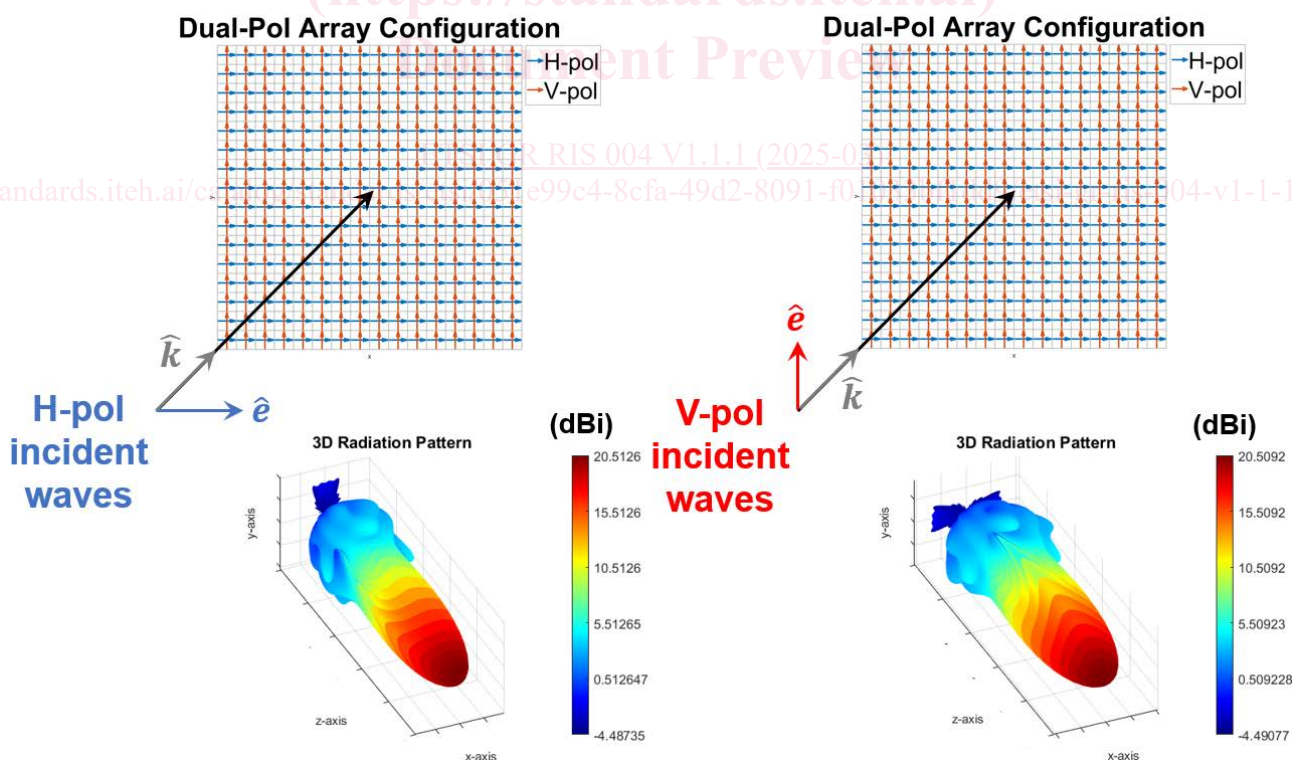


Figure 4.3-3: Scenarios of orthogonally polarized EM waves impinging on a RIS which fully support dual polarization control and their corresponding radiation characteristics

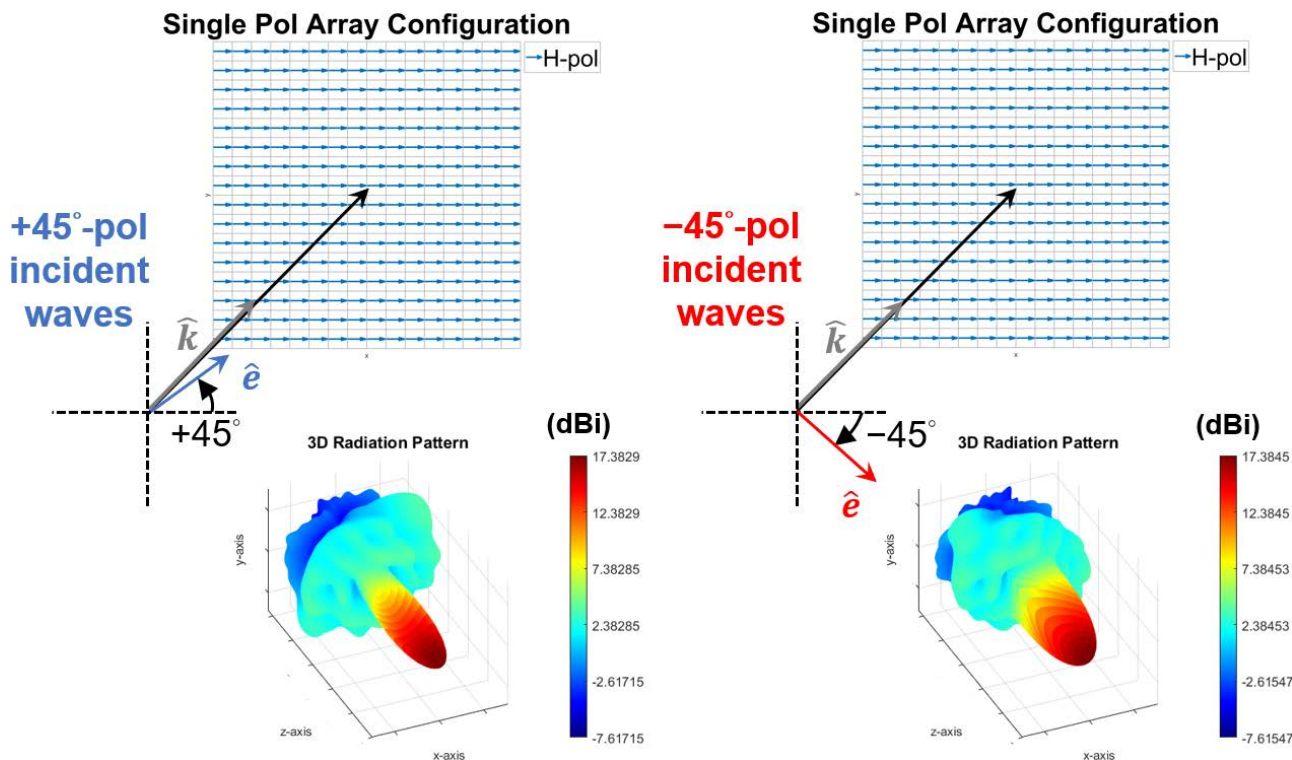


Figure 4.3-4: Unipolarised RIS illumination scenarios and radiation characteristics of orthogonally polarized EM waves impinging on a RIS at a slant angle of 45 degrees and -45 degrees with respect to the RIS arrangement

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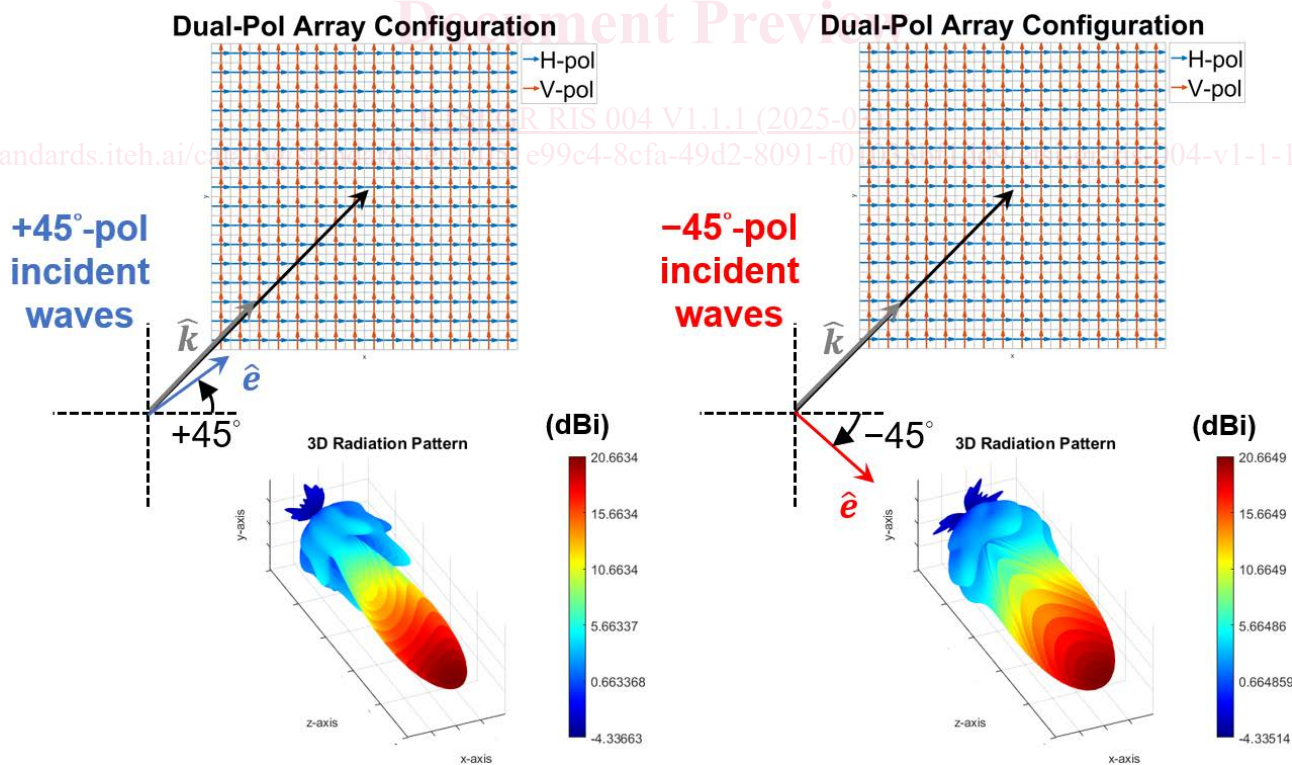


Figure 4.3-5: Dual-polarized RIS illumination scenarios and radiation characteristics of orthogonally polarized EM waves impinging on a RIS at a slant angle of 45 degrees and -45 degrees with respect to the RIS arrangement

4.4 RIS controller

Critical design aspects for RIS controller typically include:

- Power consumption
- Switching speed
- Cost

The selection of electronic components will vary depending on the phase switching mode, which could be either analogue or digital. The power consumption of the RIS controller is largely shaped by the number of required control lines and GPIO pins, which drastically increases in case of 2-Dimensional beam steering mode of operation. Digital logic expanders and transistor switching matrices can be used to reduce the number of utilized GPIO pins on the microcontroller/FPGA, but inevitably they add to the total system delay, which can be expressed as follows:

$$d_T = d_{sw} + d_{CPU} + d_{DAC} + \sum_{m=1}^M d_g + \sum_{m=1}^M d_p$$

where d_{sw} is the switching delay of the unit cell switching element, d_{CPU} is the microcontroller time delay that includes the rise/fall time, d_{DAC} is the time delay of the DAC in case of analogue switching method, M indicates the number of logic elements in the chain, d_g is the time delay of each additional logic gate in the chain and d_p is the propagation delay for each path in the dielectric material.

It can be experimentally shown that the total system delay is largely dominated by the d_{DAC} in an analogue RIS, therefore a digital RIS has the benefit of faster switching speed. However, the actual requirement for d_T will be dictated by the operational environment, which is subject to the 5G NR frame structure. This requirement can be calculated based on the Subcarrier Spacings (SCSs) specified in Table 5.3.2-1 of ETSI TS 138 101-1 [i.7], which are different for FR1 and FR2. For example, in a downlink dominated scenario, the entire Channel State Information (CSI) from the UE could be contained within a single time slot. Assuming FR1 frequency band and 15 kHz SCS, the d_T should be less than 1 ms to prevent packet loss during UE movement.

4.5 RIS interfaces

The RIS as a whole can be modelled as the combination of RIS controller and RIS panel (see Figure 4.5-1). The RIS panel comprises a group of elements, which can reflect, refract, or absorb incident radio waves. The various types of RIS will be detailed in later clauses of the present document. The RIS controller refers to a component of RIS, responsible for configuring the RIS elements to achieve a wanted way of manipulating the incident radio wave, potentially processing any signalling received from another network node. The configuration of the RIS element by the microcontroller is conveyed through control signalling from the RIS controller. Inside RIS, one interface is the interface between the RIS microcontroller and RIS panel to transmit the control signals.

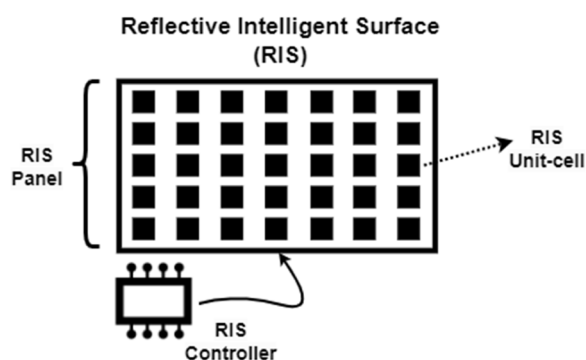


Figure 4.5-1: Illustration of a RIS comprising a RIS controller and a RIS panel

Integration of RIS into the network facilitates various applications, extending beyond the coverage-focused roles of integrated access and backhaul and network-controlled repeaters. The RIS multi-functionality allows the use range to expand from improving coverage to enabling wireless power transfer, supporting ambient backscatter communications, enhancing positioning accuracy, and strengthening secure communication.