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FEASIBILITY STUDY OF THE 2.7–2.9 GHZ FREQUENCY BAND FOR S-BAND WEATHER RADAR: OPERATIONAL AND REGULATORY PERSPECTIVES IN INDONESIA

Maulana Putra*[1], Sugiarto[1], Eko Wardoyo[1], Nasrul Wathon[1], Hanif Andi Nugraha[1]
Indonesian Agency for Meteorology, Climatology and Geophysics
E-mail: maulana.putra@bmkg.go.id

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Abstract

Weather radar is a vital component of atmospheric observation systems, particularly in tropical regions such as Indonesia that are highly vulnerable to extreme rainfall. The S-band frequency range is well known for its low rain attenuation and favorable propagation stability, making it suitable for long-range weather monitoring. However, the expansion of International Mobile Telecommunications (IMT) services in adjacent frequency bands introduces challenges related to spectrum coexistence and potential interference that require comprehensive assessment. This study evaluates the technical feasibility and regulatory compatibility of the 2.7–2.9 GHz frequency band for S-band weather radar operation in Indonesia by considering tropical rainfall characteristics, electromagnetic wave propagation, and national spectrum management dynamics. The analysis employs rain attenuation and rainfall distribution models based on ITU-R recommendations, along with a review of national and international spectrum regulations, including an assessment of potential interference from IMT systems through unwanted emission and emission mask analyses. The results indicate that S-band weather radar operating at 2.7–2.9 GHz exhibits low rain attenuation under high-intensity rainfall conditions and is capable of maintaining wide-area observational coverage. From a regulatory perspective, this frequency band is formally allocated and enables safe spectrum coexistence with IMT systems through the application of protection criteria, unwanted emission control, and appropriate guard band arrangements.

Keywords: Weather Radar, S-Band, Frequency Band

INTRODUCTION

Weather radar is a primary operational instrument in modern atmospheric observation systems due to its capability to monitor precipitation continuously with high spatial resolution and wide coverage [1]. In maritime tropical regions such as Indonesia, weather dynamics are predominantly governed by convective systems with high rainfall intensity [2, 3]. These characteristics make the interaction between weather radar electromagnetic waves and precipitation a key factor in determining observation quality, particularly in maintaining wide observation ranges. Therefore, selecting weather radar frequency bands must consider wave-propagation characteristics, particularly attenuation, to ensure reliable long-range observations. The increasing occurrence of extreme rainfall, flooding, and high-impact weather events in Indonesia demands weather radar systems that are not only sensitive but also capable of wide operational coverage. Several studies and technical recommendations indicate that S-band weather radar exhibits low rain attenuation [1, 4]. However, its utilization must be systematically assessed to ensure compatibility with Indonesia's atmospheric characteristics and national spectrum usage dynamics. Along with the growing demand for radio spectrum in the wireless communication industry, the use of the same or adjacent frequency bands to weather radar systems has intensified, potentially causing interference when microwave emissions from other devices are received by radar systems. To date, most reported interference cases have involved C-band radar; however, similar incidents in the S-band are increasing, as this band is also used by radionavigation radar systems for both civil and military purposes [5]. This condition increases the urgency of this study, particularly in relation to the development of International Mobile Telecommunications (IMT) services in adjacent frequency bands, which must be managed through appropriate technical and regulatory approaches. Previous studies have discussed the technical parameters of S-band weather radar, the quality of polarimetric radar products, and protection criteria against interference [6-8]. On the other hand, ITU-R documents provide standard models for rainfall distribution and rain attenuation that are widely used in radio system planning. However, most of these studies have not explicitly linked the technical performance of S-band radar with Indonesian tropical rainfall statistics and the suitability of national spectrum regulation within a single integrated analytical framework. Based on this review, a research gap remains in evaluating the use of the 2.7–2.9 GHz frequency band for S-band weather radar through an approach that integrates wave-propagation aspects, tropical rainfall distribution, and spectrum regulation. In particular, there is a lack of studies assessing the implications of spectrum coexistence with IMT systems operating in adjacent frequency bands. This gap results in the absence of a comprehensive scientific basis for informed decision-making and policy formulation. This study contributes to the scientific literature by analyzing the technical feasibility of S-band weather radar propagation at 2.7–2.9 GHz and evaluating compliance with national and international spectrum regulatory requirements. In addition to assessing rain attenuation and propagation stability, this study also examines potential interference from IMT systems through unwanted emission and emission mask analysis. This approach provides an integrated analytical framework that connects meteorological, spectrum management, and regulatory aspects.

METHODS

This study adopts a literature-based approach, drawing on documents on radio wave propagation and rain attenuation, particularly ITU-R recommendations and technical documents on S-band weather radar. The analyzed data include technical parameters of S-band weather radar, such as operational range, Pulse Repetition Frequency (PRF), pulse width, sensitivity, attenuation characteristics, and frequency spectrum allocation regulations as the basis for evaluating the suitability of the frequency band for weather radar operations. Technical feasibility analysis is conducted by evaluating electromagnetic wave propagation characteristics at 2.7–2.9 Hz in a high-rainfall tropical environment using rain attenuation models [9] and rainfall distribution models [10]. In addition, this study examines compliance with national frequency regulation and the potential for inter-service interference, and assesses the operational role of S-band radar in supporting weather monitoring across Indonesia. Regulatory suitability analysis is carried out through a normative review of the frequency spectrum management framework. This analysis evaluates the frequency-allocation status, applicable service equivalence, and interference-protection criteria to ensure reliable weather radar operations. Furthermore, the analysis includes an assessment of potential cross-service interference from IMT systems operating in adjacent frequency bands, including requirements for unwanted emission control and emission masks, to ensure safe and sustainable spectrum coexistence.

RESULTS AND DISCUSSION

3.1 Technical Feasibility of Using the 2.7–2.9 GHz Frequency Band for S-Band Weather Radar

The use of S-band weather radar operating at 2.7–2.9 GHz is highly optimal, as radar systems within this range typically feature peak transmit power of 400–750 kW, pulse widths of 1–4.7 µs, RF bandwidths of 4–13 MHz, and pencil-beam antennas with gains reaching 38–45 dBi. These characteristics provide high sensitivity to hydrometeors and enable observation ranges exceeding 400 km [11], as illustrated in Figure 1. These parameters are consistent with Table 2 of Recommendation ITU-R M.1464-1, which presents the performance of two representative weather radar systems operating at 2.7–3.0 GHz with high efficiency for precipitation detection and atmospheric dynamics observation [12]. As an archipelago country with vast maritime areas and tropical weather dominated by convective systems, Indonesia requires long-range, low-attenuation weather radar systems, making S-band radar at 2.7–2.9 GHz a relevant solution for supporting marine weather observation and mitigating extreme weather risks in national waters.

The main advantage of S-band weather radar is its superior rain penetration [13]. In tropical regions such as Indonesia, convective rainfall is characterized by very high intensity and larger drop sizes [14, 15]. Lower operating frequencies, such as those of S-band radar, experience minimal attenuation, thereby preserving rainfall structure information over long distances [16]. Analysis of return signal quality parameters, including reflectivity (Z), differential reflectivity (ZDR), and correlation coefficient (ρhv), indicates that S-band radar under low-interference conditions can maintain the accuracy of basic radar products [7]. This is reinforced by Annex 3 of Recommendation ITU-R M.1464-1, which states that the minimum signal level for stable processing corresponds to an S/N of approximately −3 dB, while interference begins to degrade reflectivity accuracy when I/N reaches −9 dB (1 dB bias). Furthermore, the variance of radial velocity (for V and ρhv estimation) increases significantly at I/N = −3 dB, indicating that the 2.7–2.9 GHz band remains highly suitable provided that adequate spectrum protection is ensured [12].

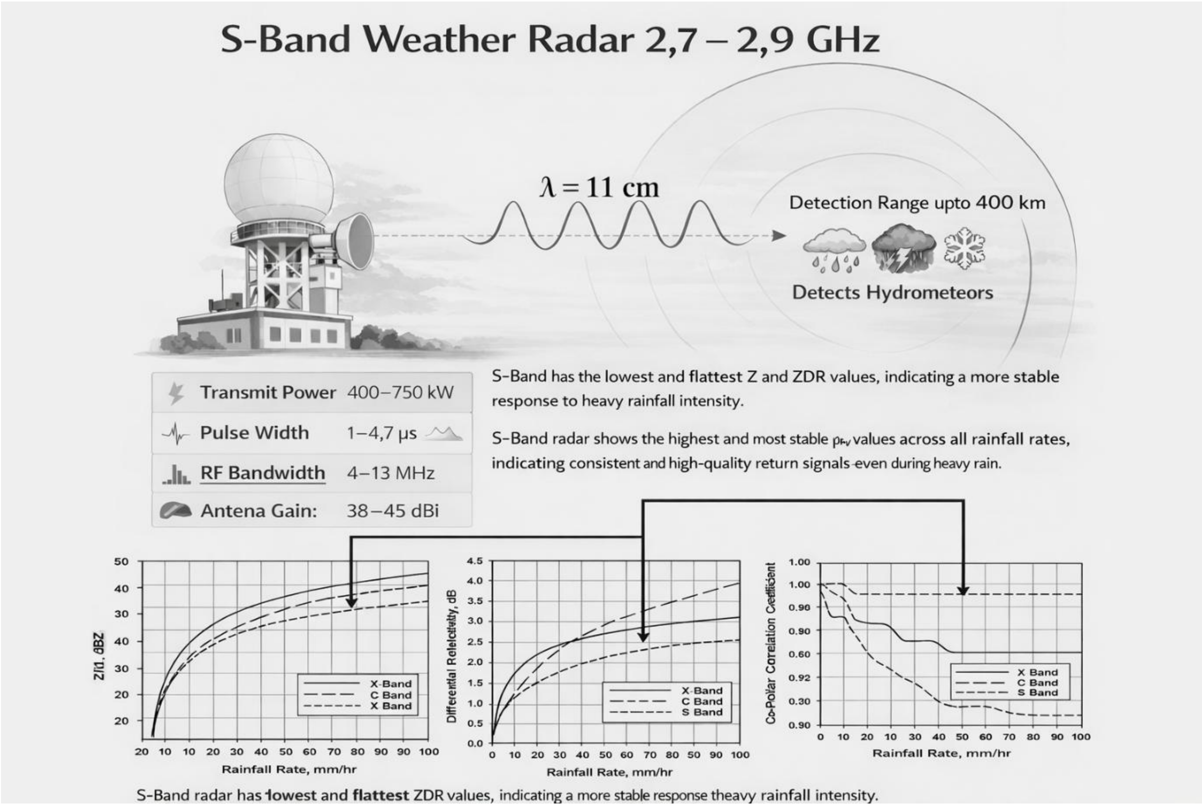

Figure 1. S-band weather radar (2.7–2.9 GHz) schematic with a wavelength of approximately 11 cm, capable of observing up to 400 km with low attenuation.

Simulations of tropical rainfall distribution based on ITU-R P.837-8 and attenuation models from ITU-R P.838-3 show that wave propagation at 2.7–2.9 GHz remains stable under heavy rainfall conditions. Extreme rainfall rates at the study location are represented by R_p (mm/h). Specific rain attenuation dB/km is expressed as $\gamma R = kR^{\alpha}$, where k and α depend on frequency and polarization. As an approximation at 3 GHz (representative of S-band), ITU-R P838 coefficients are approximately $k_H \approx 1.39 \times 10^{-4}, \alpha_H \approx 1.232$ (horizontal polarization) and $k_V \approx 1.94 \times 10^{-4}, \alpha_V \approx 1.069$ (vertical polarization). Thus, for rainfall intensity R = 100 mm/h:

$$\gamma R, H \approx 1.39 \times 10^{-4}\,(100)^{1.232} \approx 0{,}04\ dB/km$$
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Path attenuation over an effective rain path lengthL_{eff} can be estimated as $A_R \approx \gamma R\, L_{eff}$. For L_{eff} = 50 km, $A_R \approx 1.5 - 2\, dB$, indicating that rain attenuation in the S-band remains relatively low even under intense rainfall conditions.

3.2 Regulatory Compatibility

The 2.7–2.9 GHz frequency band used by S-band weather radar has been officially allocated by the Government of Indonesia through the Indonesian Radio Frequency Spectrum Allocation Table under Ministerial Regulation No. 12 of 2022 [17] designating this band for the radiolocation service, including meteorological radar. This allocation ensures that S-band weather radar operations comply with national regulations and align with ITU Region 3 allocations, which designate the band as a primary allocation for radiolocation and radionavigation services.

Empirical findings from spectrum sharing policy implementation indicate that frequency sharing in the 5 GHz band has increased interference incidents affecting C-band weather radar and significantly degraded observation quality, despite the implementation of protection provisions under ITU Radio Regulations and ITU-R recommendations. This condition suggests that reactive protection measures are insufficient, necessitating a more preventive spectrum management approach to safeguard critical meteorological radar services. Accordingly, the planned and ongoing deployment of mobile IMT services in the 2.6 GHz band requires particular attention to spectrum operational aspects, especially the potential for IMT system emissions to leak into the S-band weather radar spectrum, as illustrated in Figure 2. The proximity of these frequency bands poses a risk of interference from 4G LTE Base Transceiver Stations (BTS), particularly in areas with high BTS density. Experience from C-band weather radar deployment in the 5 GHz band demonstrates that interference from RLAN technologies has significantly degraded radar data quality, even with the implementation of Dynamic Frequency Selection (DFS), indicating the inadequacy of reactive protection approaches [18]. Supporting policies such as guard band allocation and emission mask enforcement are therefore essential to ensure safe spectrum coexistence, particularly as the number of S-band radar installations in the national observation network increases alongside the projected growth of 4G/5G IMT systems. At the international level, Recommendation ITU-R M.1849-3 [19], provides the basis for national spectrum policy formulation for S-band weather radar. This document states that meteorological radars worldwide primarily operate in three main bands, one of which is 2,700–2,900 MHz. Recommendation ITU-R M.1849-3 further stipulates that RR No. 5.423 applies to this band, under which meteorological radar operates on an equal basis with aeronautical radionavigation. In addition, the recommendation describes the technical characteristics of 2.8 GHz radar, its sensitivity to interference, and the need to apply an I/N protection criterion of −10 dB to maintain the accuracy of fundamental radar products, such as reflectivity, radial velocity, and spectrum width. Consequently, Indonesia's national regulations are not only consistent with the ITU framework and reinforced by global technical standards for spectrum planning and interference mitigation, but also promote spectrum harmonization among stakeholders and strengthen inter-agency coordination involving BMKG, Komdigi, AirNav, and the Indonesian Armed Forces to ensure interoperability of the national weather radar network.

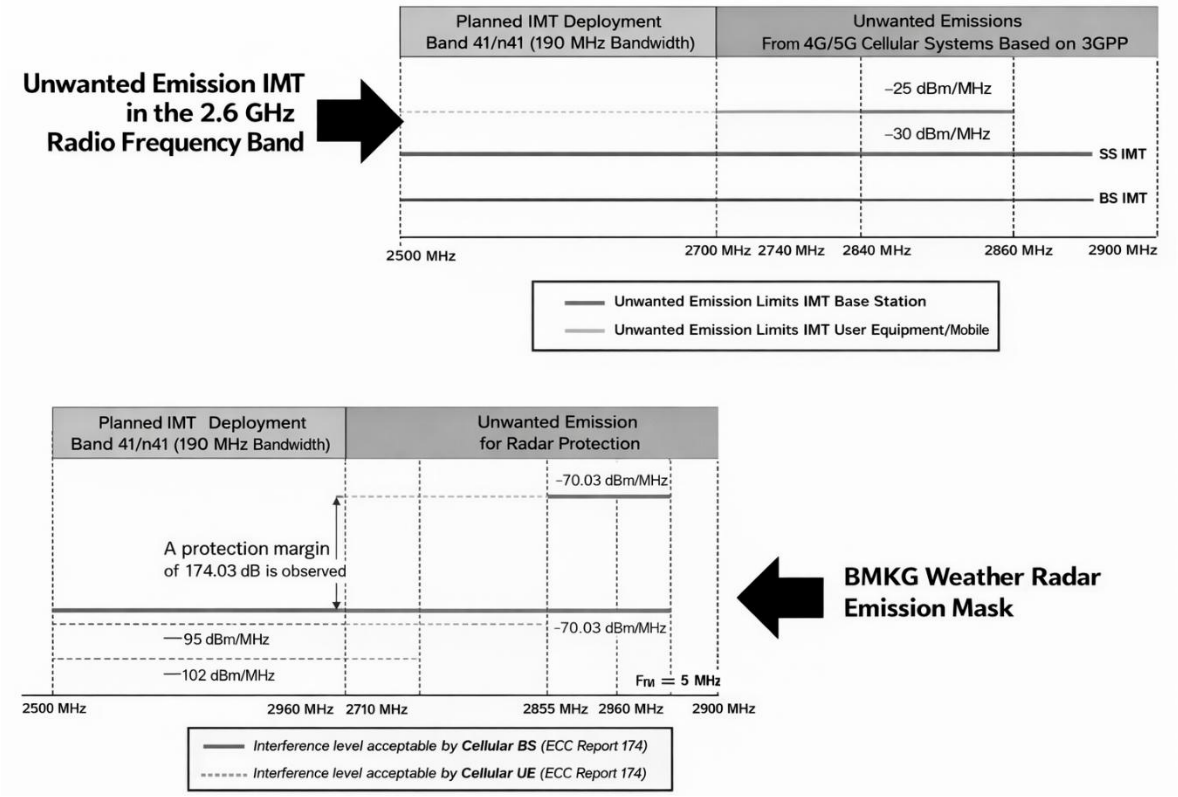

Figure 2. Analysis of unwanted emission and emission mask between S-band weather radar spectrum and IMT systems operating in the 2.6 GHz band.

CONCLUSION

This study demonstrates that the use of S-band weather radar operating in the 2.7–2.9 GHz frequency band is both technically and regulatorily feasible for supporting weather observation systems in Indonesia. Propagation analysis confirms that this frequency band exhibits low rain attenuation and high signal stability under high-intensity rainfall, enabling wider observation ranges. From a regulatory perspective, the 2.7–2.9 GHz band has been legally allocated for radiolocation services and is consistent with the ITU-R framework, while also allowing safe spectrum coexistence with IMT systems operating in adjacent frequency bands through the application of protection criteria, unwanted emission control, and emission mask regulations. Therefore, the utilization of S-band weather radar in this band not only fulfills national meteorological operational requirements but also aligns with principles of efficient, coordinated, and sustainable spectrum management amid increasing radio spectrum congestion.

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