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FIELD MEASUREMENT TEST ON PROTECTION RATIO FOR DVB-T2 INTERFERED BY TV WHITE SPACE DEVICES

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Abstract

TV white space (TVWS) refers to the unused UHF and VHF spectrum owned by primary users, such as TV (DVB-T2) broadcasters in a certain location. The protection of primary users' interference from white space devices has been the major implementation issue. Protection ratio setting is commonly used to limit the amount of transmission power that white space devices can permit. In the present study, the simulation and experiment for the proposed protection ratio values are compared. Simulation using Monte Carlo has been conducted. Field measurements were implemented to see whether the protection ratio value could be used to assist the government in implementing TVWS. The outcomes showed that the simulation-based protection ratio was 1 dB greater than the field test result. The results indicate that the simulation model can be used as a reference for the government to estimate the value of the protection ratio and facilitate better efficient implementation.

Keywords: Index Terms—TVWS; Protection Ratio; DVB-T2; Field Measurement

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Introduction

White space refers to the unused frequency spectrum in the wireless spectrum. In 2011, the Federal Communications Commission (FCC) and the Electronic Communications Committee (ECC) have opened up the opportunity to use white space channels (*Third Memorandum Opinion and Order, in the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices below 900 MHz and in the 3 GHz Band*, 2012). Both agencies have published a TV White Space (TVWS) framework using different approaches, primarily to protect primary users, i.e., Digital Television Terrestrial (DTT) broadcasters. The TVWS framework is tailored to the environment. However, no framework is the same across countries that implement TVWS (TRAAC, 2014). Owing to the interference problem, authorities in many countries argue about whether to allow the TV channels or other bands for secondary purposes (Foo, 2017; Freyens & Loney, 2013; Nekovee, Irnich, & Karlsson, 2012). Therefore, the FCC and ECC use the protection ratio value to protect the primary users of Digital Television Terrestrial (DTT). In this study, we consider

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DVB-T2 as the DTT standard Note, in which the protection ratio is referred as the ratio of the primary system's field strength and the secondary system's field strength in the receiver (ITU-R, 2007; *Planning Criteria, Including Protection Ratios, for Digital Terrestrial Television Services in the VHF/UHF Bands*, 2017; *Planning Criteria, Including Protection Ratios, for Second Generation of Digital Terrestrial Television Broadcasting Systems in the VHF/UHF Bands*, 2015). The protection ratio maintains a minimum carrier-to-interference (C/I) ratio. The European Telecommunications Standards Institute (Union, 2012) provides the minimum desired signal-to-noise ratio (C/N) that a DVB-T2 system can tolerate, revealing that the C/I value will be equivalent to C/N with the absence of an intruder. With or without an interferer, if the ratio of the signal intensity (C) to the unwanted signal (N + I) is less than a specified threshold, the receiver can receive better information. On the other hand, the C/I value is measured at the receiver input based on the antenna gain and cable loss. In practice, the field strength is used to calculate the transmitter coverage area. The propagation model, transmitting antenna gain, and noise have effects on the value of the field strength. The magnitude of the field strength at the receiver level varies, which depends on the location (Lessy Sutiyono Aji, Witjaksono, Wibisono, & Gunawan, n.d.). Therefore, the protection ratio must accommodate these variations.

A study (L S Aji, Juwono, Wibisono, & Gunawan, 2018) uses Monte Carlo simulation to propose a new protection ratio calculation against White Space Device (WSD). The study (L S Aji et al., 2018) complements the value of the protection ratio, where the FCC proposes a more specific DTT system, namely DVB-T2. However, this approach (L S Aji et al., 2018) lacks field measurement. As a result, the present study reports field measurements to compare the simulation findings of the protection ratio value with the real conditions. In this analysis, we use a case study of DTT TVRI Patuk Jogjakarta's coverage region in Indonesia. DVB-T2 64 QAM is the digital TV standard used in Jogjakarta. The white space device used in the case is the GWS 3000, which has a 5 MHz bandwidth (FCC, 2018; Inc., 2013).

The measurement method is adopted based on the recommendation by the International Telecommunication Union (ITU) (ITU-R, 2016, 2018; ITU, 2011; *Planning Criteria, Including Protection Ratios, for Digital Terrestrial Television Services in the VHF/UHF Bands*, 2017). During the field measurement, we found that the bandwidth of the GWS 3000 equipment differed from the ITU guidelines. As a result, a significant discrepancy is noted between the simulation and the field measurements. After adjusting the WSD bandwidth in the GWS 3000 device stimulation, the results of the Monte Carlo simulation computation showed that the protection ratio value was 1 dB higher than the protection ratio value acquired from the field experiments.

The rest of the paper is structured as follows: Section II revisits protection ration matters, including the DVB-T2 and WSD standards. Section III discusses the methodologies used in modeling and carrying out the field measurements. Section IV presents the results and analysis. Finally, Section V concludes the paper.

A. Protection Ratio

To preserve a specified minimum C/I value, the protection ratio is defined as the ratio of the primary user's (DTT) field strength value to the secondary user's (WSD) field strength value, as measured at the receiver. C/I is defined as the ratio of the intended signal strength to the interferer signal strength at the receiver input (Achtzehn, Riihijärvi, & Mähönen, 2014). The protection ratio varies depending on the DTT system. As a result, determining the DTT system becomes critical in providing protection requirements. To correctly receive information, the distinction between DTT systems is critical to evaluate the minimal C/N value required by DTT recipients. The discrepancy in the C/N value will influence the device's sensitivity level, thereby impacting the protection ratio value as computed on the DTT receiver's sensitivity level. Table I shows the DVB-T2 and WSD/IEEE 802.22 WRAN specifications. The IEEE 802.22 was chosen to represent the white space in outdoor conditions.

Tabel I
Specifications Of Dvb-T2 (ITU-R, 2014; Union, 2012) **And Wsd/Ieee 802.22** (IEEE, 2011)

Specification	DVB-T2	IEEE 802.22/ WSD
Modulation	64 QAM	64 QAM
Noise Floor	-129.16 dBm	-105.071 dBm
Sensitivity	-109.63 dBm	-67.067 dBm
Freq. Range	610 – 634 MHz	610 – 634 MHz
Transmitter Height	40 Meters	40 Meters
Receiver Height	10 Meters	10 Meters
Power	60 dBm	Varying
C/N	18.89 (19.53 dB)	(18.3 dB)

Method

A. The calculation of Protection Ratio by simulation

Path loss $PL(d)$ at a given location is randomly distributed owing to the shadowing effect at many measurement locations (Ribeiro et al., 2012). A statistical approach is appropriate for this case, using the Monte Carlo method, which relies on repeated random sampling to obtain values that represent uncertain conditions (L S Aji et al., 2018; Gunawan, Saraswati, & Aji, 2019; Oberle, 2015).

This present study uses the same simulation applied by (L S Aji et al., 2018) to find the value of the protection ratio as follows (see Fig. 1):

1) The DTT transmits power (PDTT) is set to 60 dBm (1000 watts).

2) The distance between the DTT transmitter and the victim link receiver (VLR) is set to one kilometer.
3) The white space transmitter is one kilometer away from the VLR.
4) The heights of the DTT transmitter and the WSD transmitter height are set to hDTT = hWSD = 40 m.
5) The height of the VLR antenna is 10 meters.
6) The WSD transmit power is adjusted such that the interference probability is less than 5%.

Furthermore, the aforementioned scenario in the VLR implies that the DTT and WSD transmitter field strength levels are the same. As a result, the ratio of P_{DTT} to P_{WSD} at the transmitter is identical to the E_{DTT} to E_{WSD} ratio at the receiver.

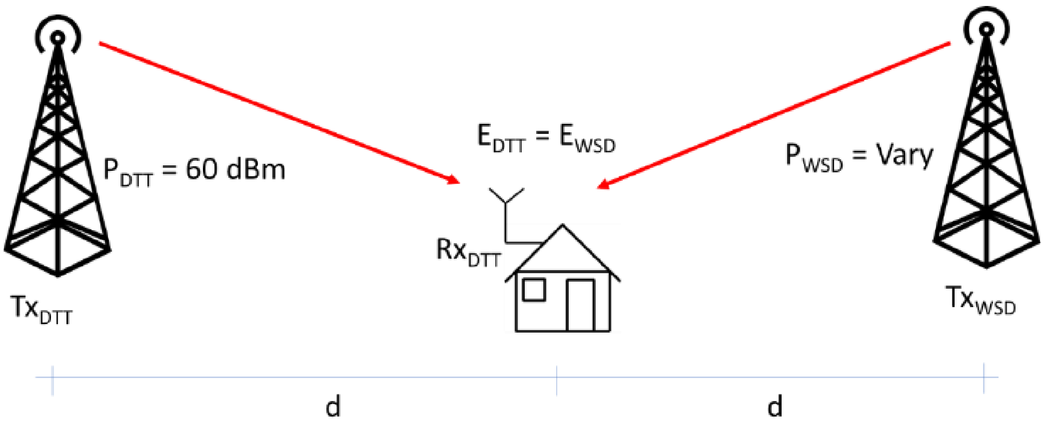

Figure 1
Simulation scenario (L S Aji et al., 2018)

It is assumed that the white space transmits normal distribution power with a standard deviation of 5.5 dB owing to the impact of field circumstances. The protection ratio value is the ratio between P_{DTT} and P_{WSD}, where the probability of interference $P_r\{Int\}$ is below 5%.When there is no interference, the level of confidence is 95% (du Prel, Hommel, Röhrig, & Blettner, 2009; Rorabacher, 1991). Equation (1) defines the algorithm to find the protection ratio values. Equation (2) reveals that the ratio of P_{DTT} to P_{WSD} used in the calculation is at the condition where DTT field strength DTT E_{DTT} is bigger than the minimum field strength value E_{min}.

$$PR = \left(\frac{P_{DTT}}{P_{WSD}} \middle| P_r\{Int\} \leq 5\%\right) \tag{1}$$

Where,

$$P_r\{Int\} = \Pr\left\{\frac{P_{DTT}}{P_{WSD}} \geq {}^{C}/_{I},\ E_{DTT} > E_{min}\right\}, \frac{P_{DTT}}{P_{WSD}} = N(\mu, \sigma) \tag{2}$$

Fig. 2 depicts the relationship between the PDF of the desired signal and the PDF of the undesired signal. The likelihood of disturbances occurrence is a circumstance in which the C/I minimal value is difficult to be attained. The blue mark represents the desirable signal's PDF. The red mark represents the undesired signal's PDF. As mentioned in equation (1), the disruption occurs inside the circle, revealing where the point of the probability is below 5%, as shown in Fig. 2.

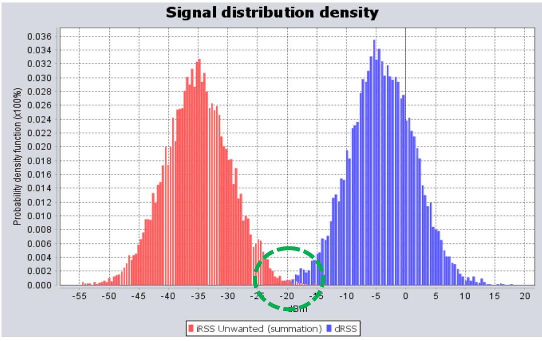

Figure 2
Relation between PDF wanted signal and PDF unwanted signal

The amount of unwanted/undesired signals is determined by the masking limit of the WSD. As shown in Figure 3, the IEEE 802.22 recommends the masking limit for WSD. The attenuation outside the usable bandwidth is 55 dBc to protect the primary user from interference. The FCC, in the third memorandum of opinion and order, revised the attenuation from 55 dBc to 72.8 dBc to accommodate differences in measurements due to differences in bandwidth (*Third Memorandum Opinion and Order, in the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices below 900 MHz and in the 3 GHz Band*, 2012).

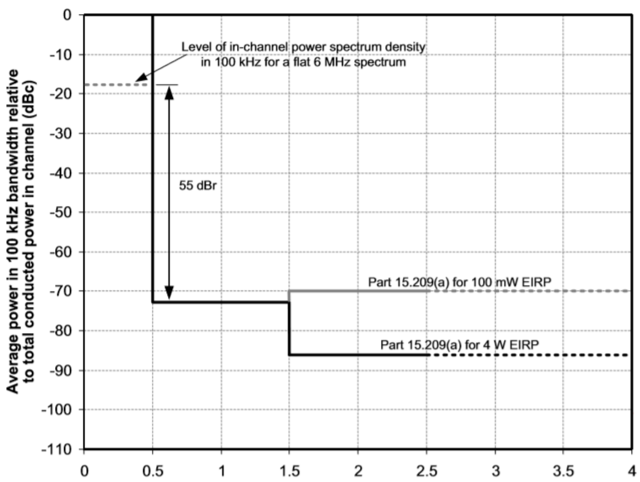

Figure 3
Masking limit WSD (IEEE, 2011)

B. Field Measurement Methodology

To verify the accuracy of the simulation model, the protection ratio field measurement is used to compare the findings of the Monte Carlo simulation with the real measurement results. The measurement is performed at two locations. Fig. 4

depicts the position of the TVRI Patuk transmitter and the two measurement locations.

Figure 4
Field measurement location

In Fig. 4, the measurement site is within the TVRI Patuk service area. TVRI patuk has a 150-meter transmitter height and a transmit power of 5000 watts. Table II shows the digital broadcast system used by TVRI Patuk.

The features of the white space equipment comprise of the fixed type and a maximum transmit power of 20 dBm or equivalent to 100 mW, which includes other technical specifications following the GWS 3000 device standard specifications (FCC, 2018; Inc., 2013). The white space transmitting antenna is mounted at a height of 20 meters above the transmitting tower. On the other hand, the TV signal receiving antenna and white space receiver is mounted at a height of 10 meters above the ground, as illustrated in Fig. 5.

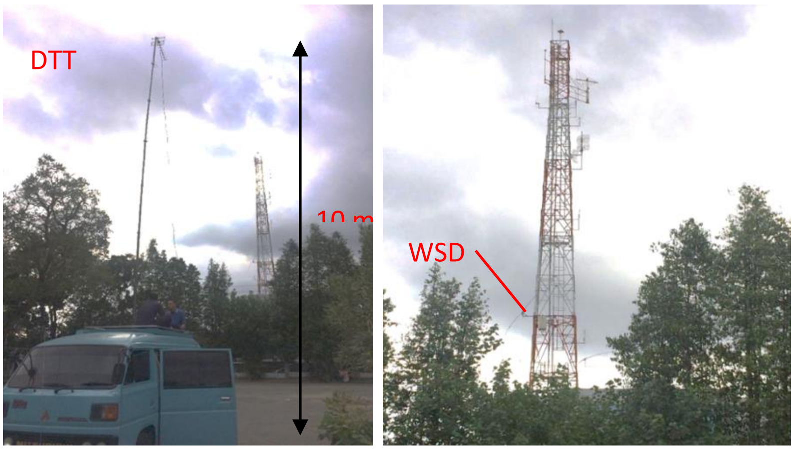

Figure 5
The Placement Setting of White Space transmitter and TV Digital Receiver

A visual approach is used to compute the quantity of the DVB-T2 protection ratio, as recommended by the ITU (ITU-R, 2016). The transmission power of white space steadily increased until a subjective failure point (SFP) is achieved, as indicated by visual disturbance or a reduction in video quality (*Planning Criteria, Including Protection Ratios, for Digital Terrestrial Television Services in the VHF/UHF Bands*, 2017). The Agilent N9344C was used as a spectrum analyzer. However, the Rohde & Swartch EFL 240 was used to assess digital TV reception quality. To assess the protection ratio, the minimum field strength value is set to 65 dBV/m (ITU-R & BT.417-5, 2002). Fig. 6 summarizes the methodology of the measurement scenario. The digital broadcasting TV receiving antenna uses a Yagi antenna (9.88 dBi gain antenna). However, the Anritsu MP651B antenna is used for white space receivers. A 10 meters long RF cable is also used to connect the receiving antenna with the measurement instrument.

Table 2
The Spesification System of DTT Tvri Patuk

Spesification	Values
Modulation	64 QAM
Code Rate	4/5
FFT	16 K
Guard Interval	1/8
Pilot Patern	PP8
FEC	64 K

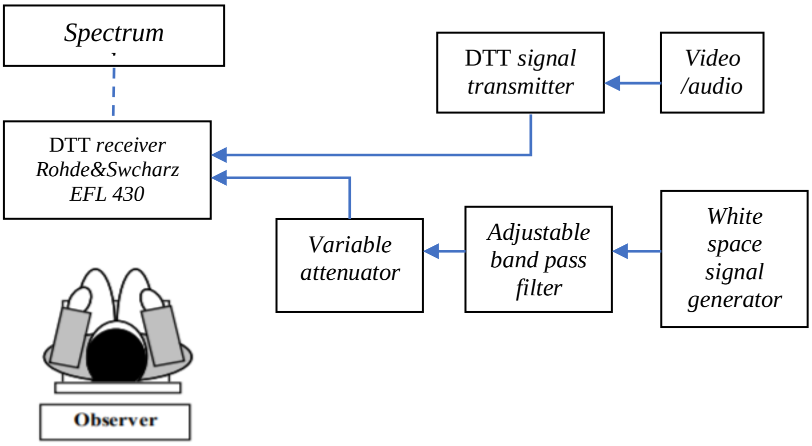

Figure 6
The protection ratio measurement scenario

Results and Discussions

A. Simulation Results

This section shows the result of the protection ratio for DVB-T2, in which the IEEE 802.22 transmitter is an interferer using the approach of the previous section. In Indonesia, particularly during the DVB-T2 deployment, not all TV transmitters use the same modulation scheme. This study employs the DVB-T2 protection ratio and a 64 QAM system based on the Jogjakarta TV modulation scheme. The simulation is run with WSD, used as a fixed white space device; the scenario is described in Section III. The fixed equipment is chosen because these devices are ideal for rural regions, particularly in developing countries. The Ricean fading channel arises at the outdoor fix device (ITU-R, 2014). Table III lists the detailed parameters used in the simulation.

First, the desired received signal strength (dRSS) and the interferer received signal strength (iRSS) are calculated. To accommodate the fading effect, 10000 random values are generated for each dRSS and iRSS value with a standard deviation of 5.5 dB, as illustrated in Fig. 7. Note that The Office of Communications recommends a minimum of 1000 iterations to arrive at the desired value using the Monte Carlo method (Ofcom, 2010). However, Winston (Winston, 2000) suggested that more iterations will reduce the error value. In this study, 10000 repetitions were used to get the maximum error value of 0.00498 (Driels & Shin, 2004). Fig. 7 depicts an example of generating a random number of 10000 repetitions, representing the variation of the dRSS value received by the DVB-T2 receiver. These random numbers are generated for iRSS and dRSS at each test channel to determine their effect on the first and second co-channel and adjacent channels.

Table 3
Dtt Parameters To Be Implemented In The White Space Channel In Calculation Algorithm

Details	
Standardization	DVB T-2
Bandwidth	8 MHz
FFT size	16K
Channels	28 – 45
Constellation	64 QAM
Pilot Pattern	PP2
Code Rate	4/5
Guard Interval	1/8
Block Length	64800
C/N	18,98
DTT Antenna Height	40 m
EIRP	1000 W
Antenna's Radiation Pattern	Omnidirectional

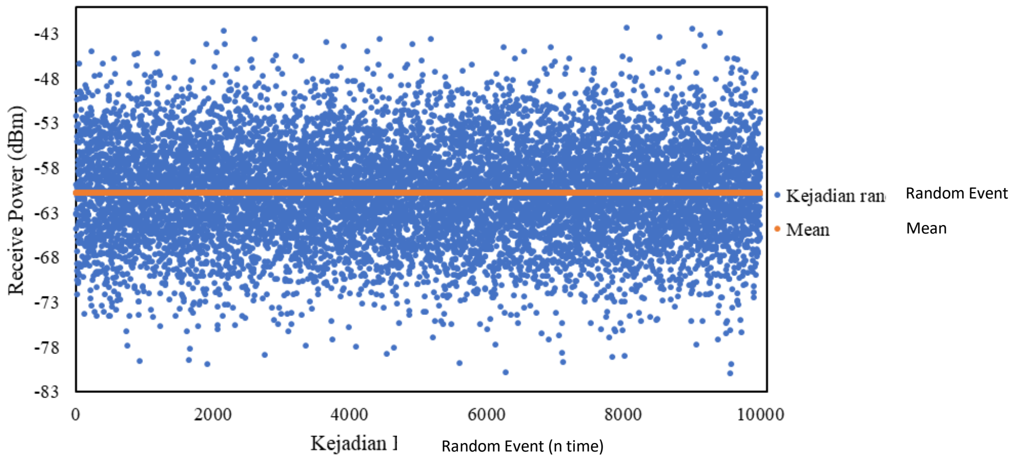

Figure 7
dRSS generation

Fig. 8 shows the calculation procedures of the maximum transmitted power of a white space transmitter. The maximum transmitted power of white space is the amount of maximum transmit power that shows the maximum probability value of interference to be 5% (Cheng, Wang, Yun, & Lee, 2014; I.-K. Cho, Lee, & Park, 2013; I. Cho, Lee, & Park, 2012; Mathe, Freitas, Farias, & Costa, 2014). In other words, with a significance value (p) of 5%, the minimum value of the probability of non-interference (PoI) is 95%. By using equation (1), the value of the protection ratio is obtained and summarized in Table 4.

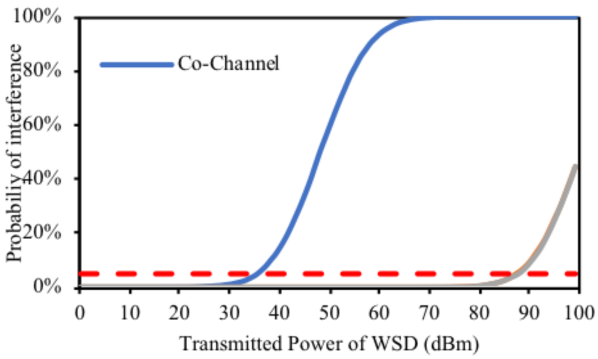

Figure 8
Maximum WSD transmit power on DVB-T2 64 QAM system

Table IV shows the protection ratio values based on the simulation result. The stated value is rounded up from the actual value of the simulation results (ITU-R, 2016). The symbol $\Delta f = \{0, \pm 1, \text{and} \pm 2\}$ represent the co-channel, the first adjacent channel, and the second adjacent channel.

Table 4
The Protection Ratio Values Based on Simulation

Δ f	64 QAM
0	25
±1	−28
±2	−28

B. The Protection Ratio Values based on Field Measurement

For each signal, the power value received by the measuring equipment is calculated based on the measurement findings. When the DTT reception was disturbed, the protection ratio value was calculated by subtracting the received DTT power from the WSD received power. Table V gives a recapitulation of the measurement findings.

Table 5
The Protection Ratio Values Based on Field Measurement

No	White Space Transmitter Coordinate		Receive Power DTT (dBm)	Receive Power WS (dBm)	PR (dB)
	Latitude	Longitude			
1	7°48'19.28"S	110°23'32.74"E	-112,85	-83,57	29,28
2	7°47'10.54"S	110°22'37.66"E	-105,10	-76,59	28,51

For location 2, the protection ratio measurement was 29.28 dB for sites 1 and 28.51 dB. The protection ratio was 29.05 dB when an average of the two values was approximated. When the white space operated on the same channel as the principal user/co-channel, the protection ratio was calculated. The measurement results could not be acquired for the activities of neighboring channels since the WSD GWS 3000 device had a maximum power of 20 dBm, and no interference had been identified for the primary user. Although the point of failure for neighboring channels had not been identified, it was demonstrated that TVWS operations on adjacent channels had significant potential.

As listed in Table V, the protection ratio value based on simulations is 25 dB for WSD operations on a co-channel. As determined from field measurements, the amount of protection ratio is 29 dB, leading to differences of 4 dB. From the result, the simulation assumes that the FCC requirement for WSD bandwidth is 1 MHz (FCC, 2012). When the WSD bandwidth in the field measurement is 5 MHz, the usable bandwidth is 3 MHz based on the GWS 3000 tool requirements, as illustrated in Fig. 9. The change in bandwidth produces a difference in the iRSS quantity at the receiver side, resulting in a greater protection ratio. If the simulation uses the same bandwidth as the GWS 3000 device, the maximum WSD transmitted power value is 30 dBm, according to (1). Thus, the protection ratio is 60 dBm – 30 dBm = 30 dB for a DTT transmit power of 60 dBm. Based on these findings, a 1 dB discrepancy is still noted between the measurement and simulation results. This is because the simulation value of 1 dB is added as an erosion margin for the device and other variations (Beek et al., 2012).

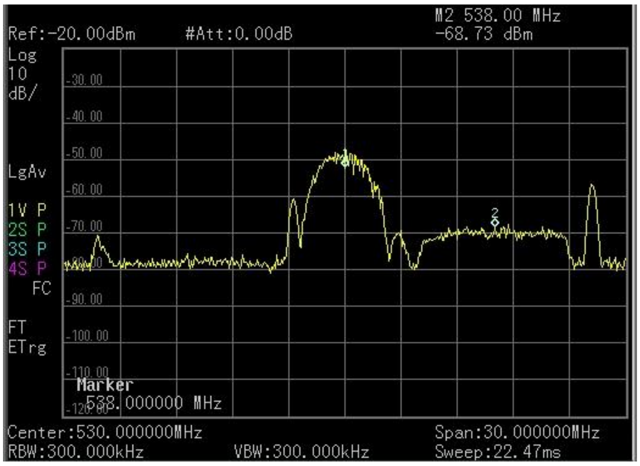

Figure 9
White Space Emission at a maximum power of WSD transmitter

Based on the findings of these field measurements, it is reasonable to conclude that the value of the protection ratio based on the Monte Carlo simulation and the field measurements results are insignificantly different. Alternatively, the simulation-based protection ratio value can be implemented in the field. Moreover, the greatest value of the 5% interference can match the real field circumstances. However, the demonstrated protection ratio is only for co-channels. Since the GWS

3000 device has a maximum transmit power of 100 mW, it cannot cause interference to adjacent channels. Furthermore, the number of test points is restricted to two. In the future, more points are required to enhance data quality and present findings that represent varied circumstances in the field.

Conclusions

The simulation results are compared with the field measurement results of the TVRI Patuk service area, Jogjakarta. The outcomes showed that the WSD channel width based on the FCC recommendations was different from the WSD channel width of the GWS 3000 device. After adjustment, it was found that the protection ratio value based on the simulation was 30 dB, whereas the protection ratio value from the field measurements was 29 dB, revealing a difference of 1 dB. This indicates that the Monte Carlo is quite close to the results of field measurements. The government can use the results to define the protection values. Using simulation only, the government can still obtain valid results without field measurements. However, it is necessary to add points to enrich the data to obtain results that can represent various conditions in the field.

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