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A Consideration for Field Strength Analysis Based on Rec. ITU-R P.1546 Applicable to ATV to DTV Conversion

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Abstract

In this paper, using the Rec. ITU-R P.1546 explaining a propagation prediction model in the VHF and UHF bands, we propose the analytical methodology for calculating the service distance and field strength for analogue and digital TV receivers. From the derived formulation of the receiver field strength, some computation results are presented and discussed in terms of the equivalent level of service caused by analogue to digital TV conversion. The suggested method is also applicable to the analysis of frequency coordination or compatibility from unwanted signal in VHF and UHF bands.

Keywords : Rec. ITU-R P.1546, receiver sensitivity, field strength, propagation model

I. Introduction

Due to the advent of knowledge-based information society since 2000, a digital revolution has rapidly impacted whole industries. Also advanced information and communication technologies have played a special role in creating convergence services between communication and broadcasting. One change has been digital TV (DTV) broadcasting replacing the current analogue system[1][2]. The Korea Communications Commission (KCC) has already announced that digital broadcasting will be fully provided by the end of 2012. The electromagnetic wave laws of Korea will basically require the equivalent level of service after the conversion of analogue TV (ATV) to DTV.

In general, the service distance of ATV is not equal to that of DTV due to the different threshold field strength of the receiver[3]. This results from the different input broadcasting signal, especially for modulation methods. Also, the transmitting power of ATV is much higher than that of DTV, and so it is crucial for cell planners not only to design optimum channel assignments, but also to allocate proper broadcasting districts[4]. Since the public desire the same quality of service after adopting DTV, from a service provider point of view, in advance, it is necessary to analyze the service distance needed to achieve the same quality for DTV broadcasting by virtue of a proper propagation prediction model of field strength.

As previous works, field strength measurement at frequencies of around 300 MHz over sea path was performed to gather information about the occurrence of ducting/super-refraction and signal-fading effects with antenna heights appropriate to intership communications in the British Channel Islands[5]. Also, radio propagation in urban area was studied for link budget and radio coverage design based on theoretical and experimental prediction for mobile application, considering various elevations of base station

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and moving subscriber antenna with respect to building rooftops[6]. Recently, propagation properties of ultrahigh frequency waves under viaducts were presented for mobile digital TV coverage in case of the transmitting antenna being higher than viaduct deck, where the model covers direct propagation, ground reflection, transmission, as well as wedge diffraction to reveal the law of signal path gain under viaducts[7].

On the other hand, International Telecommunication Union Radiocommunication Sector (ITU-R) has also published several Recommendations for radio propagation predictions in VHF and UHF bands. Especially, Rec. ITU-R P.1546 provides guidance on point-to-area prediction of field strength for broadcasting and mobile services[8-10]. In addition, Rec. ITU-R BT.1368 defines planning criteria for various methods of providing digital terrestrial television services in the VHF/UHF bands[11].

In this paper, an analytical methodology for calculating the service distance to assure a satisfactory picture or quality for TV receivers is proposed based on Rec. ITU-R P.1546. From the derived formulation of the receiver field strength, some computational results are shown here for both kinds of TVs, and system factors including a percentage of location are also reviewed to determine the equivalent level of service caused by ATV to DTV conversion.

II. Formulation of Receiver Field Strength

The Rec. ITU-R P.1546 describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range of 30 MHz to 3000 MHz[8] and can be used for calculating field strength values over land, sea and/or mixed land-sea paths between 1.0 ~ 1000 km for effective transmitting antenna heights of less than 3000 m. The propagation curves in this Recommendation mean the electric field strength for 1kW effective radiated power (ERP) at nominal frequencies of 100, 600, 2000 MHz, respectively. For any other frequencies, interpolation or extrapolation of the value obtained for these nominal frequency values should be used to find field strength values via the methods in this Recommendation. This interpolation or extrapolation method can be extended to obtain field strength values over various parameters such as frequency, distance, antenna height, and time variability.

Fig. 1 depicts a simple geometry for a transmitter and TV receivers including a repeater. The received TV signal can be expressed by[12,13]

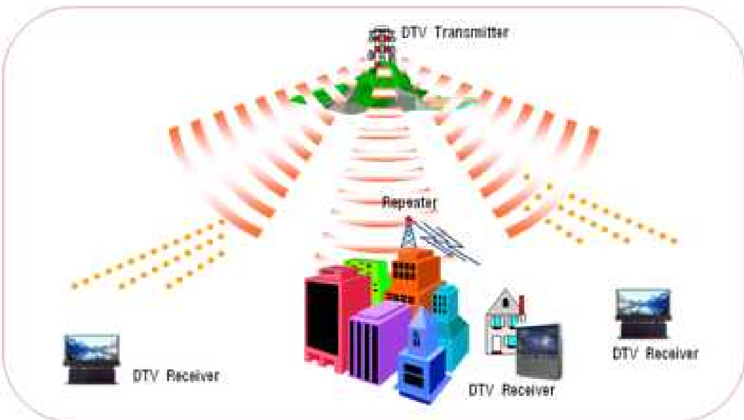


그림 1. TV 송신기와 수신기에 대한 간단한 구조
Fig. 1. A simple geometry for a TV transmitter and receivers

$$P_r = P_t + G_t + G_r - L_t - L_r - L_p \quad (1)$$

where P_t is the transmitting power (dBm), G_t means the transmitting antenna gain (dBi), G_r is the receiving antenna gain (dBi), L_t is the total insertion loss of the transmitter (dB), L_r is the total insertion loss of the receiver (dB), and L_p stands for the propagation loss between the transmitter and receiver (dB).

The receiver threshold level can be expressed by[12]

$$P_{r-th}(dBm) = 10\log(kTB) + NF + S/N \quad (2)$$

where k is the Boltzmann constant (=1.38 x 10^{-23} *J/K*), *T* is the Kelvin temperature in *K*, *B* is the receiver bandwidth in Hz, NF is the noise figure of the receiver in dB, *S/N* is the signal-to-noise ratio in dB for the given bit error rate (BER) depending on the modulation method, and fMHz is the transmitting center frequency in MHz.

On the other hand, converting Eq. (2) into electric field strength in dB(μV/m), including the antenna gain and total insertion loss of the receiver, Eq. (3) can be obtained as [14]

$$E_{Pr-th} = P_{r-th}(dBm) + 20\log f_{MHz} + 77.2(dB) - G_r(dB) + L_r \quad (3)$$

In this simulation, we adopted the propagation loss curves shown in Rec. ITU-R P.1564, and those curves, related with electric field strength in dB(μV/m), were derived for 1kW ERP conditions. Since 1.0 kW ERP (Effective Radiated Power) is equal to about 62.1 EIRP (Effective Isotropic Radiated Power), propagation loss L_p in dB can be expressed in terms of electric field strength, $E_{P.1546}$ as follows

$$L_p = 139.3 - E_{P.1546} + 20\log f_{MHz} \quad (4)$$

Substituting Eqs. (3) and (4) into Eq. (1), the electric field strength of the receiver, $E_{Pr\text{-}th}$ in dB(μV/m), as a function of $E_{P.1546}$ can be derived by[15,16]

$$E_{Pr-th} = E_{P.1546} + P_t + G_t - L_t - 62.1 \quad (5)$$

III. The Concept of Equivalent Quality of Service

Let's consider the equivalent quality of service in the conversion from ATV to DTV broadcasting. Fig. 2 shows the geometry of service distance assuring the quality of both TVs. D_{-d} and D_{-a} denote the distance resulting from the receiver threshold field strength for DTV and ATV, respectively. If D_{-d} is equal to D_{-a} for both system parameters, then the equivalent level of service is realized.

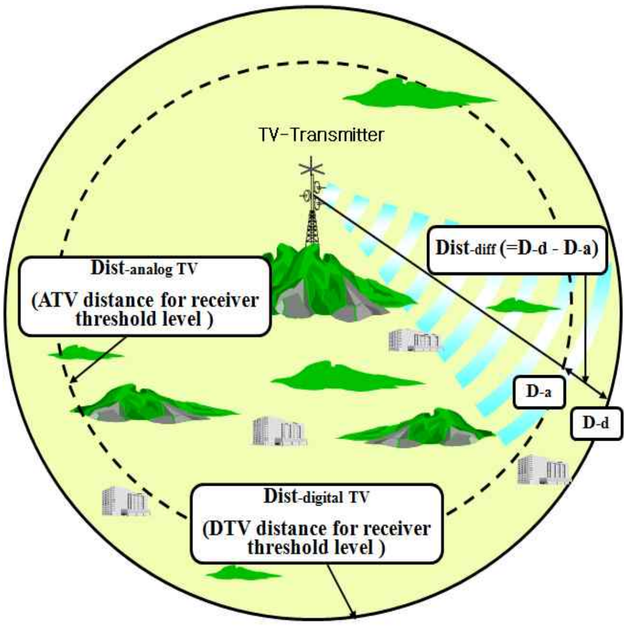


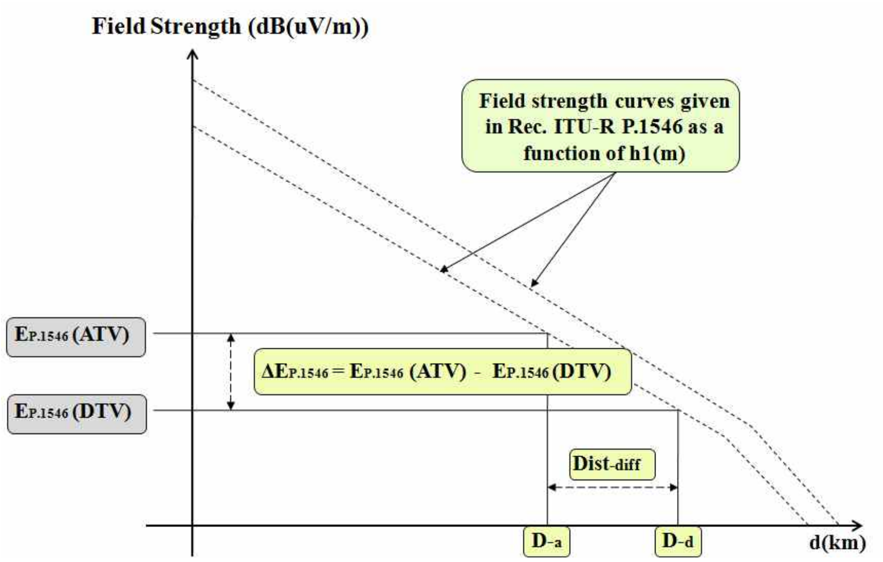
그림 2. ATV 및 DTV 에 대한 서비스 거리의 구조
Fig. 2. The geometry of service distance for ATV and DTV

In addition, Fig. 3 illustrates the relation of the receiver threshold level and its distance for both TVs in terms of electric field strength based upon the curves of Rec. ITU-R P.1546. To keep same service distance, the difference of field strength, $\Delta E_{P.1546}$ is given by

$$\Delta E_{P.1546} = E_{P.1456}(\mathrm{ATV}) - \Delta E_{P.1546}(\mathrm{DTV}) = 0 \qquad (6)$$

Consequently the equivalent level of service distance can be obtained. Thus it is possible to get Eq. (6) by adjusting system parameters such as transmitting power and antenna gain.

Fig. 4 represents the systematic diagram for deriving the equivalent level of service, which consists of three parts. The input is the threshold field strength of the receiver regarding the current and new services. The system means



그리 3. ATV 및 DTV에 대한 거리와 전계강도 간의 관계
Fig. 3. The relation between distance and field strength for ATV and DTV

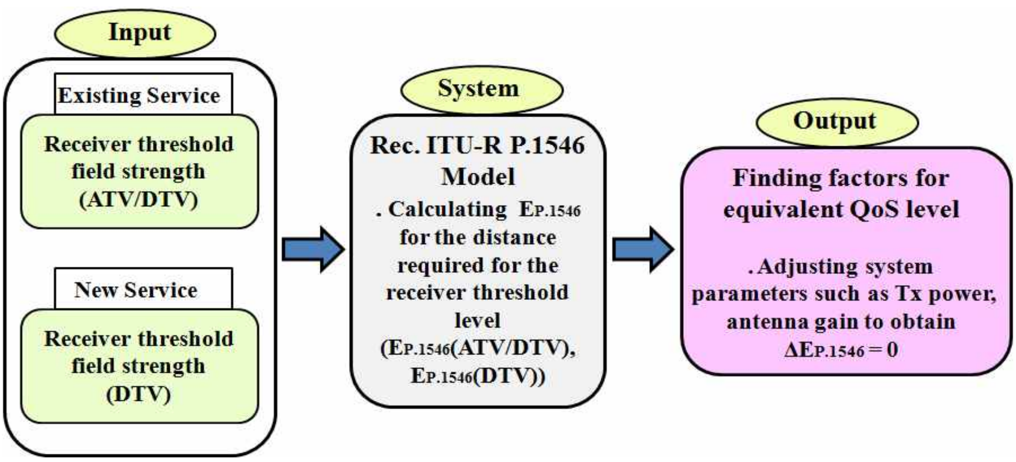


그림 4. 등가 서비스 수준을 유도하기 위한 시스템적 도표
Fig. 4. Systematic diagram for deriving the equivalent level of service

Rec. ITU-R P.1546 model, which describes the procedure for calculating the field strength value to two different services. Finally, the output seeks the factors related with providing the equivalent level of service, which can be used for adjusting system parameters such as a transmitter power and antenna gain.

IV. Computation Results and Discussion

1. Simulated results for ATV and DTV Receivers

For instance, the variables needed for calculating receiver threshold level and field strength are assumed as shown in Table 1. The values taken for each parameter are a general guideline for terrestrial digital broadcasting systems with 64-QAM, and the frequency of 600 MHz is presumed as the center frequency of DTV band from 470 MHz to 698 MHz in Korea. Also the value of S/N is given for 64-QAM at BER of 10^{-6}. In addition, the feeder losses of transmitter and receiver are assumed to be zero, respectively, for convenience, and probabilities of time and location are both 50 % for the land path.

표 1. 시뮬레이션에 적용된 시스템 변수
Table 1. System variables used for simulation

f(MHz)	*B(Hz)*	*NF(dB)*	*S/N(dB)*	P_t*(dBm)*	G_r*(dBi)*	G_t*(dBi)*
600	$6x10^6$	2.0	22.0	60	10	20

Consider that ATV services are to be provided for a sparsely populated region, where better receivers and antenna installations are likely to be used, the service provides may find it desirable to set the appropriate median field strength for protection against interference. So, in order to get the threshold field strength for ATV to ensure a satisfactory picture, the median field strengths for protecting against interference as well as the absence of interference are given in Table 2 for each band[4]. These values refer to the field strength for a rural district at a height of 10 m above ground level, which gives satisfactory quality of service. However, according to Rec. ITU-R BT. 417-5, the public generally begin to lose interest in installing television reception equipment when the field strength falls much below these levels. The required threshold field strength under interference is a little larger than that under non-interference because the received signal under interference, in general, enhances the noise floor or degrades the C/N.

표 2. ATV에 대한 전계강도의 권장하는 한계 제한
Table 2. Recommended threshold limit of field strength for ATV

Band	*I*	*III*	*IV*	*V*	*Remarks*
f(MHz)	41~68	162~230	470~582	582~960	
dB(μV/m)	+46	+49	+58	+64	with interf.
dB(μV/m)	+40	+43	+52	+58	w/o interf.

In order to compare the service distance between ATV and DTV, the assumptions for analysing both are made as shown in Table 3. The threshold field strength for ATV is 64 dB(μV/m) from Table 2 under the interference, and 40.5 dB(μV/m) is obtained for DTV by Eq. (3) and Table 1.

표 3. ATV 및 DTV 간에 서비스 거리 비교를 위한 가정
Table. 3 Assumptions for comparing service distance between ATV and DTV

Type	*f(MHz)*	*Tx power, Antenna Gain*	*dB(μV/m)*	*Remarks*
ATV	600	*Under the same conditions*	+64	*with interf.*
DTV	600		+40.5	*w/o interf.*

Fig. 5 shows the overview of distance required for the threshold field strength as a function of transmitting power and antenna height, and Fig. 6 presents the detailed distance for ensuring quality of service. Note that the service distance of DTV is much farther than that of ATV for the given transmitting power.

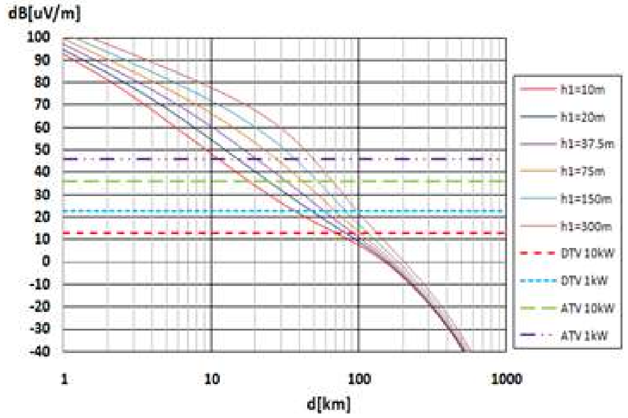


그림 5. 양 TV에 대해 서비스 거리 및 전계 강도의 개관
Fig. 5. Overview of service distance and field strength for both TVs

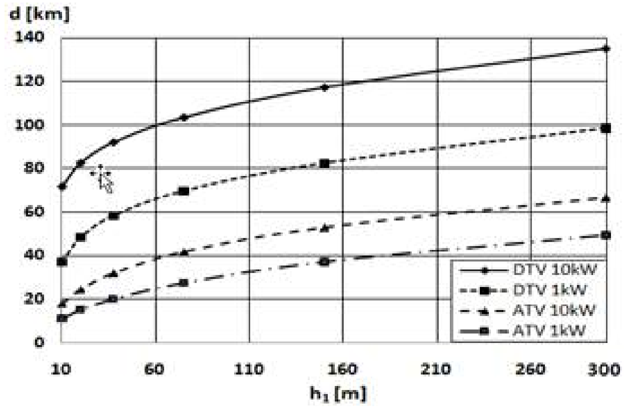


그림 6. 송신 전력과 안테나 높이에 대해 상세한 거리
Fig. 6. Detailed distance for transmitting power and antenna height

On the other hand, to find the equivalent service distance for ensuring the picture quality between two TVs, the corrected average power of DTV asking for the same service distance was calculated by about 4.5 and 45.1 W for ATV transmitting peak power of 1.0 and 10 kW, respectively.

2. Simulated results for a frequency shift of the DTV channels

Let's consider the frequency shift case, where the current DTV channel changes inevitably due to fully channel reallocation during DTV adoption. Korea has adopted the technical standard of Advanced Television Systems Committee (ATSC) for DTV with 8-Vestigial Side Band (VSB), and its spectrum with 6 MHz bandwidth is shown in Fig. 7 with National Television Standards Committee (NTSC) for ATV[2].

In order to draw the equivalent level of service for a given frequency shift from 500 MHz to 700 MHz, the simulation parameters are as shown in Table 4 for the center frequency of 500 MHz, where S/N is 14.9 dB at segmentation error rate (SER) of 1.93 x 10^{-4}[2]. Transmitter feeder loss, L_t is 1.5, 3.0, 6.0 dB for h1 of 75, 150, 300 m, respectively, resulting from the assumed feeder loss of 0.02 dB/m.

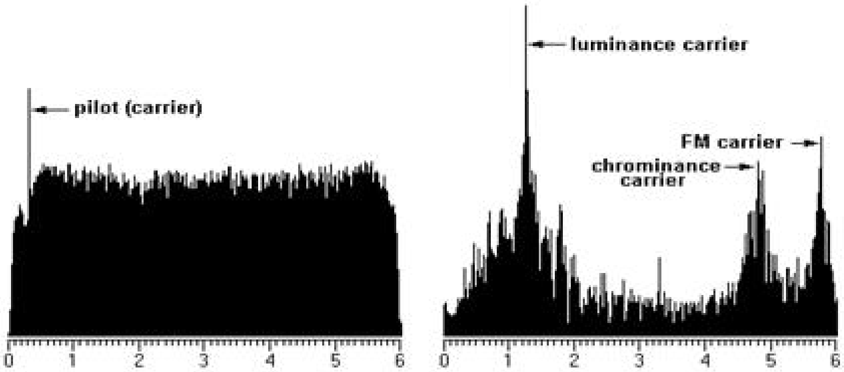


그림 7. DTV(왼쪽)과 ATV(오른쪽)의 스펙트럼
Fig. 7. Spectra of DTV(left) and ATV(right)

표 4. 현재 DTV의 시스템 변수
Table 4. System variables of current DTV

f(MHz)	*P_t(dBm)*	*B(Hz)*	*NF(dB)*	*S/N(dB)*	*G_r(dBi)*	*G_t(dBi)*	*L_r(dB)*
500	50	6x10^6	7.0	14.9	12.0	20	3.0
700					14.0	22	5.0

The calculation was performed at the receiver height of h2 =10 m and transmitter height of h1=75, 150, 300 m. From these conditions, the calculated threshold field strength of the receiver, $E_{P.1546}$ is 37.9 dB(μV/m), and its distance corresponding to the threshold field strength is shown in Fig. 8.

For the centre frequency of 700 MHz, the assumed parameters are also shown in Table 4, where all conditions are the same except for frequency dependent parameters. Taking the feeder loss of 0.025 dB/m, L_t is given by 1.9, 3.8, 7.5 dB for h1 of 75, 150, 300 m, respectively. From these conditions, the calculated threshold field strength of the receiver, in terms of $E_{P.1546}$, is 40.8 dB(μV/m), and its distance corresponding to the threshold field strength is illustrated in Fig. 9.

Table 5 shows the summarized results for Figs. 8 and 9 in view of receiver threshold distance as a function of h1, and reveals that the service distance at 700 MHz for h1=300 m is reduced by about 9.4 % compared with that at 500 MHz. Therefore, by adjusting system parameters such as transmitting power and antenna gain, the equivalent level of service can be achieved.

표 5. DTV에 대한 서비스 거리의 비교
Table 5. Comparison of service distance for DTV

Items		*f = 500 MHz[a]*	*f = 700 MHz[b]*	*ΔDist. (%)= 100 x (b-a)/a*
Distance for Receiver threshold level, d (km)	h1=75m	50.9	46.7	-8.3
	h1=150m	60.0	54.8	-8.7
	h1=300m	68.1	61.7	-9.4

On the other hand, if the interference is taken into account in the received signal, only S/N in Eq. (2) is degraded according to the maximum allowable I/N, the power ratio of interference to noise. Then the resultant threshold field strength, Eq. (3) is changed depending on I/N. In consequence, it is noted that the service distance will be a little shorter than that for non- interference case.

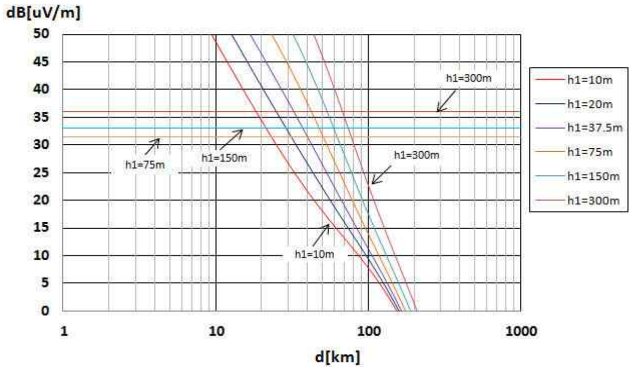


그림 8. 500 MHz 에 대한 거리 및 전계강도의 개관
Fig. 8. Overview of distance and field strength for 500 MHz

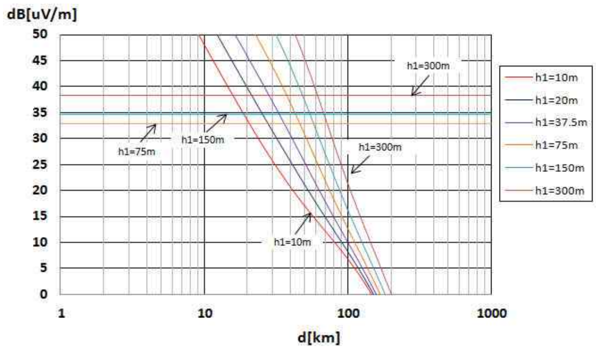


그림 9. 700 MHz 에 대한 거리 및 전계강도의 개관
Fig. 9. Overview of distance and field strength for 700 MHz

3. Simulated results for a location variation in land area-coverage prediction

In order to check the field strength and service distance for varying percentage of location, the corrected field strength, E dB(μV/m) exceeded for q percentage of locations is given by[8]

$$E(q) = E(median) + Qi(q/100) \times \sigma L(f) \quad (7)$$

Where Qi(x) is a inverse complementary cumulative normal distribution as a function of probability and σ L(=K+1.3log(f)) means a standard deviation of the Gaussian distribution of the local means in the study area, K is constant, and f is a required frequency in MHz.

The parameters used here for simulation are shown in Table 6. The receiver threshold field strength for DTV is about 33.4 dB(μV/m) without interference calculated from Eq. (3) with relevant parameters in Table 6. Figs. 10 and 11 show the overview of threshold service distance for percentage location q(%)= 50 and 99 as a function of transmitting power and antenna height. The curves in each figure means field strength values exceeded at each percentage of locations within any area of approximately 500 m by 500 m and for 50 % of time. From Table 7, it is interesting to note that the threshold service distance is gradually reduced as q increases.

표 6. 시뮬레이션을 위한 시스템 변수
Table 6. System variables for simulation

Parameters	***Values taken***
Channel center Freq.	f: 600 MHz
Study area	rural, K=0.5
Tx power	DTV: 1, 10 kW
Tx ant. height	h1: 150,300,600m
Rx ant. height	h2: 10m
Receiver threshold field strength	For ATV: 64 dB(μV/m) with interf. 58 dB(μV/m) w/o interf.
	33.4 dB(μV/m) for DTV w/o interf.
Channel bandwidth	B: 6.0×10^{6}Hz
Noise figure	NF: 2.0 dB
Signal-to-noise ratio	S/N: 14.9 dB at SER $=1.93\times10^{-4}$
Ant. gain	G_t : 20.0, G_r:10.0(dBi)
Insertion loss	L_t=L_r=0.0(dB)

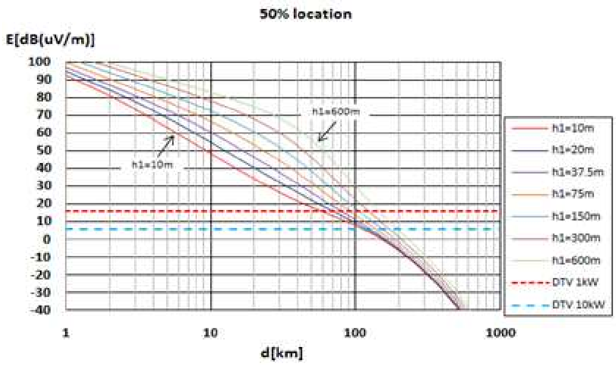


그림 10. 50% 위치에 대해 거리 및 전계강도의 개관
Fig. 10. Overview of distance and field strength for 50% location

Finally, in order to check the service distance for percentage location q between ATV and DTV, Table 8 shows calculated Tx power for both TVs enabling the same threshold service distance. The value of the threshold field strength for ATV is taken from Table 2, based on Rec. ITU-R BT.417-5. For instance, taking a look at ATV Tx power of 1 kW under interference, the required DTV Tx power is 0.88 W for 50 % of location, which brings to the same service distance as ATV. As increasing percentage lo-

표 7. q 에 대해 한계 서비스 거리의 변화
Table 7. Variation of threshold service distance for q

q(%)	***Tx power (kW)***	***Distance, d(km)***		
		h1(m)=150	300	600
50	1	105.60	122.99	147.11
	10	152.35	170.91	196.47
60	1	101.72	118.94	142.86
	10	146.65	165.13	190.58
70	1	97.77	114.81	138.47
	10	140.77	159.15	184.47
80	1	94.40	110.17	133.57
	10	134.16	152.42	177.58
90	1	87.73	104.17	126.80
	10	125.47	143.54	168.45
99	1	75.92	91.46	111.86
	10	107.25	124.72	148.91

표. 8. 양 TV에 대해 Tx 전력의 비교
Table 8. Comparison of Tx power for both TVs

Parameters			***DTV Tx power (Watts)***					
			q = 50	60	70	80	90	99
ATV Tx power	with interf.	1 kW	0.88	1.12	1.46	1.95	2.96	7.97
		10 kW	8.80	11.18	14.45	19.51	29.62	79.67
	w/o interf.	1 kW	3.50	4.45	5.75	7.77	11.79	31.72
		10 kW	35.04	44.52	57.54	77.68	117.93	317.15

cation q from 50 to 99, the required DTV Tx power also varies from 0.88 to 7.97 W. According to the output results from Table 8, it is to note that the larger percentage location q gets, the more Tx power is required.

V. Conclusion

In this paper, using the Rec. ITU-R P.1546 to describe a method for point-to-area radio propagation predictions for terrestrial services in the frequency range of 30 MHz to 3000 MHz, we suggested the analytical methodology for calculating threshold service distance to ensure a satisfactory picture or quality of analogue and digital TV receivers. Based upon the analytical formulation for a TV receiver derived from Rec. ITU-R P.1546, some computational results were presented and compared for two TV system parameters, and important factors such as a frequency shift of channel and a percentage of location were reviewed in terms of the equivalent service level required for ATV to DTV conversion or caused by DTV channel reallocation.

This suggested method can be applied not only to calculate the field strength of DTV receivers to ensure quality of service, but also to select the optimum site of a transmitter or repeater. In addition, the formulation developed here is also applicable to the analysis of frequency coordination or compatibility from an unwanted signal in VHF and UHF bands.

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