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Empirical single frequency network threshold for DVB-T2 based on laboratory experiments

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Abstract: DVB-T2 broadcasting with a single frequency network (SFN) allows an efficient management of frequency utilization and extends the coverage area, which will enable more people to view a broadcast. The SFN mode also increases the concentration of the signal in overlap areas. However, some difference of overlap areas in actual use of SFN networks may have some degradation of the received signal due to the effect of the SFN. In this research, we analyze SFN broadcasting in SISO mode. This paper represents the effects of delays on the SFN signal over different delay times within the guard interval (GI) by analyzing the minimum reception threshold. The analysis of received signal power, MER, bBER, LBER, and noise margin are studied using an actual digital television transmitter for the experiment. The results show that the minimum thresholds for a delay time at 0 microseconds will require higher receive signal power than other delay times within the GI. The results of this experiment are useful in designing the SFN network and make it possible to determine the appropriate C/N threshold for the design of the digital terrestrial television network.

Key words: DVB-T2, single frequency network, reception threshold

1. Introduction

In this paper, we study the broadcasting of DVB-T2 digital terrestrial television [1]. In addition to multifrequency network (MFN) broadcasting, there is another transmission broadcasting mode called single frequency network (SFN) [2], which has more advantages than the MFN mode. The SFN system can manage the proper frequency and bandwidth efficiently. Another advantage of the SFN mode is that the coverage area can be easily expanded using the same frequency. Using a low-power transmitter makes the SFN system highly flexible. For example, if one of the main transmitters fails, then the coverage area does not entirely disappear because some areas can receive signals from other SFN transmitters. For example, the viewer may still be able to receive signals from another transmitter in the network area if the signal is stronger than the minimum threshold requirement.

Many studies have analyzed SFN transmissions for DVB-T2 by finding the minimum carrier-to-noise (C/N) requirement for real broadcasts compared with implementation guidelines and laboratory measurements [3]. The SFN channel was determined by finding the path loss gain by analyzing and evaluating the effects of the multipath channel. In[4], the authors studied and investigated the SFN gain from real broadcast measurements. In [5], atuhors propose the SFN gain calculation of the difference of signals received from various overlap transmitters. In [6, 7], authors proposed an analysis of the SFN gain when the modulation error ratio (MER) changed due to the propagation channel with reception of a signal from more than one transmitter.

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In some SFN coverage areas, the quality of the received signal may deteriorate due to the effect of the SFN propagation channel. The work in [8] proposed the XiaBertoni model and a model based on the Hata for analyzing SFN propagation. The work in [9] proposed the analysis of long path delays for received signal multipath in SFNs. The performance of SFNs depending on different Doppler frequencies was presented by laboratory and field measurement in [10]. The quality of service (QoS) was shown by the result of MER at the receiver, and the delay of received signals from the SFN network will especially affect the MER [11]. The effect of interference in the SFN of DVB-T2 depends on the influence of the guard interval (GI) duration. In [12], authors presented the result of bit error rate due to the GI duration. Furthermore, many echo delays produce the power and IQ imbalance that causes degradation of the signal quality. In [13], IQ imbalance and residual carrier frequency offset (CFO) affected the capacity symbol error rate (SER). Intersymbol interference (ISI) also occurs due to the echo delay effect. In [14], authors proposed a new channel estimation and an interpolation technique to eliminate the effect of phase rotation caused by symbol timing offset (STO), which can help to solve ISI problems.

However, there are few studies on receiving signal threshold requirements, especially for SFNs, and particularly studies on the effects of echo delay within GI protection. The results of this research show the effect of the relative delay and relative amplitude, which is important and useful for SFN network design to set the transmission power and to calibrate the echo delay to an appropriate setting for the coverage area.

2. Single frequency network

A SFN is the transmission of the same data at the same frequency and time on multiple transmitters. Consequently, the receiver will receive the signal from several transmitters. However, the signal looks like multipath signals. The receiver can receive the signal successfully when all of the signals from all transmitters arrive at the same time within the GI range. In the DVB-T2 system, the GI can be appropriately configured to the coverage area with suitable design of the SFN. However, it may still be necessary to analyze the performance to achieve the best performance. The received signal of a SFN is shown in Figure 1.

In DVB-T2, there are several setting modulation parameters to select appropriate multipath protection.

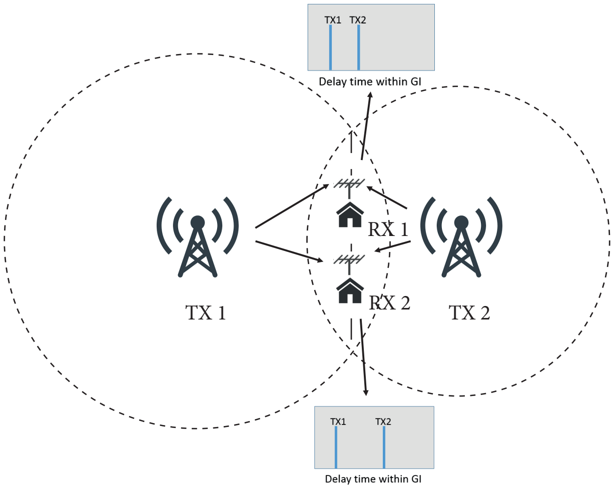

Figure 1. Received SFN signal.

The field test of the DVB-T2 modulation parameter was presented in [15]. Choosing the right GI will solve the ISI and multipath problems because the multiple carrier has a fixed value per symbol. The value of the reflections that are shorter than the GI indicates the error of the pilot frequency response. If the pilot signal inserted in the symbol fails, the receiver cannot estimate and correct the frequency response. If the multipath is longer than the GI, then the received signal will suffer from ISI. The gap between the carrier prevents the Doppler shift effect caused by ISI. If the Doppler shift is very small compared to spacing, then the signal will be fairly immune to ISI. The symbol period and the number of frequencies can be adjusted according to the DVB-T2 standard and GI depending on this parameter setting. Consequently, the implementation of the SFN has many different settings. The best reception of DVB-T2 occurs when the appropriate equalization value is chosen. The signal delay time within the GI is shown in Figure 2.

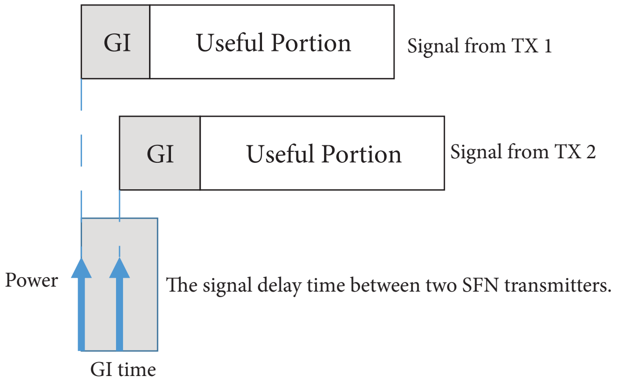

Figure 2. Signal delay time within the GI.

2.1. SFN signal model

Many factors can affect the SFN gain value. The major factors are the power imbalance (PI), relative delay ($\triangle_t$), propagation channel (σ_{sp}), pilot pattern (PP), and code rate (CR). These parameters involve SFN signaling in both SISO and MISO modes [16, 17]. However, there are differences in the impact of different network features. The number of transmitters in the SFN is $y = 1, \ldots\ldots, T$. For general SISO transmission, this can be expressed as

$$r_S(t) = \sum_{i=1}^{m} h_i(t - \tau_i) * x(t), \tag{1}$$

where h_i and τ_i are the channel impulse responses and delays from each transmitter in the SFN system that are visible from the receiver, and m is the number of received multipath components.

2.2. SFN measurement

In the measurement of the SFN signal, the received signal is the same as the reception of the echo signal. The channel response can be written as follows:

$$h_S(t) = \sum_{i=1}^{L} \alpha_i \delta(t - \tau_i), \tag{2}$$

where L is the number of echoes, while α_i and τ_i are the complex gain and delay.

Within the GI time, successful reception in terms of the quasi-error free (QEF) criteria [18] depends on whether the receiver can equalize the signal and overcome the effects of echoes. The correction efficiency depends on two main factors: the echo delay and the echo power. This is important to guarantee the effectiveness of the SFN network.

2.3. Channel estimation and equalization

Even though the input signal of the receiver is properly synchronized, the output signal after FFT demodulation may not be the same as the original signal. The carrier signal derived from reception in terms of the amplitude and phase from FFT demodulation may be affected by the channel response. The complexity of the amplitude carrier can be written as follows:

$$Y_{k,l} = H_{k,l} X_{k,l} + N_{k,l}, \tag{3}$$

where $X_{k,l}$ is the complex modulation symbol constellation of carrier k and symbol l of the original transmitted signal. $Y_{k,l}$ is the amplitude of the received signal, $H_{k,l}$ is the complex frequency response of the channel in symbol l by sampling frequencies k, and $N_{k,l}$ is the noise signal on the receiver added to the system. Since DVB-T2 receivers can receive reference signals from continual pilots and scattered pilots, channel evaluations can be achieved by perceiving that the information was sent by those the pilot cells, which can be expressed by the following equation:

$$H'_{k,l} = \frac{Y_{k,l}}{C_{k,l}} = H_{k,l} + \frac{N_{k,l}}{C_{k,l}}, \tag{4}$$

where $C_{k,l}$ is the complex amplitude of the reference pilot cells. In the maximum channel correction value, the channel response is defined as $H'_{k,l}$. There are only reference cells k, l. The channel response $H_{k,l}$ varies with frequency and time.

3. Objective

The objective of this work is to obtain digital TV reception in the SFN mode in different areas. The receivers can receive signals from multiple transmitters that transmit within the same GI time. In each reception area, the echo delay is different. Although the echo delay is different, the echo delay is still inside the GI, and the receivers can receive the signal. The main objective of this research is an analysis of the minimum threshold reception of DVB-T2 in SFN mode and the development of an experimental model for the SFN in SISO. The analysis of the delay effects during the GI is done with measures such as the SFN gain, received signal power, and modulation error ratio (MER). In our analysis, comparison between the normal received signal power result and the minimum received signal power result was used for evaluation, and the minimum threshold of the SFN signal of DVB-T2 was obtained. Correlation was used to analyze the effect of the minimum signal delay requirement within the GI time. Measuring the difference in the echo delay is difficult in field tests. Therefore, in this research, a laboratory measurement model was used to simulate all delay time situations in the GI. Two SFN transmitters were used, and the static local delay time of both transmitters was changed during the GI time to analyze and find the minimum threshold reception for the desired SFN signal.

4. Laboratory measurements

The experimental equipment is shown in Figure 3. The MPEG 2 Transport Stream (TS) is derived from the MUX provider. This experiment uses TS signals from the MCOT MUX provider. MCOT is one of the four

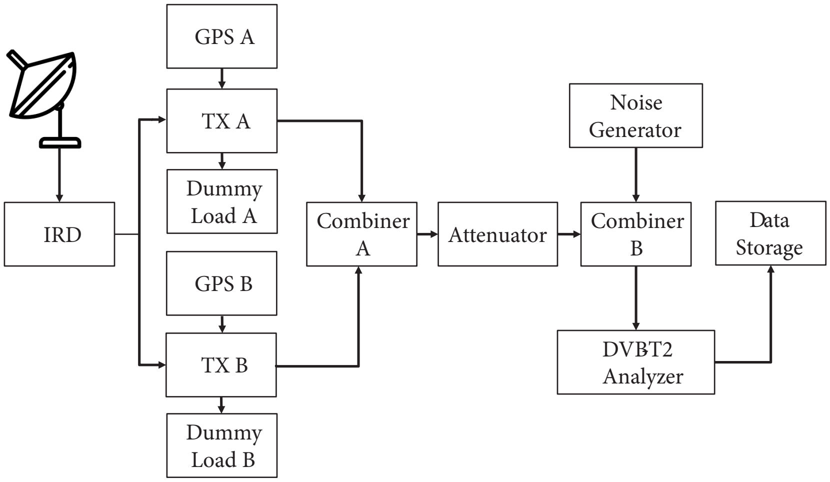

Figure 3. Block diagram of SFN measurement system for DVB-T2.

MUX providers in Thailand. TS signals are sent to the DVB-S2 modulator from the head-end center and sent to satellites for distribution to the DTV network. Integrated receiver/decoder (IRD) receivers receive signals from the head-end center via satellites. The received signal output is the TS signal, which is sent via the asynchronous serial interface (ASI) port to both output ports of the IRD. The signal from the IRD is the modulator interface signal (T2-MI). This T2-MI signal of DVB-T2 is based on DVB Document A136. The modulation parameter of the T2-MI signals is shown in Table 1. T2-MI signals are sent to both DVB-T2 transmitters. The transmitter has an RF output power of approximately 1 W because the transmitter used to generate the exciter function as an output signal does not have high RF power. In the actual broadcast, the exciter will use RF power PA to drive a high RF power output. The DVB-T2 transmitter used in the experiment was a Syes PCM 1, and both transmitters are connected to the global positioning system (GPS) to lock the time base to synchronize the signals. Due to the inevitability of SFN transmission, there must be a consistent time base. The output from both transmitters for this experiment can be obtained from the RF monitor port, which is coupled to the transmitter output. This experiment uses 100 mW transmit power. The coupling signal at the RF monitor port is –3 dBm. By combining the RF signals from both transmitters, the RF power is approximately –7 dBm after combining with two transmitters, and this RF signal is connected to a 13 dB attenuator to reduce the RF signal to roughly –20 dBm (signal loss in the cable and the combiner) or approximately 87 dBμV at 50 ohm impedance, which is suitable for experiments and analysis. This research uses a ROVER HD PROTAB DVB-T

Table 1. DVB-T2 parameters for Thailand.

Parameter	Values
Frequency	514 MHz
Bandwidth	8 MHz
Pilot pattern	PP2
Guard interval	19/128
Constellation	64 QAM
Constellation rotation	On
Code rate	3/5

/ DVB-S / T / C analyzer for the experiment. The signal is measured and stored in two ways. The measurement data with normal signal strength and minimum signal strength are recorded. The minimum signal requirement is based on the low signal threshold at the quasi-error free (QEF) criteria. The bit error rate before LDPC (bBER) must have error bit less than 1×10^{-2} or 1×10^{-7} after LDPC (LBER). Another method used to measure the QEF criteria is the measurement of minimum signal strength that makes the quality of experience (QoE) not missing continuously for no more than 20 s. All of the measurement data are obtained by changing the static local delay of the transmitter from 0 μs to 270 μs, divided into 10 μs steps. Each step is stored 20 times, and each time, the received signal power, MER, bBER, LBER, and noise margin are collected. All data are analyzed and evaluated using the polynomial regression model (PRM), and the correlation coefficient of the normal signal strength and minimum signal strength has been analyzed and presented. The minimum SFN signal requirements are then verified for DVB-T2. The equipment of the SFN experiment is shown in Figure 4.

Figure 4. Equipment of the SFN experiment.

4.1. Experimental parameters of DVB-T2 for SFN

The minimum signal requirement threshold for the SFN was tested using the modulation parameters broadcast in Thailand. Digital television terrestrial broadcasting in Thailand is regulated by the National Broadcasting and Telecommunications Commission (NBTC), which assigns parameters for broadcasts. The frequency range in Thailand is 510 MHz to 790 MHz. This experiment uses a frequency of 514 MHz for transmission. The maximum bit rate that can be sent with this parameter is 27.4 Mbps. One multiplexer (MUX) can broadcast 8 channels, divided into six standard definition (SD) and two high definition (HD) channels. The transmission rate of each data channel is approximately 1.28–1.6 Mbps for SD and 5.92-7.2 for HD. The change in the data transfer rate depends on the performance of the parameter modulation encoding. For Thailand, the results are as shown in Table 1.

4.2. Minimum received signal required

Due to the modulation of digital TV transmission, much data transmission is required, so quadrature amplitude modulation (QAM) is used for modulation, which consists of IQ signals. The phase shift of the I and Q signals makes a constellation point, and the data symbol will send by reference all of the dots in the constellation point. For this reason of digital television transmission, the carrier wave strength measurement is important for inspection of the signal quality. Therefore, the minimum signal strength of C/N is important for the perceived receiver efficiency with the minimum C/N signal, which can be expressed by the following equation:

$$C/N = Ps_{min} - F - 10log(kT_0B), \tag{5}$$

where C/N is the signal to noise ratio (dB), Ps_{min} is the minimum signal at the receiver input (dBμV), F is the noise generated by the receiver (dB), K is the Boltzmann constant $= 1.38 \times 10^{-23}$ Ws/K, B is the receiver noise bandwidth (Hz), and T_0 is the absolute temperature = 290 K.

4.3. Modulation error ratio

The modulation error ratio (MER) is a measure of modulation quality performance for digital television. It is measured from the coupling RF test port at the transmitter or even from the broadcast reception. For QAM transmission, the measured signal is in the form of a constellation diagram. The MER measurements can be shown, such as the dot amplitude and phase error in the constellation diagram. The vector error of the IQ signal is the value obtained from the comparison of the measurement of the ideal IQ signal and error IQ signal, given the sum of the squares of the ideal signal vector size (I_j, Q_j) divided by the sum of the squares of the error vector $(\delta I_j, \delta Q_j)$. The MER has units of dB. Consequently, the MER is equal to the ratio of the mean square (RMS) between the reference signal and the error vector, as calculated from the following equation:

$$MER = 10log\left[\frac{\sum_{j=1}^{N}(I_j^2 + Q_j^2)}{\sum_{j=1}^{N}(\delta I_j^2 + \delta Q_j^2)}\right]. \tag{6}$$

5. Channel process

The processing efficiency of the SFN signal can be obtained from the analysis of spectrum variation. The comparison between the normally received signals and minimum received signal required is done by using the correlation coefficient method. The polynomial regression model is used to predict the behavior of SFN signals due to the change of delay time within the GI. Verification of the chosen model is done to see whether it is appropriate or not by residual analysis. Details are shown as follows.

5.1. Spectrum variation

The delay time between two transmitters and multiple transmitters has a significant effect on SFN channels. The factor most affected by the delay time is the degradation of the received signal. The most severe impact is the delay time at 0 dB, which is called the 0 dB echo. The receiver is most affected when the signal from two transmitters arrives at the receiver at the same time with the same power level, as found from the experimental model. The standard deviation of the spectrum in the 8 MHz bandwidth range is used to analyze the spectrum variation at each delay time within the GI. The spectrum variation is used to describe the channel [3], as shown in Table 2.

The equations used to evaluate the variation of the spectrum due to the effect of delay time shift are gathered from the data collection of the SFN transmission experiment at 514 MHz and 8 MHz. The sampling rate is from 509.791 MHz to 517.943 MHz, with a sample spacing of 86 kHz for 94 samples throughout the 8 MHz bandwidth range. Each delay time session is collected 20 times to obtain reliable data. A total of 1880 samples are collected every 10 μs throughout the GI delay time, which are then used for calculating the spectral

Table 2. Channel classification.

Spectrum variation (dB)	Channel
$0 \leq \sigma_{sp} \leq 1$	Gaussian
$1 \leq \sigma_{sp} \leq 3$	Rician
$\sigma_{sp} \geq 3$	Rayleigh

variation for each delay time. Eqs. (7) and (8) describe the spectrum variation:

$$\bar{p} = \frac{1}{N}\sum_{n=0}^{N-1} p(n), \tag{7}$$

where $\bar{p}$ is the mean of the spectrum power, N is the number of spectrum power samples in the 8 MHz bandwidth, and $p(n)$ is each power sample in the spectrum bandwidth range.

$$\sigma_{sp} = \sqrt{\frac{\sum_{n=0}^{N-1}(p_i - \bar{p})^2}{N-1}}, \tag{8}$$

where σ_{sp} is the spectrum variation, N is the number of power samples within the 8 MHz spectrum bandwidth, p_i is each power sample within the 8 MHz spectrum bandwidth, and $\bar{p}$ is the mean of the spectrum power.

5.2. Correlation coefficient

The correlation of the typical strength of the DVB-T2 signal for SFN transmission during normal signal strength and minimum signal strength can be verified by a correlation coefficient. Knowing the correlation makes it possible to understand how the two signal strengths affect the same reception or difference.

$$\rho_{X,Y} = corr(X,Y) = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y}, \tag{9}$$

where ρ is the correlation coefficient, X and Y are the variables that are compared, μ_X and σ_X are the mean and standard deviations of X, and μ_Y and σ_Y are the mean and standard deviation of Y.

If we have serial data of the measurements, X and Y can be written as x_i and y_i, where $i = 1, 2, ..., n$, for which the sample correlation coefficient can be used to estimate the Pearson correlation r between X and Y, which is the sample correlation. The coefficient can be written as

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}, \tag{10}$$

where $\bar{x}$ and $\bar{y}$ are the mean of the random variables of X and Y, and s_x and s_y are the standard deviations of the variables X and Y.

5.3. Polynomial regression model

For estimation and prediction, the polynomial regression model is used to inspect and predict the variation of the experimental data measurements. In this experiment, the measured values change over the delay time in the GI, in which the measurement data are very different. The use of this model is very useful for analyzing data with different fluctuations.

The measurement data are given as $\{(X_t, Y_t), t = 1, ..., T\}$, where X_t is the delay time in the GI, and Y_t is the predicted value. Therefore, the polynomial regression model can be written as

$$Y_t = c + \sum_{i=1}^{p} \alpha_i X_t^p + \varepsilon_t, \tag{11}$$

where c is a constant, ε_t is the random error condition of X_t, α_i is a parameter of the model, and p is the order of the model.

The order of the polynomial regression model in this study is 8. In addition, to improve the numerical properties of the polynomial repression model, $\hat{X}$ is centralized and resized:

$$\hat{X} = \frac{X - \mu}{\sigma}, \tag{12}$$

where μ is the mean of X and σ is the standard deviation of X

5.4. Residual analysis

After choosing the appropriate prediction model, validation of the selected model is very important to be able to know whether the model chosen is appropriate or not. Model validation by checking the difference between the actual measured values and the prediction value is called residual analysis, which uses the following equation:

$$e = y - \hat{y}, \tag{13}$$

where e is the error value or residual, y is the actual measured value or the observed value, and $\hat{y}$ is the value from the prediction model according to $\sum e = 0$.

6. Results and discussion

The result from the DVB-T2 signal analyzer is shown in Figure 5. The signal spectrum resulting from SFN reception with a signal delay of 0 μs is shown in Figure 6. It can be seen that the signal is greatly reduced throughout the 8 MHz spectrum bandwidth range, which results from the 0 dB echo phenomenon. The spectral value varied, and the power amplitude was not the same throughout the range of the 8 MHz bandwidth over the 20-s period of measurement recording. The maximum degradation value is approximately 20 dB from the received signal threshold at roughly 40 dBμV. The received signal at delay 0 μs exhibits a great reduction, where the signal strength power from two transmitters is equal. The result is that there is no received signal or intermittent reception.

Figure 7 shows the spectrum of the reception at a 60 μs delay. It is evident that the spectrum is significantly less than that at the 0 μs delay. The signal has a slight deviation in the spectrum. This is similar to the MFN receiving signal. This figure shows the spectrum result of the threshold received signal of the SFN transmission.

Figure 8 shows the results of the simulation experiments based on the laboratory measurements to find the received signal strength compared with the delay time between two transmitters for SFN transmission. At 0 μs of delay time in GI, the degradation of the received signal is approximately 12 dB from 87 dBμV of approximate signal strength. The PRM is used to display the predictive value of the received signal based

PLAN: EUROPE
MODULAT: DVBT2
BW: 8
DC@RF: OFF
FREQ: 514.00
CHAN: 26
POWER: 67.7dBuV
MER:13.5dB
C/N:13dB
NsMAR:0.0dB
QLY:MARG
bBER:1x10-2
LBER:1x10-8
ERR:999
VPID:1101 APID:1102 PMT: 110
CARRIER : 16K DVBT2
CONST. : 64QAM
ENCRYPT.: Clear
NID: 12547
NETW: MCOT

INFO : PLP #1/1 -(Base)
TYPE: DATA1
Code Rate: 3/5
CONST: 64QAM
RotateCon: ON
PLP FEC: 64K
LNB Curr: 0mA
NID: 12547
NETW: MCOT

PLAN: EUROPE
MODE: DIGITAL
REF.PWR: 80dBuV
MRK.FR: 514.00
CHAN: 26
SPAN: SP 10
Att:20dB
MRK.P: 66.3dBuV

DIGITAL TV FREQ: 514.000MHz BW: 8MHz DCatRF: OFF
DVB-T2 FFT:16K G.I.:19/128 BPSK PP2 PAPR:NONE
PWR:67.9dBuV
MER: 13.0dB
bBER: 1.0E-02
aBER: 2.0E-05
ERROR: 0
NsMarg: -0.5dB
CellID: 0
Tracking points: 2
Lat.: ---
Long.: ---
Alt: ---
Speed: ---
Time: ---
PRESS ENTER TO STOP MEASURES

Figure 5. Display from the DVB-T2 signal analyzer.

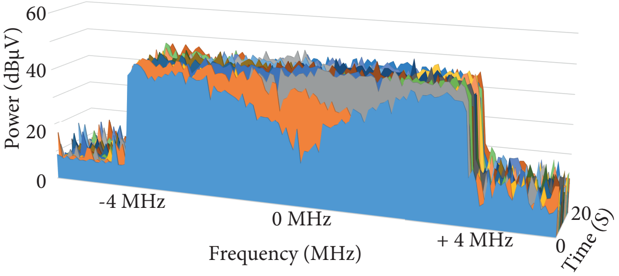

Figure 6. Spectrum of the SFN receiving with a delay of 0 μs.

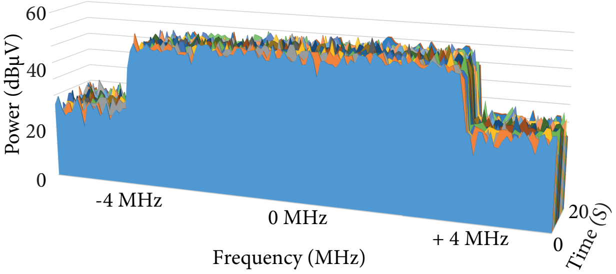

Figure 7. Spectrum of SFN receiving with a delay of 60 μs.

on the experiment. The minimum threshold requirement of the DVB-T2 received signal in the SFN system is roughly 66 dBμV. The degradation rate is also significant during the delay period of 0 μs. The degradation is reduced to approximately 3 dB compared to the delay time in other time periods. The correlation coefficient was used to compare the correlation between the normal strength and the minimum received signal required threshold strength and it was 0.6266, which is considered to be in the same direction but not exactly the same. This experimental test of the delay times between 0 μs and 270 μs covers the delay time of the GI. The GI of the SFN parameter setting for this experiment is 266 μs.

Figure 9 shows that the MER of the received signal at normal strength is approximately 17 dB, which, at a delay time of 0 μs, requires an increase of the MER by approximately 6 dB because at this delay time the effect of the 0 dB echo causes interference and degradation. For the MER at the minimum received signal threshold, the average value for all of the delay times in the GI is approximately 8 dB, and a higher MER at a delay time of 0 μs of approximately 6 dB is required. The correlation coefficient is 0.6973. The correlation is in the same direction for the normal signal and the minimum signal required.

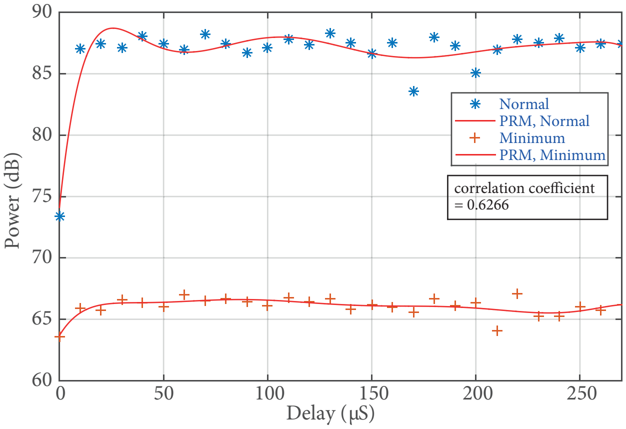

Figure 8. Comparison of delay and power.

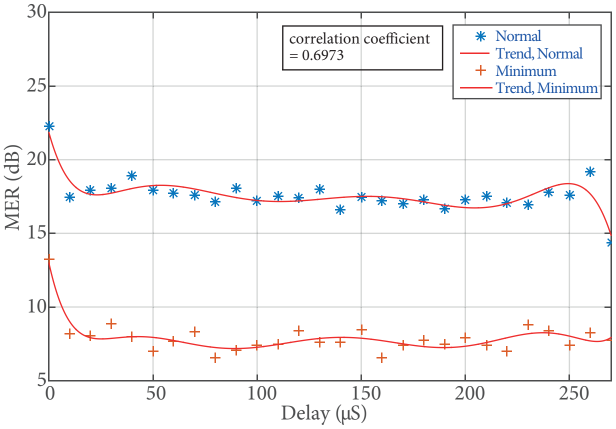

Figure 9. Comparison of delay and MER.

The spectral variation value is shown in Figure 10. The spectrum of the received signal in the 8 MHz bandwidth range changes with the time delay of the SFN transmission between two experimental transmitters. The spectrum deviation for the received signal at the normal received signal strength and the minimal received signal strength has a very small difference and a high deviation as the delay time approaches 0 μs in the same form. The spectral deviation is in the range of approximately 3 dB to 3.5 dB, and there is a greater deviation at the end of the GI. The correlation coefficient indicates that both signals are similar and change following the same pattern during the various delays.

Figure 11 shows the signal stability from the noise margin that can be obtained. If the value is high, the signal is stable enough and is not lost. The margin to the minimum received signal requirement is approximately –6 dB, and when the delay time approaches 0 μs, the higher noise margin is approximately 0 dB.

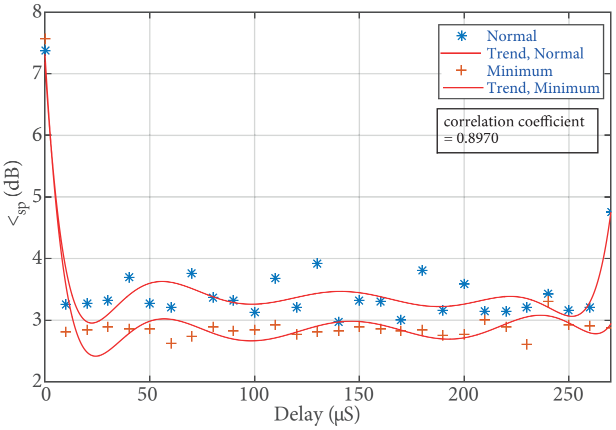

Figure 10. Comparison of delay and spectrum variation.

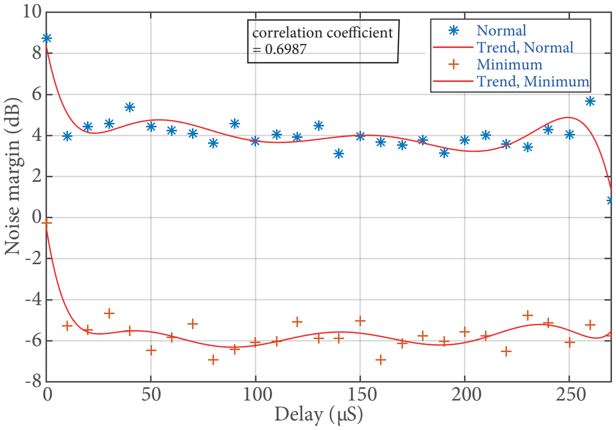

Figure 11. Comparison of delay and noise margin.

Figure 12 shows the laboratory measurements of experimental results, where the C/N at the minimum received signal strength is approximately 23 dB throughout the delay time range. The delay time period approaching 0 μs will be roughly 20 dB, which means a 3 dB loss. Therefore, this signal strength is more difficult to obtain, and at this point, an additional 3 dB is needed to allow the receiver to resume normal reception.

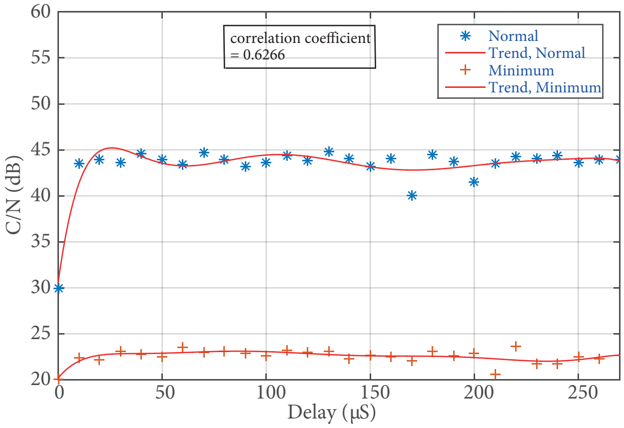

Figure 12. Comparison of the delay and C/N.

The minimum requirements for DVB-T2 to receive signals in the SFN mode are shown in Table 3. The information in the table includes the minimum values that can be received in terms of the power, MER, spectrum variation, noise margin, and C/N. These values are expressed as the mean and standard deviation (STD) throughout the delay range between 0 μs and 270 μs. Normal vs. min. correlation is the relation between the normal received signal and the minimum received signal. All values show that the relationships are in the same direction, especially the values of the spectrum variation of the normal received signal reception and the minimum received signal reception, with a correlation coefficient of 0.8970. The R-squared value shows the PRM order of 8 in error tests. All values of R-squared are greater than 0.5, which means that this prediction model produces results close to the actual experimental data, proving its prediction success.

Table 3. Minimum requirement for DVB-T2 to receive signals in the SFN mode.

Minimum requirement	Mean (dB)	STD (dB)	Normal vs. min. correlation	R-squared
Power (dBμV)	66.03	0.7695	0.6266	0.5255
MER	7.93	1.1786	0.6973	0.7791
Spectrum variation	3.02	0.8822	0.8970	0.9263
Noise margin	–0.53	1.6144	0.6987	0.7789
C/N	21.03	0.7695	0.6266	0.5255

7. Conclusion

In this research, the minimum requirement of DVB-T2 reception for a SFN was presented. Laboratory measurements were performed by modeling a synchronization test of DVB-T2 signals from two transmitters. The experiment was performed by changing the static delay of the transmitter for a performance test in the

GI range to analyze the effect of the SFN. The experiment was recorded and the received signal was inspected by the DVB-T2 analyzer. This research uses DVB-T2 modulation parameters for broadcast digital terrestrial television in Thailand for the SFN mode. The minimum received signal threshold of the SFN was confirmed by the QEF criteria test.

The experimental data are stored in large numbers to ensure reliability. Every 10 μs of delay time is repeatedly measured 20 times, dividing the delay time into 27 ranges from 0 μs to 270 μs. We measured both the normal reception and minimum receiving signal. The measurement data were the power, MER, spectrum variation, noise margin, and C/N. The total number of measurements was 5400 times. The received signal threshold at the QEF criteria throughout the delay time within the GI corresponded to the received signal power of 66.03 dB, MER of 7.93 dB, a noise margin of 3.02 dB, and C/N of 21.3 dB. Since the experiment was a closed system, no multipath and external noise existed; the measurement channel is equivalent to a Rician channel. The limitation of this experiment is that the modulation parameters are used for broadcasting in Thailand only. The evaluation of the SFN specifically analyzes the received signal power from two transmitters that broadcast to the receiver at equal signal strength levels. This scenario is the most likely to affect the received SFN signal. In reality, the signals from both transmitters may reach the receiver with different signal strengths. Even in a real propagation channel, the received signal will be affected by the environment and terrain, which may be different from these results. However, the experimental results can be used as a guide for network planning design and network efficiency improvement for SFN broadcasting, as well as for designing a gap filler system.

Future work will investigate the SFN effect in various delay time periods, in which the signal strengths from two transmitters are unequal. Additionally, experiments with various types of multipath channels with the SFN will be performed to analyze the effects of Rician and Rayleigh channels, as well as experiments in various frequency ranges. All of this can be used as a guideline for designing a single frequency network nicely.

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