Sensors & Transducers, Vol. 158, Issue 11, November 2013, pp. 200-208

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A Practical Method of Coverage Assessment and Measurement for Digital Terrestrial Television Broadcasting

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Received: 19 August 2013 /Accepted: 25 October 2013 /Published: 30 November 2013

Abstract: This paper specifies the objective assessment and measurement method for signals coverage quality of single transmitter and outdoor fixed reception of digital terrestrial television broadcasting system, wherein transmission system of single frequency network is used to convert the input data stream to output RF signal. Any equivalent measurement to guarantee the same measurement uncertainty can also be adopted. *Copyright © 2013 IFSA.*

Keywords: Digital terrestrial television broadcasting, Single frequency network, Transmission system, Signal coverage, Fixed reception.

1. Introduction

Digital terrestrial television single frequency network (SFN) [1] is a digital television coverage network where several synchronized transmitters in different locations simultaneously send the same signal over the same frequency channel to realize the reliable coverage throughout a given territory. In the digital terrestrial television single frequency network, TS from multiplexer is firstly transported to single frequency network adapter for adaption, and then TS including SIPs comes into being to be transported to several transmitters through program distribution network, and transmitted after being converted to radio frequency by synchronizing handling [2-3]. See the sketch map of digital terrestrial television single frequency network architecture in Fig. 1.

Based on the main characteristic of transmission system, the main research in this paper focuses on the objective assessment and measurement method for signals coverage quality of single transmitter and outdoor fixed reception of digital terrestrial television single frequency network.

2. Transmission System Operation Mode

2.1. Constellation Mode and Forward Error Correction Rate

In order to meet different transmission requirements, five constellation modes are supported: 64QAM, 32QAM, 16QAM, 4QAM and 4QAM-NR, and the bit symbols corresponding to constellation point are 6 bits, 5 bits, 4 bits, 2 bits and 1 bit, respectively. The constellation mapping mode of 4QAM-NR is the same as that of 4QAM, except that NR coding is adopted before 4QAM mapping [4-7].

In the case of same frame header mode and same forward error correction code rate, the payload data rate of 4QAM-NR is 1/2 of that of 4QAM, and the payload data rates of 16QAM and 64QAM are 2 times and 3 times of that of 4QAM, respectively. In the case of same forward error correction code rate and same channel condition, anti-interference performance of 4QAM is strongest, and that of 64QAM is relatively worst.

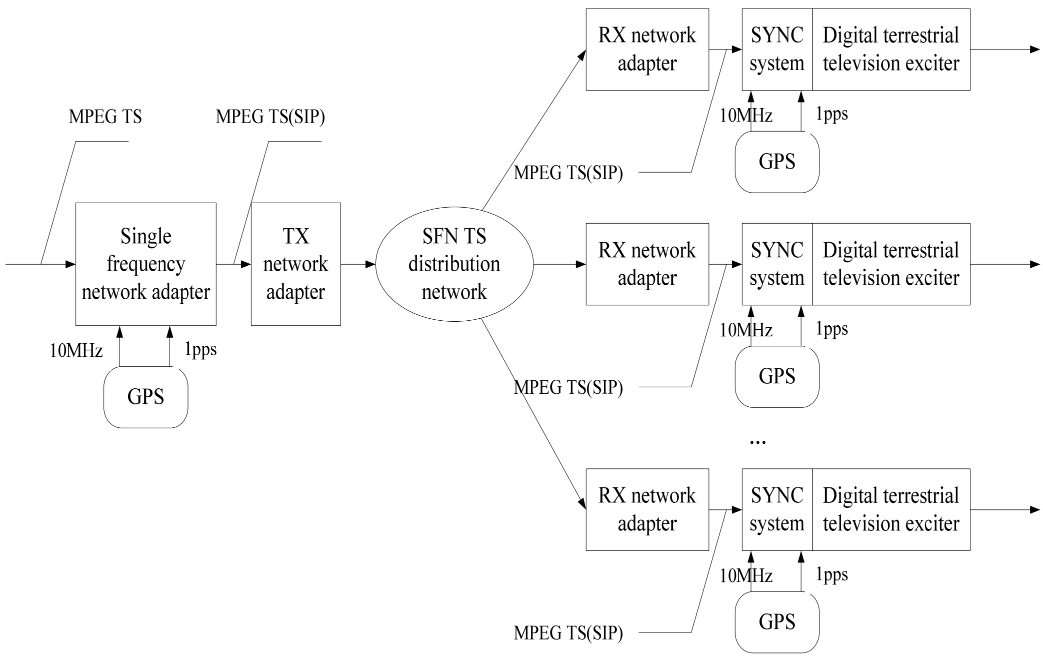

Fig. 1. Sketch map of digital terrestrial television broadcasting single frequency network architecture.

Forward error correction encoding, time-domain symbol interleaving, etc. are adopted to guarantee the robustness of digital terrestrial television signal transmission, and the following three forward error correction code rates are specified: 0.4 (3008/7488), 0.6 (4512/7488), 0.8 (6016/7488), where forward error correction code rate 0.4 has the highest error correction capability and the greatest redundancy so that this mode is applicable to strong-interference channel. On the contrary, forward error correction code rate 0.8 has the least redundancy and lowest error correction capability.

The performance of specific transmission mode depends on the combination effect of forward error correction code rate and mapping mode. As far as performance is concerned, the choice of signal constellation mapping mode can't be separated from the choice of forward error correction code rate. Table 1 illustrates the carrier to noise ratio thresholds in Gaussian channel, Ricean channel and Rayleigh channel of all combination of constellation mapping mode and forward error correction code rate[8]. The carrier to noise ratio thresholds may be improved to certain extent by the enhancement of receiver implementation level in Ricean channel and Rayleigh channel.

As illustrated in Table 1, in the case of Ricean channel, the carrier to noise ratio threshold of forward error correction code rate 0.8 is about 4 dB higher than that of forward error correction code rate 0.4 in 4QAM mapping mode, the carrier to noise ratio threshold of forward error correction code rate 0.8 is about 6 dB higher than that of forward error correction code rate 0.4 in 16QAM mapping mode, the carrier to noise ratio threshold of forward error correction code rate 0.8 is about 8 dB higher than that of forward error correction code rate 0.4 in 64QAM mapping mode[9-11]. The variation of carrier to noise ratio thresholds above will be greater in the case of Rayleigh channel.

Table. 1. Carrier to noise ratio thresholds.

Mapping modes	**Forward error correction code rates**	**Carrier to noise ratio thresholds (dB)**		
		Gaussian channel	**Ricean channel**	**Rayleigh channel**
4QAM	0.4	2.5	3.5	4.5
16QAM	0.4	8.0	9.0	10.0
64QAM	0.4	14.0	15.0	16.0
4QAM	0.6	4.5	5.0	7.0
16QAM	0.6	11.0	12.0	14.0
64QAM	0.6	17.0	18.0	20.0
4QAM-NR	0.8	2.5	3.5	4.5
4QAM	0.8	7.0	8.0	12.0
16QAM	0.8	14.0	15.0	18.0
32QAM	0.8	16.0	17.0	21.0
64QAM	0.8	22.0	23.0	28.0

Compare the carrier to noise ratio thresholds of combinations comprising of mapping mode and forward error correction code rate and having the same payload data rate, such as (16QAM, 0.6) and (64QAM, 0.4), (16QAM, 0.4) and (4QAM, 0.8), so that the impact of combinations of mapping mode with forward error correction code rate in different channels can be observed.

Frame Header Options

Transmission system of digital terrestrial television usually works under the condition of complex multipath channels, for example, signals are reflected by different buildings and different terrains & ground objects, one receiver can receive the signal transmitted by the adjacent transmitter in the surroundings of single frequency network and deal with it as return signal [12]. The occurrence of multipath signals will exercise much influence on the reception performance of receiver, resulting in the increase of system bit error rate so that the receiver fails to be in normal operation.

The basic transmission element in national standard of digital terrestrial television is called signal frame, consisting of frame header and frame body, which can provide PN pseudo-random sequence for fast synchronization and efficient channel estimation & equation [13-16]. To withstand the multipath interference of different delays, three length options for frame header are provided with details shown in Table 2.

Table 2. Frame header options.

Frame header options	Number of symbols in frame header	Frame header length	Signal frame length
Option 1 (PN420)	420	55.56 μs	4200 symbols
Option 2 (PN595)	595	78.7 μs	4375 symbols
Option 3 (PN945)	945	125 μs	4725 symbols

The greater frame header length is, the more propitious to withstand the long-delay returns yet decreasing payload data rate in one signal frame. Greater length for frame header can be considered to apply to larger range of single frequency network.

2.2. Number of Subcarriers

There are two options for number of subcarriers: C=1 and C=3780. The two subcarrier modes have uniform bandwidth, uniform payload data rate, uniform timing clock, uniform system information and uniform frame structure, the difference between which is whether to pass through IFFT processing element. Except IFFT element, other system function elements are completely shared, so that the two modes have the same implementation structure.

2.3. Interleaving Mode

Time-domain symbol interleaving technology is adopted to improve the capability to withstand pulse jamming. Time-domain symbol interleaving is applied across many signal frames. Convolutional interleaver based on constellation symbol is used for the interleaving of data symbols. Two interleaving modes are specified, whose interleaving depth is concerned with parameter M (the buffer size of basic delay element), the mode of M=720 is long interleaving, and the mode of M=240 is short interleaving.

Long interleaving is used to deal with greater length of burst transmission error, which is usually generated from serious pulse noise or shading.

2.4. System Information

System information is import part of signal frame, system information symbols are part of frame body data, each signal frame includes 36 system information symbols to be mainly used to identify system operation mode and provide demodulation information including: constellation mapping modes, forward error correction code rates, interleaving modes, number of subcarriers[17].

Spread spectrum and Walsh code protection are adopted for system information of digital terrestrial television, so that guarantee the reliable recovery of system information in complex and severe channels.

2.5. Payload Data Rate in One Signal Frame

Transmission system of digital terrestrial television can support the payload data rates from 4.813 Mbps to 32.486 Mbps in 8 MHz transmission bandwidth. Parameters to influence the payload data rate in one signal frame are as the following: forward error correction code rates, constellation mapping modes, frame header options.

Payload data rate in one signal frame is concerned with constellation mapping modes, forward error correction code rates and frame header options, as illustrated in equation (1):

$$R_U = R_S \times b \times R_{FEC} \times \left(L_{data} / L_{Frame} \right), \quad (1)$$

where, R_U is the payload data rate in one signal frame; R_S is the constellation symbol rate (7.56 MSps); b is the number of bits mapped to 1 constellation symbol (64QAM: b=6, 32QAM: b=5, 16QAM: b=4, 4QAM: b=2, 4QAM-NR: b=1); R_{FEC} is the forward error correction code rate (3008/7488, 4512/7488, 6016/7488); L_{data} is the number of effective data symbols in one signal frame

(3744 symbols); L_{Frame} is the signal frame length, that is, number of symbols in one signal frame (4200, 4375, 4725 symbols).

According to the above equation, payload data rates in one signal frame can be observed in Table 3.

Table 3. Payload data rates in one signal frame (unit: Mbps).

Signal frame length		4200 symbols		
FEC code rate		0.4	0.6	0.8
Mapping	4QAM-NR			5.414
	4QAM	5.414	8.122	10.829
	16QAM	10.829	16.243	21.658
	32QAM			27.072
	64QAM	16.243	24.365	32.486

Signal frame length		4375 symbols		
FEC code rate		0.4	0.6	0.8
Mapping	4QAM-NR			5.198
	4QAM	5.198	7.797	10.396
	16QAM	10.396	15.593	20.791
	32QAM			25.989
	64QAM	15.593	23.390	31.187

Signal frame length		4725 symbols		
FEC code rate		0.4	0.6	0.8
Mapping	4QAM-NR			4.813
	4QAM	4.813	7.219	9.626
	16QAM	9.626	14.438	19.251
	32QAM			24.064
	64QAM	14.438	21.658	28.877

Note: the mode with slash means this mode is not included [18-19].

The relations of payload data rates in one signal frame and constellation mapping modes & forward error correction code rates are illustrated in Fig. 2.

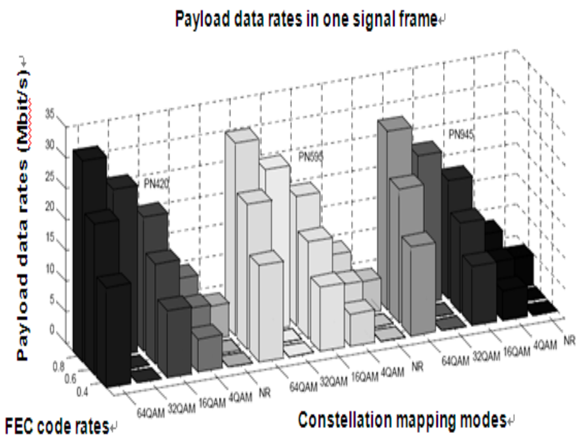

Fig. 2. Payload data rates in one signal frame.

3. Transmitter Input Signal

A range of usable bitrates from 4.813 Mbps to 32.486 Mbps are specified, that is, payload data rates in one signal frame. The bitrates required by different services should be specified during the planning. Since the impairment caused by video encoding is closely concerned with compression algorithm, compression bitrate and compression cascade stages, which bitrate adopted by broadcasting finial stage should be considered together with phases of record, collection, editing, upload, etc. As far as SDTV system with MPEG-2 is concerned, most television programs adopt bitrates of 4 Mbps to 5 Mbps for final broadcasting to reach relatively satisfying quality, yet some television programs which have rigorous vision requirement may demand the bitrates of 6 MHz or more to reach satisfying effect[20-22]. As far as HDTV program with MPEG-2 video compression algorithm, bitrate of 20 Mbps can reach preferable quality for now. With the enhancement of source encoding technology and maturity of new algorithms, the bitrates required to develop diversified services will fall continually.

Audio bitrate adopting MPEG-1 Layer II stereo encoding usually is 192 kbps or 256 kbps, certain new algorithm can reach preferable quality with 128 kbps according to the actual test results [23]. 5.1 channel surround sound may adopt the bitrates of 320 kbps to 448 kbps, and the choice of specific bitrate mainly depends on compression algorithms.

Analog television set chooses program via RF channel, yet digital terrestrial television broadcasting may provide multiple programs in single channel, and EPG (Electronic Program Guide) assists the audience to choose program. The bitrates required by EPG depend on transmitted program number, the extent of detail to provide program information, and broadcasting period, which are usually 200 kbps to 1 Mbps for now.

If the system has conditional access function, front end need broadcast the information of EMM, ECM, etc., so that some bandwidth should be reserved for CA [24-25]. The bitrates for CA system mainly depend on the implementation manner, user quantity, and whether to use multiple simulcrypt CA systems, which are usually 100 kbps to 500 kbps for now.

If the system launches data broadcasting services, front end need transmit data broadcasting service information, so that some bitrates should be further reserved for data broadcasting system, which mainly depend on data broadcasting service categories and specific demands. The required bitrates should be calculated according to application demands.

On the whole, one fixed bitrate is assigned to each service, and alterable bitrates may also be applied. Some MPEG encoding and multiplex equipment are allowed to provide bitrate dynamic control to each service, such as statistical multiplexing, which can dynamically assign the bitrate applied to each service according to service content. But when demultiplex

& remultiplex processing exists in rear-stage, dynamic multiplex stream will cause problems for remultiplex.

4. Transmission System Output Signal

4.1. Spectrum Mask

Spectrum of adjacent channel isn't completely inexistent in transmission system output signal, whose level depends on the characteristics of prefilter after signal generating, nonlinear distortion of power amplifier, the characteristics of filter behind amplifier, etc.

Out-of-band radiation of digital terrestrial television broadcasting signal cause interference with adjacent channel, so that the attenuation amount of these out-of-band spectrum should be specified. Two spectrum masks are specified:

For the case where a transmitter for digital terrestrial television broadcasting is co-sited with, and operating on an upper or down channel adjacent to, an analog television transmitter (PAL system), spectrum mask is given in Fig. 3. No polarization discrimination between digital and analog television is used; the radiated power from both transmitters is the same. If the radiated powers from the two transmitters are different, proportional correction can be applied.

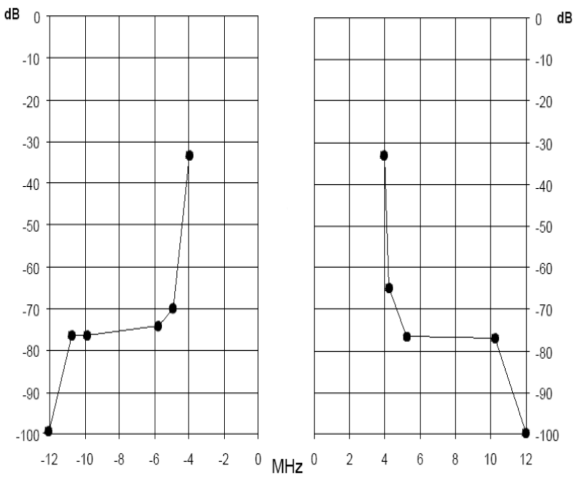

Fig. 3. Spectrum masks for a digital terrestrial television transmitter operating on an upper or down adjacent channel to a co-sited analog television transmitter.

For critical cases such as digital terrestrial television channels adjacent to other services (e.g. with lower power), a spectrum mask with higher out-of-band attenuation may be needed. A spectrum mask for critical cases is shown in Fig. 4.

Spectrum attenuation amount in the above figure is the ratio of measured power in 4 kHz bandwidth at a given out-of-band frequency point to the total signal power in 8 MHz bandwidth.

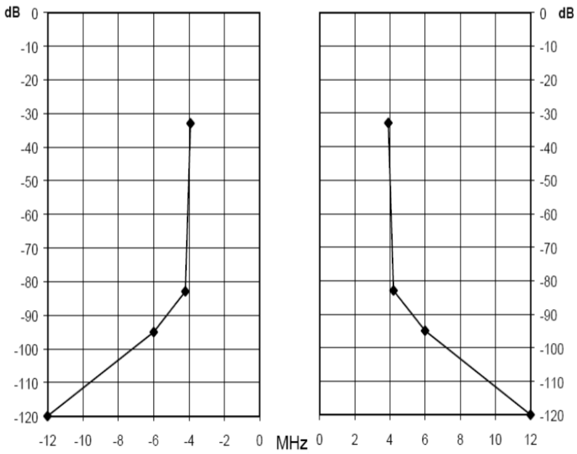

Fig. 4. Spectrum mask for critical cases.

4.2. Protection Ratio

When planning digital terrestrial television broadcasting network or single transmitting station, the interference among transmission systems which are the same or different, should be considered. Protection ratio is usually adopted to describe the capability to withstand the interference from other system signals. Protection ratio is the value of wanted-to-interference signal power ratio at the receiver input measured at the given objective or subjective impairment threshold point of wanted signal.

Protection ratios of all operation modes should be determined by measurement. The measurement is usually made in the specified lab environment. Protection ratio value is not only concerned with the performance of corresponding system operation mode, but also depends on implementation level of system equipment. Co-channel protection ratio mainly depends on system performance, adjacent channel protection ratio depends on the out-of-band amount of interference signal in wanted signal channel and receiver channel filter. Protection ratio performance of receiver may improve during the implementation process of digital terrestrial television broadcasting, so that the requirement for protection ratio will be correspondingly adjusted with technology progress.

5. Assessment Method

5.1. Assessment Parameter

Two parameters of field strength and signal margin are used in this paper to objectively assess coverage quality of digital terrestrial television broadcasting signals. Field strength indicates received signal strength, which varies with measurement location and receiving antenna height, and the variability depends on amplitude and phase combination of several paths that reach the receiving antenna. Signal margin indicates the maximum signal attenuation amount required by transport stream bit error rate for successful reception at measurement location. Bit error rate shows system receiving performance, associated with amplitude and phase of each path, and also closely associated with the relative delays among several paths and other factors.

Therefore there is no fixed corresponding relation between field strength and signal margin; coverage quality of digital terrestrial television broadcasting signals can be objectively assessed by way of comprehensive consideration for field strength and signal margin.

Coverage Quality Grades

For digital terrestrial television broadcasting it would seem impossible to maintain a method based on the subjective five-grade scale for analog vision quality because of the cliff effect of digital television. However, according to the signal margin space between signal reception status and "cliff effect" point, signals coverage quality of outdoor fixed reception of digital terrestrial television broadcasting can be divided into five objective assessment grades, defined in Table 4.

Table 4. Objective assessment grades for signals coverage quality.

Field strength (E)	Signal margin above objective decision threshold (M) (dB)			
	M<0	0≤M<5	5≤M<10	10≤M
E<E70	1	1	2	3
E70≤E<E95	2	2	3	4
E95≤E	2	3	4	5

Interpretation of Coverage Quality Objective Assessment Grades

The five objective assessment grades for coverage quality in Table 4 can be further classified into three extents of coverage level: "inadequate", "adequate" and "better than adequate", herein Q1 and Q2 grades are "inadequate", Q3 grade is "adequate", Q4 and Q5 grades are "better than adequate".

6. Measurement Method

6.1. Measurement System

Besides broadcasting transmitting equipment, required by measurement system to make outdoor fixed reception measurement are stream generator, adjustable attenuator, field strength meter/spectrum analyzer, receiving antenna and connection feeder, testing receiver, transmission analyzer, positioning equipment, etc., see the sketch map in Fig. 5.

6.2. Measurement System Calibration

Stream generator: generate the pseudo random binary sequence test stream 215-1 or 223-1 for bit error rate statistics.

Transmission analyzer: be used for bit error rate statistics of test stream, supporting the pseudo random binary sequence test stream 215-1 or 223-1.

Positioning equipment: measure the geographical surroundings (longitude, latitude, altitude, etc.), horizontal precision: ≤7 m, vertical precision: ≤10 m.

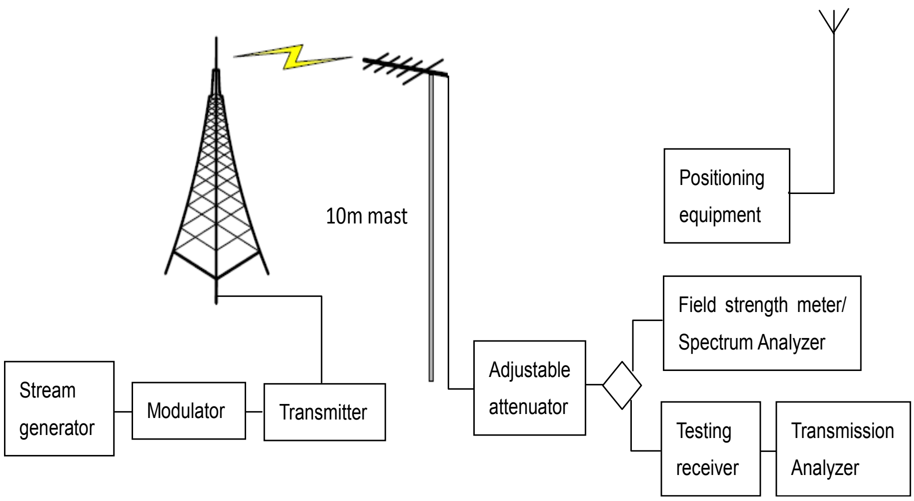

Fig. 5. Sketch map of measurement system.

The purpose of measurement system calibration is to verify and confirm the transmitting parameters, and ensure the measurement system at reception exactness and reliability. When calibrating the measurement system, the following are required: the polarization mode of receiving antenna the same as that of transmitting antenna, the line-of-sight path between calibration measuring point and transmitting point, to be open flat and without obstacles of building, huge forest, etc. around calibration measuring point, without returns reaching calibration measuring point, and to be away from airports, main transport highways, high-voltage transmission lines, substations, factories, etc[26].

Ensure no obvious interference from the above facilities, and background noise level 20 db lower than wanted signal level.

According to effective radiated power Pt of transmitting antenna and distance *d* between measuring point and transmitting antenna, use equation (2) to calculate signal field strength E_c at calibration measuring point.

$$E_c\left(dB\mu V/m\right)=10\log\left(P_t\right)\left(kW\right)-20\log\left(d\right)\left(km\right)+106.92 \quad (2)$$

Raise the receiving antenna to 10 m height above ground level, adjust the attenuation amount of adjustable attenuator to 0, adjust antenna pointing to make receiver input signal level highest, and get the signal field strength E_m at measuring point by field strength meter and attached receiving antenna. If the signal level V_m at input of testing receiver is measured by spectrum analyzer, etc., signal field strength at measuring point should be calculated by equation (3) based on receiving antenna coefficient K corresponding to the frequency band and feeder loss L_c between receiving antenna and spectrum analyzer.

$$E_m\left(dB\mu V/m\right)=V_m\left(dB\mu V\right)+L_c\left(dB\right)+K \quad (3)$$

If the error between the calculation value and measurement value of signal field strength is within 3 dB, note the information of signal field strength, longitude, latitude, altitude, antenna height, antenna pointing, etc. at calibration measuring point, and then begin the measurement at other measuring points. If the error between the calculation value and measurement value of signal field strength is beyond 3dB, it is required to verify the parameters concerned, check up the instruments and equipment or replace calibration measuring point, and recalibrate the measurement system to ensure measurement exactness. Furthermore, if exceptions occur at other measuring points of measurement system, it is required to recalibrate at calibration measuring point.

6.3. Measurement Steps

For each measuring point the specific measurement location should ensure that the measurement process carries through safely and successfully, the polarization mode of receiving antenna is the same as that of transmitting antenna, and the measurement location is free of serious obstruction or interference (other than the special requirements). Besides receiving antenna height of 10 m at measuring point, the typical height of present television receiving antenna herein can be adopted for measurement.

The specific measurement steps are as follows:

a) Note the geographical surroundings information of longitude, latitude, altitude, etc. by positioning equipment, note weather and measurement time, and note the geographical surroundings at measuring point and other factors to influence signal reception, such as overhead lines, trees and billboards, by taking photograph, videos, notes, etc.;
b) Raise the receiving antenna to 10 m height above ground level;
c) Adjust the attenuation amount of adjustable attenuator to 0, adjust antenna pointing to make receiver input signal level highest, and the operations according to different reception conditions are as follows:
    1) If the receiver fails to receive, adjust the receiving antenna pointing properly, and the operations after adjustment according to different reception conditions are as follows: If adjusting antenna pointing still fails to receive, restore antenna pointing till receiver input signal level is highest, note signal margin $M < 0$, and note antenna pointing, receiving signal spectrum and measured signal field strength or level (to be converted to field strength by equation (3)), then turn to step e; If succeeding in receiving after adjusting antenna pointing, note the final antenna pointing, receiving signal spectrum and measured signal field strength or level (to be converted to field strength by equation (3));
    2) If the receiver succeeds in receiving, note antenna pointing, receiving signal spectrum and measured signal field strength or level (to be converted to field strength by equation (3));
d) Increase the attenuation amount of adjustable attenuator till reception fails, decrease the attenuation amount with step not more than 1 dB, measure and note the signal level when reaching objective decision threshold, calculate and note the signal margin *M*;
e) Assess the coverage quality grades according to Table 4, and the operations according to different assessment results are as follows:
    1) If quality grade is Q4 or Q5, the measurement at this measuring point is finished, and then the measurement at next measuring point might be carried out;
    2) If quality grade is Q3, it is required to lower antenna height and observe the variation of signal strength, and the operations according to different results are as follows: If signal strength increases,

choose the corresponding height to return to step c to carry out complementary measurement (note the distance from antenna to ground level) according to signal strength; If signal strength decreases, the measurement at this measuring point is finished, and then the measurement at next measuring point might be carried out;

3) If quality grade is Q1 or Q2, it is required to lower antenna height and observe the variation of signal strength, and the operations according to different results are similar to the above.

7. Simplified Assessment and Measurement Methods

7.1. Background

Field strength measurement usually requires field strength meter and attached receiving antenna, bit error rate measurement usually requires stream generator, transmission analyzer and testing receiver. Considering that field strength meter, domestic receiver and monitor can be equipped more easily in many cases, signal coverage quality can also be assessed by measuring ordinary receiver input signal level and by subjective decision threshold measuring signal margin. In such a case the building of measurement system is relatively simple and equipment of special test stream generator, testing receiver and transmission analyzer aren't required. Signal coverage quality can be measured and assessed in the course of normal program broadcasting.

7.2. Simplified Assessment Quality Grades

According to the five assessment grades for signals coverage quality, Table 5 gives the corresponding simplified assessment grades.

Table 5. Objective assessment grades for signals coverage quality (simplified assessment method).

Receiver input signal level (V)	Signal margin above subjective decision threshold (M) (dB)			
	M<0	0≤M<5	5≤M<10	10≤M
$V \le V_{min}$ [a]	1	1	2	3
$V_{min}<V_{min}<V_{min}$+6dB	2	2	3	4
V_{min}+6dB≤V	2	3	4	5

7.3. Simplified Measurement System

Besides broadcasting transmitting equipment, required by simplified measurement system are adjustable attenuator, field strength meter, receiving antenna and connection feeder, domestic receiver, monitor, etc., see the sketch map in Fig. 6.

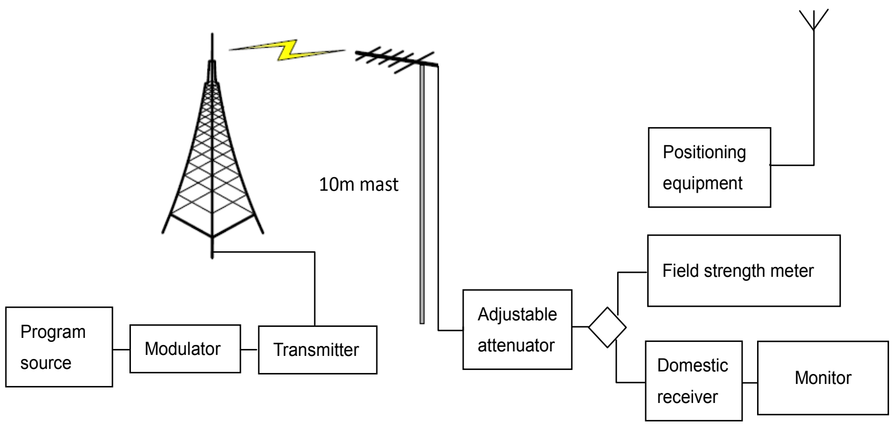

Fig. 6. Sketch map of simplified measurement system.

8. Conclusion

Digital terrestrial television single frequency network (SFN) is a digital television coverage network where several synchronized transmitters in different locations simultaneously send the same signal over the same frequency channel to realize the reliable coverage throughout a given territory.

Based on the main characteristic of transmission system of SFN, this paper specifies the objective assessment and measurement method for signals coverage quality of single transmitter and outdoor fixed reception of digital terrestrial television broadcasting system. Any equivalent and simplified measurement methods to guarantee the same measurement uncertainty can also be adopted.

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