Results of Field Tests of the ISDB-T_B System at 8 MHz in Botswana

Eduardo S. Bueno, Gunnar Bedicks, Jr., Cristiano Akamine, and Edson L. Horta

***Abstract*—Botswana performed field tests of the Integrated Services Digital Broadcasting – Terrestrial version B (ISDB-T_B) system in order to choose which standard should be used by the country. This paper presents the results of performance tests of the ISDB-T_B system and an analysis of test results from the cities of Gaborone, Mahalapye, Maun, and Tsabong. The system was configured with an 8 MHz bandwidth and central frequency of 770.000 MHz. The system was evaluated with fixed reception using a single monopole antenna. Data collected in the field were used to analyze the power level, C/N ratio, Bit Error Rate (BER), and Quasi Error Free (QEF). The results corroborate in the adequate reception of the test signal.**

***Index Terms*—Bandwidth , Integrated Services Digital Broadcasting – Terrestrial version B (ISDB-T_B), Fixed reception.**

I. Introduction

THIS paper presents the results of performance tests for the ISDB-T_B standard, operating at 8 MHz, in four cities of Botswana: Gaborone, Mahalapye, Maun, and Tsabong. The system was evaluated on channel 58, with a frequency of 770.000 MHz. ISDB-T_B was designed to provide high quality audio and picture for fixed and mobile reception. It was also designed to deliver flexibility, interactivity, and expansion capabilities [1].

ISDB-T_B is derived from the Japanese ISDB-T system and employs the H.264 video codec, the MPEG-4 AAC HE audio codec, and a Brazilian middleware (DTVi). It uses VHF (channels 7-13) and UHF (channels 14-69) bands, with a 6 MHz bandwidth [2-8]. This system was developed in Brazil, where its performance operating at 6 MHz for fixed, mobile, and portable reception was demonstrated. [7-8]. The research conducted in order to approve the system also influenced its adoption by other countries, such as Peru, Argentina, Chile, Venezuela, Ecuador, Costa Rica, Paraguay, Philippines, Bolivia, Uruguay, and the Republic of the Maldives [7], [8]. Recently, Botswana adopted ISDB-T_B after analyzing the results presented in this paper.

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II. ISDB-T 8 MHz

The ISDB-T system was developed in Japan. It uses BST-OFDM modulation with 13 segments and operates using 6, 7 or 8 MHz channels (BW_{TV}) [9]. Each segment contains a carrier set that occupies 1/14 x BW_{TV} [10]. Thus, the bandwidth of one segment is equal to 571.40 KHz when a BW_{TV} of 8 MHz is used. The 13 segments can be combined in up to three hierarchical layers, A, B, and C. The ISDB-T transmission system can be represented by three stages: re-multiplexing, channel coding, and modulation [11].

In the first stage, the MPEG-2 TS (188 bytes) coming from the multiplexing stage is responsible for BTS generation. The BTS is composed of a single TS of 204 bytes and a constant bitrate of 4 x Fs_{IFFT} (sampling frequency of the Inverse Fast Fourier Transform) at the modulator. This frequency is calculated from the IFFT size and the effective duration of the OFDM symbol. For 8 MHz, Fs_{IFFT} = 8192/756 µs = 10.8359 MHz, yielding a BTS bitrate of 43.3439 Mbps. BTS is composed of the TSP from each layer and null packets, called BTS frames. The packets must be ordered to guarantee the hierarchical transmission of a single TS and to minimize processing by the receiver [12]. The null packets are inserted to maintain the constant bit rate independent of the modulation parameters [11]. The channel coding is formed from a Reed Solomon block (188,204,8), an energy dispersal block formed by a 15-bit PRBS generator, a byte convolutional interleaver, a convolutional coder with a mother code rate of 1/2 (G1 = 171oct; G2 = 133oct) and puncture adjust for the rates R = 1/2, 2/3, 3/4, 5/6 or 7/8.

At the modulation stage, the channel coding signal is parallelized and processed by a MUX convolutional interleaving. Mapping is done for QPSK/DQPSK, 16-QAM or 64-QAM modulations. The layers are combined and time interleaved using 0 ms, 100 ms, 200 ms or 400 ms intervals [1], [9], [13]. The second stage of the modulation consists of one OFDM modulator operating with an inverse fast Fourier transform. The carrier amount (Nc) is 1405 in mode 1 (2K), 2809 in mode 2 (4K) or 5617 in mode 3 (8K) [9]. The output of the OFDM modulator is appended with a cyclic prefix formed by a copy of the end of the OFDM symbol. This prefix can be adjusted for GI 1/4, 1/8, 1/16 or 1/32, providing robustness against Inter-Symbol Interference (ISI) [14].

As the Fs_{IFFT} is directly related to the modulator bandwidth, this stage determines the occupation of the OFDM spectrum. The useful bandwidth BW used by the 13 segments is 7.43 MHz. Independent of BW_{TV}, the re-multiplexing, channel coding, and modulation stages are the same. The useful bitrate

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for segment Rb can be calculated using (1). D_{cs} is the data carrier amount: 96 in mode 1, 192 in mode 2 or 384 in mode 3. Nb is number of bits per symbol: 2 for QPSK, 4 for 16-QAM or 6 for 64-QAM. RS, the Reed Solomon code ratio, is 188/204.

$$Rb = \frac{1}{Tu} \cdot Dcs \cdot Nb \cdot R \cdot RS \cdot GI' \quad (1)$$

$$Tu = \frac{Nc-1}{BW} \quad (2)$$

$$GI' \frac{1}{GI+1} \quad (3)$$

ISDB-T was designed and tested at 6 MHz [2], [4], [10], and [15-17]. However, the performance does not change at different bandwidths. Planning criteria, including protection indices, for terrestrial digital television services were designed and tested at 8 MHz [18]. It is recommended that a receiver's tuner unit be compliant with ITU-R BT.1368-9, (see Tables I and II). The transmission parameters employed to obtain the measurements, which are presented in Table II, were 64-QAM modulation and an inner code of 3/4. Tables III and IV present the receiver parameters used in the tests.

The maximum signal level injected at the receiver input was -20 dBm in order to eliminate any risk of damage.

TABLE I
SENSITIVITY AT RECEIVER INPUT

Frequency [MHz]	UHF 600			
System	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8
P*min* [dBm]	-92	-93	-84	-76
(C/N) [dB]	6.20	4.90	14.60	22.00

TABLE II
PROTECTION RATIOS

Undesirable signal	Item	Protection ratio [dB]
Digital transmission ISDB-T	Co-channel Lower adjacent channel Upper adjacent channel	+20 -30 -30
Analog transmission I/PAL	Co-channel Lower adjacent channel Upper adjacent channel	+5 * *

* Not established by a standard

TABLE III
SENSITIVITY AT RECEIVER INPUT [dBm]

Modulation Scheme	Inner-code coding ratio 1/2	2/3	3/4	5/6	7/8
QPSK	-94.2	-92.9	-91.3	-90.7	-89.9
16QAM	-89	-86.7	-85.9	-84.5	-83.7
64QAM	-84.1	-81.3	-80	-77.5	-76.1

TABLE IV
TRANSMISSION PARAMETERS AND REQUIRED C/N RATIO [dB]

Modulation Scheme	Inner-code coding ratio 1/2	2/3	3/4	5/6	7/8
QPSK	3.3	4.9	5.7	6.8	7.6
16QAM	8.9	11.2	12.3	13.4	14.3
64QAM	14.2	17.2	17.9	19.6	22

Prior to the field tests, some laboratory tests were made with two objectives in mind. The first was determining the receiver behavior for specific BER values. The second was analyzing the relationship between C/N and BER in a laboratory environment. This relationship can then be used as a reference for an analysis of the field tests. The laboratory tests were conducted in a controlled environment and were completely immune to external interferences.

During the field tests, the signal was transmitted from a tower 50 meters above the ground. In Gaborone, the transmission station was 1205 meters above sea level. In Mahalapye, the station was on a mountain with an altitude of 1245 meters. In Maun, the altitude was 950 meters, and in Tsabong, the altitude was 968 meters.

The same transmitter was used in each city. The RF transmission system is composed of an antenna, a transmission line, and high power amplifiers, all designed for the ISDB-T_B system. The transmission equipment includes a TS server, an ISDB-T_B exciter, RF amplifiers, and channel filters.

The system parameters were configured according the standards [9] and [19]. Table V shows the modulation parameters used in the tests. The transmitter used UHF channel 58 (center frequency of 770 MHz) with an 8 MHz bandwidth. The antenna was an omnidirectional Jampro Trunstile, with a gain of 8.23 dBd. The mean power level of the RF amplifiers was 1 Kw, with ERP ≅ 34 dBw (considering cable and conector losses).

TABLE V
ISDB-T PARAMETERS

Bandwidth	8 MHz		
Mode	3 (8K)		
Guard Interval	1/16		
Layer	A	B	C
Segments	1	3	9
Carrier Modulation	QPSK	16-QAM	64-QAM
Convolutional Coder	1/2	2/3	3/4
Time interleaving [ms]	=287	=287	=287
Bit Rate [Mbps]	0.44	3.52	17.84

The procedure used was based on test procedures from the evaluation of other DTV transmission systems, along with the recommendations and standards for this system. Based on [10], [20], and [21], the test plan was developed, and a measurement system was created in order to perform the field tests. The main task of the field tests was to measure the performance of a DTV system transmitting on UHF channel 58 (776 – 774 MHz). The mean signal power at an 8 MHz bandwidth, C/N ratio, BER, localization and perceived video quality, QEF [21], were measured. The subjective evaluation of the video quality was an adaptation of the ITU [20] using four grades (see Table VI). Grades "1" and "3" indicate intermittent reception, where "3" indicates that the image does not annoy the viewer and "1" indicates that the image does. BER values indicate an approximate range that would be measured at the receiver used in the tests. The BER values, obtained before the Reed Solomon coding, were measured in the laboratory.

TABLE VI
QUALITY RATING SCALE

Grade	Image	BER
5	error free	0.00E+00 – 2.00E-04
3	slightly annoying	4.50E-04 – 2.40E-03
1	very annoying	5.50E-03 – 1.20E-02
0	no lock	1.48E-02 – 1.00E+00

The field tests were performed in conjunction with the Department of Broadcasting Services (DBS) and the Botswana Telecommunications Authority (BTA), which provided the test vehicle (Fig. 1), equipped with measurement instruments for the ISDB-T_B system. The tests were performed at 41 locations in the four different cities. The reception measurements were obtained using a monopole antenna with -2.26 dBd gain, located 2.5 meters above the ground.

The setup used in the field tests is shown in Fig. 1. An ISDB-T_B receiver was used for channel decoding. Performance was measured using a subjective reception analysis, similar to [20]. An Anritsu MS8911B signal analyzer was used to measure the signal intensity level and analyze the signal characteristics. The system was calibrated, and the receiver was tested prior to the tests, in order to confirm that its sensitivity met specifications [17] and [18].

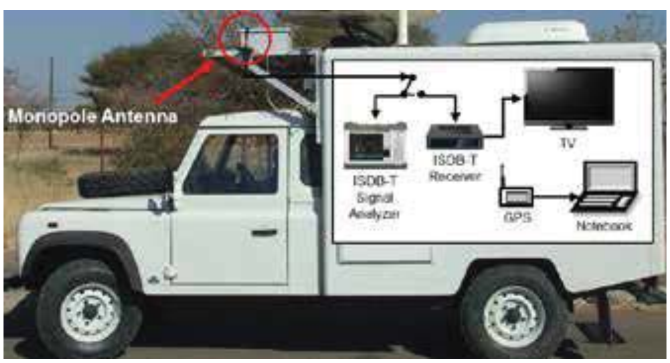

Fig. 1. Transmission System

The measurement methodology was based on [21] and other test procedures used to evaluate DTV transmission systems [10], [22-25].

The test vehicle was moved to each predetermined test site, where the following characteristics were recorded: time, geospatial coordinates, local environmental characteristics, urban density and traffic. The main reason for this was to characterize the test site with regard to the buildings and local traffic, which may cause unwanted effects on the signal reception. The power level, C/N and BER were also recorded for each test site. For each location, it was necessary to manually search for the receiver channel. The reception quality was measured using a subjective analysis. This analysis was performed by observing an image for sixty seconds, QEF, and grading it according to Table IV.

IV. DTV FIELD TEST RESULTS

This section describes the most important measurements for designing digital transmission systems. Many data sets were collected at each location in order to evaluate the signal reception quality under different interference and fading conditions in the field.

Four small cities in Botswana were analyzed, with a total of 41 measurement locations, covering the entire area of each city. In the results, DBA refers to the distance from the test site to the antenna, and the BER values were obtained before the Reed Solomon coding.

Gaborone, the largest city in Botswana, had 17 measurement locations (Fig. 2). In contrast to other cities in Botswana, Gaborone has many buildings and intense traffic, and some of the test sites did not have a direct line-of-sight to the transmission tower.

Fig. 2. Test Sites in Gaborne

In Gaborone, some test sites did not obtain adequate reception, as shown on Table VII. Test sites 1, 5 and 7 were graded "0", "0" and "1", respectively. These locations are urban areas and 10 km from the transmission tower. The buildings caused signal obstruction and reflection. Site 12 is an industrial zone and received a grade of "0". Site 14 is a residential zone and received a grade of "3". Both locations are approximately 15 km from the transmission tower and are obscured by buildings in the city center. Hence, test site 12 did not receive sufficient signal intensity, and site 14 had a close-in echo of -30 dB relative to the main signal (Echo to Carrier ratio = E/C = -30 dB), due to the existence of buildings.

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TABLE VII
RESULTS OF FIELD TESTS AT GABORONE

Site	Location	DBA [Km]	Signal Level [dBm]	C/N [db]	BER	Grade
1	Civic Center	10.70	-79.0	7.5	1.65E-02	0
2	Tsholofelo P.	7.54	-67.0	24	0.00E+00	5
3	Broadhurst	7.62	-66.0	18	0.00E+00	5
4	Ledumang SSS	4.40	-44.6	24	0.00E+00	5
5	MMC	9.85	-78.7	11	1.65E-02	0
6	Block 7	8.90	-65.0	23	0.00E+00	5
7	Mogoditshane	10.90	-78.0	18	6.64E-03	1
8	Ledumadumane	9.09	-57.0	23	0.00E+00	5
9	Phakalane	4.30	-58.4	24	0.00E+00	5
10	Gaborone N	4.72	-67.5	22	2.20E-04	5
11	CBD	10.70	-63.0	21	2.50E-05	5
12	Gaborone W	15.35	-81.0	7	1.65E-02	0
13	Gaborone W	14.40	-74.0	21	0.00E+00	5
14	Old C. Hall	14.75	-77.8	17.1	2.50E-03	3
15	Old C. Hall	14.20	-76.6	19	4.50E-05	5
16	Block 9	14.60	-72.1	22	0.00E+00	5
17	SSKA	3.52	-59.6	20.6	0.00E+00	5

In Mahalapye, 7 measurements were performed (Fig. 3). This city has only houses and moderate traffic, and the transmission tower is on a mountain 1245 meters above sea level. Although there was a large distance from the city to the tower, every test site had a direct line-of-sight to the transmission tower.

Fig. 3. Test Sites in Mahalapye

Every test site in Malahapey obtained adequate reception, with grades of “5”. The results are presented in Table VIII.

In Maun, a small city with low traffic, there were 10 measurements (Fig. 4). It has three districts far from the center of the city, which caused fading, and there is an airport in the center.

In Maun, only one location did not obtain adequate reception, as shown in Table IX. Site 5 is a rural zone, 32.9 km from the transmission tower, and obtained a grade of “3”, due to the low intensity signal and multipath interference. The maximum echo, which was also a close-in echo, had an E/C = -20 dB.

TABLE VIII
RESULTS OF FIELD TESTS AT MAHALPYE

Site	Location	DBA [km]	Signal Level [dBm]	C/N [dB]	BER	Grade
1	D. Ward	10.90	-53.1	22	0.00E+00	5
2	Tshikinyega	12.20	-60.4	23.6	0.00E+00	5
3	Xhosa	13.90	-71.5	21.6	2.00E-06	5
4	Xhosa 1	13.50	-62.3	22.3	1.00E-06	5
5	Flowertown	16.30	-59.1	24.2	0.00E+00	5
6	T. Ward	14.60	-70.9	23.4	0.00E+00	5
7	Mahalapye W	12.50	-52.0	23.6	0.00E+00	5

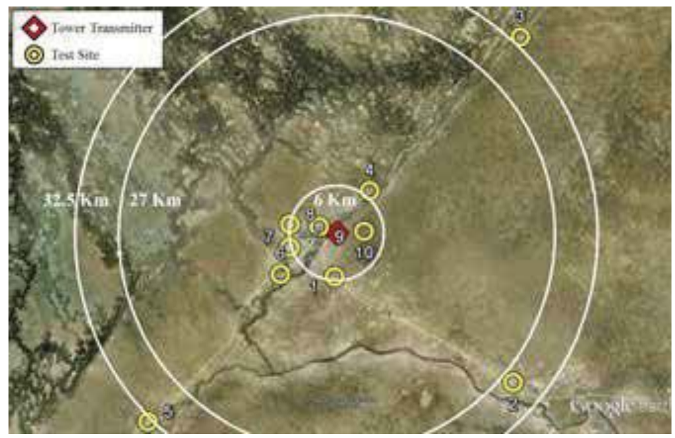

Fig. 4. Test Sites in Maun

TABLE IX
RESULTS OF FIELD TESTS AT GABORONE

Site	Location	DBA [Km]	Signal Level [dBm]	C/N [dB]	BER	Grade
1	Matshwane	5.40	-51.1	23	0.00E+00	5
2	Chanoga	28.40	-76.7	19.2	4.70E-05	5
3	Shorobe	33.30	-78.0	18.7	1.77E-04	5
4	Boronyane	6.60	-59.1	25.7	0.00E+00	5
5	Kimana	32.90	-77.7	18.5	1.21E-03	3
6	Shashe	8.67	-68.5	21.7	2.00E-06	5
7	Bomadi	6.13	-60.0	23.4	0.00E+00	5
8	Botshabelo	5.93	-63.0	23.2	0.00E+00	5
9	Airport	2.31	-68.6	19.7	2.20E-05	5
10	Disaneng	3.33	-50.4	23.3	0.00E+00	5

In Tsabong, a small city with low traffic, 7 measurements were made (Fig. 5). In this city, only one site did not obtain adequate reception, as shown in Table X. Site 7 is a rural zone, 26.1 km from transmission tower, next to the border with South Africa. It is surrounded by mountains and obtained grade of “3”, due to low signal intensity.

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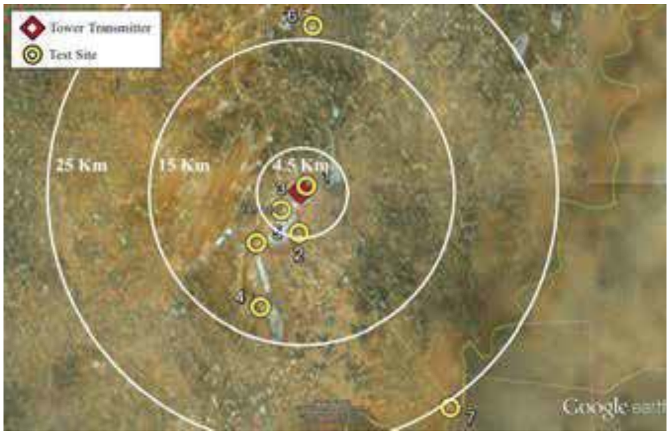

Fig. 5. Test Sites in Tsabong

TABLE X
RESULTS OF FIELD TESTS AT TSABONG

Site	Location	DBA [Km]	Signal Level [dBm]	C/N [dB]	BER	Grade
1	BDFCamp	0.60	-47.8	24.6	0.00E+00	5
2	Mokha	4.48	-67.7	21.5	3.00E-06	5
3	Tsabon M.	2.60	-47.7	24.5	0.00E+00	5
4	Logaganeng	12.30	-61.5	26	0.00E+00	5
5	-	6.87	-52.80	24.7	0.00E+00	5
6	Maleshe	15.80	-72.0	21.9	4.00E-06	5
7	MacCathy	26.10	-78.7	17.8	8.60E-04	3

Table XI provides a direct comparison between the signal reception qualities of the four cities in Botswana. Reception margin is an important parameter of DTV service. It indicates whether a digital TV signal can be received without errors and how many dB the C/N ratio may be degraded before reaching the reception limit (Fig. 6) [23], [25].

TABLE XI
FIXED SERVICES AVAILABILITY

Grade	Gaborone	Mahalapye	Maun	Tsabong	Total
5	70.59%	100.00%	90.00%	85.71%	82.93%
3	5.88%	0.00%	10.00%	14.29%	7.32%
1	5.88%	0.00%	0.00%	0.00%	2.44%
0	17.65%	0.00%	0.00%	0.00%	7.32%

In Fig. 6, C/N ration are on the horizontal axis, and BER measurements are on the vertical axis, using a logarithmic scale. The values above the points represent the grades. In Fig. 6, the curve represents the laboratory tests, performed in a controlled environment, completely immune from external interferences. From these results, it was observed that for C/N ration above 17.5 dB, no errors are seen at the receiver. Based on the field tests, C/N ration below 15 dB obtained a grade of "0". These values were discarded. C/N ration between 17 dB and 18.5 dB obtained grades of "3" or "1". C/N ration above 18.7 dB obtained a grade of "5".

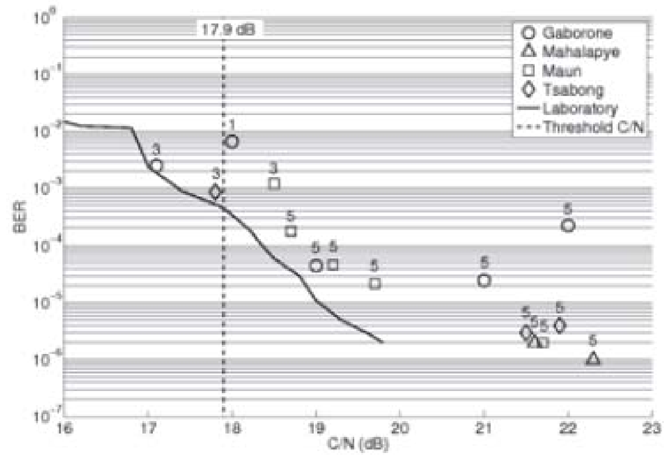

Fig. 5. BER x C/N (Comparison of Field and Lab Test)

V. DTV FIELD TEST ANALYSIS

With ISDB-T_B, the minimum C/N ration at the receiver in the tests was 17.9 dB (BER = 2.0E-4, before Reed Solomon coding), as characterized in the laboratory. Furthermore, the minimum field intensity for fixed reception was Pmin = -80 dBm. However, it is worth mentioning that this minimum C/N ration (17.9 dB) was obtained from subjective evaluations of video quality, QEF, under controlled conditions, without multipath interference. In the field tests, the threshold C/N ration may be higher [10], [23] and [25]. The C/N ration is an important factor for satisfactory reception (Fig. 6). The majority of test sites had the possibility of perfect reception when the C/N ratio was greater than 17.9 dB, the receiver protection ratio threshold. However, high C/N ration do not guarantee good reception. For example, a DTV receiver may fail when there is multipath interference. This is demonstrated by the existence of error in the reception signal at two test sites with C/N ratios greater than 17.9 dB.

The results for Mahalapye, Maun and Tsabong, which are shown in Table XI, are better than those for Gaborone because echoes are generally found in urban areas, where there is no direct line-of-sight without physical obstruction to the transmission tower from the reception location [10]. The effect of echoes can be seen at three test sites (1, 5 and 7) close to downtown Gaborone, 10 km from transmission tower. Test site 1 had a power level of -79 dBm, which is close to the reception threshold, and there was also a close-in echo with E/C = -4.5 dB, produced by the surrounding structures; the grade at this site was "0". Test site 5 had a power level of -78.7 dBm, which is close to the reception threshold, and there was also a close-in echo with E/C = -10 dB; the grade at this site was also "0". Test site 7 had a power level of -78 dBm, which is within the reception threshold, but there was a close-in echo with E/C = -10 dB. Its grade was "1", and its C/N ratio was 18 dB, which is close to the minimum value. Test sites 12 and 14 in Gaborone were approximately 15 km from the transmission tower and also did not obtain adequate reception. Test site 12 had a power level of -81 dBm, which is insufficient signal intensity, yielding a grade of "0". Test site 14 had a power level of -77.8 dBm, which is within the

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reception threshold, but there was an echo with E/C = -35 dB, and its grade was “3”. Its C/N ratio was 17.1 dB, which is less than the minimum value.

Mahalapye had the best performance because it is a secondary city, and the transmission tower was on a mountain, with direct line-of-sight to all reception locations. Thus, the signal intensity ranged from -52 dBm to -71 dBm.

In Maun, test site 5 had a power level of -77.7 dBm, which is within the reception threshold, but there was a close-in echo with E/C = -20 dB. Its grade was “3”, and its C/N ratio was 18.5 dB, which is greater than the minimum value. In Tsabong, test site 7 was 26.1 km from the transmission tower, and the power level was -78.7 dBm, which is close to the reception threshold. Its grade was “3”, and its C/N ratio was 17.8 dB, which is less than the minimum value.

In the field tests, 34 of 41 locations obtained good reception quality using a monopole antenna. Among the seven locations with poor reception, two of them had a C/N ratio greater than 17.9 dB, but the reception was intermittent. This intermittent reception was due to distortion of the received signal caused by multipath interference in addition to the noise. The other five locations did not have sufficient signal intensity above the noise level.

VI. Conclusion

Field tests were performed at 41 location tests in Botswana for digital TV signal. These tests showed that the ISDB-T_B system had a service availability of 82.93% at the test sites. The urban zones have lower C/N ratios than other locations. Furthermore, in urban areas, the probability of signal distortion due to multipath interference is very high and yields a high probability of poor reception quality. It was verified that reception quality is determined mainly by the C/N ratio and signal distortion due to multipath interference.

A digital TV modulation system is chosen based on how well it can fulfill the particular requirements and priorities of a country. Additionally, other non-technical factors, such as geographic, economic and political relations with neighboring countries, have to be considered. Each country needs to determine its needs and then study the available information about the performance of different systems in order to choose the best one. On February 26, 2013, Botswana adopted the ISDB-T_B system as its standard for digital terrestrial TV. Botswana was the first country in Africa to adopt the ISDB-T_B system.

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