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Experimental Investigation of Digital TV Signals with Multipath in Curitiba

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***Abstract*—This article describes experimental propagation measurements of DTV signals in the urban region of Curitiba. A digital TV analyzer manufactured by Rohde & Schwarz, model ETL was used [1], which is able to differentiate open TV channel signals received via different paths. At each measuring location, the geographical coordinates, the relative intensity, the relative delay of each of the ten most intense echoes received, the recording time, and the channel power were recorded. A vertical monopole antenna tuned to the channel frequency and mounted two meters above ground level on the top of a special purpose vehicle was used as the receiving antenna. Signal frequency spectrum and the subjective quality of the received signal were simultaneously observed. Both the path loss and the echo pattern were measured. 1580 samples were recorded, taken approximately five meters apart in various regions of the city and were compared with current propagation models. The power and delay of every multipath version was checked to evaluate the efficiency of the guard interval. The effects of distance and elevation of the reception site were investigated, as well as the presence of channel-modifying obstacles. Analysis of the results included the comparison of received power measurements with the Okumura-Hata model calculations. The multipath delay data was analyzed as per recommendation ITU-R P.1407 [2]. Preliminary results show the robustness of the ISDB-T$_B$ system against UHF propagation in Curitiba. Some aspects of the measurements elicit further investigations that can be carried out with the same resources.**

***Index Terms*—Digital TV, Multipath, Measurements, Urban propagation, UHF.**

I. Introduction

THE main purpose of a broadcasting system is to maximize the number of receptors able to capture a signal that it is compatible with the acceptable quality standards established for the service from the technical point of view or the marketing point of view. Knowing the actual coverage provided by a transmitting station for digital TV is an area of interest for broadcasting managers. It is very unlikely that the signal quality is acceptable in the entire coverage area. Locations of failures and the reasons for failures in coverage is an area that broadcasting station technical teams continue to investigate. The advent of digital TV has brought doubts about the real effect of propagation on multiple path signals, characteristic of urban regions can have on a digital transmission. For the regions where the signals fails, is this because of the low received signal power or could this be caused by the arrival of successive versions of the signal that went through multiple pathways? In this study, an experimental approach was chosen in order to answer these questions.

Financial support provided by CAPES, through the project 'Formação de Pessoal Qualificado em TV Digital no Paraná' process 23038.2355/2008-16 AUX-PE-RH-TVD 249/2008

II. Materials and Methods

Given the dispersion values to be expected when measuring received power, a higher number of samples reduce uncertainties. For the measurements in this analysis, 1580 samples were collected. To enable accurate data collection and to eliminate human errors in transcription and annotation, an automated system was used. It is based on a ETL digital TV analyzer produced by Rohde & Schwarz Company [1].

A route was chosen for the test that presented various propagation conditions: direct sight, shading caused by the terrain or constructions, high relative signal intensity with multiple paths in some places, and low-intensity signals reflected in other regions of the route . The route taken can be identified in Fig. 1 with the received power within the range between -30 dBmW and -70 dBmW.

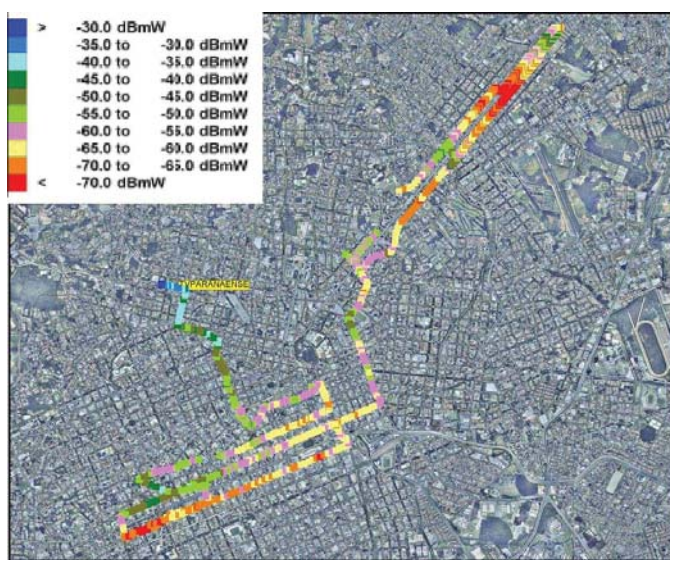

Fig. 1. Route taken in Curitiba by the reception vehicle

The whole measuring system was mounted on a vehicle specially prepared for this activity. The vehicle boasts an inverter system, capable of providing adequate AC power for the measuring instruments on board. A GPS receiver is coupled to the measuring system so that the coordinates where the measurements were made were automatically incorporated into the table with the measured values without human intervention. For most of the trial, further measurements were taken approximately every thirty meters along the route. This separation to the order of 60, tends to maintain statistical independence between two adjacent measurements. A second spectrum analyzer, capturing the same signals by an equivalent antenna, but separate, was kept under observation during the experiment, in particular to indicate the regions where the received signal spectrum was no longer on a single plane, a fact that by itself is an indication of propagation by multiple paths.

The receiving antenna chosen was a vertical monopole antenna to reduce directionality reception influences. The idea is that all echoes are received with about the same gain, no matter the direction from which it comes. It was fixed on the vehicle two meters from the ground. The antenna used in the experiment measures 11cm, approximately $\lambda 4$ in the central frequency of 635 MHz in channel 41, granted to Rede Paranaense de Comunicacao, whose 8 kW transmitter, antenna tower and station were used as the signal source for testing. In this evaluation, a total loss of 1.28 dB was considered due to RF switches, connectors, and lines of transmission, which leads to a coherent EIRP with that reported in [3]. The additional loss of 0.17 dB is attributed to the fact that throughout the test, the receiving antenna is always found below the main beam of the transmitting antenna, outside the maximum gain direction. The power effectively radiated in dBm can be expressed by the following equation:

$$EIRP_{dBmW} = 60 + 10log_{10}(8kW) + 10.7dBd + 2.14dB - 1.28dB - 0.17dB = 80.24dBmW \quad (1)$$

For reception, the gain of the monopole was estimated at -1 dBd, due to the absence of a full grounding plane in the assembly of the vehicle. An additional loss of 7 dB was tentatively attributed to the difference in polarization used in the transmission (horizontal) and reception (vertical). A power splitter was used to send equivalent signals to the ETL and a digital TV receiver, which allowed a subjective evaluation of the received signal throughout the test. The loss in the power divider is 3.2 dB. Added to the loss in the cables, the total loss in reception of 9.42 dB. If d is the distance in km separating the receiver from the transmitter, and *L(d)* is the loss due to propagation, the received power P_{dBm} in dBmW, it can be expressed by

$$P_{dBmW} = 71 - L(d) \quad (2)$$

Various propagation models were compared to measurements obtained. The received power values in each of the 312 simulations were calculated using equations available in [4], or generated by EDX software [5]. For example, in the region of Av. Canada the models in Table I were simulated, with the average error and the standard deviation expressed in dB.

The variation of *L(d)* with *d* is dictated by the model chosen, as detailed in the following section.

III. Reviewed Models

With the volume of measurements and models experimented with, it was necessary to delimit the analysis of those situations with more elucidatory character. The following subsections discuss these choices.

A. Free Space Model

In this model, the received power is given by

$$P_{dBmW} = 71 + 20log_{10}\left(\frac{\lambda}{4\pi d}\right) \quad (3)$$

The free space model is represented, along with other information, in Fig. 2.

TABLE I
PROPAGATION MODELS WITH EDX SOFTWARE USED ON AV. CANADA

Propagation Model	Mean error (dB)	Standard deviation (dB)
Anderson 2D v1.00	15.54	10.22
FCC – EDX	31.22	9.65
FCC – FCC	31.33	9.69
FCC – Pt22	31.22	9.65
FCC + RMD	21.81	9.60
Free Space + RMD	20.22	8.74
Hata-extended-open	14.59	9.33
Hata-extended-suburban	-3.44	9.33
Hata-extended-urban	-12.68	9.33
ITU-R 1546 cold sea curves with delta H	41.90	9.11
ITU-R 1546 cold seas curves without delta H	41.90	9.11
ITU-R 1546 Land curves with delta H	27.86	9.34
ITU-R 1546 Land curves without delta H	27.86	9.34
ITU-R 1546 Warm sea curves with delta H	41.90	9.11
ITU-R 1546 Warm sea curves without delta H	41.90	9.11
ITU-R 370 Cold sea curves with delta H	41.97	9.12
ITU-R 370 Cold sea curves without delta H	41.97	9.12
ITU-R 370 Land curves with delta H	41.97	9.12
ITU-R 370 Land curves without delta H	41.97	9.12
ITU-R 370 Warm sea curves with delta H	41.97	9.12
ITU-R 370 Warm sea curves without delta H	41.97	9.12
ITU-R 370 + RMD Cold sea curves with delta H	32.14	8.60
ITU-R 370 + RMD Cold sea curves without delta H	32.14	8.60
ITU-R 370 + RMD Land curves with delta H	32.14	8.60
ITU-R 370 + RMD Land curves without delta H	32.14	8.60
ITU-R 370 + RMD Warm sea curves with delta H	32.14	8.60
ITU-R 370 + RMD Warm sea curves without delta H	32.14	8.60
Longley rice v1.2.2	17.64	10.30
Okumura-Hata-open	23.95	9.50
Okumura-Hata-suburban	5.92	9.50
Okumura-Hata-urban	-3.32	9.50
TIREM – EDX	17.13	10.03

doi: 10.18580/setijbe.2015.7 Web Link: http://dx.doi.org/10.18580/setijbe.2015.7

 / ISSN (Print): 2446-9246 / ISSN (Online): 2446-9432

B. Free Space Model with diffraction

It is equivalent to the previous model, with the following refinements [5]: the passages with direct view will be considered as the vectorial sum of the radius directly to that reflected in the ground; and the route segments beyond the direct view, rounded up to ten obstacles has its attenuation by diffraction added, according to the Epstein-Peterson technique of successive triads [5].

C. Okumura-Hata Model

The Okumura-Hata model used in this study, to verify its adequacy for experimental measurements was the 'big cities in frequencies above 300 MHz', as shown in [4]:

P » L ysF :x{ wwE txsxHK 54 C :B ; F suztHK 54 C :D ; F
:u HK 54 C :ssywD ; F v { Ey:vv { F
xwwHK 54 C :D ; HK 54 C : @ ; ; (4)

In this expression, f is the frequency of the carrier in MHz, h_t is the height in meters of the center phase of the transmitting antenna, and h_r is the height of the receiving antenna in meters. The actual height that the antenna was effectively fixed to the vehicle was two meters in relation to the ground. To verify agreement with the experimental data, five curves were drawn using the Okumura-Hata model. Three of them used the correct height of the transmitting antenna, and three different values for the height of the receiving antenna: 2, 9, and 14 m. In the other two curves, the actual height of the receiving antenna at 2 m was maintained, and the height of the transmitting antenna was varied to the fictitious values of 30 and 1000 m, in order to investigate the effect of average land elevation on the propagation path. This information is detailed in Fig. 2. As can be seen by the monotonic decrease and constant rate of these curves, the Okumura-Hata model referred to in this subsection does not take into consideration the effects of diffraction.

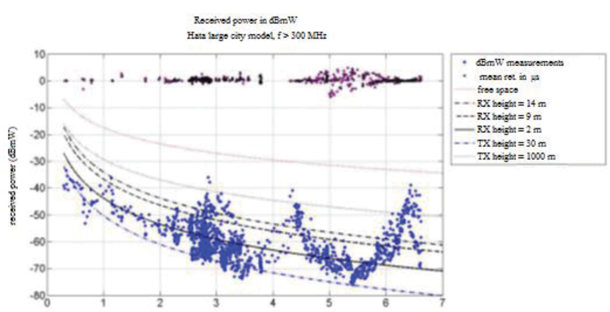

Fig. 2, Comparison between the received power measurement values with those predicted by the free space and Okumura-Hata models

D. Hata model with diffraction

The tool [5] in the Hata-extended-open and Hata-extended-suburban models, adds loss due to the effects of diffraction to the model described above through the Epstein-Peterson technique. A comparison of the measurements taken on Av. Canada is shown in Figs. 3 and 4.

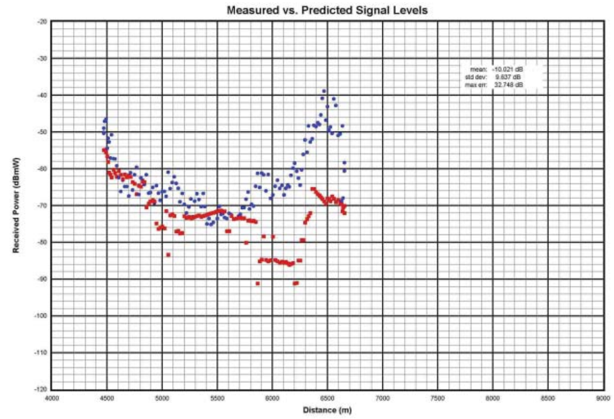

Fig. 3. Measured values of received power (blue circles) and the predictions made using the Hata-extended-suburban model, which includes the effect of diffraction following the Epstein-Peterson technique (red squares).

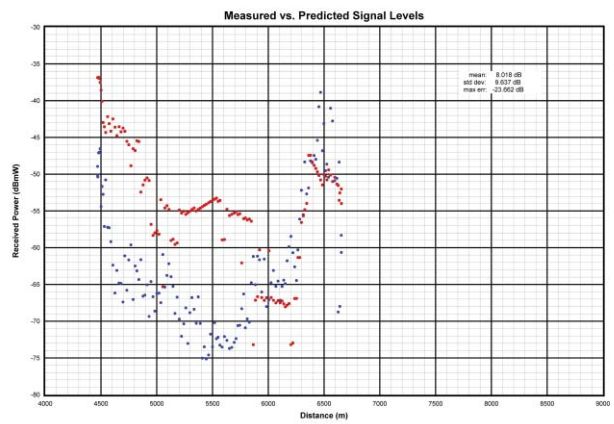

Fig. 4. Measured values of received power (blue circles) and those predicted by the Hata-extended-open model, which includes the effect of diffraction following the Epstein-Peterson technique (red squares).

IV. Echo Profiles

Besides the analysis of the received power, in the same trial information about the propagation by multiple paths was collected.

The ETL instrument is able to discern digital TV signals displaced in time and superimposed on the main signal. It is possible to measure the delay and intensity of each COFDM version. The version with a higher received power is chosen as a reference; it is assigned the intensity of 0 dB. The other copies of the received signal have their intensities measured in dB with respect to most intense version, so the values in dB are always negative. Their delays are also referred to the stronger version, even if it had not been the first to be received. In the chosen mode for the test, the ten echoes perceived to be the most intense are presented, each with a specific delay in relation to the most powerful. It means that there may be echoes with negative delays if the most intense version had not been the first to arrive. Sometimes these signals with a negative delay are called pre-echoes. A profile of typical echoes, as shown by ETL is shown in Fig. 5.

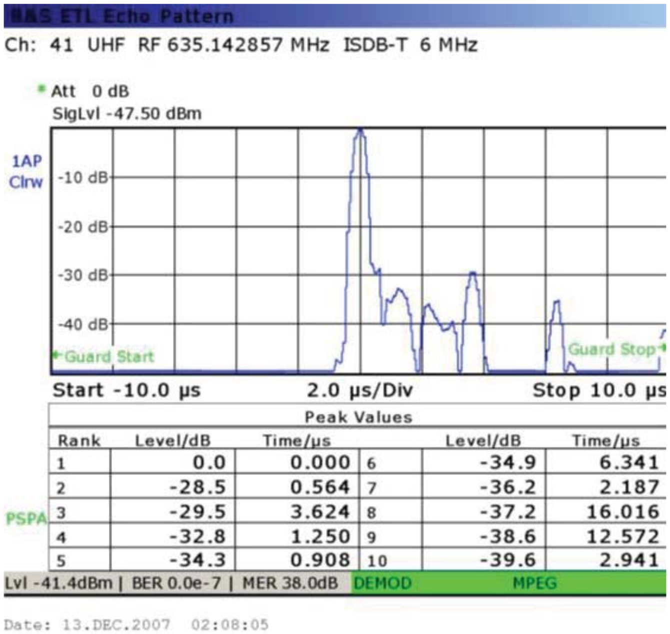

Fig. 5. Typical echo profile

Each of the 1580 measures taken during the test is associated with twenty figures relative to echoes. Ten of these are the intensities, in dB, with relation to the most intense. The ten other values are the delays in microseconds, also relatively to the most intense echo.

In order to summarize the information contained in these 31,600 numbers, the formulation of ITU-R was used [2], the so-called 'average delay' T_D and '*rms* scattering delay' S, for convenience is repeated below:

$$T_D = \frac{\sum_{i=1}^{N} P_i t_i}{\sum_{i=1}^{N} P_i} \qquad (5)$$

$$S = \sqrt{\frac{\sum_{i=1}^{N} P_i t_i^2}{\sum_{i=1}^{N} P_i} - \frac{\left(\sum_{i=1}^{N} P_i t_i\right)^2}{\left(\sum_{i=1}^{N} P_i\right)^2}} \qquad (6)$$

Note that the average delay T_D is a weighted average of the N delays taken into consideration (in our experiment there were ten). The weight of each delay in the media formation is its relative power. It is a central tendency measure.

The *rms* spreading is a dispersion measure that evaluates how much the delays are spreading in time.

V. Results Analysis

The measurements collected were analyzed from two points of view: the power received, and the echo profile caused by multipath. The following two subsections discuss each aspect.

A. Received power results analysis

By observing Fig. 2, we can see that the Okumura-Hat model, although providing a reasonable adjustment to the measurements of distances between 1.2 and 2.2 km, it could not model the signal propogation that is caused by the terrain and buildings. In particular, in the range between 3.5 and 4.4 km, and again between 5.4 and 6.4 km, the received power increases in distance; such behavior cannot be reproduced in the Okumura-Hata model.

To adapt the model for the above behavior, it is necessary for the model to consider the diffraction effect, and take into account the topographic data. This refinement is incorporated, among others, into the 'free space + RMD', 'Hata-extended-suburban' and 'Hata-extended-open' models. A comparison of the last two models with the measurements collected on the first pass on Av. Canada is shown in Figs. 3 and 4. In these, it can be seen that the models reproduce the weak signal ranges that, in the measurements is those taken between 5.4 and 5.7 km. This appears to be a better prediction with the 'Hata-extended-suburban' model until 5.65 km; after this distance, the 'Hata-extended-open' model best fits the experimental data.

B. Multipath results analysis

To better interpret the measured data, it is useful to imagine two similar situations, with the only exception being the direct signal; in the second scenario, the direct signal is 10 dB weaker than the first scenario. All the other reflected signals are the same in both situations. As the intensities are measured in relation to the most intense echo, which always evaluates to 0 dB, it is as if all the reflected echoes had suffered a tenfold increase in their power in the second scenario, compared to the first. It means that the weights of all the delays of the reflected signals become ten times larger. As a consequence, the average delay T_D had a considerable increase, even if the echoes have remained exactly the same.

Based on this reasoning, it is possible to conclude that a reduction in the direct signal is accompanied by an increase in the 'average time delay' parameter. Conversely, one elevation of the average delay is an indication of direct signal weakening, possibly a consequence of the loss of direct sight between the transmitter and receiver.

The measurements collected support this consideration. The route areas that have a perceptible increase in the average delay correspond to regions where there has been a reduction or even a suppression of the direct signal. In Fig. 2, in the area between 5 and 6 km, the increase of the average delay coincides with a decrease in received power. Both alterations occurred in a region of lower land, reinforcing the indication of the direct signal loss.

Another direct signal weakening indication is the occurrence of pre-echoes. The existence of negative delays signifies that the most intense echo was not the first to arrive. Therefore, the direct signal is not as strong, which indicates a likely obstruction in the first Fresnel ellipsoid.

C. Guard interval verification

The guard interval used by the digital TV transmitter that served as a signal source for the test is 63 µs.

It must be ascertained whether echoes that came after this interval have sufficient intensity to provide some risk of disturbance. In Fig. 6, the greatest delays found for each measurement are shown.

The capacity of a delayed signal to produce a disturbance depends on its intensity and its delay with respect to the main signal. In an ISDB-T_B system, a test [6] quantified the potential for a single echo and is shown in Fig. 7.

doi: 10.18580/setijbe.2015.7 Web Link: http://dx.doi.org/10.18580/setijbe.2015.7

A significant gap can be seen between the maximum delays measured in relation to the adopted guard interval.

VI. CONCLUSION

The analysis of 1580 signal intensity measurements and the echo profile and in each of them allows, among other considerations, the following conclusion:

- The Okumura-Hata model for large cities and frequencies above 300 MHz, while having provided an adequate approximation for small distances, it seems unable to cope with the Curitiba terrain variations, which were not very strong in the areas covered during the test. Errors higher than 30 dB are noted in Fig. 2.

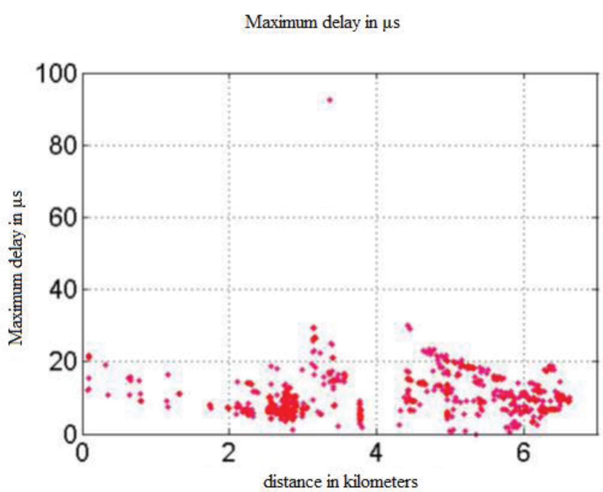

Fig. 6. Maximum delay value found for each measurement

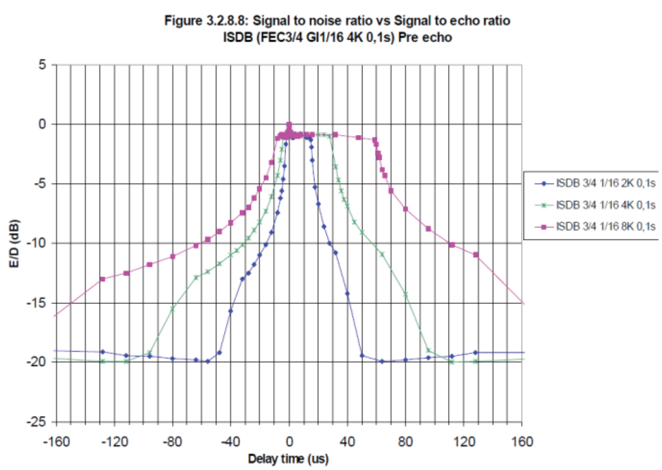

Fig. 7. Maximum admissible values for echo intensity in the ISDB-T_B system [6].

- It is important that the propagation model considers the topography and the diffraction in order to predict shadow areas within the area of coverage.
- Rare occurrences of degradation in image quality occurred in the exact locations where the signal level was low, comparable to the tuner sensitivity of -77 dBm used in the test. This fact is a strong indication that degradation is solely due to signal weakness; the measured multipath signals do not cause, per se, perceptible degradation in the received image.
- In the few regions where it was found, the signal weakening extended over several wavelengths. This means that the cause is the obstruction of the direct path (shadowing) by terrain or constructions. It is not caused by fast fading, as a result of multipath.
- In Fig. 2, it can be seen that an increase in the average delay measured correlates with a reduction in direct signal.
- Before the break found in the measurements, an eventual reduction in the guard interval can be considered, with the consequent possibility of an increased bit time rate.
- The occurrence of multipath is not always harmful; their existence allows reception in some locations that without the contribution of multiple paths would only have a signal with a power lower than the sensitivity of the receivers.
- The automated collection system used for measurements in the field proved to be practical in use. Measurements can be taken with the vehicle in motion, and a sensible number of locations can be assessed in a relatively short time, about 800 locations per hour. This allows a confident knowledge of the broadcasting coverage, in a fast way with greater accuracy than the models.

VII. FUTURE RESEARCH

Some additional aspects can be analyzed concerning digital TV propagation in the urban region of Curitiba. The inclusion of the effect on the topography of the land caused by buildings in the model is one of them. Also intriguing is the fact that two models were necessary to obtain good adaptation to a single measured area. Another useful target for future research is the ability of the DTV signals to be captured within buildings since most broadcast television receivers make use of internal antennas.

ACKNOWLEDGMENT

The team that carried out this would like to express gratitude to Rede Paranaense de Comunicação, who kindly provided human resources and material, without which the work would not have been possible; the professors and LCD laboratory researchers of the Post Graduation Program in Electrical Engineering and Industrial Computing UTFPR, Curitiba campus, whose guidance and encouragement initiated and continued throughout the project.

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Cite this article:
Costa de Borba, M. A., Neves Mayer, C. E., Ono Fonseca, K. V., de Almeida Prado Pohl, A., de Ramos Good, K., Mildemberg, L., Wosch, D. L. , and Martins, R. A. ; 2015. Experimental Investigation of Digital TV Signals with Multipath in Curitiba. ISSN Print: 2446-9246 ISSN Online: 2446-9432.doi: 10.18580/setijbe.2015.7 Web Link: http://dx.doi.org/10.18580/setijbe.2015.7