Identify areas of shadow through interpolation algorithms in the UHF frequency band of Digital Terrestrial Television (DTT)

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Abstract **- In this document the presence of shaded areas is determined by applying three interpolation algorithms, called: Natural Neighbor Interpolation, Linear Interpolation and Nearest Neighbor Interpolation; individually executed in a computer program created within the GUI environment MATLAB. Measured points are interpolated in terms of field strength and MER, taking into account the reference levels established in accordance with the Technical Standard for the broadcasting of Digital Terrestrial Television in Ecuador and specifications recommended by the ISDB-Tb adopted by the country. The results will be presented in the virtual map provided by Google Earth software, which facilitates the representation of the signal level that will serve to display shaded areas and an analysis of the results and validation of each interpolation algorithm is performed by error calculations. Additionally, a coverage prediction software in ICS TELECOM be performed with models P.1546 and ITU-R ITU-R P.1218 propagation, to compare actual measurements taken at various points within the selected measurement area with those estimated by the software.**

Index Terms **- Natural Neighbor Interpolation, Linear Interpolation, Nearest Neighbor Interpolation, MER, GUI, ISDB-Tb, ICS TELECOM.**

I. INTRODUCTION

The impact of DTT due to technological improvements and the benefits it has, has meant that in several countries decide to end the analogue TV transmission and to start the digital TV transmission, this process is called analog switch. This process encourages the other countries to get involved in this technological change and adopt a standard that allows use of DTT service.

Ecuador has received this transmission system and plans to make the analog switch in 2018. To which must be carried out several technical tests, especially those related to the issue of coverage.

Currently the DTT is transmitted using the Brazilian ISDB-Tb in several provinces, and despite the constant attempts to spread the digital signal, there are sectors that do not have this facility, given that Digital Terrestrial Television does not support average, unlike the analog system it is even possible to see blurry images. With DTT, the case is different, the screen is pixelated or directly be black if not arrive with enough power.

Although the equipment is in good condition, there are areas that orographic difficulties or dispersion, DTT signal reaches with difficulty to carry the signal to remote places and sparsely populated, for that satellite communication is used which is extremely expensive. Exemplifying the situation, it is not appropriate to make an investment of millions of dollars to provide television service to very few users, in addition to assuming the cost of maintenance. Why a methodology that helps estimate the knowledge of the places identified as shaded areas, to provide better service to viewers through gap filler transmitters are low power is required. Thus the present titling project aims to identify shadow areas corresponding to the digital terrestrial television channels in the UHF band currently operating in the city of Quito. For that, you have selected a sector belonging to the Metropolitan District of Quito where measurements have been made with equipment provided by the ARCOTEL.

II. MEASUREMENT METHODOLOGY

It is based on the collection of measures signal level (expressed in units of electric field strength) and the geographical position of each measurement point received by a spectrum analyzer. Furthermore, additional measurements of BER (Bit Error Rate) and MER (Modulation Error Rate), in which the quality of digital signal reception is seen take place. Static and Dynamic: To do this, two types of measurements for each DTT channel currently operating in the city of Quito classified were made.

These measurements are made in the selected measurement.

A. *Static measurements*

Static measurements refers to measures field strength and Modulation Error Rate received by the R & S ETH equipment, at fixed points within the measurement area, to conduct an analysis of digital and spectral type.

Static points are distributed in a manner similar to that indicated in Fig. 1 for each DTT channel.

Fig. 1. Static points in Google Earth, Channel 26

B. Dynamic measurements

It is called dynamic measurements to measures field strength obtained by the drive test, using the ARGUS software and vehicle mobile monitoring SACER (Automatic Control System Radio Spectrum), which will take over the area selected measurement. Dynamic measurements are shown in the Fig. 2 and they were made for validation of interpolation algorithms by calculating the error by interpolating these measurement points color mapping the electric field intensity of the remaining points is obtained.


Fig. 2. Location dynamic points in Google Earth

C. Selecting the Measurement Area

ARCOTEL executed test drive several tests that provide reference information regarding areas of the city where signal reception is poor or nonexistent.

According to tests run by ARCOTEL techniques, identified areas with low values of MER, they correspond to the following: The Boot, San José de Chilibulo and La Mena. Therefore, the selected measurement area belongs to the People Committee, close to La Boot sector about 36967.0758 m ^ 2. This area measures to determine the existence of shady areas, apparently is not identified within the group of areas with coverage problems will be taken.

In Fig. 3 the outline of the selected measurement area for the development of this project, the same that is exposed on the map of Google Earth is shown.

Fig. 3. Selected measurement area on the map of Google Earth

D. General scheme Measurement System

In Fig. 4 the general scheme of the measurement system used is shown in which the mobile monitoring station SACER indicated, the team R & S ETH and ARGUS software with a GPS positioning system integrated.

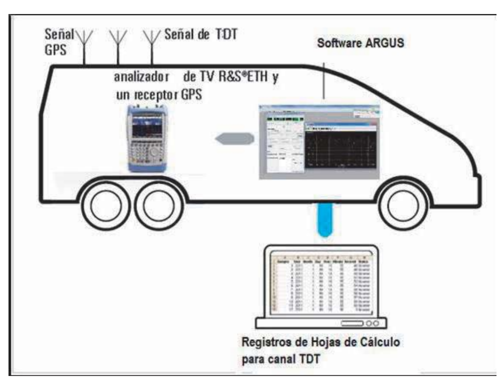

Fig. 4. General scheme Measurement System

III. ALGORITHMS

In this section, the theoretical analysis of algorithms interpolation will be made, which will be simulated in the computer software MATLAB to interpolate additional points to be measured, so that it is possible to map the signal levels received for each TV channel digital Terrestrial.

Interpolation algorithms proposed for the development of this project are: Nearest Neighbor Interpolation, Linear Interpolation and Natural Neighbor Interpolation. Explained below.

A. Nearest Neighbor Interpolation

It is a method that bases its interpolation in the closest known point and discards the rest of neighboring points. To which takes into account the distances from the point to be estimated all known points, selecting the distance to the nearest, ie less distance to that point. Using equation (1) is intended to represent the above [1].

$$P(x,y) = min_{d_k} P_m(x_m, y_m) \qquad (1)\ [1]$$

Donde:
$P(x,y)$: Point (x, y) interpolated.
$P_m(x_m, y_m)$: Unknown points.
d_k: Distancia a cada uno de los puntos conocidos.

B. Linear Interpolation

Linear interpolation is the algorithm that is interpolated based on straight lines, using two known points adjacent to the area where the unknown point is interpolated.

The interpolating function is a straight line connecting the two points as shown in Fig. 5; the blue line functions linearly interpolating between the two red dots are the known values to find the value at the point (x, y), which is the unknown value to be estimated.

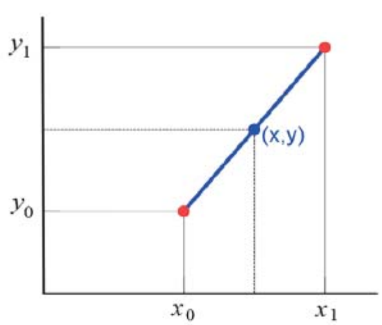

Fig. 5. Linear Interpolation

The mathematical expression for this method corresponding to two dimensions, is defined as follows:

$$P(x,y) = P_0(x_0, y_0) + u\left(P_1(x_1, y_1) - P_0(x_0, y_0)\right) \quad (2)\ [1]$$

The variable u denotes the distance between the interpolated point and the corresponding known. It can take values from the interval [0, 1], i.e., one end of the line takes the value of 0 and its opposite takes the value of 1. If the variable u is outside this range, extrapolation is presented.

C. Natural Neighbor Interpolation

This method takes into account the nearby points or natural neighbors around who want to interpolate. Each dot is assigned an area or region through a geometric construction, known as the Voronoi diagram [1].

For this type of interpolation the mathematical expression modeling the weighted average natural neighbors or points around which you want to interpolate, is as follows:

$$P(x,y) = \sum_{m=1}^{n} f_m(x,y) * P(x_m, y_m) \qquad (3)\ [1]$$

$P(x_m, y_m)$: m indicates the points corresponding to natural neighbors around the point P (x, y) to be interpolated.
$f_1(x,y), f_2(x,y), f_3(x,y), \ldots, f_m(x,y)$: Indicates the coefficients weights each point.

To better understand obtaining coefficients, an example shown in Fig. 6, which consists of five natural neighbors $P(x_1,y_1), P(x_2,y_2), P(x_3,y_3), P(x_4,y_4), P(x_5,y_5)$ belonging to an area called voronoi diagram identified by the initials $(A_1, A_2, A_3, A_4, A_5)$, respectively.

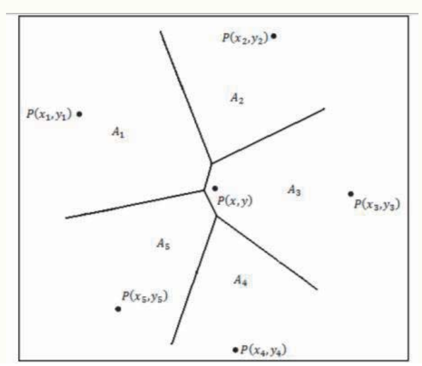

Fig. 6. Representación de 5 vecinos naturales [1]

Voronoi polygon is created, around the point to be estimated P (x, y). The f_m coefficients (x, y) are defined by the portion of overlap between the new polygon and the initial polygons as shown in Fig. 7.

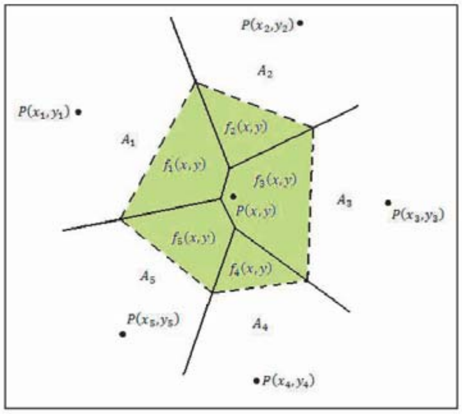

Fig. 7. Coefficients$f_m(x, y)$

A test scenario performed in MATLAB software simulation, in which interpolation algorithms Nearest Neighbor, Linear and Natural, known for four points, with a value equal to 3m resolution applies arises.

The (x, y) axes are represented by geographic coordinates expressed in decimal degrees, on Google Earth map of the location of the known points that form the interpolation grid is displayed, as shown in Fig. 8:

Fig. 8. Interpolation grill

Grilled about interpolation (2268 x 2268) m, with an area of 5143824 m^2 , it has 4 known points P1, P2, P3, P4. Each point is assigned the following values 20, 80,100 and 60 respectively. The color bar is in the range of 15 and 110.

As shown in Fig. 9, unknown points have been estimated taking the point value closest known, so that when you reach the middle of the grid change color abruptly because it is considered the point value known more nearby.

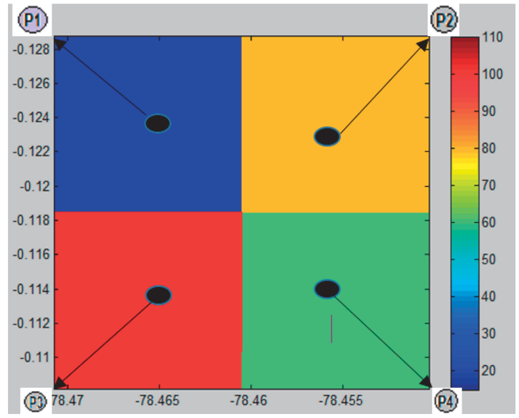

Fig. 9. Test Zone: Nearest Neighbor Interpolation, Resolution: 3m, 4 known points

Then a simple example that applies linear interpolation is performed.

As in the previous case, a test scenario is generated in the MATLAB simulation software equal to the section 2.3.1. In this example, four known points located at the vertices of the grid interpolation is used as shown in Fig. 10.

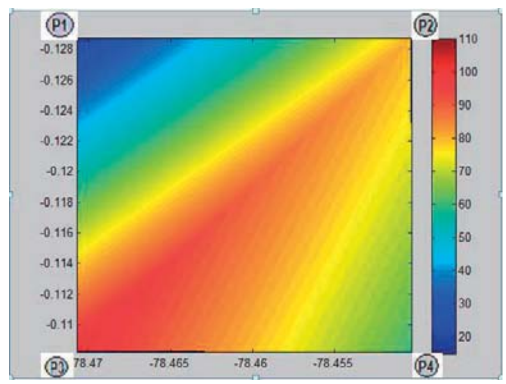

Fig. 10. Test Zone: Linear Interpolation, Resolution: 3m, 4 known points

Points P1, P2, P3, P4, are assigned the following values: 20, 80,100 and 60 respectively.

The graph shows that diagonal faded colors is obtained, the main linear junction can be seen, is the P2 to P3 of. In this regard the key change due to the variation of the values at the vertices of the diagonal points forming the polygon is presented.

Fig. 11 a test scenario is presented with the same dimensions as set forth in Fig. 8 and four known points are interpolated using the Natural Neighbor Interpolation algorithm.

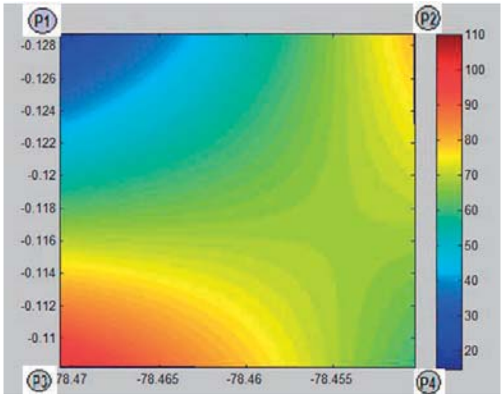

Fig. 11. Test area: Natural Neighbor Interpolation, Resolution: 3m, 4 known points

In Fig. 11, you can see the difference in the outcome of interpolation relative to the previous two. In this case, no abrupt changes in values, or variation of tones according to diagonal displays; since this interpolation method takes into account all available neighboring or nearby values thus achieved approximate values closer to reality estimate.

Thus, having known points uniformly distributed, this algorithm performance noticeably improves. However, accuracy and performance requires greater computational load since it must perform the calculation of the Voronoi polygon for each of the points, which requires greater capacity by increasing the processing time.

IV. SIGNAL THRESHOLD

The thresholds of signal reception into account in determining the shadow areas are: electric field strength and Modulation Error Rate.

A. Electric Field Intensity

The minimum required level of electric field strength is 51 dBuV / m and values which are below that threshold will be considered as shaded areas, according to the provisions of the Technical Standard for the broadcasting of DTT in Ecuador [2].

B. Modulation Error Rate

It is a quality indicator of the modulated digital signal representing quantitatively the vector error by the difference between the ideal signal should be received and the actual signal that is received with errors.

In the constellation diagram, the modulation error rate represents the accuracy of a digital constellation. The dispersion of the points from the expected value affects a degree of high or low MER; a greater dispersion is achieved low MER, while less dispersion high MER value is achieved.

Error Rate Modulation establishes a relationship between the received signal power and the power of the error signal, typically expressed in dB as shown in Equation 4.

$$MER_{dB} = 10 * log\left(\frac{P_{error}}{P_{señal}}\right) \quad (4)\ [3]$$

Donde:

P_{error}: Mean square error

$P_{señal}$: RMS value of the transmitted signal

It is also expressed in percentage, using the equation 2.2:

$$MER(\%) = \sqrt{\left(\frac{P_{error}}{P_{señal}}\right)} * 100\% \quad (5)\ [3]$$

Technical Standard for the broadcasting of digital terrestrial television in Ecuador specifies that the value measured error rate modulation at the transmitter must be equal to or greater than 32 dB.

The manual developed by Rohde & Schwarz cited in [3], involves issues related to technical parameters that assess the quality of the signal as the modulation error rate; in this regard, it states that the optimal values of MER at reception are in the range from 20 to 30 dB, except for portable receivers in which the acceptance range varies from 13 to 20 dB.

V. VALIDATION OF INTERPOLATION ALGORITHMS

Based on the interpolation of dynamic measurements of field strength which are located in the contour of the measurement area, the other internal parts of the area, which has been selected a sample of 42 points estimated is estimated to compare with those measured with the system used by ARCOTEL SACER. Thus, the estimated points, will be evaluated for dynamic points were measured within the area.

The Table I indicated the error rate for each interpolation algorithm.

TABLE I
PERCENTAGE OF ERROR INTERPOLATION ALGORITHMS

A.I Natural	A.I Linear	A.I Nearest
6,45%	7,45%	9,34%

The Figs. 12, 13, 14, represent statistical graphics, in which the difference between the measured points is displayed and those estimated in a sample of 43 points, made for each interpolation method.

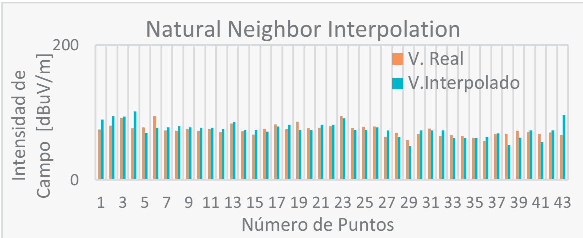

Fig. 12. Statistical Representation vs. actual values interpolated values with Natural Interpolation Algorithm

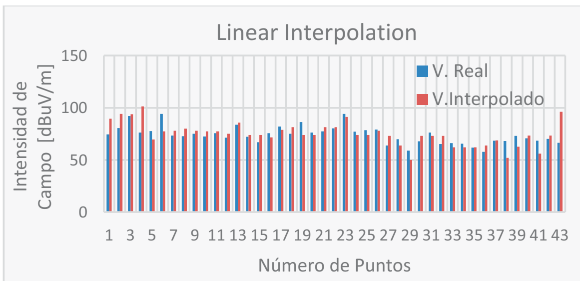

Fig. 13. Statistical Representation vs. actual values interpolated values with Linear Interpolation Algorithm

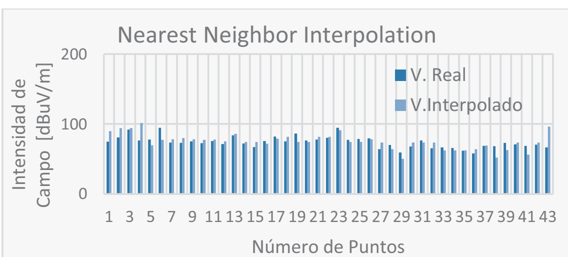

Fig. 14. Statistical Representation vs. actual values interpolated values to the algorithm Interpolation Nearest

VI. PREDICTION OF COVERAGE WITH TELECOM SOFTWARE ICS

TELECOM ICS software provided by ARCOTEL to estimate the possible shadow areas by displaying coverage on the main screen of that program was used; result of the configuration of various technical parameters corresponding to the Digital Terrestrial Television stations currently operating in the city of Quito transmitters.

coverage simulations obtained with the ICS software TELECOM based on the ITU-R P.1546 recommendation and that obtained by interpolating points measured using the interpolation algorithm Natural, graphically compare each graph also specifies its palette for interpretation of field strength measurements in the measurement area.

Analyzing the two graphs the simulation with the ICS TELECOM seen, the result on the ground is a uniform color pretending that measures field strength does not vary from one point to another. While the graph obtained based on actual measurements, variations in field strength measurement field it stands.

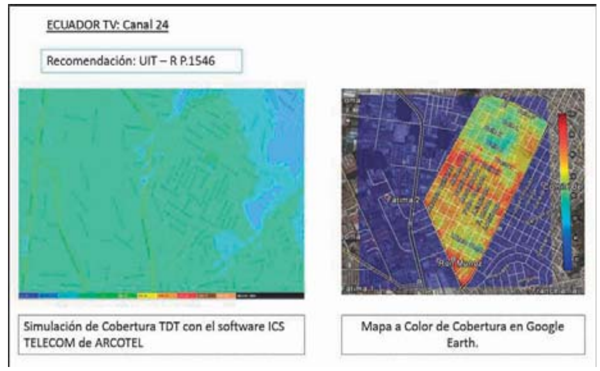

Fig. 15. Coverage maps with ITU-R P.1546 recommendation on the ICS TELECOM and Google Earth

Then, in Fig. 16 graphically compares the simulation based on interpolation of measured points obtained by the simulation software ICS TELCOM applying the propagation model ITU-R P.1812. Like the previous case each graph specifies its palette for the interpretation of field strength measurements in the measurement area.

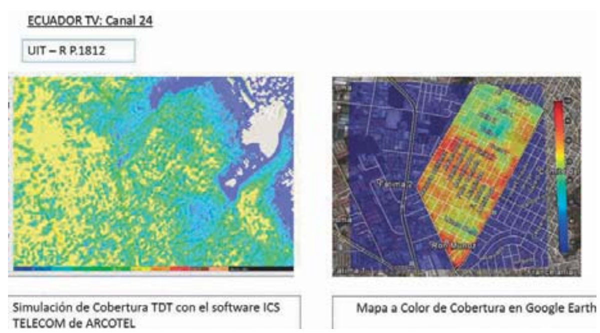

Fig. 16. Coverage maps with ITU-R P.1218 recommendation on the ICS TELECOM and Google Earth

In the simulation performed by the ICS TELECOM different shades of colors can be seen, this means that there are different values of field strength in the estimation of coverage and this result coincides largely with interpolation of the measured points are displayed on Google Earth.

VII. RESULTS

The results based on interpolation of static measurements of field strength and error rate modulation, represented on the map of Google Earth, by which is to determine the existence of possible areas of shade in the measurement area are analyzed selected results indicated by graphical interfaces in MATLAB GUI.

A. Interpolation of Static Measurements Channel 26

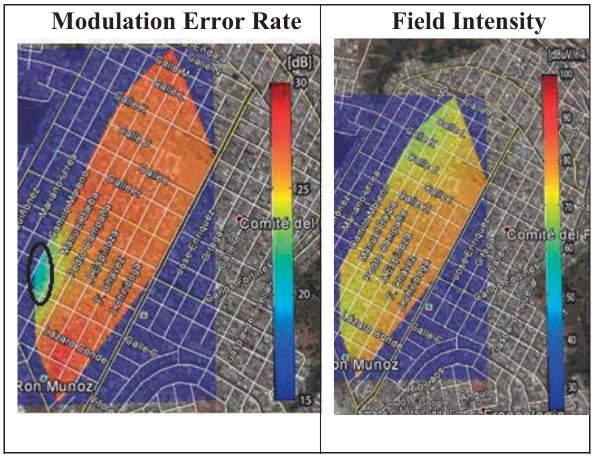

Fig. 17. Color map estimation in MATLAB point field strength and MER channel 26

Analysis of results:

The color maps presented in Fig. 17 corresponding to 26 indicates that the area selected for measurement, MER values and field strength exceed the thresholds established for each case. However, at the lower left of the chart Interpolation Points MER (indicated by a circle) it is graphically seen a slight decrease in the values of MER although the values of field strength does not vary drastically in that sector regard, in TABLE II, some points that refer to that sector shown.

TABLE II
SAMPLE POINTS INTERPOLATED CHANNEL 26

Longitude [°]	Latitude [°]	MER [dB]	Field Intensity [dBuV/m]
-78,4699	-0,12375	20,8402559	73,48722746
-78,4699	-0,12388	21,3890906	73,05292431
-78,4699	-0,12379	21,0232008	73,34245974
-78,4698	-0,12343	21,0293676	74,17319991

B. Interpolation of Static Measurements Channel 30

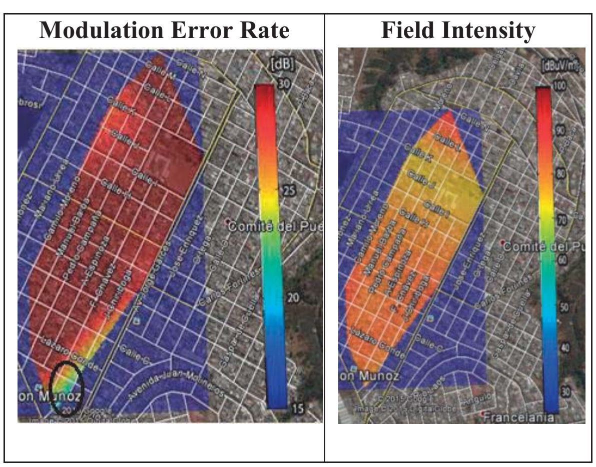

Fig. 18. Color map estimation in MATLAB point field strength and MER channel 30

Analysis of results:

The color maps presented in Fig. 18, results of the interpolation values of MER and field strength for the channel 30, it indicates that the area selected measurement there is no quality problem digital signal or received signal level since both exceed the threshold values established in each case.

It can be seen by the color maps in the lower right of the graph Interpolation Points MER (indicated in a circle) part, there is a slight decrease in the values of MER although the values of field strength are by above the threshold, as the sample of randomly selected points in this sector, which are indicated in TABLE III.

TABLE III
SAMPLE POINTS INTERPOLATED CHANNEL 30

Longitude [°]	Latitude [°]	MER [dB]	Field Intensity [dBuV/m]
-78,4693	-0,1263	20,94234	80,02390363
-78,4694	-0,1265	19,9796	79,35102605
-78,4694	-0,1264	20,8914	79,96738676
-78,4692	-0,1262	21,0441	80,136937

C. Interpolation of Static Measurements Channel 36

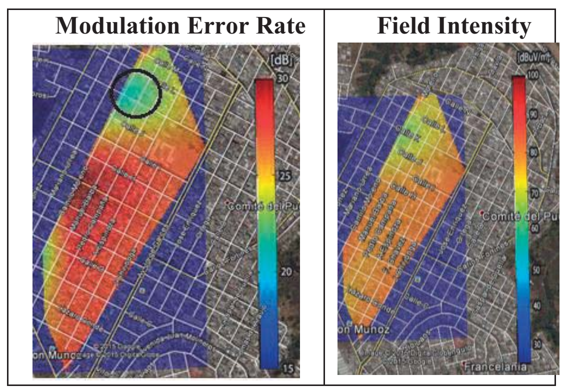

Fig. 19. Color map estimation in MATLAB point field strength and MER channel 36

Analysis of results:

In color maps presented in FIG. 19, shown in the upper left (designated a circle) that the values of SRMs are in threshold limit, as indicated in Table IV, although the values of field strength represented in the color map outweigh the limit of its respective parameter, ie, 51 dBuV / m.

TABLE IV
SAMPLE POINTS INTERPOLATED CHANNEL 36

Longitude [°]	Latitude [°]	MER [dB]	Field Intensity [dBuV/m]
-78,4679	-0,11977	21,468476	65,73972963
-78,4677	-0,11946	21,0497207	65,44669156

-78,4676	-0,11940	21,4473546	66,64102341

D. Interpolation of Static Measurements Channel 39

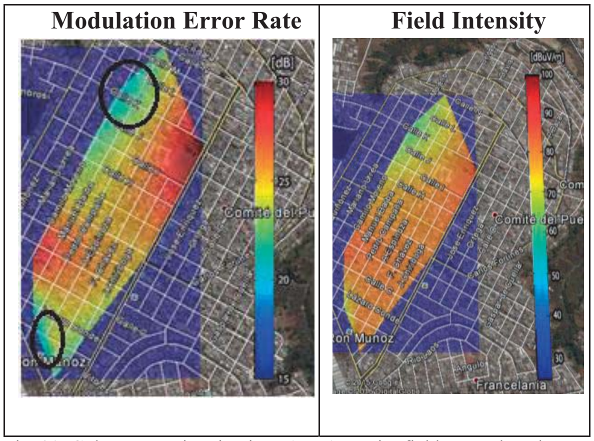

Fig. 20. Color map estimation in MATLAB point field strength and MER channel 39

Analysis of results:

The color maps presented in Fig. 20, the result of interpolation values of MER and field strength for the channel 39, indicates that there MER values that are at the limit of their respective at the edges of the measurement zone threshold. However, in the color map interpolated points electric field strength, the estimation of values if it exceeds the corresponding limit, as indicated numerically in Table V.

TABLE V
SAMPLE POINTS INTERPOLATED CHANNEL 39

Longitude[°]	Latitude [°]	MER [dB]	Field Intensity [dBuV/m]
-78,46744	-0,119234	21,446456	67,91653586
-78,46762	-0,119372	20,966543	67,11114404
-78,46766	-0,119460	20,947046	66,98632032
-78,46793	-0,119912	21,188966	67,87406821
-78,46807	-0,120274	21,917448	69,74595861
-78,46973	-0,125923	20,931847	74,57128702
-78,46946	-0,126466	21,880187	79,24412037
-78,46955	-0,126240	22,318479	77,22869168

E. Interpolation of Static Measurements Channel 41

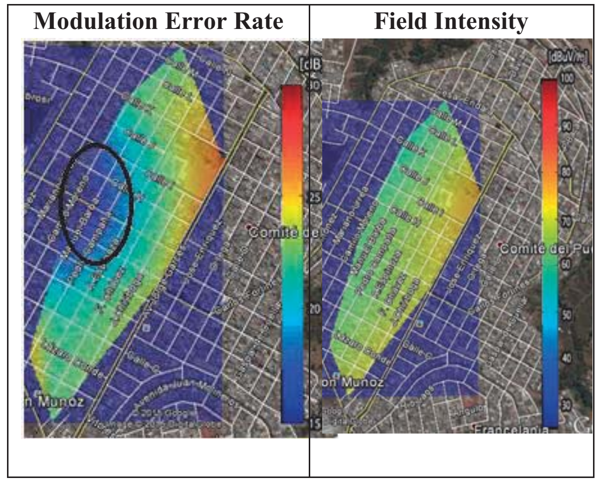

Fig. 21. Color map estimation in MATLAB point field strength and MER channel 41

Analysis of results:

In the color map regarding points MER interpolated, represented in Fig. 21, differs there affect the quality digital signal as in the area indicated by a circle, point estimates are below the set threshold for MER. However, in the color map regarding points interpolated intensity electric field exceeding the threshold values for said parameter. This implies that there is no coverage in a given sector since receiving the digital signal is poor and does not allow proper display of the television program broadcast.

TABLE VI
SAMPLE POINTS INTERPOLATED CHANNEL 41

Longitude [°]	Latitude [°]	MER [dB]	Field Intensity [dBuV/m]
- 78,468520	-0,1214945	16,4382833	63,49520542
-78,46834	-0,1223080	17,7166485	65,84623354
-78,46861	-0,1222628	16,4884805	64,73384392
-78,46874	-0,1223984	16,3020097	64,87125386
-78,46861	-0,1226696	17,5330459	64,87125386
-78,46896	-0,1226696	16,5886105	65,06085112
-78,46896	-0,1228052	17,0819114	63,76931339
-78,46910	-0,1230311	17,6323757	63,46979562
-78,46887	-0,1230311	18,0852154	64,30977078
-78,46887	-0,1221272	15,0421584	63,5480651
-78,46887	-0,1226696	16,7841348	63,98722029
-78,46816	-0,1211781	18,3711805	64,03723125
-78,46874	-0,1218560	15,2376191	63,6118151

VIII. CONCLUSIONS

- The ARGUS software SACER Mobile Station test drive allows for various frequencies, like the R & S ETH team. However, their measurement methodology differ because the first, allows you to run the drive test simultaneously for a whole group of frequencies, while with the team R & S ETH must be configured for each frequency, ie individually. For this reason, for dynamic measurements, it is preferred to use the ARGUS software Mobile Station SACER, noting that the data of interest was the signal level at reception and the geographical position for each measurement point for each center frequency Television stations.

- According to the result shown in Table I, the interpolation algorithm lower percentage of average error is Natural Neighbor Interpolation, its efficiency is greater than in the two interpolation algorithms studied, because it takes into account all neighboring points to the point estimate, however, that advantage works at the cost of longer processing time.
- By the color maps obtained as a result of measures MER interpolation and field strength for each channel TDT it is seen that at points where the signal level is high reception available MER low values; concluding that not necessarily have intensity values above the threshold of protection set of 51 dBuV / m field, ensuring adequate quality reception of digital content on television. Therefore, digital analysis made based on interpolation MER measurements versus spectral measurements based on field strength is prioritized.
- The toolbox of Google Earth in MATLAB, is a tool that allows the display of the values of field strength or MER (each mapped value of a particular color) in each position of the measurement zone, allowing to observe the physical obstructions that appear in the propagation path, such as mountains, buildings, hollows or elevations.
- In this article a solution coverage prediction is proposed to determine the shadows, setting the stage measurement also using the graphical user interface (GUI) facilitates the use of the program, useful for any researcher interested in analyzes field, who need not have knowledge of programming used but should only know the proper formats of input data for MATLAB.
- On the article 10 of the Technical Standard established for DTT in Ecuador, sets the level of minimum field strength to be protected is of 51dBuV / m, otherwise you can witness shaded areas. However, in some parts of the area where measurements, despite exceed this value, the diagram of constellations shown blurred and MER values were made were below the threshold (20 to 30 dB) or limit thereof , possibly caused due to multipath fading effects and signal suffering. Therefore, it is suggested to review what quoted in that article and take into account the error rate modulation to define the presence of shaded areas.

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