Field Measurements and Parameter Calibrations of Propagation Model for Digital Audio Broadcasting in Norway

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***Abstract*— During 2017, digital audio broadcasting (DAB) replaces frequency modulation (FM) broadcasting and becomes the only technology for national terrestrial audio broadcasting services in Norway. As Norway is the first country that replaces FM completely with DAB, it is of great importance to measure the signal strength of such a technology in massive deployments and to tune a simulation model as a reference for future studies. Therefore, field measurements of received signal strength are carried out in a typical Norwegian area in this work. Based on the data obtained from the measurements, a simulator with a recent empirical propagation model, namely, ITU-R P.1546-5, has been calibrated. The findings, in short, suggest that different clutter codes and attenuation parameters have to be tuned according to the measurement results in order to increase the precision of the simulation model. By properly tuning the parameters in the model, the precision has increased 91.7% compared with the default configuration. In addition, the tuned model is validated through another field measurement in a different area and obtains an increased precision of 72.9%.**

***Index Terms*—DAB signals, simulated signal strength, field measurements, ITU-R P.1546-5, clutter and attenuation.**

I. Introduction

As digital communications become ubiquitous, digital audio broadcasting (DAB), which is a digital technique that can replace frequency modulation (FM) broadcasting, becomes more and more popular. There are many countries that provide regular audio broadcasting services based on this technology. In 2017, Norway has gradually closed FM broadcasting in different communities and adopted DAB instead in order to provide a better broadcasting service.

There are extensive studies that have been carried out in the DAB research [1]–[3], especially for the performance of DAB services. Since the signal strength of DAB is pivotal in planning and implementing DAB transmitters, the propagation model, which can be used to calculate the signal strength in a given area [4]–[6], becomes crucial. There exist different DAB propagation models from International Telecommunication Union (ITU) for signal strength calculations [7]–[9]. Evaluations and improvements of the models have also been carried out in literature [10], [11]. Since the existing studies are either based on Lab tests or targeting at legacy ITU propagation models, this study, on the contrary, investigates the most recent version of the ITU-R P.1546 model [12] based on field measurements in a national-wide DAB environment that is fully functioning and is currently in use.

Norwegian Communications Authority (NKOM) has studied DAB signals, and considered the ITU-R P.1546 model as the best fit for simulations over different Norwegian topography. However, the previous studies at NKOM are performed over wide range areas which may not be sufficient for certain scenarios that require high precision. For example, when conducting simulations over a small city called Rjukan with an area of 3.12 km^2, results showed that the field strength would be insufficient[1]. In contrast, the field measurements over that area showed the opposite. This is because, for simulation results of average signal strength over wide areas, strengths in small areas can be canceled out if they are insignificant in the large context. Clearly, the previous simulations calculated by the model may not be precise enough when examining areas that are of small size. Therefore, it is crucial to zoom into the picture and obtain a smaller confined area for comparison between measured values and simulated values, and consequently tune the simulation parameters based on reality.

In this work, we focus on a few typical areas and carry out extensive field measurements with high resolution. Thereafter, we will calibrate parameters in a simulator based on the measurements and obtain a precise simulator for future studies. More specifically, the aim of this work is therefore to examine small areas with resolution 100 by 100 m^2, trying to point out solutions that may generate simulation results with higher precision in reflection of DAB signal field strength. The main contributions of this work are as follows:

- Massive field measurements of signal strength with high resolution for DAB have been carried out. All the measurement data is attainable upon request.
- Based on the measured data, the parameters of the simulator according to ITU-R P.1546-5 model have been calibrated, which can be utilized for future studies as references.

The remaining sections of this article are organized as follows. Section II presents the location and the equipment for

[1]Insufficient field strength is when the measured received field strength is less than 42 $dB(\mu V/m)$, which is a value defined as minimum in coverage maps provided by the "National Digital Broadcasting Norway AS" [13].

the measurements and the simulator for the propagation model. The calibration of the simulator is presented in Section III where the results conducted with the proposed calibration are also shown. Section IV validates the calibrations before we conclude this work in Section V.

II. Approach for measurements and simulations

In this section, the field measurement configurations, the propagation model, and the simulator are detailed.

A. Location of the measurements

The measurements of received field strengths were accomplished over a route from Risdal to Vatne in Froland municipality of Norway, named as Route 1 for simplicity. Froland is located in southern Norway, where the topography is characterized by forest areas, bodies of water and farm lands. The route is a typical rural area and is about 6.7 kilometers one way. We measured back and forth along the route once.

B. Equipment of the measurements

The field measurements of DAB signal strength were conducted using a Rohde & Schwarz (R&S) ETL TV Analyzer [14]. The instrument was connected to a quarter wave whip antenna [15] that was placed over a circular ground plane of 120 centimeters in diameter on the roof of a car. The height of the ground plane above ground was configured as 1.9 meters and the antenna was configured to match the frequencies of DAB signals in frequency block 13F (239.2 MHz) which was utilized in the measured area. The R&S instrument was also connected to an external GPS antenna to relate the field strength values to GPS coordinates. Before the field measurement process was initiated, calibrations of the instrument and the antenna were performed and verified by NKOM.

C. Values of the measurements

For Route 1, 218 measurements were conducted as shown in Fig. 1 for details. Since the car was driven back and forth along Route 1, the measured values are roughly symmetric with respect to the 110th measurement. Table I illustrates a snapshot of the measured data. The strength of the measurements is in dB scale and the unit of the strength is $\mu V/m$ for all measurements and simulated values in this paper.

Table I
Snapshot of measurement data for Route 1.

GPS Longitude	GPS Latitude	Strength	Time
8.150007	58.673658	57.53	2017/03/07/09:27:09
8.149165	58.673535	56.96	2017/03/07/09:27:18
8.148392	58.673305	56.87	2017/03/07/09:27:27
8.147562	58.672985	54.96	2017/03/07/09:27:36

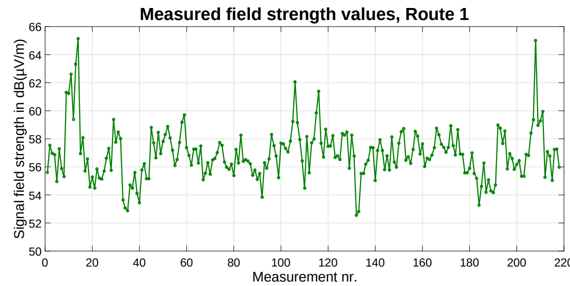

Figure 1. Measured field strength values for Route 1. The measurements are roughly symmetric around the 110th measurement.

D. Propagation model and configurations utilized in simulations

Among numerous propagation configurations and technical agreements, Norway has signed "Final acts of the regional radiocommunication conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)" (the GE06 agreement) and "Final act of the CEPT T-DAB planning meeting" (the CO07 agreement) for DAB [8], [9], where different reference planning configurations (RPCs) are suggested. The propagation model ITU-R P.1546-2 is recommended in the GE06 agreement. Revisions of this model have later been released, and the latest version of the model is version 5 (ITU-R P.1546-5) [12], approved in September 2013. For our simulation, the ITU-R P.1546-5 model is applied and the parameters used in the propagation model are based on provisions given in the GE06 agreement [8], to be detailed presently.

The ITU-R P.1546-5 propagation model is based on empirical derived field strength curves [12]. Using the method outlined in this recommendation, predicted field strengths can be calculated. In this model, the field strength is related to percentage of time, frequency, height of sender, height of receiver and distance between sender and receiver etc [12]. Different corrections that either strengthen or weaken the signal strength in the calculations can be applied. One of the corrections is associated with obstructions between sender and receiver, referred to as clutter. Examples of clutter are trees, buildings and other man-made structures. Depending on the terrestrial conditions, the clutters can be significantly different.

For the parameters used in the propagation model, a mix of RPC 4 and RPC 5 from the GE06 agreement [8] is chosen. In more details, the location probability is set to 95% and the height of the receiving antenna used in simulations is 1.5 meters. The frequency used in simulations is 239.2 MHz. Percentage of time applied is 50% for wanted signal and 1% for unwanted signal. These configurations are utilized both for simulations over Route 1 and Route 2 (to be detailed in the Section IV) of this study.

The map data for simulation is obtained from "the Norwegian Map Authority" [16]. To facilitate the calibration, a square of a chosen size in the map is defined as a pixel. This gives the possibility for comparison between the calculated value for that pixel based on the simulation model and the measured values located inside that pixel. In this study, we divided the map into 100 by 100 m^2 as a pixel.

E. Software for simulations

The simulator utilized for this study is ICS telecom (image cartography system for telecommunications) from the company ATDI. ICS telecom provides a simulation tool of radio frequency from 8 kHz to 450 GHz [17], which has been widely used in network planning and spectrum engineering. Several propagation models are available in this simulator for DAB, including the ITU standardized models mentioned above.

In ICS telecom, several parameters can be added and tuned. By default, the software uses the parameters provided by ITU for calculations of received field strengths, and presumably the configuration of the ITU-R P.1546-5 model in the simulator is identical to the pre-defined standard. As the topography in Norway can be quite different from the places where the ITU default values are derived, the profile of the parameters may vary. Therefore, it is of great importance to tune these parameters and to calibrate the simulator according to the field measurements so that the predicted signal strength from the simulator can achieve an improved accuracy, which can be utilized for future references.

It is worth mentioning that the purpose of this work is not to modify the well defined and recognized ITU-R P.1546-5 model. Instead, we will examine and tune the clutter parameters in the simulator based on the measurements in order to obtain more accurate simulations. Note that a simulated value is a function of many parameters besides different clutters. As other parameters are determined once the location and the measurement environment are configured, we focus on tuning the clutter profiles in this calibration.

III. Simulator Calibration

A. Result before tuning

Before we demonstrate our results of tuning, a simulation result without tuning of the clutters over Route 1 is shown in Fig. 2. As observed in Fig. 2, the simulation result without tuning of attenuation parameters gives an inaccurate prediction of the field strength values that are supposed to be experienced in the field. More specifically, the measured field strength values are distinctly higher than the expected values provided by the simulator. A simulation being pessimistic to the field strength can be unfortunate, due to increased network construction expenses when lower or insufficient field strengths are predicted for an area. According to the ITU-R P.1546-5 model [12], the standard deviation[2] (STD) of the difference between the simulated result and the measurement should be less than or equal to 5.5 dB $(\mu V/m)$, i.e., requiring at least 68% percent of samples within this range, according to normal distribution. However, the percentage of the differences between the current simulated values (without tuning) and measured values that are within[3] ± 5 dB was only 4.59%. In addition, the average difference between simulated values and measured values is about 13.55 dB. Therefore, a calibration is very necessary.

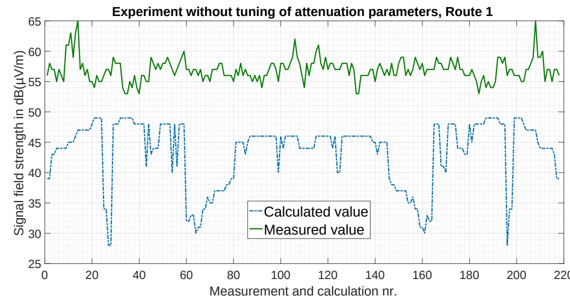

Figure 2. Route 1 without tuning of attenuation parameters (default). Measured value in green (solid line) and simulated value in blue (dashed line).

B. Parameter calibrations

1) Clutter categories and percentages: Before tuning the values of attenuation for different clutters, the clutter codes (clutter categories) and their percentages need to be clarified based on the terrestrial information in the area of measurements. According to the map data and the field estimations of Route 1 during the trip for the measurement, the clutter categories are found as “Forest”, “Open” and “Hydro”, and their shares of the measured area in percentage are calculated and shown in Fig. 3. Forest is representing the highest percentage, while Open and Hydro terrain are smaller parts of the total geomorphology for the area. When the categories and the percentages of clutters are found, we can proceed to the tuning of attenuation values.

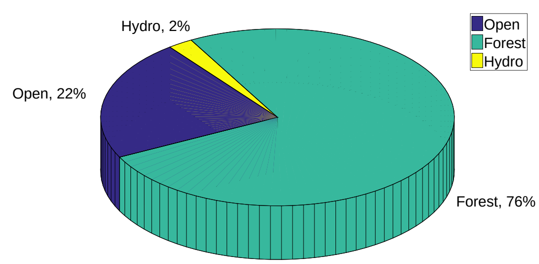

Figure 3. Clutter codes present in Route 1.

2) Mathematical display of calibration: To calibrate the simulator, we would like to reduce the difference between the simulated value, defined by $X_i(r_1, r_2, ..., r_m) \in \mathbf{X}$, and the measured strength, defined by $Y_i \in \mathbf{Y}$, where r_1 to r_m represent m attenuation values of clutters (In this particular case, $m = 3$, indicating “Forest”, “Open” and “Hydro”) and $i = \{1, 2, \ldots, I\}$ is the index of the corresponding values of the measurements and the simulations. Formally, the objective of the calibration can be presented as:

[2]In ITU-R P.1546-5 model, there is no requirement for the mean value of the differences. Obviously, the mean value should be as close to zero as possible.

[3]According to ITU-R P.1546-5 model [12], the required STD is 5.5 dB. As the granularity in the simulator is 1 dB, we select a tighter value, i.e., 5 dB in our study.

$$\begin{aligned} \underset{\{r_1, r_2, \ldots, r_m\}}{\text{Minimize}} \quad & \text{Mean}(|\mathbf{Y} - \mathbf{X}|), \\ \text{subject to} \quad & \text{STD}(\mathbf{Y} - \mathbf{X}) \leq \delta, \end{aligned} \tag{1}$$

where δ is the tolerance of the STD. Clearly, the aim of tuning the clutters is to reduce the difference between the measurements and the simulations statistically. More specifically, we minimize the mean values of the differences while keeping the variance within the tolerance of STD, i.e., 5 dB.

3) Calibration approaches: The formulation of the problem in Eq. (1) is utilized to help with explaining the target of calibrations. We will not solve the problem via a rigorous optimization manner because the ITU model is based on interpolation/extrapolation from empirically derived field-strength curves, which does not offer a closed-form formula for optimization purpose. Therefore, a trial-and-error method was conducted based on our experiences and intuition. By testing different combinations of parameters and their impacts on the simulated field strength values, it is possible to find a set of parameters that give improved accuracy of simulations. In more details, we will try different values of attenuation for the clutters and find out the one that has the minimum mean value with the STD constraint satisfied. In addition, we also check the percentage of difference that is within the tolerance δ, denoted by η. To calculate η, the following formula is applied:

$$\eta = \frac{\left(\text{Nr. of samples where } |\mathbf{Y} - \mathbf{X}| \leq \delta \text{ holds}\right) \times \mathbf{100}}{\text{Total number of samples}} \%.$$

The intuition that guides our trial-and-error method is as follows. We know that the strength will increase if the attenuation of any clutter decreases. Therefore, we try to reduce the attenuation values of all clutters at the same time and bring up the mean value of the simulated strength first. When all clutters have about -23 dB attenuation, the mean value of the simulation is close to the measurements. Thereafter, we tune individual clutter by plus or minus a few dB to reduce the STD while keeping the mean values close to the measurements.

After numerous attempts to place different clutter parameters in the simulator, the difference between simulated field strength and measured field strength is statistically reduced. We find the combination that gives the minimum mean with the constraint fulfilled among all attempts and will report the results in the next subsection. Note that this trial-and-error approach is not trivial as it requires a proper understanding of the channel model and the attenuation property, and it is time-consuming for the simulator to run for each trial.

C. Result after tuning

By default, the attenuation values are set to 0 dB for all clutters while the calibrated values are demonstrated in the second column of Table II. The height of the clutter codes used for the simulations over Route 1 and the reflection coefficients are also given in the same table for completion. These parameters offer the best achieved result in terms of the simulation's compliance to the measured values in our trials, and thereby result in the highest simulation precision for the experiments of this study. Note that the attenuation values are negative, meaning that the clutters in fact strengthen the propagation of the signal.

Table II
CLUTTER CONFIGURATIONS AFTER TUNING FOR ROUTE 1.

Clutter code	Attenuation (dB)	Height (m)	Reflection coef.
Open	-26.6	0	0.250
Forest	-20.7	12	0.111
Hydro	-26.7	0	0.020

The result of the simulation with tuned attenuation parameters (see Table II) is visualized in Fig. 4. As shown in Fig. 4, the simulated field strength values follow the major progress of the measured values, making the simulation after tuning more accurate in terms of the simulation's compliance to measured values. For this case, the percentage of the difference that is less than or equal to 5 dB, i.e., η, is 96.33%, and an average of -0.33 dB in difference between the simulated and the measured values is achieved. Clearly, the calibration of tuned attenuation parameters improved the simulation precision. Note that although the average value of differences is -0.33 dB lower than 0, the percentile is within the ITU-R P.1546-5 model [12] model that requires 68%. Therefore, the model after calibration fulfills the ITU standard.

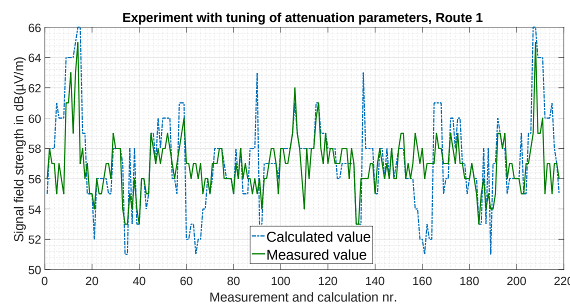

Figure 4. Route 1 with tuning of attenuation parameters. Measured value in green (solid line) and simulated value in blue (dashed line).

The difference between simulated and measured values can also be shown statistically by representing the two data sets in normal distributions, as depicted in Fig. 5. The distribution after tuning clearly represents a more accurate simulation, which has been placed over a lower average value and is more pointing than the simulation before tuning. Comparing the percentage of differences that are within ±5 dB before and after tuning, i.e., 4.59% and 96.33%, the improvement after tuning achieves 91.74%. Obviously, the improvement of tuning is significant.

IV. VALIDATION OF CALIBRATION

Although the parameters in Table II provide a relatively accurate simulation result, it is still necessary to check if those parameters can be applied to another area with similar geomorphology. To validate the findings that are conducted in Route 1, another route from Lillesand to Risdal in Aust-Agder, named as Route 2, is tested, which is 64 kilometers long. For this route, 531 measurements are conducted. The

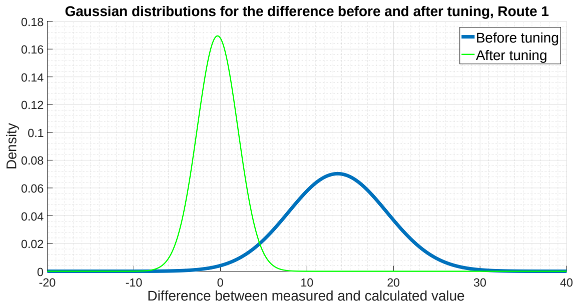

Figure 5. Gaussian distributions of the difference between measured values and calculated values before and after tuning. The bold curve represents the result before tuning in this figure.

measurements are carried out in the same way with the same equipment for Route 1 in frequency 239.2 MHz.

To display the necessity of calibration, a simulation result without tuning of the attenuation parameters is displayed in Fig. 6 for Route 2. Comparing the difference between simulated field strength and measured field strength, the percentage of the difference that is less than or equal to δ (5 dB) is only 6.97%. The average difference between the compared data is as large as 18.33 dB.

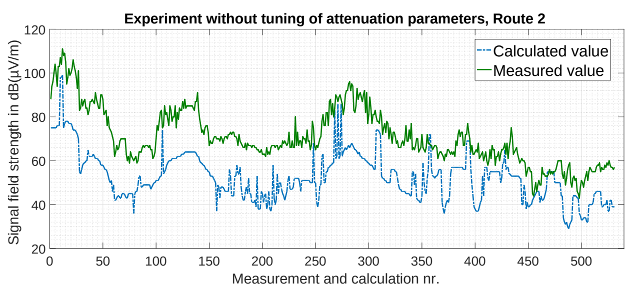

Figure 6. Route 2 without tuning of attenuation parameters (default). Measured value in green (solid line) and simulated value in blue (dashed line).

Again, before parameter tuning, the categories and the percentages of clutters are to be determined. The area of Route 2 has a similar topography to Route 1 with two new types of clutter codes that are not presented in the area of Route 1. The new clutter codes are Village and Dense urban as shown in Fig. 7. As illustrated, the two new clutter codes represent 11% of the total area of measurements. Similar to Route 1, forest is still the largest share of the terrain, while Open and Hydro terrain are smaller, but still representing a bigger share than Village and Dense Urban. Village and Dense Urban are the clutter codes that present in the start of the drive of Route 2, located near the center of Lillesand city.

To validate the findings in Route 1, the parameters for attenuation are set as identical to the ones of Route 1 for the clutter codes that are present in both routes. The attenuation values for the new clutters are found based on the previous-mentioned trial-and-error method presented in Section III. The values of the parameters are given in Table III. By using the configurations in Table III, the simulation result of Route 2

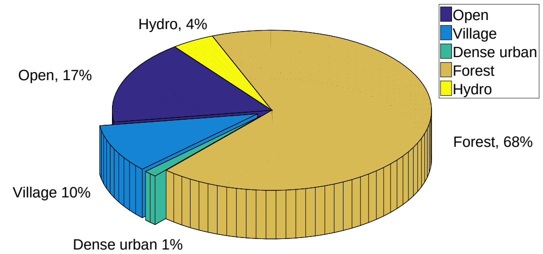

Figure 7. Clutter codes present in Route 2.

is shown in Fig. 8, where the simulated field strength values match the measured values better. For this case, 79.85% of the differences between calculated values and measured values are less than, or equal to 5 dB. An average of 0.7345 dB is also achieved. Therefore, the result also fulfills the ITU requirements.

Table III
CLUTTER CONFIGURATION AFTER TUNING FOR ROUTE 2.

Clutter code	Attenuation (dB)	Height (m)	Reflection coef.
Open	-26.6	12	0.250
Village	-21.8	6	0.300
Dense urban	-25.4	20	0.300
Forest	-20.7	0	0.111
Hydro	-26.7	0	0.020

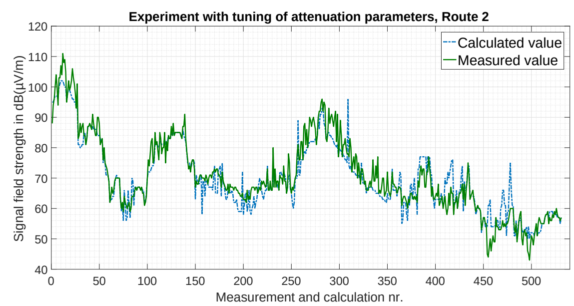

Figure 8. Route 2 with tuning of attenuation parameters. Measured value in green (solid line) and simulated value in blue (dashed line).

The tuning described above does increase the precision, resulting an improvement of 72.88% compared with the previous simulation done without tuning. The improvements can also be shown by representing the simulations with and without tuning in normal distributions, as shown in Fig. 9. The distribution for simulation with tuning has less standard deviation and is placed over a lower average value than that without tuning. This result shows that the simulation with tuned parameters decreases the difference between measured and simulated value, which confirms the correctness of the attenuation factors found in the previous section.

To sum up, the comparisons before and after calibration for Route 1 and Route 2 are summarized in Table IV. Clearly, our calibration of the ITU model improves the accuracy of simulations significantly. Therefore, the simulation model can be utilized to calculate the DAB signal strength in small scale areas with more confidence.

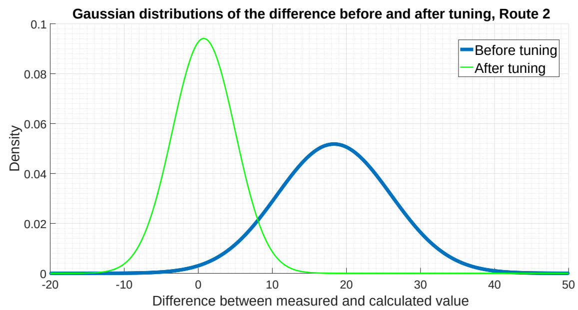

Figure 9. Gaussian distributions of the difference between measured values and calculated values before and after tuning. The bold curve represents the result before tuning in this figure.

Table IV
STATISTICS BEFORE AND AFTER TUNING

Calibration (Route 1) Improvement: 91.74%	**Before tuning** Mean: 13.5505 dB Std.dev.: 5.6780 dB % of difference $\leq 5dB$: 4.59%	**After tuning** Mean: -0.3257 dB Std.dev.: 2.3534 dB % of difference $\leq 5dB$: 96.33%
Validation (Route 2) Improvement: 72.88%	**Before tuning** Mean: 18.3277 dB Std.dev.: 7.7009 dB % of difference $\leq 5dB$: 6.97%	**After tuning** Mean: 0.7345 dB Std.dev.: 4.2381 dB % of difference $\leq 5dB$: 79.85%

V. Conclusion

In this work, we measure the signal strength of a DAB network that is currently in-use and calibrate the clutter parameters in the ITU-R P.1546-5 model according to the field measurements. By comparing the measurements and the simulation results before and after calibration, we conclude that the parameters in the model need to be tuned when conducting simulations over small scale areas, and that the model is precise when it is well calibrated. The findings in the attenuation, i.e., the values in Tables II and III, can be adopted as references for simulations using the same model over similar terrestrial areas.

Acknowledgment

This work has been carried out in collaboration with NKOM. The authors would like to thank NKOM for the technical support of this work.

References

[1] B. L. Floch, J. C. Rault, P. Siohan, R. Legouable, and C. Gallard, "The Birth of Digital Terrestrial Broadcasting in Europe: a Brief History of the Creation and the Standardization Phases of Digital Audio Broadcasting (DAB) and Digital Terrestrial TV Broadcasting (DVB-T)," in *2010 Second Region 8 IEEE Conference on the History of Communications*, Nov. 2010, pp. 1–6.

[2] M. S. Baek, S. Park, G. Kim, Y. H. Lee, H. Lim, Y. J. Song, C. H. Im, and Y. T. Lee, "Design and Performance Evaluation of Digital Radio Measurement Test Beds for Laboratory Test: DAB, DAB+, and T-DMB Audio," *IEEE Transactions on Instrumentation and Measurement*, vol. 62, no. 2, pp. 451–459, Feb. 2013.

[3] M. Srivastava and B. Singh, "Detailed Performance Analysis of Digital Audio Broadcasting under Different Modulation Schemes and Channels," in *2016 International Conference on Control, Computing, Communication and Materials (ICCCCM)*, Oct. 2016.

[4] S. R. Saunders, *Antennas and Propagation for Wireless Communication Systems*, 2nd ed. Hoboken, N.J: Wiley, 2007.

[5] W. Hoeg and T. Lauterbach, *Digital Audio Broadcasting: Principles and Applications of DAB, DAB+ and DMB*, 3rd ed. Chichester: Wiley, 2009.

[6] ITU, "Recommendation ITU-R P.1406-2 Propagation Effects Relating to Terrestrial Land Mobile and Broadcasting Services in the VHF and UHF Bands," Jul. 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.1406-2-201507-I!!PDF-E.pdf

[7] ——, "ITU-R Recommendations," 2017. [Online]. Available: http://www.itu.int:80/en/publications/ITU-R/pages/R-REC.aspx

[8] ——, "Final Acts of the Regional Radiocommunication Conference for Planning of the Digital Terrestrial Broadcasting Service in Parts of Regions 1 and 3, in the Frequency Bands 174-230 MHz and 470-862 MHz (RRC-06)," Jun. 2006. [Online]. Available: http://search.itu.int/history/HistoryDigitalCollectionDocLibrary/4.129.43.en.100.pdf

[9] ——, "Final Acts of the CEPT T-DAB Planning Meeting," Jul. 2007. [Online]. Available: http://www.cept.org/files/1051/Topics/Broadcasting/T-DAB/WI95revCO07/WI95revCO07.pdf

[10] P. Hesami and N. Noori, "Evaluation and Improvement of the Field Prediction Method in Recommendation ITU-R P.1546-3," in *2009 3rd European Conference on Antennas and Propagation*, Mar. 2009, pp. 2276–2279.

[11] S. H. Bae and D. H. Cha, "A New Approach for 1km Urban Propagation Model of the Recommendation ITU-R P.1546," in *2014 USNC-URSI Radio Science Meeting (Joint with AP-S Symposium)*, Jul. 2014, pp. 235–235.

[12] ITU, "Recommendation ITU-R P.1546-5 Method for Point-to-Area Predictions for Terrestrial Services in the Frequency Range 30 MHz to 3 000 MHz," Sep. 2013. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.1546-5-201309-I!!PDF-E.pdf

[13] O. J. Torvmark and T. Gaustad, "Dekningskart." [Online]. Available: http://radio.no/dekning/

[14] R&S, "R&S ETL TV Analyzer - Overview," 2017. [Online]. Available: https://www.rohde-schwarz.com/us/product/etl-productstartpage_63493-9255.html

[15] SCAN ANTENNA A/S, "E60-300f 0 dB (M6)." [Online]. Available: http://www.scan-antenna.com/product/e60-300f-0-db-m6

[16] The Norwegian Mapping Authority, "About the Norwegian Mapping Authority," Jan. 2013. [Online]. Available: http://kartverket.no/link/589f64192c634b4c8e9bc8af0b6a162d.aspx%3Fepslanguage=en

[17] ATDI, "ICS Telecom," 2015. [Online]. Available: http://www.atdi.com/ics-telecom/