HD Radio™ Measurements and Coverage Studies

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Abstract – *Since the initial HD Radio coverage tests, the main objective has always been to demonstrate the successful demodulation of the signal for a given field strength, in a specific type of environment (urban, suburban, mountainous, rural land, etc.). While this avenue is a good indicator of the resulting usable coverage, it does not provide the required information regarding the proper hardware operation nor detailed correlation between simulation and actual implementation. With the upcoming implementation of SFN repeaters and network improvements, new measurement techniques are required to provide information about the performance of the overall system. This paper will explain different approaches to achieve this goal and will illustrate these approaches with concrete examples.*

INTRODUCTION

Most measurement systems consist of the following:

- A receiver: either simply a field strength meter or a more complex demodulator;
- A geo positioning device (GPS);
- A recorder: from simple memory to an entire computer.

Once the measurement campaign is completed in the field, the operator extracts the data and analyzes the results back at the office. This process usually takes the form of coverage maps, statistical evaluation and, in some cases, comparisons with simulations. Only at this stage, which can occur from a few hours to multiple days after the data gathering phase is completed (and quite often, not even in the same city), can the engineer conclude if the station under test was performing as expected. But how do we define those expectations?

What happens if parameters were wrong during the measurements? What if a new interferer is present or if the antenna is defective? If any of these types of situations are detected while doing the measurements, shouldn't the operator take the time to gather additional data in those critical areas? But first, how does he detect that something is going wrong in the first place?

SOLVING THE PROBLEM BEFORE IT HAPPENS

The only way to ensure that the recorded data is valid is to know what to expect before the campaign. To achieve this, we either need to achieve real-time simulation comparisons with the data during the gathering process, or pre-upload a simulation file that will be used for real-time comparison. Since simulation software solutions can be expensive, and require the user to verify the validity of the data (topographical, morphological, system, FCC database, etc) prior to use and take longer to compute the simulation than it takes to record the data, we opted for an approach of pre-simulating the required information and uploading only the simulation data file into the measurement system prior to the campaign.

This approach also has the advantage that the engineer that knows how to operate the simulation software has time to properly gather the information about the broadcast system and ensure that the simulation data is valid prior to starting the campaign.

Another advantage is that the tedious gathering of the data in the field can be handled by junior engineer / technician who can simply drive around to record the data and let the system verify whether or not the parameters that are recorded are valid. If they are not, he can quickly reach his senior engineer while still in the field, in order to address the problem and/or take more measurements in critical areas.

With this approach, working time and travelling costs can be reduced, in the case where the recorded data is not valid due to problems with the transmission system or even, in some cases, problems with the recording system. One, for example, would then not have to redo the entire campaign when the input connector has failed.

SYSTEM DESCRIPTION

The following diagram highlights the operating principle of the system:

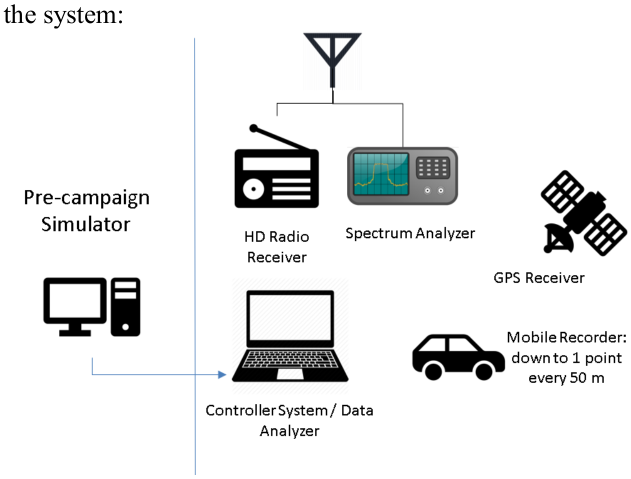

Figure. 1: Basic Operating Principle

Where systems are responsible for:

- **Pre-Campaign Simulator:** engineers can use their preferred software, simulation model, own set of parameters, receiver simulator, etc. The only requirement is to use a common output format so that the real-time system controller can interpret, decode and compare the simulated data with the recorded data.
- **Receiving Antenna:** we recommend using a single antenna to feed all of the receivers. The antenna must be calibrated in frequency across the whole FM spectrum to compensate for the different gain from lower to higher frequencies.
- **Power Splitter:** at the antenna output, we would use a low-noise power splitter / amplifier. This ensures that all the rest of the systems receive the same signal quality and compensate for cable signal losses. Again, this device must be calibrated.
- **HD Radio Receiver(s):** the HD radio test receiver is used to evaluate the demodulated signal quality, record the audio stream (both analog and digital), interpret key metrics, such as CD/No, SNR, Multipath, HD Acquired, HD Audio Decoding, etc. Note that multiple HD Radio receivers can be used in the system in order to measure multiple stations in a given market.
- **Spectrum Analyzer:** the spectrum analyzer is used to evaluate the field strength level of all recorded stations, as well as all possible interfering stations. We usually record up to 7 channel power levels for each station under study (explained in detail below).
- **GPS Receiver:** one key component of the system is the ability to geolocalize all measurements. To ensure proper precision, a 5 Hz GPS system with WAAS/EGNOS capability is used. This allows the system to record data every 150 feet while driving at 55 mph.
- **System Controller:** this is the heart of the system. The computer communicates with the HD Receivers via SNMP and receives the information from the spectrum analyzer and the GPS via USB. The controller also compares the recorded data with the simulated data and sounds alarms when problems are found (explained in detailed below). Finally, the system controller is also used to generate the reports. Those can be in the form of Google Earth™ data format or in CSV format that can easily be interpreted with Microsoft Excel™.

PREPARING THE SIMULATED DATA

As indicated above, the system is not tied to any simulation tool. For each station under study, the following simulations are computed in advance so that the system can analyze and make decisions regarding the validity of the measurement data:

- **Modeling of the Main Station:** this is required to assess the coverage of the main station.
- **Modeling of the HD Radio Components:** in cases where the HD station uses that same antenna and modulator, only the differential in dBc for the lower and upper carriers are required. Note that we do analyze the upper and lower HD components separately. We also need to model the HD Radio demodulator so that we can assess the HD Acquired and Audio Decoding statuses of the receiver.
- **Modeling of the Surrounding Interferers:** in addition to the main channel, we do require the information about the first and second (upper and lower) adjacent stations. This allows the system to evaluate if an interfering station was "planned" or not.

For the simulations, we recommend using the following basic planning parameters:

  - **Propagation Model:** a terrain sensitive model should be selected, such as Longley-Rice, CRC-Predict or ITU-R Rec. 1546.
  - **Simulated Antenna Height:** 2m (car rooftop).
  - **Simulated Statistical Reliability:** 50% (time and location). Even when considering a digital modulation of HD Radio, the statistical behaviour of the field strength when performing measurements is still 50%.
  - **Database:** Using the best topographical and morphological databases available like SRTM 2 (USA) or CDED (Canada).

For the system to ingest the simulated data, one must provide the following information (format):

- **Prepare the Data in a Grid Format:** A typical grid of 800 X 800 pixels (640,000 points) at approximately every 250 yards with a total grid size of 125 miles X 125 miles centered around the transmitter provides good comparative results within the entire expected station coverage. For lower class stations, a smaller grid can be considered.
- **Simulation Data:** the system can read a CSV file, where each line includes the latitude, longitude and each field strength value for the second and first adjacent channels (upper and lower), the main channel and the lower and upper HD Radio band. The last columns are Boolean information representing the expected status of the HD Receiver (HD Acquired state and Digital Audio decoding state).
- **Additional Information:** The system needs to know the main station location (in latitude and longitude), its frequency, its altitude above mean sea level and its antenna pattern (in .PAT format). This information is required to derive the measured resulting antenna pattern.

PERFORMING THE MEASUREMENTS

Once the system is fully loaded with the simulated data for each station under test, we are ready to plan the campaign. Prior to start, it is important to verify with the local operators that all stations under test are performing as per their licensed parameters.

For the route selections, we recommend doing measurements in a flower petal shape from the transmitter to the outskirts of the signal (down to about 50 to 40 dBµV/m). At least 6 to 8 petal patterns should be done. If possible, 2 final all around loops (one at 54-60 dBµV/m and one at 70 dBµV/m) should be completed. This configuration will allow for a good mix of data, from multiple radials to all around coverage evaluation. Once this basic dataset is completed, specific areas should be considered:

- **Main Market Area:** completing additional measurements in the main market area is suggested. The station program manager and sales department appreciate to know that the main market is well covered (or if not, how to fix this).
- **Potential Interference Zones:** if the license already includes some areas where interference can occur, make sure to characterize these zones so that the extent of the interference is within the agreed predictions.
- **Difficult Geography:** problematic areas are usually roads following a river or creek in mountainous areas. This is usually known for strong multipath behavior which can degrade the analog component and where it is important to measure that the digital component can be successfully decoded.
- **Known Weak Zones:** If a repeater or a translator is being considered, it is important to ensure sufficient data collection in the target zones.
- **SFN Repeater Zones:** whether using an analog or a digital SFN repeater, the overlapping and synchronization zones are critical and need to be properly tested. Simple field strength values are not enough and metrics like SNR, multipath, Cd/No and Digital Audio decoding are required.

KEY METRICS

As previously explained, the system evaluates critical metrics in order to assess the coverage and performance of the station. Of course, the first set of metrics comes from the Field Strength Level recorded by the spectrum analyzer. For each station under investigation, we are evaluating several channel powers, as defined in the following Figure 2:

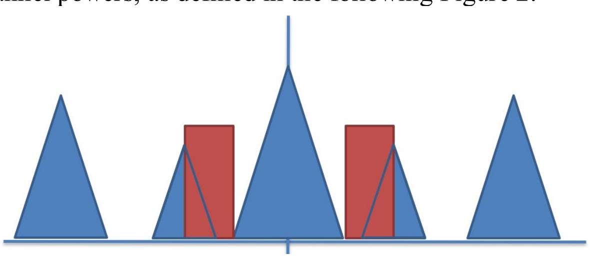

Figure. 2: Channel Power

In the above figure, the system calculates the channel power for:

- **Main Channel Power:** This represents the main blue triangle in the center of the figure. The lower and upper frequency depends on the digital mode of the HD Radio system (the user must provide this information to the system).
- **Digital HD Radio Power:** The system will evaluate from the band edge (-200 kHz and +200kHz, shown as the two red rectangles above) up to the limit of the HD Radio signal, depending on the transmission mode used (MP1, MP3, MP11, etc). The system records the lower and the upper sideband separately, to ensure that the system works as per its specifications in the case of unequal sideband operation.
- **First Adjacent Interferers:** Since half of the power of the first adjacent is located within the digital carrier, we are only measuring the outside half (from -300 kHz to -200 kHz for the lower 1st adjacent) and then add 3 dB to the result.
- **Second Adjacent Interferes:** the system computes the channel power from -500 kHz to -300 kHz (or positive values for the upper second adjacent).

Consequently, the system calculates up to 7 different channel powers for each station under test.

Other then the metrics provided by the spectrum analyzer, the test receivers provide the following information for the analog (a) demodulator and for the digital (HD) demodulator:

- **Multipath (a):** this provides critical information on the quality of the received signal. A high field strength value does not always translate into a good quality signal! This metric is also useful when attempting to synchronize analog on-channel repeaters or translators.
- **SNR (a):** this value usually follows the same trend as the Multipath value.
- **RBDS Loss (a):** this is an indication of the RBDS signal quality.
- **Stereo Indicator (a):** this is another important analog metric, which usually stays active if the receiver can detect the 19 kHz carrier.
- **HD Acquired (HD):** this indicates that the receiver has detected the presence of HD carriers and is in the process of attempting to decode them.
- **Digital Audio Acquired (HD):** this confirms if the quality level of the HD signal is good enough for the audio to be decoded. This is the key metric to evaluate the HD radio coverage.
- **Cd/No (HD):** this provides an indication of the quality of the HD Radio signal. This is a key metric when implementing and testing SFN transmitter networks.
- **Audio Recording (a and HD):** the system records the demodulated audio of each station under test, where the right channel is the analog component and the left is the digital. This recording can be use later to playback and evaluate the audio quality in critical area or even to perform PPM analysis.

REAL TIME ANALYSIS

When doing the actual measurements, how do we know if the measurements are good? Below are some tests that we have developed to provide a direct feedback to the technician performing the campaign. Note that all feedback is auditory to ensure safe driving conditions. Because of this, the basic operation requires that we connect the measurement system to the car's sound system. The operator can then select the audio of the main station under test. The system will playback the analog demodulated signal on the right channel and the digital on the left (or silence when it cannot be decoded). This setup provides a way for the operator to directly monitor both signal types, letting him know exactly where the HD signal cannot be decoded, and providing him instant feedback on the audio synchronization of the station.

Then, as the operator drives around, the system will provide audible cues through the sound system when the following event occurs:

- **System Faults:** any system fault, such as loss of GPS, loss of connectivity with a receiver or the spectrum analyzer, will be signaled to the user. Additionally, the system provides health feedback, including indicating how many points have been recorded in the past 5 minutes or warning the user of the situation where he started driving around, but forgot to start the recording.
- **Simulation Model Alerts:** if the system detects that the signal is constantly different from the simulated information, it will warn the user. This is generally implemented in two steps: an initial warning at -10 dB and an error at -20 dB (all user configurable). For example, if the system has recorded more than 10 points in a row where the signal was 10-15 dB lower than the model, an audible alarm would be played. A recovery message will also be audible, once the alarm is cleared.
- **Channel Power Alerts:** if one adjacent channel is constantly above its threshold (like 20 dB for a second adjacent and -6 dB for a first adjacent), the system will also alert the user. Other validations are also performed on the HD upper and lower bands.

If the system constantly outputs messages as above, it is because something is going wrong and it provides the opportunity for the operator to troubleshoot while he is in the field doing the campaign rather than realizing that there is a problem only during the evaluation back in the office. Generally, 2 types of problems can be seen: recording system problems (bad connector, cable, wrong frequency) or transmission system problems (transmission issues to be investigated, or operational issues like operating on a standby low power antenna, etc.). Considering that the most important measurements are done out of town and involve travel, it is critical to find out that something is wrong as quickly as possible, as it saves time and money.

Alert messages can also help in detecting areas where pirate transmitters are used. If the adjacent levels are outside of the modelized expectation, it means that more power is received than what the FCC database indicates. The user can then identify the area and take more measurements in that area that can then be used to find the rogue operator or to support the case with the FCC.

Finally, the operator knows that all went well if only a few messages are heard during the measurement campaign. This provides confidence that, once finished, he can pack up the system and return to his office with little concern that something unexpected will be found during the post-processing of the data.

DATA (POST)-PROCESSING

The reason we indicate "post" in parenthesis is simply that the system cannot provide all of the information to the user while he is still driving. But the system can effortlessly create easy-to-read Google Earth KML map files and Excel-friendly CSV outputs that the user can quickly generate while having a coffee break or back at the hotel. If something in the results stands out that the real-time analysis did not pick up, the user can simply return to the problematic area and acquire more data or investigate the source of the problem (interferer, faulty equipment at the transmitter site, etc.). The ultimate goal is to provide the maximum diagnostic capabilities to the user while he is still in the field.

EXAMPLE OF COVERAGE EVALUATION

The following figures demonstrate key outputs of the measurement system:

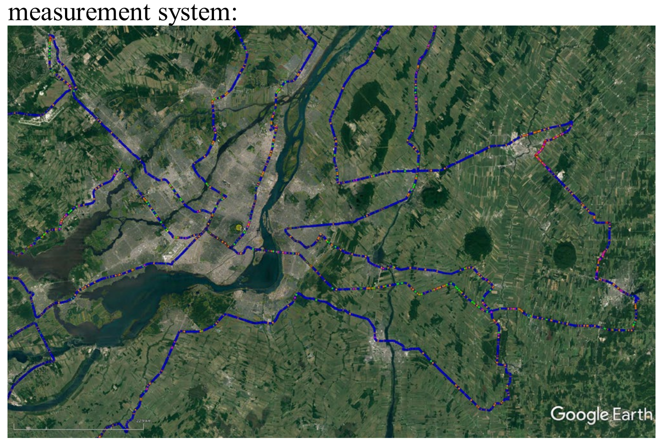

Figure. 3: Total HD Power vs Analog

Figure 3 shows the area (dark blue) where the HD Radio Signal Power (combined for lower and upper sidebands) is within the specifications while the other colored data points denote areas where the HD channel power was not correlated with the analog components. This could create interference with the analog host or, in other cases, degradation of the HD signal.

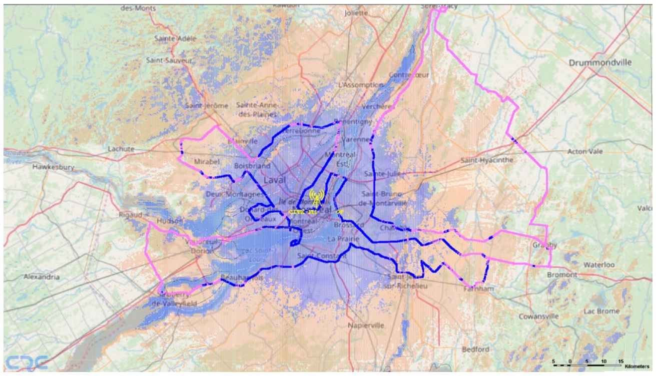

Figure. 4: Measurement of HD Audio Decoding

Figure 4 shows the measurement data (dark blue) where the HD Radio Signal was decoded for this station in comparison with the simulation data (light blue). For this station, we can assess that the simulated HD acquired level vs the actual measurements is quite correlated. But as indicated before, the goal of the measurement system is to ensure that the performance of the transmission system meets its specification. One other metric to assess the performance is to compare the measured RF level vs the simulated RF level. The following Figure 5 demonstrates the histogram of the differences between the measured values minus the simulated values. As we can find the highest bin is the -1 to +1 dB of difference, meaning that most of our sampling measurements are in-line with the model.

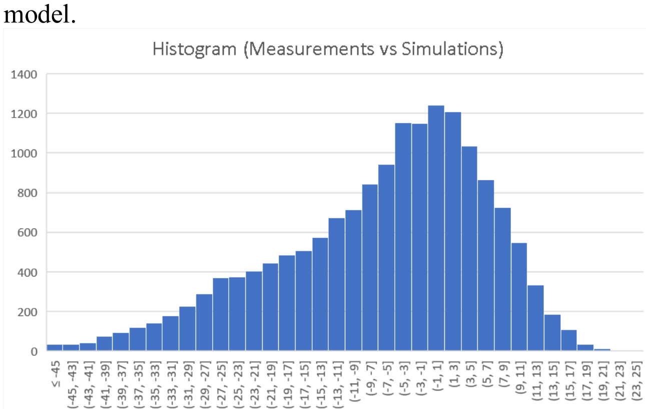

Figure. 5: Measurements vs Simulations

The issue with the previous graph is that, although it provides a good indication that the system is performing as expected, it lacks information regarding where the highest differences were measured. Figure 6 below demonstrates the median error for every 10 degrees sector around the antenna, when considering the signal difference on data points between 3 and 30 miles.

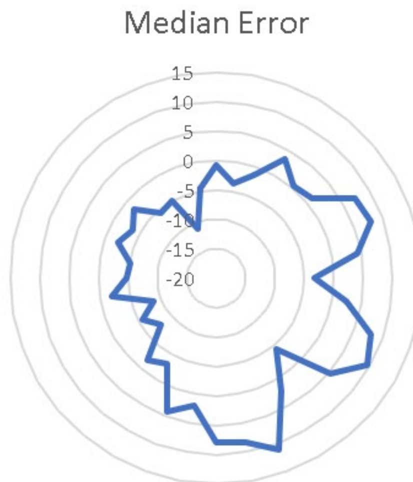

Figure. 6: Median Error (Measurements – Simulations)

Once we plot the median error on a radial map, we can easily assess the areas where the antenna is not performing as expected (this system was supposed to be a non-directional antenna). We were expecting all values to be located near 0. As it was identified, this antenna system was not operating properly. After the antenna replacement, we conducted the measurements again and found the results displayed in the following figure:

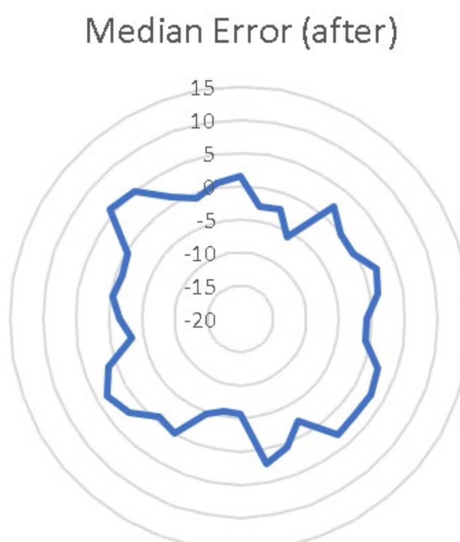

Figure. 7: Median Error after Antenna Replacement

CONCLUSION

We have demonstrated that the objective of performing a measurement campaign is not simply to assess if the coverage is met, but mainly to identify if the investment in the transmission system (antenna, transmitter, etc.) is performing as is should be. Also, due to the scarcity of available broadcast engineering resources, it is important to ensure that the time spent on measurement in the field is maximized, where direct feedback from the measurement system allows for a much quicker and a more accurate diagnosis of the system under test.

Finally, with the congestion of the FM spectrum, station optimization will only be possible if we can effectively assess the deficient coverage areas. This can be done by analyzing the surrounding interfering stations, the performance of the HD upper vs lower carriers and other key metrics.