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July 26, 2022

VIA EMAIL (AUDIOFILINGS@FCC.GOV)

Marlene H. Dortch, Esq.
Secretary
Federal Communications Commission
45 L Street, NE
Washington, DC 20554
Attn: Audio Division, Media Bureau

Request for Extension of Experimental Authority
WWFD(AM), Frederick, Maryland
FCC Facility ID No. 47104
File Nos. BSTA-20180628AAI,
BESTA-20190605ABK,
BESTA-20200629AAH,
BESTA-20210716AAF

Dear Ms. Dortch:

Washington DC FCC License Sub, LLC ("WDFL"), the licensee of WWFD(AM), Frederick, Maryland ("WWFD"), by its counsel and pursuant to Section 5.203 of the Commission's rules, 47 C.F.R. § 5.203, hereby requests a one-year extension (to and including **August 4, 2023**) of the Experimental Authorization which permits WWFD to conduct testing of all-digital AM transmission technology utilizing the station's existing antenna facilities.[1] For the reasons set forth below, WDFL believes that one additional year of experimental operations will permit WWFD to address several unresolved issues from the experiments it has conducted to date. In particular, WDFL, in conjunction with Xperi Corporation, will focus on the testing and experiments described on Page 4 of this request and in the attachment. WDFL anticipates that a one-year extension will be sufficient to conclude these experimental operations.

WWFD's groundbreaking all-digital experiments beginning in 2018 led directly to the successful adoption of new rules in 2020 permitting AM stations to voluntarily transition

[1] *See* Letter from Joseph Szczesny, Engineer, Audio Division, Media Bureau to Ryan M. Vandewiele, WDFL (Aug. 5, 2021).

to all-digital operations using the MA3 mode.[2] MA3 is the primary AM all-digital service mode, and the mode that WWFD has been utilizing since 2018.[3]

Continued experimental operations would be in keeping with the FCC's previous statement that broadcasters "are encouraged to experiment with an all-digital service, with appropriate authorization."[4] WWFD will continue to examine representative equipment, methods, and techniques, and conduct subjective coverage testing. WWFD will also continue to assess the increasing potential for the general public (through HD-Radio systems) to readily receive all digital AM transmissions with commercially-available receivers already in use by listeners.

During the extended testing period, all-digital operation of WWFD will continue consistent with the technical information provided in the original request for Experimental Authorization ("Original Request").[5] However, analog operation of WWFD may be temporarily utilized from time to time. WWFD's associated FM translator facility, W232DG, Frederick, Maryland, FID 139260, will continue providing service to analog listeners during periods of all-digital operations, as described in the Original Request.

Testing will continue to be conducted in cooperation and association with Xperi. Specific information about the additional planned testing is attached.

Technical Contact Information

Contact information for the individual responsible for WWFD's technical operations, and for use in the event of an interference problem, is as follows:

Dave Garner
Director of Engineering
Hubbard Radio, LLC
5425 Wisconsin Ave
Chevy Chase, MD 20815
Tel: (202) 895-5056
Email: dgarner@wtop.com

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[2] *All-Digital AM Broadcasting; Revitalization of the AM Radio Service*, MB Docket No. 19-311, Report and Order, 35 FCC Rcd 12540 (2020) ("*R&O*").
[3] *See* National Radio Systems Committee NRSC-5-C In-band/on-channel Digital Radio Broadcasting Standard, September 2011; Doc. No. SY_SSS_1 082s rev. F, HD Radio AM Transmission System Specifications, iBiquity Digital Corporation, 8/24/11.
[4] See *Digital Audio Broadcasting Systems*, Second Report and Order, 22 FCC Rcd 10344, 10353 ¶ 22 (2007).
[5] File No. BSTA-20180628AAI.

Compliance with Section 5.203

The proposed experimental operations comply with Section 5.203. The authorized power of the station will not exceed more than 5% above the maximum power specified.[6] Emissions outside the authorized bandwidth will be attenuated to the degree required.[7] WWFD requests continued authority to operate on an all-digital basis 24 hours per day, subject to non-interference to other stations.[8] Because WWFD's experimental operations will be in lieu of its analog operations, the prohibition of sponsored programs and commercial announcements does not appear to apply;[9] to the extent necessary, a waiver of Section 5.203(c)(4) is requested because the all-digital operations of WWFD essentially serve as a replacement of the analog service. Regularly scheduled programming will be transmitted concurrently with the experimental transmissions without any significant impairment of service.[10] No charges will be made, either directly or indirectly, for WWFD's experimental operations.[11]

For these reasons set forth above, WDFL believes that the public interest would be served by an extension of WWFD's Experimental Authorization.

Should there be any questions concerning this request, please contact the undersigned.

Respectfully submitted,

Washington DC FCC License Sub, LLC

/s/ David A. O'Connor
David A. O'Connor
Its Counsel

Enclosure
cc (by email): Joseph Szczesny, Jerome Manarchuck,
James Bradshaw, Son Nguyen (FCC)
Dave Garner, Director of Engineering, Hubbard Radio

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[6] 47 C.F.R. § 5.203(c)(1).
[7] *Id.* § 5.203(c)(2).
[8] *Id.* § 5.203(c)(3).
[9] *Id.* § 5.203(c)(4).
[10] *Id.* § 5.203(c)(5).
[11] *Id.* § 5.203(c)(6).

Planned testing by Xperi Corporation at WWFD

Xperi Corporation, in conjunction with Hubbard Broadcasting, Inc. and its licensee subsidiary WDFL, would like to conduct further tests using WWFD as a test facility. Xperi believes that this further testing will help improve upon the current MA3 system, as well as provide useful information and new services to the broadcast industry. The list of testing we would like to conduct are the following, but not limited to:

- Expanded testing of the use of an HD2 Supplemental Program Service (SPS) channel, creating a second audio service in addition to the main program service (MPS). The primary focus of this testing will be to field-test receiver chipsets, in order to ensure that new HD Radio receivers are capable of decoding AM HD2 channels, and correctly displaying associated metadata.
- Testing changes to the MA3 waveform by reducing the power level of the unmodulated pilot carrier level while maintaining licensed power. Possible tradeoffs will be examined: robustness in primary coverage area vs. the absolute limit of receivable signal, reception in the null of a directional antenna system with a reduced Reference carrier, effects on fast receiver acquisition, and any possible effects on SPS (HD2) transmissions.
- The addition of different data services, alongside current data services already deployed now. In particular, services that enable and disable devices for the purpose of power grid management will be explored.
- Testing of Emergency Alert System services and new advanced alerting services.
- Testing the performance of MA3 vs. analog in different all-Electric Vehicles, particularly with a modified Reference carrier level.
- Documenting the procedures involved and effects upon the listening experience when switching between analog, MA3, and hybrid operations, in order to give station operators a better understanding of the tradeoffs between the possible operating modes within the AM service.

Exploring the Effects of Directional Antenna Pattern Bandwidth on MA3 Transmissions

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Abstract – WWFD (820 kHz, Frederick MD), commenced operations on July 16th, 2018 as the first AM broadcast station to transmit full-time using the HD Radio MA3 all-digital AM mode. For nighttime operation, WWFD utilizes a two-tower directional array, forming a simple pattern with one null. When preparing for MA3 transmissions, the antenna system was modified for improved bandwidth, but also with the goal of reusing as many components as possible in order to reduce digital conversion costs. As a result, the pattern bandwidth in the null direction may not be fully optimized. In this paper, an effort is made to characterize the received signal in and off-axis to the null direction, in order to document the real-world failure conditions of MA3 transmissions. By examining the received signal using a spectrum analyzer and a test receiver that monitors the received signal constellations, the maximum tolerable distortion with regards to amplitude and phase can be characterized. It is hoped that such data will be of use in the design or modification of antenna systems where all-digital operation is contemplated.

The Antenna System

The WWFD nighttime antenna system consists of two towers, 73.5 degrees tall, with 16.5 degrees of top-loading as part of the top level of guy wires. The towers are physically spaced 60 degrees apart, with Tower 2 oriented at an angle of 253 degrees from Tower 1. Tower 1 is the reference, and Tower 2 is driven with a ratio of 0.89 and with 122 degrees of phasing as compared to Tower 1. Power is fed to the antenna system via a simple Ohm's Law power divider [1], with the phase to each tower adjusted via T networks. A cardioid pattern is formed (Figure 1).

The oldest components in the WWFD phasor and Antenna Tuning Units (ATUs) date to WMHI, a 500 watt daytime directional station on 1370 kHz, which first signed on in 1961. In 1988, the towers were reoriented on the property, and the frequency was changed to 820 kHz in order to allow for the current (4.3 kW non-directional daytime, 430 watts directional nighttime) operation. Components from the original antenna system were repurposed with thrift and economy in mind, and in 2018 the same considerations were prominent in the station's conversion to MA3 all-digital operations [2]. As a result, some compromises were unavoidable in the retrofit of the array, such as the pattern linearity and bandwidth in the null direction. Since the null is rather deep, it is instructive to examine how the

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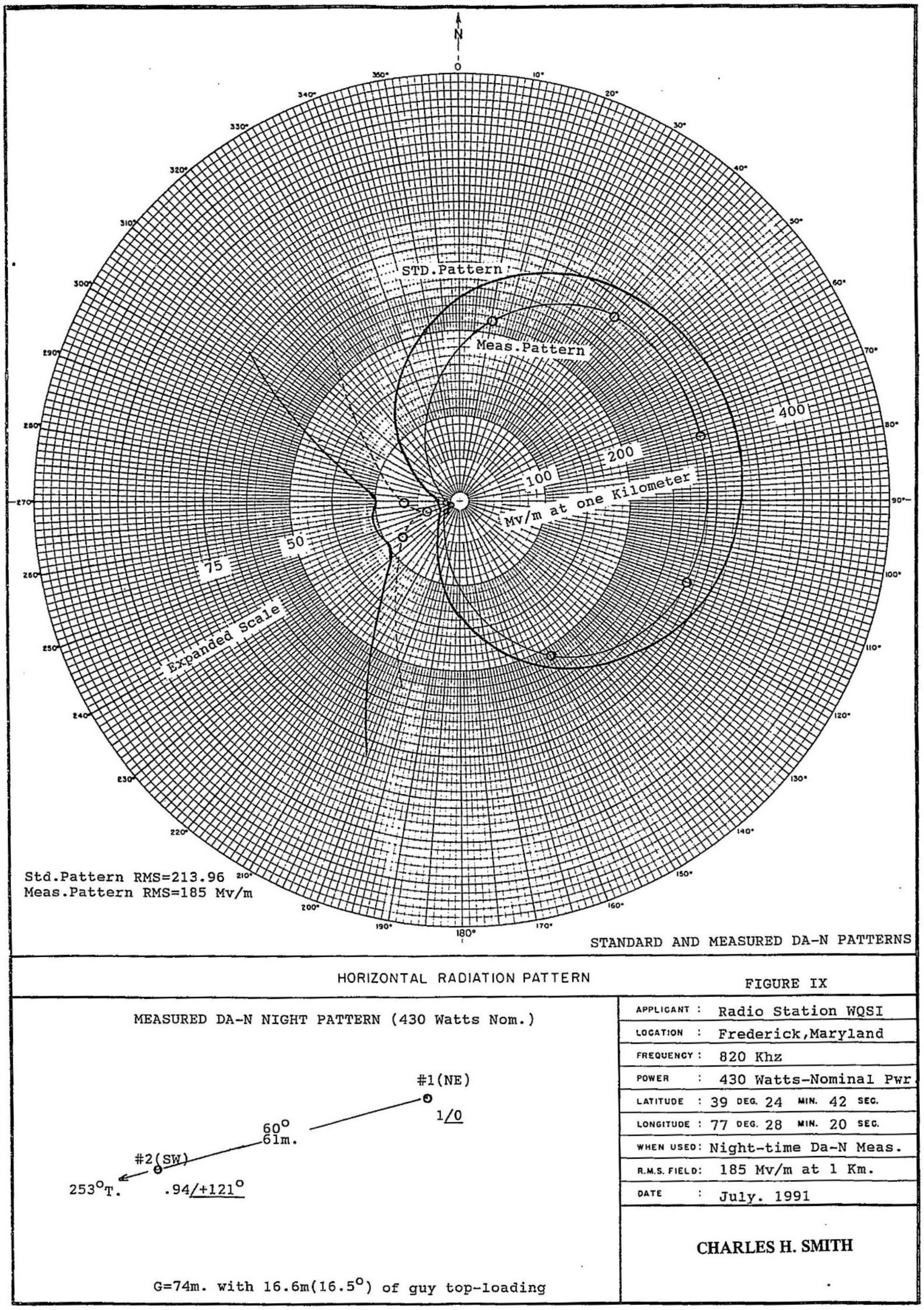

FIGURE 1: THE WWFD NIGHTTIME ANTENNA PATTERN.

station's MA3 transmissions perform on and adjacent to that radial. Such "real world" data from a necessarily imperfect antenna system adds to the knowledge base as to when all-digital MA3 transmissions fail due to inadequate null-fill in the array.

Examining the MA3 Waveform in the Context of the Antenna System

A discussion of the MA3 waveform is available in the literature [3], and a plot of its magnitude versus frequency is given in Figure 2. Because of the functionally random nature of the data points within the signal constellations, the waveform, when viewed using a spectrum analyzer with sufficient video averaging, can easily reveal amplitude nonlinearities within a transmission channel. As a result, the waveform as viewed on a spectrum analyzer can serve to approximate the amplitude nonlinearities of a directional AM antenna system as a function of azimuth.

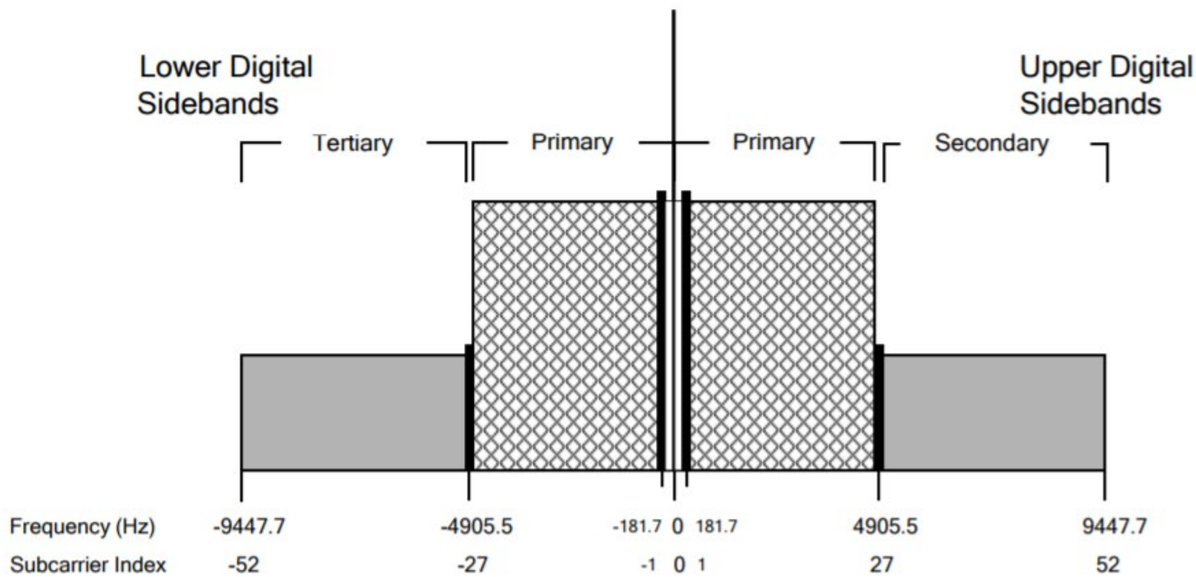

FIGURE 2. THE MA3 WAVEFORM [3]. NOTE THE REFERENCE CARRIER AT 0 FREQUENCY, WHICH AIDS IN RECEIVER SYNCHRONIZATION.

Here, measurements taken along an arc cutting through the system's null, compared to a measurement taken in the major lobe of the array, serve to characterize the approximate in-channel amplitude response of the antenna system. At the same time, an examination of the signal constellations provides insight as to phase distortions that may occur as a function of azimuth, referenced to the signal in the major lobe.

In a typical digital receiver, demodulation involves several processes, for example automatic gain control (AGC), which utilize phase-lock and equalizer loops [4]. Since such circuits provide correction for channel distortions, typical field measurements can only indicate when the entire transmission-reception process (channel corruption plus channel correction) breaks down. By travelling along an arc, noting points of reception failure, and taking these measurements, information as to how much amplitude and phase nonlinearity can be tolerated before system failure can be gained. Such efforts provide experimental data to antenna system designers.

A well-designed directional antenna system will pass MA3 transmissions in its major lobe, but difficulties can arise at the edges of such a lobe and within the null areas. A deep null can create either a ripple or notch in the channel passband, which compromises the digital carriers. The WWFD nighttime antenna system contains one such deep null, and thus provides an opportunity to characterize the impacts of nonlinearities typical in directional AM antenna systems on all-digital transmissions.

Test Procedure

A test vehicle (Figure 3) is outfitted with an omnidirectional, medium wave loop antenna, mounted as close to the center of the roof as possible. This antenna feeds a test receiver capable of depicting the signal constellations, as well as a spectrum analyzer to monitor the amplitude linearity of the received signal (Figure 4). The vehicle's factory stock radio is used to monitor the signal for reception or no reception while in motion.

FIGURE 3. THE TEST VEHICLE.

A test route is chosen that sweeps through the null of the antenna system, starting from the north and proceeding south. The first test point is chosen to be a location to the north and far enough away from the null (on the 253 degree radial) such that reception is strong on the monitor radio. This is determined by the presence of fast receiver acquisition (typically on the order of 1.5 seconds), meaning that the Program Information Data Service (PIDS) carriers and both sets of Primary carriers are being decoded by the receiver. Field strength is then measured with a field intensity meter calibrated for MA3 measurements (a Potomac Instruments FIM-4100) to ensure that at least 0.5 mV of signal is present, which is the minimum threshold for reliable decoding of the Secondary and Tertiary carriers [4].

FIGURE 4. HD RADIO TEST RECEIVER (TOP LEFT), SPECTRUM ANALYZER HARDWARE (TOP RIGHT), AND SPECTRUM ANALYZER SCREEN SHOT (BOTTOM).

The vehicle is then driven south and stopped for stationary measurements at several places, including the three designated monitor points, which are along the 268, 253, and 238 degree radials. The vehicle is driven south until reception quality approximates the first point, indicating that the vehicle has travelled through the subtended azimuth angle where reception is impaired by the poor pattern bandwidth and null-fill performance of the antenna system. At each point, reception quality of the monitor radio is noted, and a field strength measurement is taken. A spectrum analyzer screenshot is taken to measure the amplitude ripple of the channel. Signal constellations of both sets of Primary carriers, as well as the Secondary and Tertiary carriers, are examined using the test receiver. The quality of the signal constellations indicate which sets of carriers are being successfully passed through the antenna system and decoded by the receiver. Test points are located in as open of a location as possible, and measurements are taken in the middle of the day, both in order to eliminate variables such as power line noise and skywave interference.

After the data is collected in the null direction, the vehicle is driven east of the tower site to a point in the major lobe. A set of stationary measurements is once again taken, this time to provide a reference to demonstrate the upper limit of signal quality being transmitted from the antenna system. A map of the test points to the west, as well as the reference point to the east, is displayed in Figure 5, as is the nighttime pattern of the antenna (half-NIF contour at 5.4 mV/m).

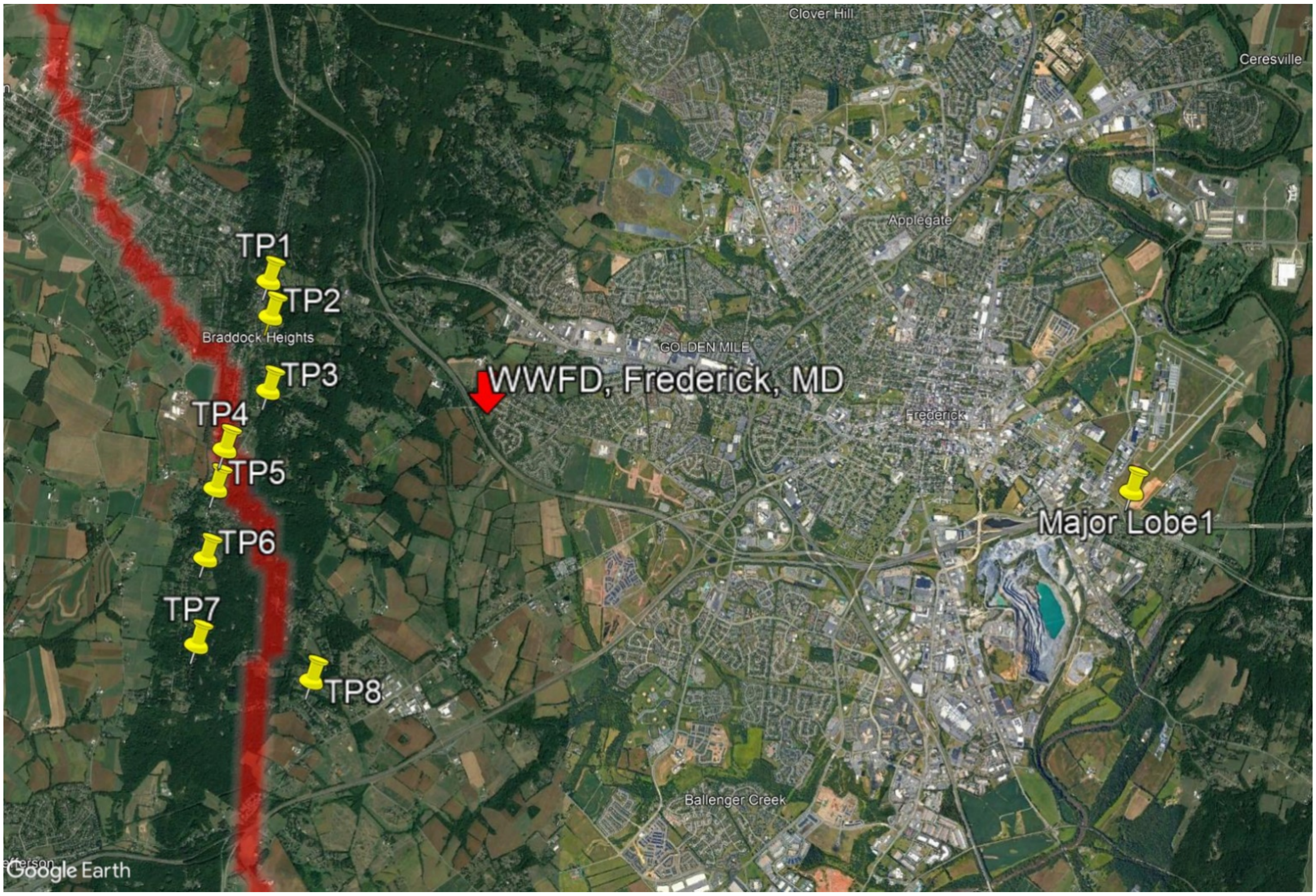

FIGURE 5. THE TEST POINTS, LABELED TP1-TP8, AS WELL AS THE REFERENCE POINT LABELED MAJOR LOBE 1. THE "HALF NIF" CONTOUR OF 5.4 MV/M IS DISPLAYED AS THE RED LINE.

Test Data

Test Point	LAT	LON	Field Strength (mV/m)	Reception
TP1	39.422695	-77.503557	4.900	Yes
TP2	39.418972	-77.503028	11.500*	Yes
TP3	39.411111	-77.502809	0.725	No
TP4	39.404667	-77.50833	1.530	Marginal
TP5	39.400471	-77.509308	1.230	Marginal
TP6	39.393055	-77.510171	0.606	No
TP7	39.383888	-77.510781	0.826	Marginal
TP8	39.380749	-77.494783	5.170	Yes
Major Lobe 1	39.405084	-77.383833	30.900	Yes

TABLE 1. TEST POINT POSITION, FIELD STRENGTH, AND RECEPTION DATA.
*THE PRESENCE OF A NEARBY TOWER LIKELY CAUSED SOME RERADIATION OF THE WWFD SIGNAL AT THIS POINT, AFFECTING THE MEASUREMENT.

Table 1 shows the test data at each point, indicating position, field strength, and whether there was reception on the stock vehicle radio. Points TP3, TP4, and TP6 correspond to the station's monitor points along the 268, 253, and 238 degree radials, respectively. The Major Lobe 1 point corresponds to a parking lot adjacent to the Frederick Municipal Airport (FDK).

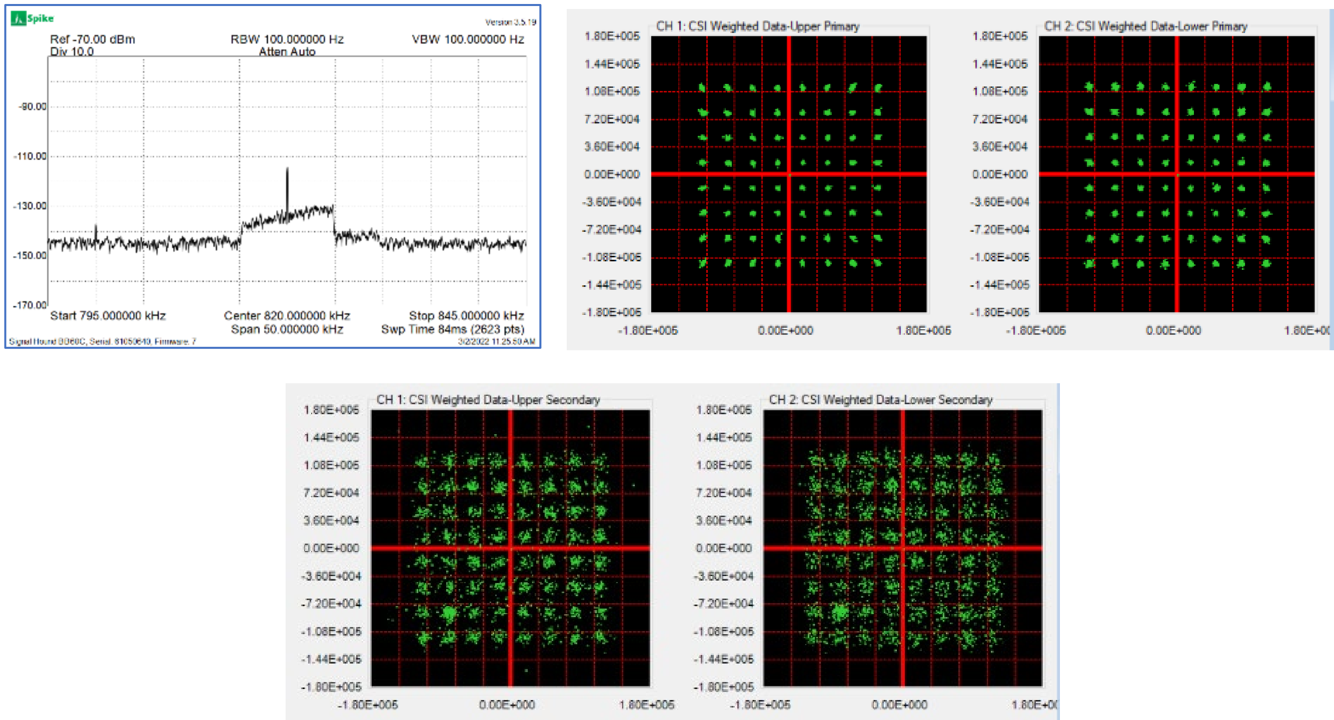

FIGURE 6. TP1: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

Data collected from the first test point, TP1, shown in Figure 6, is notable in that even though all of the carriers are coherent enough to be decoded by a receiver, the antenna system is distorting the amplitude of the MA3 carriers as a function of frequency. Using the spectrum analyzer's video averaging and markers to make an estimate, the ripple in the Primary carriers appears to be approximately 8 dB across both sets, but is limited to about 4 dB for the upper and lower ones individually.

As the vehicle is driven south, reception becomes solid as the amplitude response smooths out, and all carriers are received solidly (Figure 7). At the 268 degree radial monitor point, however, reception collapses as the Reference carrier is almost completely suppressed (Figure 8). The signal recovers somewhat at the 253 degree radial monitor point (Figure 9), as the upper Primary and Tertiary carriers are linear enough to be decoded. Note that the lower Primary carrier has approximately 8 dB of ripple and a high amplitude relative to the reference carrier, which makes its decoding unlikely. At TP5, some coherence to the lower Primary and the Secondary carriers has returned, as the ripple shifts position slightly (Figure 10). Note the amplitude distortion that creates an "X" pattern within the lower Primary carrier constellation.

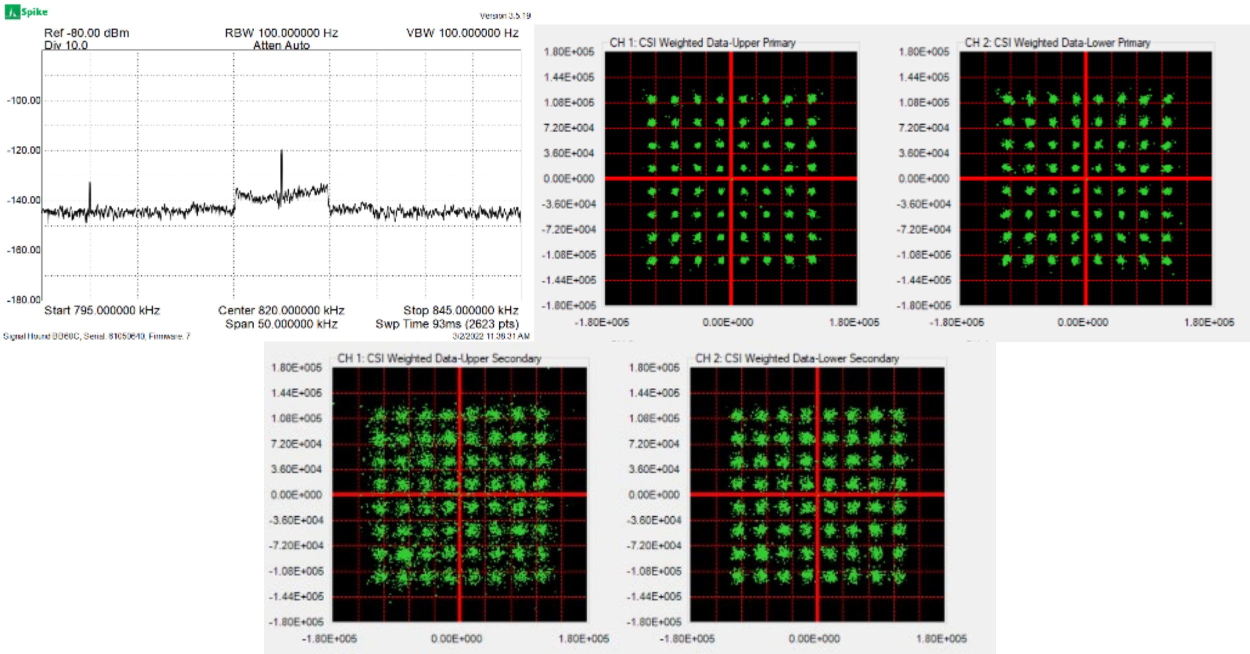

FIGURE 7. TP2: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

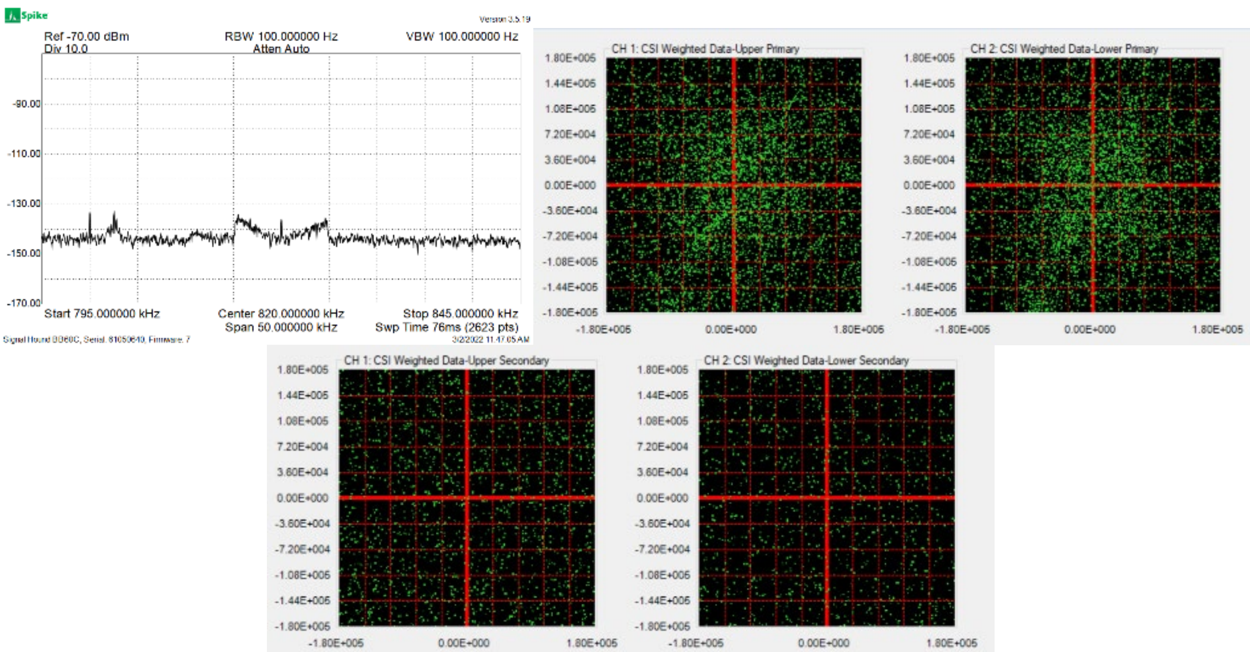

FIGURE 8. TP3: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

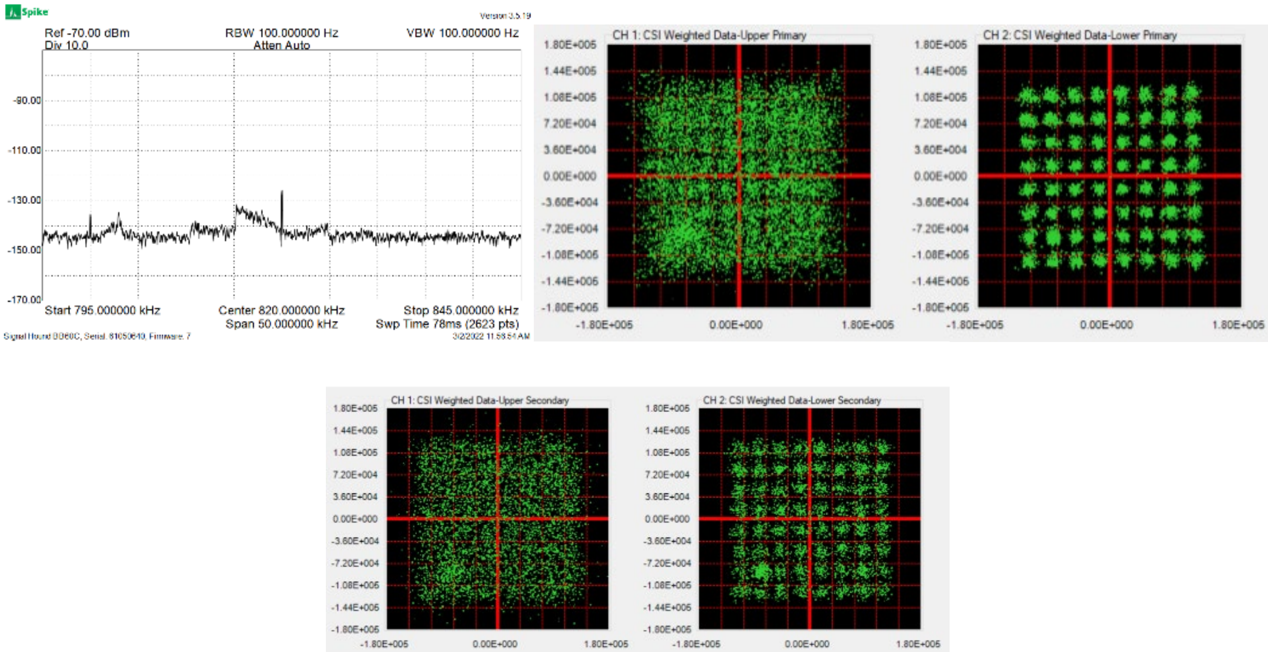

FIGURE 9. TP4: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

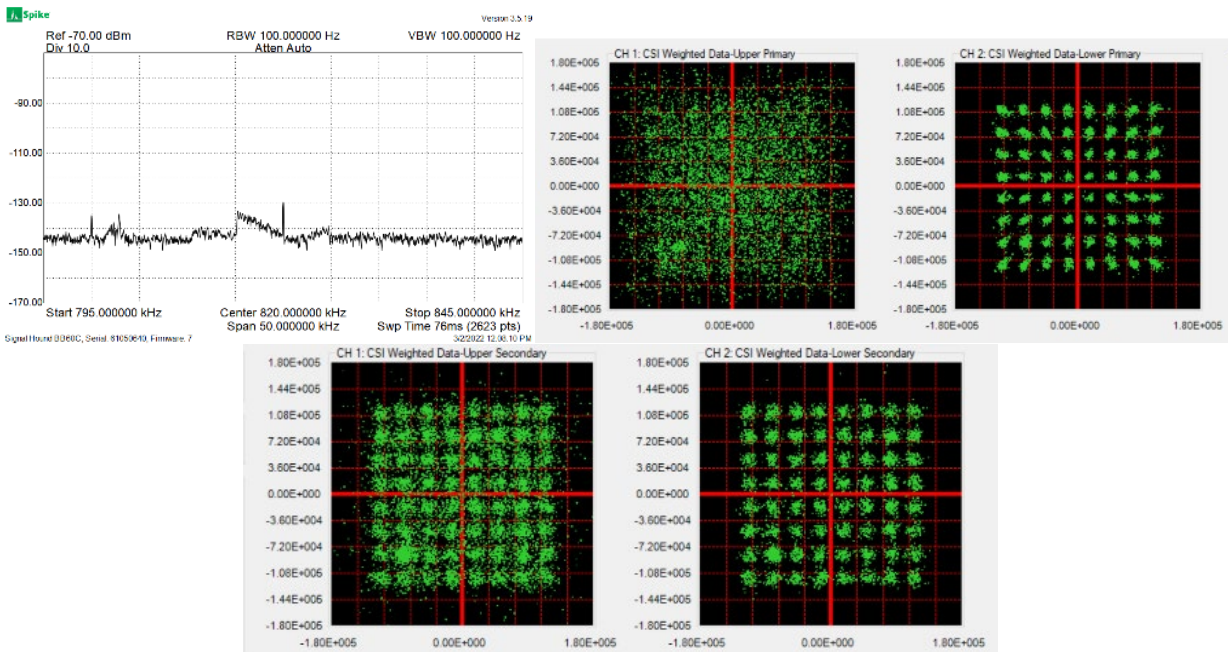

FIGURE 10. TP5: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

Reception once again collapses at TP6, the 238 degree radial monitor point (Figure 11). Note the rotation and incoherence of the signal constellations as the Reference carrier is suppressed. Reception progressively improves as the vehicle is driven through points TP7 (Figure 12) and TP8, away from the null radial, and as more carriers come into coherence. By TP8 (Figure 13), the Reference carrier has about as little suppression as in TP1.

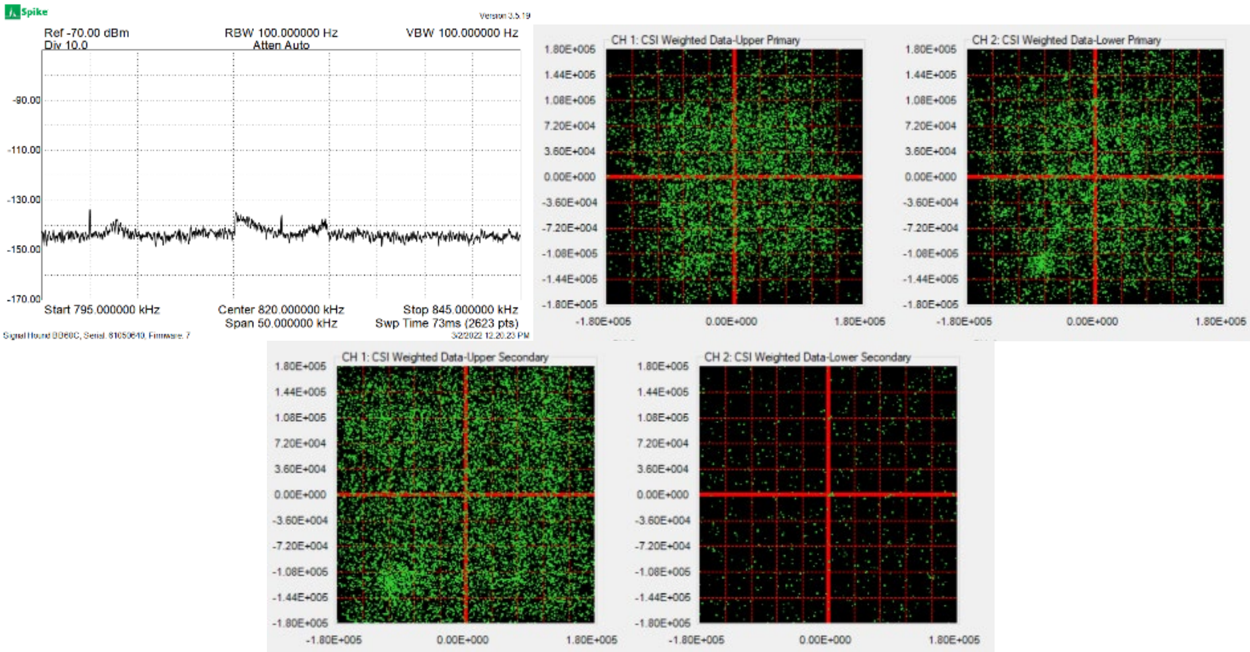

FIGURE 11. TP6: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

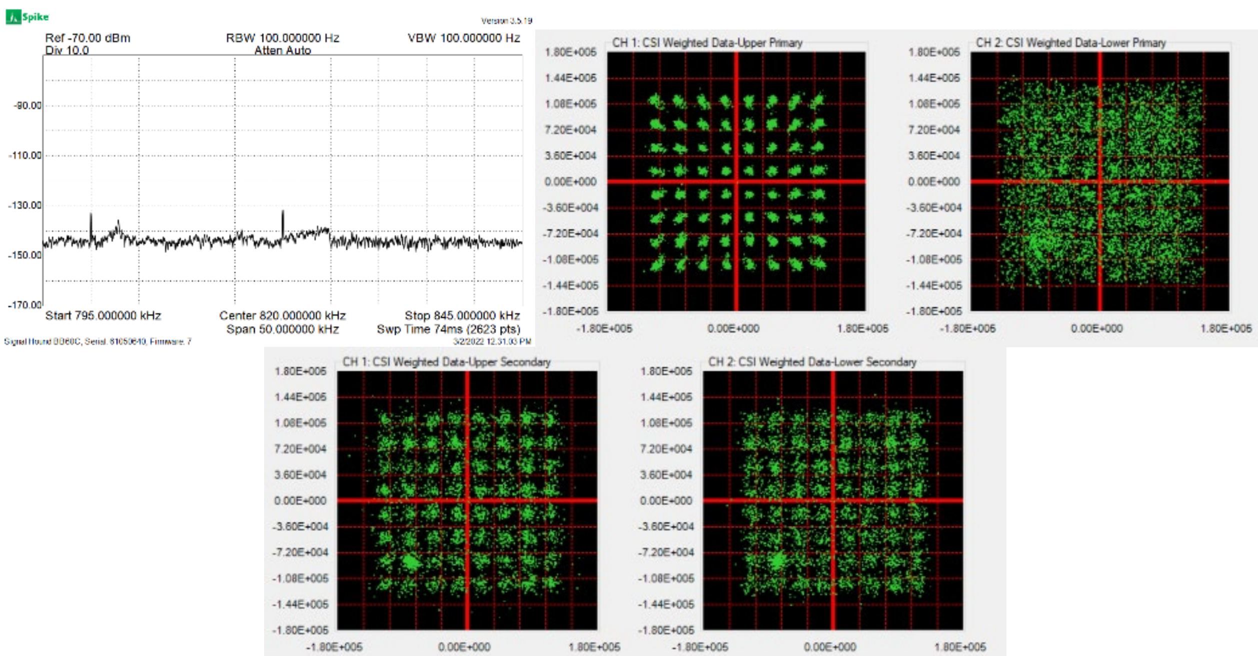

FIGURE 12. TP7: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

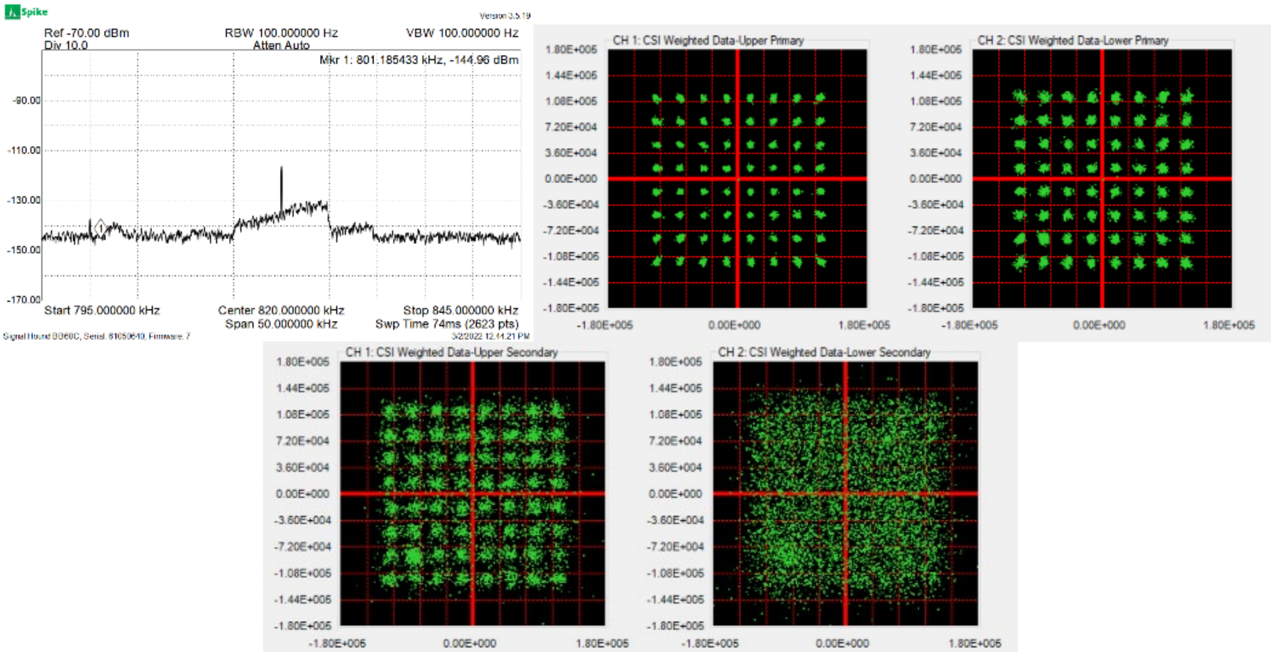

FIGURE 13. TP8: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

Having driven through the null, a point in the major lobe is chosen for reference, and the data collected is displayed in Figure 14. This point indicates the minimum amplitude and phase distortion of the MA3 signal that is caused by the antenna system.

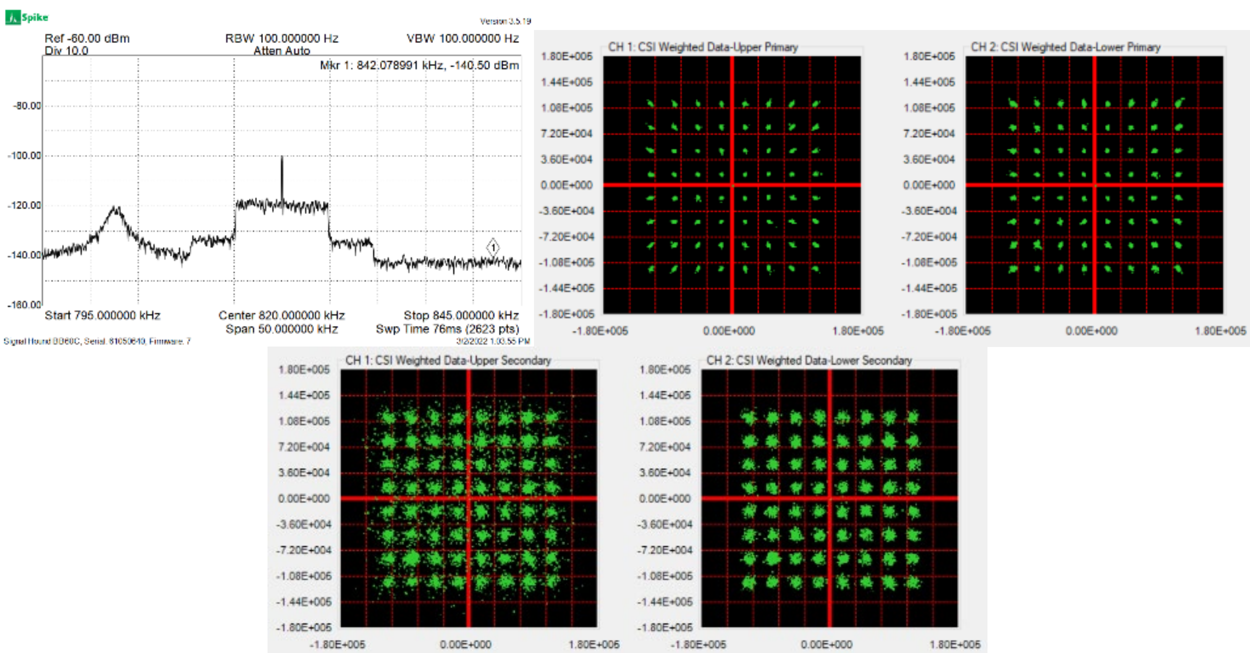

FIGURE 14. MAJOR LOBE: SPECTRUM ANALYZER VIEW (TOP LEFT), PRIMARY UPPER AND LOWER CARRIERS (TOP RIGHT), SECONDARY AND TERTIARY CARRIERS (BOTTOM).

Discussion

		Passband ripple (dB)				Constellations	
Test point	Meas. field strength (mV/m)	Upper Primary carriers (0 to 5 kHz)	Lower Primary carriers (0 to -5 kHz)	Reference carrier level, dB over Upper Primary	Reference carrier level, dB over Lower Primary	Primary Upper	Primary Lower
TP1	4.900	4	4	14	15	Solid and tight	Solid and tight
TP2	11.500	4	4	14	15	Solid and tight	Solid and tight
TP3	0.725	8	8	0	0	Incoherent	Incoherent
TP4	1.530	3	10	14	8	Incoherent	Some noise
TP5	1.230	7	5	5	10	Incoherent	Some noise
TP6	0.606	5	7	1	0	Incoherent	Incoherent
TP7	0.826	4	3	8	10	Solid and tight	Incoherent
TP8	5.170	4	5	14	15	Solid and tight	Some noise
Major Lobe 1	30.900	0	0	20	20	Solid and tight	Solid and tight

TABLE 2. SUMMARY OF TEST POINT DATA. SPECTRUM ANALYZER WAS SET FOR 100 KHZ RBW, AND A VIDEO AVERAGING OF 10.

In examining the spectrum analyzer plots for the various test points, it can be seen that the MA3 signal can be decoded despite fairly adverse channel transmission characteristics. In the WWFD test data, an amplitude ripple of 4 dB within one carrier set seemed to be compensated by the synchronization and equalization processes in the receiver. As the vehicle is moved through the test points, there appears to be a point of maximum suppression as a function of frequency varying within the channel. When this point of maximum suppression lands on the Reference carrier, the receiver cannot lock onto the MA3 signal. It is worth further exploring the effects of the level of the Reference carrier upon the receiver's ability to coherently decode the signal, as has been proposed in other contexts [6]. Where the point of maximum suppression lands also affects the slope (both steepness and positive/negative direction) of the ripple. It is here where the MA3 transmission system compensates well for these channel faults: the Lower and Upper Primary carriers are redundant, and the same applies to the Secondary and Tertiary carriers.

The receiver will still decode the MA3 signal if one set of Primary carriers is impaired. With a directional antenna system, it is entirely plausible that a receiver switches between the Lower and Upper Primary carriers, depending upon channel conditions. It should be noted, however, that if neither set of Primary carriers can be decoded, the receiver will not decode the Secondary or Tertiary carriers, even if coherent. This has implications for the coverage area of audio and data services using the Enhanced carriers, such as Station Logo, Artist Experience, and Secondary Program Service (SPS) channels: they are usable only in a subset of the Core service area.

As an aside, an examination of the signal constellations at the Major Lobe 1 test point reveals an item of note about the Secondary and Tertiary carriers: they are not as well-formed as the Primary carriers. This is not due to the antenna system, as this effect is also observed at the RF monitor port of the transmitter. These carriers are approximately 12 dB lower in amplitude than the Primary carriers. Additionally, the nighttime TPO of WWFD is 460 watts, well below the stated 5 kW capacity of the transmitter. As a result, at nighttime power levels, the Secondary and Tertiary carriers are more affected by the noise floor of the amplifiers within the transmitter than are the Primary carriers. Nighttime power levels must be considered when operating a transmitter in the MA3 mode, and for very low power levels (relative to the stated capacity of the transmitter) it may be necessary to utilize a power divider network with a resistive load in order to operate the transmitter within a range where the Secondary and Tertiary carriers can be formed with an adequate signal-to-noise ratio.

Despite the redundancy built into the MA3 transmission system, antenna system engineers and designers should not overlook the pattern bandwidth and null-fill characteristics of AM directional antenna systems. In the areas of marginal array performance, reception robustness is lost. Ensuring maximum impedance bandwidth as well as pattern bandwidth is a must for any all-digital AM transmission system. Such efforts will pay off by creating the best listener experience by maximizing the useful coverage area of an AM station with a directional antenna system.

Acknowledgements

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References

[1] King, T., Cox, B., & Moser, J., “Antenna Coupling and Phasing Systems,” *National Association of Broadcasters Engineering Handbook*, 11th Edition, 2018, p. 1215.

[2] Kolesar, D. and Raide, M., “Facility Upgrades for Full-Time All-Digital HD AM Broadcasting: A Case study,” *NAB Broadcast Engineering and Information Technology Conference*, April 2019, pp. 1-7.

[3] iBiquity Digital Corporation, “HD Radio Air Interface Design Description Layer 1 AM,” *SY_IDD_1012s,* Rev. G, December 14th, 2016.

[4] Sklar, B. and Harris, F., “Synchronization,” *Digital Communications*, 3rd Edition, 2021, pp. 619-673.

[5] Kolesar, D. and Raide, M., “A Case Study in All-Digital HD AM Broadcasting: Refinements, Performance Tests, and Lessons Learned,” *NAB Broadcast Engineering and Information Technology Conference*, April 2020, p. 9.

[6] Kolesar, D. and Raide, M., “Incorporating a Supplemental Program Service (SPS) Channel into MA3 Transmissions,” *NAB Broadcast Engineering and Information Technology Conference*, October 2021, pp. 7-8.