Analysis of Technical Reports for ZoneCasting at KSJO(FM), San Jose, CA and WRBJ-FM, Brandon, MS

Prepared for
National Association of Broadcasters
and National Public Radio

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Introduction

This document was prepared as an independent analysis of the technical reports of geo-targeted demonstration systems at FM Station KSJO, San Jose, California and Station WRBJ-FM, Brendan, Mississippi, employing "ZoneCasting™" technology.

Summary

Two field trials were performed of an on-channel booster technology called "ZoneCasting™" (ZoneCasting or ZoneCast) by the proponent, GeoBroadcast Solutions ("GBS"), allowing FM stations to "geo-target" certain portions of their authorized service area with programming that differs from the primary transmitting facility. GBS hired the firm of Roberson and Associates, LLC to conduct field trials and prepare technical reports. Through the GBS attorneys on September 17, 2021, a technical report on a field trial for KSJO(FM) was filed in response to the Commission's NPRM on FM booster stations.[1] A technical report on another field trial for WRBJ-FM was filed on March 30, 2022. As described herein, the reports contain fundamental technical issues, including incomplete and contradictory data. It is also shown that the field trials used flawed methodology and provide only partial results that do not provide a complete and accurate picture of the performance of ZoneCasting and its potential undesirable effects on station reception by listeners. Most importantly, it is shown that ZoneCasting is generally unsuitable for FM broadcasting because it can produce areas of substantial and irreparable signal interference to the host station that listeners would consider unacceptable.

Technical Basis for Signal Interference Caused by ZoneCasting

FM broadcasting is a medium that radio listeners know to be reliable and deliver high quality sound. The recent growth of digital audio for streaming and content playback has given listeners a new

1 Notice of Proposed Rulemaking in the Matter of Amendment of Section 74.1231(i) of the Commission's Rules on FM Broadcast Booster Stations, MB Docket No. 20-401, RM-11854; Modernization of Media Initiative, MB Docket No. 17-105, Adopted November 20, 2020.

reference for audio that is almost totally free of noise and interference. As a result, broadcasters and regulators should be cautious in adopting any technology changes that may degrade the perceived quality of FM radio signals. As demonstrated herein, ZoneCasting produces a form of co-channel interference that may introduce substantial degradation to a host station's audio quality.

Results of Listener Tests. ZoneCasting and the related simulcast single-frequency network (SFN) booster signal reinforcement technology (what GBS terms "MaxxCasting") were studied at NPR Labs more than a decade ago.[2] Based on NPR Labs' experience in this field, GBS engaged NPR Labs in 2012 and 2013 to produce comprehensive design criteria for both technologies.[3] Because both ZoneCasting and SFNs have the potential for interfering with the host station's primary (*i.e.*, full-service) signal, design parameters are needed to balance the potential effectiveness of a booster network against potential degradation to the host station's reception. Interference to FM reception as evidenced by degraded audio quality is a perceptual phenomenon that requires controlled listener testing to assess. The results of this testing are used to derive the design parameters. The NPR Labs work done for GBS developed test protocols by a perceptual psychologist with extensive experience in listener testing and the test system was implemented by the undersigned.

Testing involved dozens of adult listeners who were screened for hearing impairments. This number of participants was needed to ensure statistical significance of the results. A total of 622 audio test samples were collected and evaluated for the ZoneCasting technology alone (the samples were of various levels of co-channel interference) in addition to those for conventional SFN conditions.[4] The audio samples were derived from carefully selected music, speech and speech-over-music segments.

The audio samples used in these controlled tests were simulated stereo FM transmissions that were received using actual automotive receivers. To simulate realistic mobile reception conditions an RF channel simulator was used to create Rayleigh fading on the primary FM signal. The ZoneCasting

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[2] NPR Labs was the research and development office of National Public Radio, at its Washington DC Headquarters. It conducted contract research projects on technology of potential benefit to the public radio system. Research data remains the property of National Public Radio, which is a commenter in this proceeding. The ZoneCasting study results obtained from the NPR Labs listening tests have not been publicly disclosed until now.

[3] The SFN results were published in the Proceedings of the 2013 NAB Broadcast Engineering Conference, *Design Parameters for Analog FM Signal Repeaters Based on Listener Testing*.

[4] Note that the principal difference between the ZoneCasting and SFN tests is that for ZoneCasting the booster signal is a different audio program than the main signal, while the SFN tests involved simulcasting of the main signal by the booster.

booster's FM signal passed through a separate channel simulator to generate Rician fading, which is more representative of signal propagation over smaller distances with a relatively clear direct path from the booster transmitter to the mobile receiver.

The ZoneCasting test required listeners to assign a "keep on" score[5] as well as a Mean Opinion Score (MOS) on a five-point ITU scale (1-bad, 2-poor, 3-fair, 4-good, 5-excellent). Based on the 20 dB desired-to-undesired (D/U) signal ratio commonly used in the FCC's co-channel FM allocation rules, four D/U values were evaluated by the listeners: 0 dB, 5 dB, 11 dB and 18 dB.

The combined listener response to ZoneCasting interference was surprisingly critical. As the chart in Figure 1 shows, fewer than 27 percent of listeners indicated that they would keep their radio tuned to the station at the highest D/U signal ratio of 18 dB. This result suggests that even the FCC's co-channel protection ratio is marginally adequate to avoid listener tune-out. The listeners' MOS at 18 dB was poor-to-fair at 2.48 for those who would keep the radio on (continue listening) and poor (2.02) overall. The high anchor reference,[6] having only a small amount of noise and distortion, is included to show the listener's MOS score of 4.41. This produced a 100 percent keep-on score.

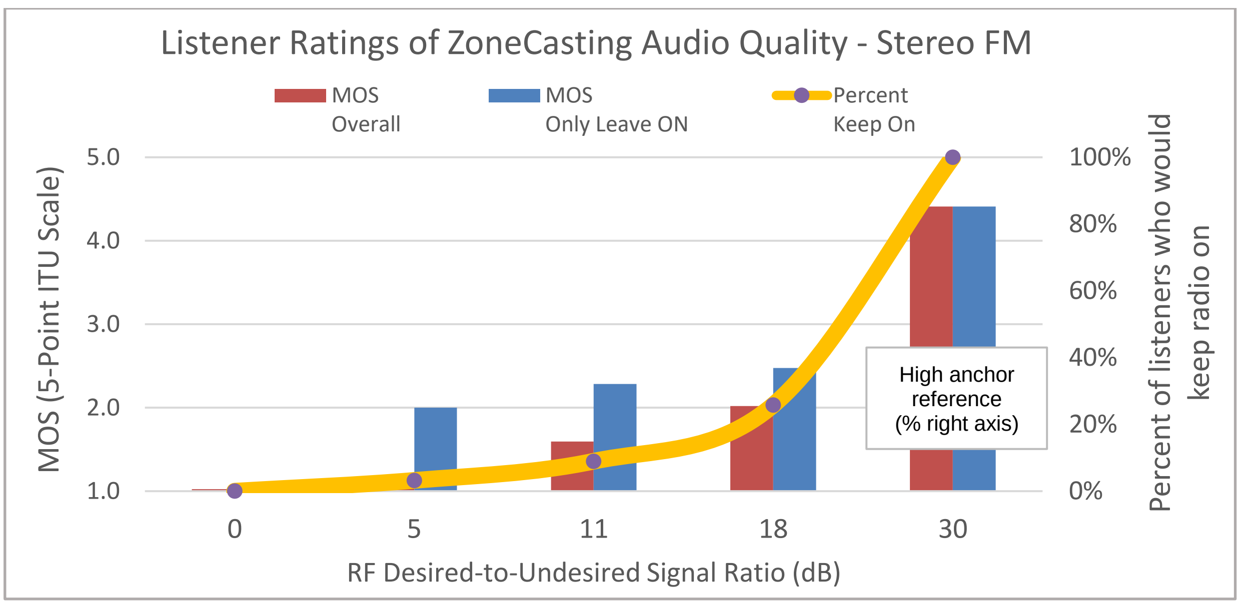

Figure 1. Listener ratings of ZoneCasting audio quality (stereo FM).

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5 A "keep on" score represents whether or not a listener would continue listening to the station or tune away from it.

6 The "anchor reference" is the MOS for the undegraded audio. A reference of less than 5 (excellent) is not unexpected. Often, people are reluctant to assign a perfect rating, assuming that there must always be room for improvement.

The results of the ZoneCasting response prompted further study. After the testing, interviews with some of the participants revealed that the intermittent "break-in" of the primary audio by different content from the ZoneCasting signal was far more annoying than equal-level bursts of neutral noise and distortion in the audio. That explained why this type of interference received such unfavorable scores, when it was first thought that 18 dB would be a tolerable D/U ratio. The D/U scores from the primary transmitter and a ZoneCasting booster are effectively reversible, so the same ratio can be applied to both the inner and outer boundary of the ZoneCasting region. A full derivation of the interference ratio for ZoneCasting Interference is presented in Appendix 1 and Appendix 2.

Interference Criterion. Based on the foregoing listener test data and application of signal statistics, the WRBJ-FM interference maps shown later in this report apply a generous 11 dB ratio to define interference, rather than the 20 dB used by the FCC for co-channel protection or 18 dB (27 percent keep-on with ZoneCasting) in the NPR Labs study. Two caveats should be noted in estimating ZoneCasting interference:

- Listeners may be highly annoyed at a calculated 10 percent probability factor (or even less)
- Car radios typically receive in stereo, which is much more susceptible to interference than monophonic FM. However, car radios employ stereo blending at low signal levels and other noise mitigation features to help improve listener keep-on. Thus, for this study it is conservatively assumed that the car radios operate more like monophonic FM receivers than stereo ones. This may not be the case for fixed receivers, however, which lack noise mitigation features and would be substantially more susceptible to ZoneCasting interference.

Considering these caveats, the predicted interference areas shown in the following maps could be considered by listeners to be much worse (larger) than what is shown.

Analysis of KSJO(FM) Technical Report

FM Station KSJO is a Class B facility operating on channel 222 (92.3 MHz) operating from Coyote Peak, located at the southern end of the Santa Clara Valley, approximately four miles from San Jose. The valley is near sea level and is surrounded by hills and mountains. The color underlay in Figure 3 is the predicted field strength of KSJO's primary transmitter using the Irregular Terrain Model (ITM, also known as "Longley-Rice"), which shows, that terrain tends to contain KSJO's primary signal within the valley and reduces effective service in outlying areas within the station's 54 dBµ service contour. For this reason, KSJO operates booster FM1, which helps to cover the communities of Dublin, Pleasanton and Livermore, which are obstructed by terrain from the KSJO main transmitting site.[7]

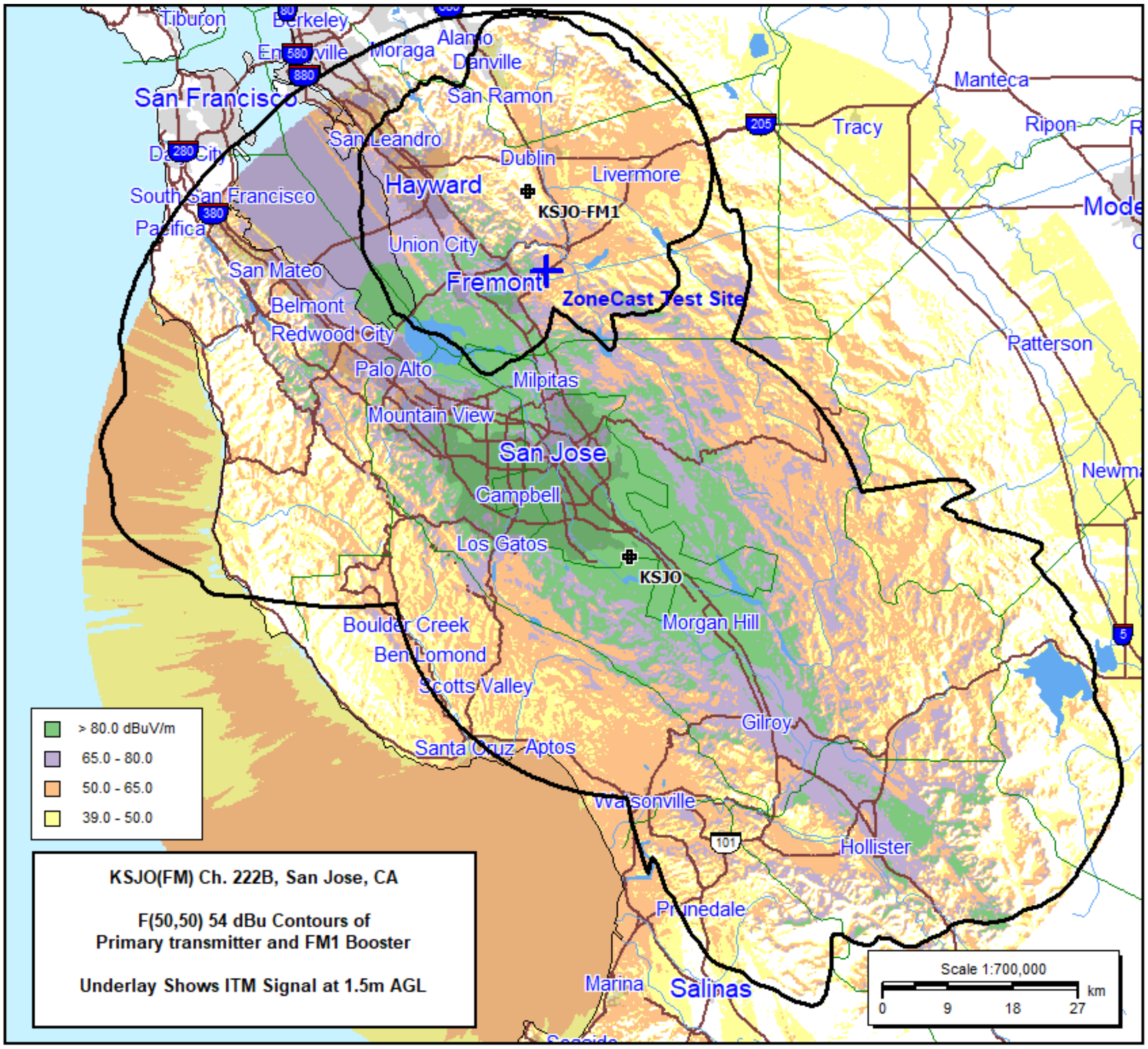

Figure 2 - KSJO(FM) ITM terrain-sensitive coverage at 1.5m AGL, with 54 dBµ service contour of primary FM and FM1 booster. Location of ZoneCast test is shown with blue crosshairs.

Figure 2 also shows the location of the only test site used for determination of the "Zone Transition Region." This site is located east of Fremont on an elevated ridgeline separating the Santa

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[7] KSJO requested a modification of booster FM1 in connection with its experimental operation "to extend and enhance the test by adding additional antennas." See Request for Extension of Experimental Authorization and Waiver, File No. 20210727AAG, granted 8/31/2021. However, it is unclear whether the change to FM1 was made, and Roberson does not mention the FM1 booster in its report, passing up an opportunity to test ZoneCasting over a large geographic area.

Clara Valley and Bay Area from the inland valley of Pleasanton and Livermore. The location was identified in KSJO's experimental request[8] as "I-680, Sheridan Site 1" but later referred to as "FM3 FM2 Booster" in the KSJO Report.[9]

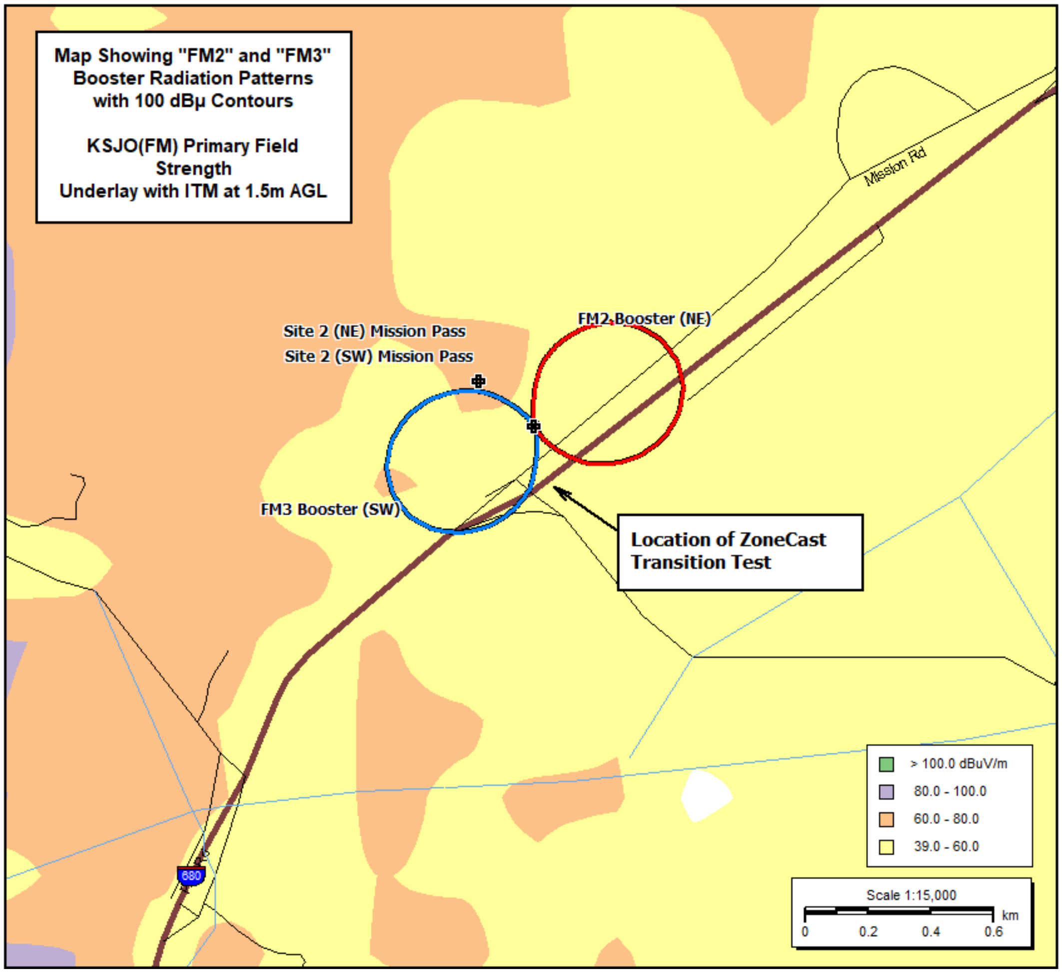

Figure 3 - Small scale view of the "FM2" and "FM3" booster site used in the KSJO field test.

A close-in view of the "FM3 FM2 Booster" test area, which is about 100 meters from Interstate 680, is shown in Figure 3. The two boosters are described in the KSJO Report as "Back-to-Back, High Front-to-Back Ratio Antennas" on a telescoping mast. The 100 dBμ field strength contours of the two boosters, shown with blue and red lines, illustrate the high directivity of these antennas. The color

8 Letter from Miles S. Mason to Marlene H. Dortch, Request for Experimental Authorization and Waiver of 47 CFR 74.1231(i), February 3, 2021 ("KSJO experimental request")

9 KSJO Demonstration System, Geo-targeted FM/HD Broadcast Technical Report, Roberson and Associates, LLC, 17 September 2021 (KSJO Report).

underlay in Figure 3 is the field strength of KSJO's primary transmitter using the Irregular Terrain Model (ITM, also known as "Longley-Rice") at a height of 1.5 meters above ground. Predicted field strengths along the roadway are between 39 dBµ and 60 dBµ; thus, KSJO's primary signal was insignificant compared with the booster signals. The KSJO experimental request notes that "the locations were selected for the experimental zone border because there is no coverage by either KSJO(FM) or KSJO-FM1 in the southern portion of the pass."[10]

The proximity of this site to the Interstate 680 test route has a large effect on the test results. Figure 4 shows a capture of Figure 12 from the KSJO Report as an aerial view with the test paths marked in aqua. The path end points in the measured "Zone Transition Region" are indicated by green and red dots.

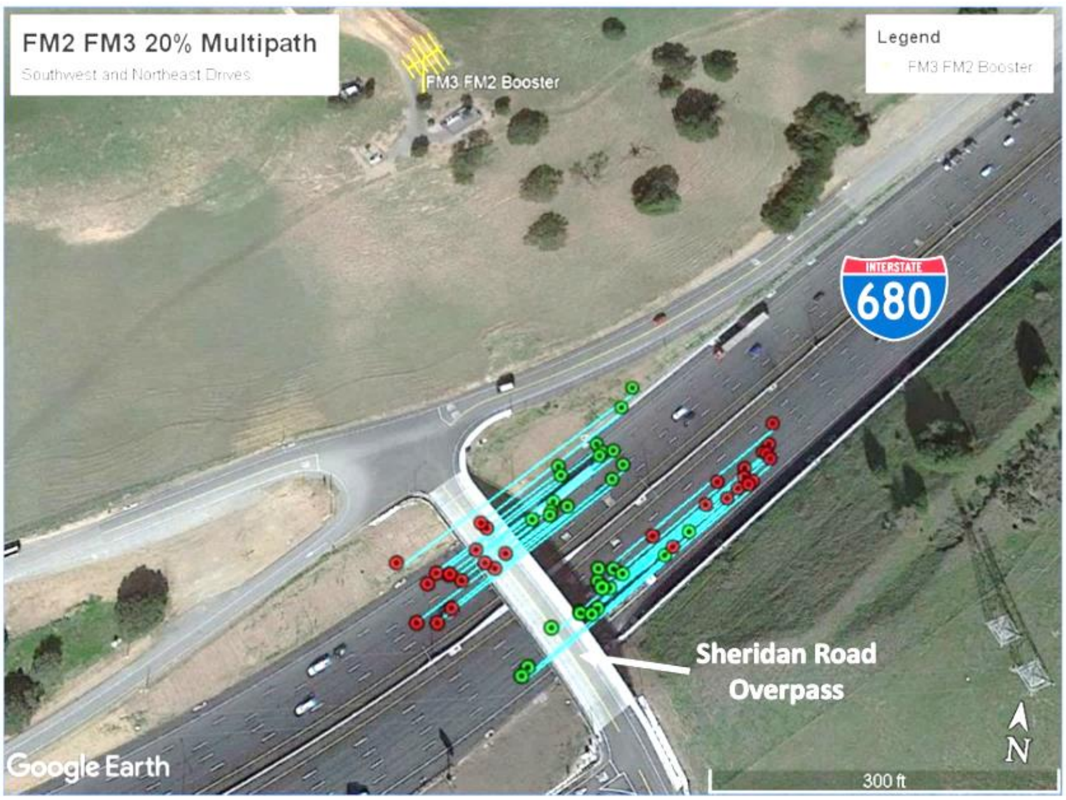

Figure 4 - Capture of Figure 12 used in Roberson KSJO report showing booster site and roadway where "Zone Transition Region" was measured.

It is apparent that the "Zone Transition Region" in the KSJO Report simply coincides with the minima between the booster signals (area between the blue and red contours) shown in Figure 3. Many

[10] KSJO experimental request, *op cit*.

of the measurements run below an overpass that can influence signal propagation. Data taken here are not representative of what would be obtained using a ZoneCasting system based upon a full-service FM signal interacting with an FM booster signal that establishes the zone, *i.e.*, the baseline ZoneCasting architecture. The zone transition in this case is simply a demonstration of the *handoff* behavior between "Back-to-Back, High Front-to-Back Ratio Antennas," nothing more.

The authors of the KSJO Report appear to take no effort to measure and evaluate signal conditions with the two boosters at more distant locations where emissions from the two boosters and the primary signal overlap. Indeed, this ZoneCast booster location is isolated, providing measurement data applicable only to a small portion of the Interstate highway.

A second, higher booster site called "I-680, Mission Pass Site 2" was also requested by KSJO, as shown in Figure 3. Its greater elevation and distance from the highway would have substantially increased the size of the so-called "Transition Region" along the highway and would have provided a better representation of the performance of the ZoneCasting system. This and the even larger FM1 booster site were authorized[11] for experimental ZoneCast testing, but are never mentioned in the KSJO Report, despite the Media Bureau's routine requirement for a "full report" of authorized experimental facilities.

The "Zone Transition Region" test of boosters FM2 and FM3 was the only test included in the KSJO Report. The isolated location and limited transition zone size make that test of little predictive value elsewhere. Due to the lack of comprehensive test results, no further analysis of interference is performed for the KSJO study.

Analysis of WRBJ-FM Technical Report

WRBJ-FM, Channel 249A is licensed to Brandon, Mississippi and is located in a rural area approximately equidistant from the towns of Brandon, Florence, Mendenhall and Pelahatchie. As Figure 5 shows, the station's 60 dBµ service contour covers a portion of the City of Jackson, the state capital. The gray shading shows the populous areas of Jackson and other towns.

[11] Letter from Miles S. Mason to Marlene H. Dortch, Request for Extension of Experiment Authorization and Waiver of 47 CFR 74.1231(i), July 27, 2021 ("KSJO additional request")

The (50,50) 60 dBμ contours of the ZoneCasting booster facilities were projected using standard techniques from the data in the WRBJ Report.[12] As shown in Figure 6, it is apparent that the 60 dBμ contours of some boosters extend well outside the service contour of WRBJ-FM. Such contour extension would be in violation of §74.1201(h) of the rules, which prohibit any extension of the service contour of the primary transmitter. While WRBJ-FM may have initially engineered the boosters to be in compliance with the rules, the contours shown in Figure 6 represent the calculated distances based on data in the WRBJ Report, which is assumed to represent the actual operating facilities tested. These discrepancies are discussed more fully in the Conclusions section.

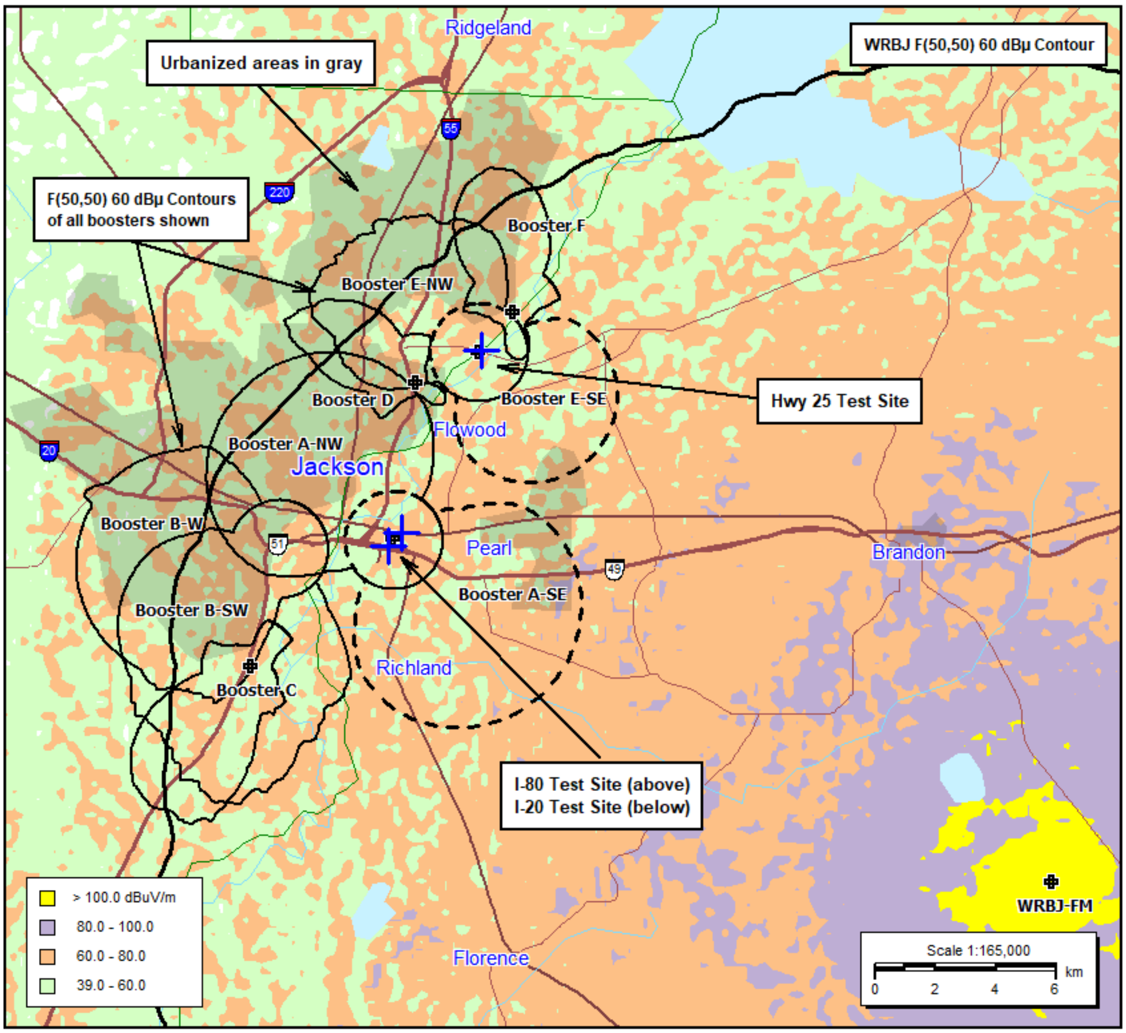

Figure 5 - ITM signal coverage of WRBJ-FM at 1.5 5m AGL with 60 dBμ contours of primary and booster.

12 WRBJ Demonstration System, Geo-targeted FM/HD Broadcast Technical Report, Roberson and Associates, LLC, 30 March 2022 (WRBJ Report).

Due to the relatively smooth terrain in central Mississippi, FM signals propagate farther than the FCC service contour would indicate. The WRBJ Report uses a minimum field strength of 39 dBμ "for monophonic FM."[13] For this study, the same 39 dBμ minimum field strength was used. Figure 6 and all other maps herein use the Irregular Terrain Model, Broadcast Mode, at 1.5 meters above ground, to represent the height of car antennas. Median time and location values are used along with standard ground parameters and 3-arc second SRTM terrain data at 250m gridding resolution.

Figure 2 of the WRBJ Report shows coverage which extends considerably less distance compared to that predicted by ITM and ends abruptly at distances of 32 to 35 km, suggesting the propagation model used does not reflect actual terrain conditions. Based on the ITM prediction, 39 dBμ FM service to mobile receivers is, in fact, shown as usable at most locations in and around Jackson.

Figure 6 is a smaller scale map providing a clearer view of the boosters used in the ZoneCasting test. The map underlay shows the ITM-predicted coverage at 1.5m AGL provided by the booster network separately from the primary coverage of WRBJ's transmitter, without consideration for mutual interference between the boosters or with the primary transmitter signal. The boosters identified as A-SE and E-SE are shown with dashed contours. They operate full time with the primary audio service and are not in the ZoneCasting network service, thus their ITM coverage is not included with the ZoneCasting boosters.

[13] *Ibid*, Footnote 3. Not identified are the height of the field above ground, the propagation model used, or time and location variability criteria.

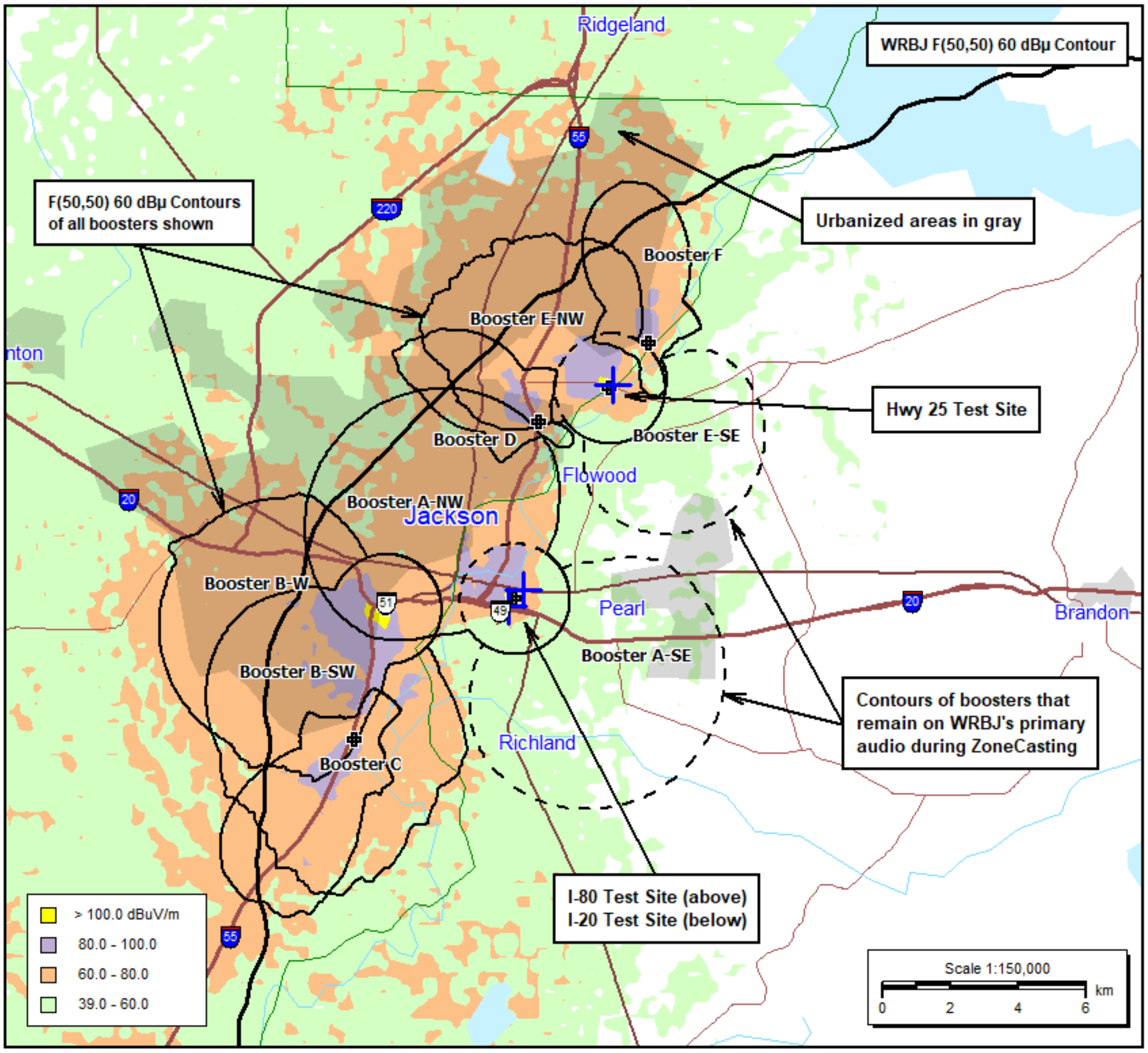

Figure 6 - ITM signal coverage of booster network only. During the ZoneCasting test, two boosters continued to carry WRBJ-FM primary audio. Three ZoneCasting transition test sites are marked with blue crosshairs.

Of particular interest are the locations of three test sites immediately adjacent to booster sites A and E. These are comprised of two pairs of highly directional transmitting antennas pointed southeast (toward the main transmitter) and transmitting a simulcast of the full-service signal, and northwest (and transmitting different content during ZoneCasting).

Figure 7 shows a small-scale map of the Highway 25 test location adjacent to Booster Site E. This is identical in arrangement to the "Zone Transition Region" site in the KSJO test discussed earlier, with booster pairs using highly-directional, back-to-back antennas. Again, orientations of the main beam of the antennas are located approximately parallel to the roadway, With this arrangement, and by only testing near these back-to-back booster installations, GBS is guaranteed to collect data showing the smallest possible transition area and with data that are also likely not reflective of anywhere else in the network.[14]

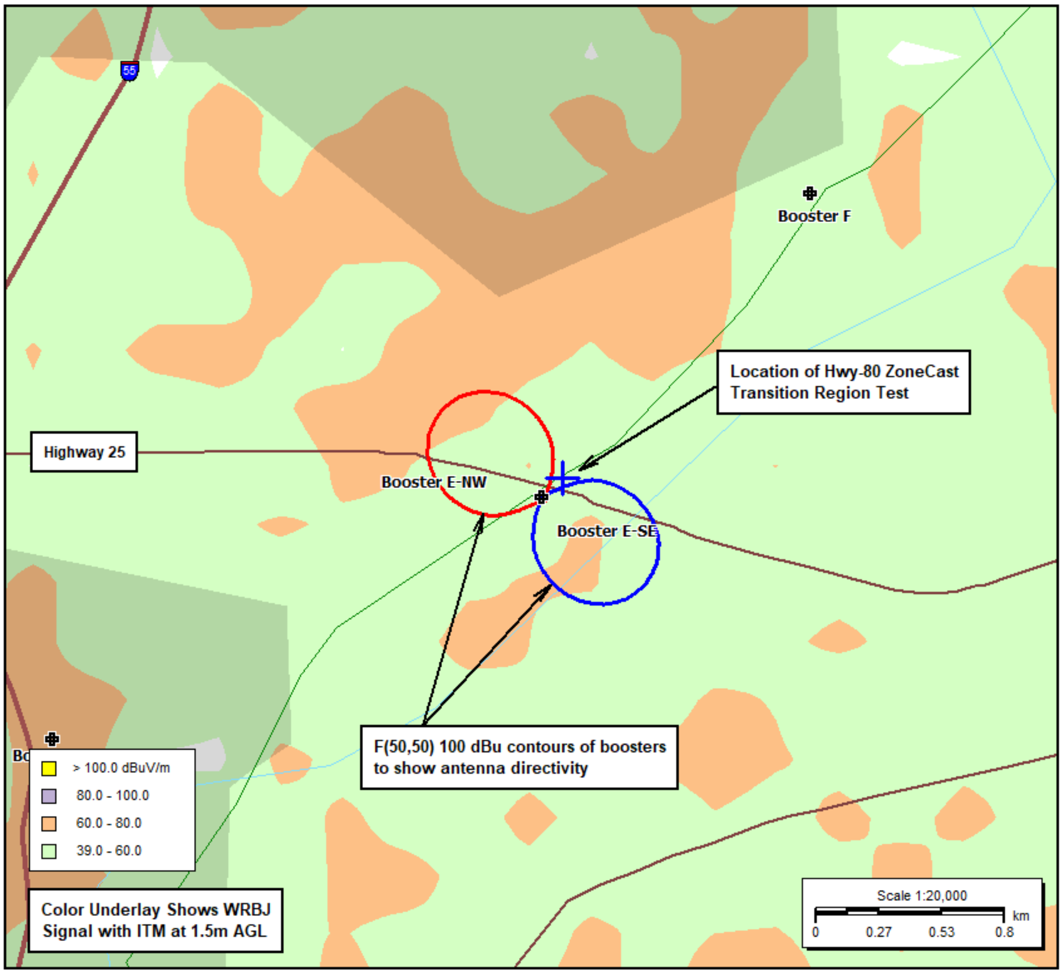

Figure 7 - Map of Hwy-25 ZoneCasting test area

The drive-by scenario is repeated for the Highway 80 and Interstate 20 test locations, shown in Figure 8. The sites share a common booster pair, A-NW and A-SE, which are rotated slightly (clockwise) in relation to the orientation of the roadways. As expected, the centers of both "Zone Transition Regions" are offset clockwise and remain at right angles to the antenna main beams.

[14] Note that as this scale small registration errors occur in roadway position. However, the location of the boosters and the drive route are determined exactly by their geographic coordinates, so the registration error in the road does not affect the relative site orientation.

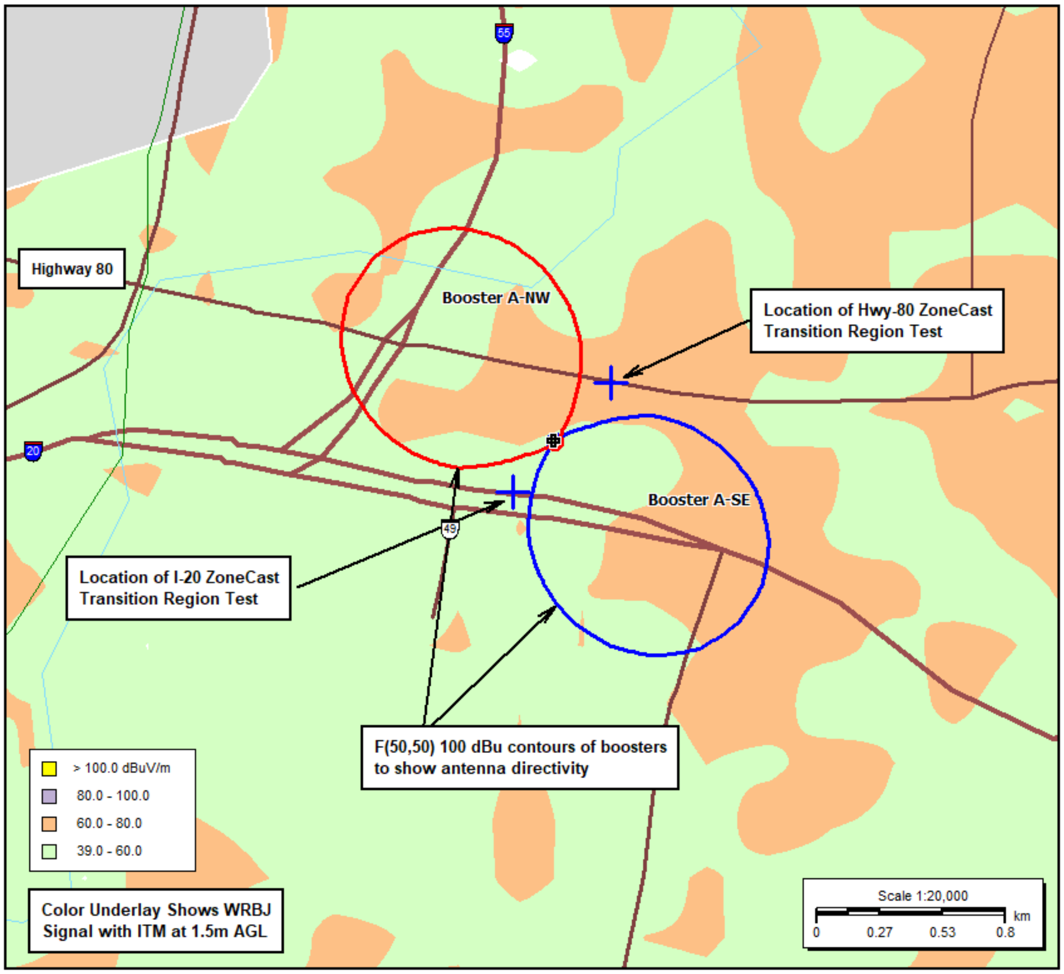

Figure 8 - Map of I-20 and Hwy-80 test areas

It is apparent that the booster configurations used strategically minimized the sizes of the "Zone Transition Regions" by placing the test sites at minimum distance from the boosters. Further, no testing was conducted in other areas of the ZoneCasting network, notably those areas that are too distant to benefit from the back-to-back antenna arrangement (which encompasses the vast majority of the zone).

Figure 9 depicts the predicted signal ratios between the ZoneCasting network and WRBJ-FM's primary signal. Using the 11 dB interference threshold to 10% of locations as derived in Appendix 1, the map shows significant areas of predicted interference – all in areas where no measurements were conducted.

Receive Condition	Color	D/U Ratio
Primary service	Green	>11 dB
Mutual interference	Red	11 dB to -11 dB
ZoneCasting service	Aqua	<-11 dB

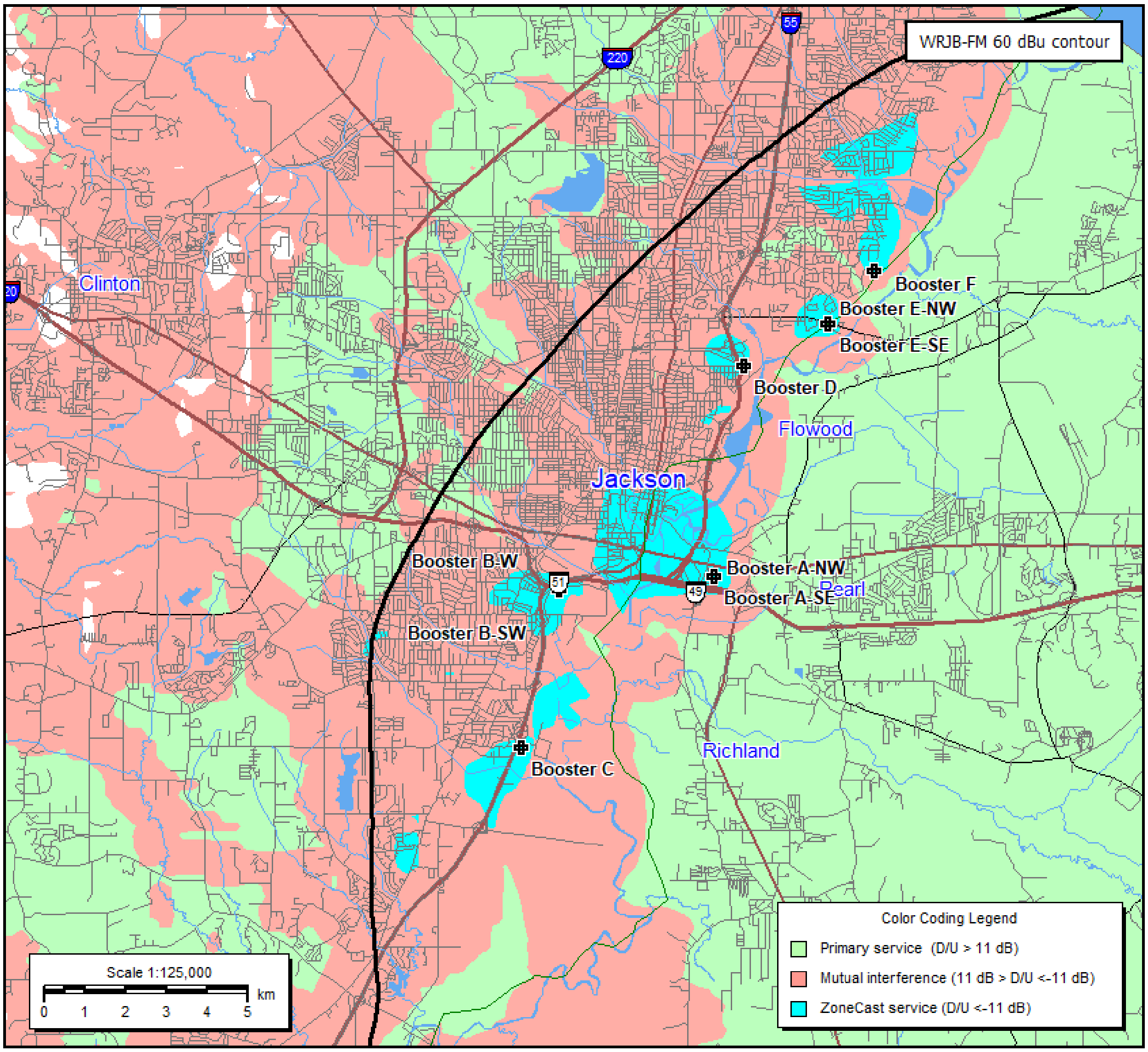

Figure 9 - Signal ratio map showing areas of predicted interference and service by the primary transmitter and ZoneCasting network

Mutual interference extends to such a degree that listener-satisfactory ZoneCasting coverage is not contiguous, as shown by the red coloring between the boosters' service areas (shown in aqua). Boosters A-SE and E-SE are reported to operate with the primary station audio during ZoneCasting operation, thus they would not contribute to interference. Since this scenario is not supported by the V-Soft Probe5 mapping software used in this report, these boosters are not active in this network depiction. Testing confirmed that their absence would has almost no effect on the map.

Comparing Figure 9 to the predicted primary coverage areas of WRBJ-FM before the addition of the ZoneCasting network, shown in Figure 5, it is clear that when ZoneCasting is in operation a substantial portion of Jackson could experience reception quality that listeners deem as "poor" and worthy of "turn-off" by 91 percent of listeners, according to the NPR Labs study data. This impact occurs both inside of WRBJ's service contour as well as in populous areas outside the contour where the primary signal is predicted to be usable by mobile receivers.

Conclusions

There are a number of flaws with the methodology used in both the KSJO Report and the WRBJ Report and the characterization of the reported results. In view of the objective information provided herein, the magnitude of potential interference to the primary (host) FM station is large and largely unavoidable. Consequently, it is the undersigned's conclusion that ZoneCasting cannot compensate sufficiently for its harm and therefore is broadly unsuitable for FM radio broadcasting. The specific flaws are described below.

Misrepresentation of transition areas. One of the most egregious issues is the depiction of interference regions between the primary and ZoneCasting booster: the KSJO and WRBJ Reports illustrate the interference, euphemistically called the "Zone Transition Region" as a thin band that appears around the perimeter of the Zone Coverage Area as shown in Figure 11. The illustration shown in Figure 11, which is included in both technical reports, appears to associate the band's cross-sectional size with the tiny handoff area where measurements were taken. These are deceptive and inaccurate showings since the measurements taken show only back-to-back booster handoff, not the extent of interference. That the report authors misunderstand the nature of ZoneCasting interference is illustrated in Section 4.1.5 (page 36) of the WRBJ-FM Report:

"One concern raised in the FCC's FM Booster NPRM was that there could be areas in which it is possible to move for long distances along a zone transition boundary, thus creating the conditions for regular and objectionable signal instability (i.e., "frequent switches between different audio programs, as determined by the FM receiver's capture effect…"

"Regarding the WRBJ design, the zone transition boundary was designed to cut across roads, resulting in a highly controlled, small distance transition region. The balance of this boundary was designed to fall on unpopulated areas without roads…"

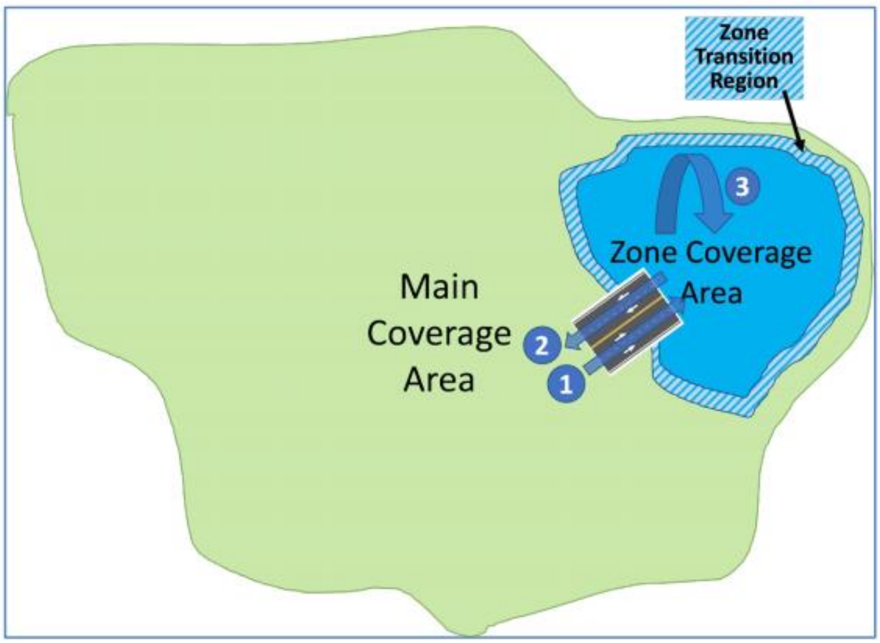

Figure 10 - Capture of Fig 4 from WRBJ Report showing size of "Zone Transition Region"

Misrepresentation of percentage of roads affected by ZoneCasting interference. The report authors compare its measurement of "mean zone transition length" (50.2 meters in the KSJO Report) with the total length of all roads in the Pleasanton (CA) area, comprising 621,000 meters of roadway.[15] In the WRBJ Report the same type of measurement in a small (73.9 meters) "transition zone" is compared with the 386,100 meters of roads in area, claiming that "only 0.11%" of roads will be affected. Claiming the size of the unique handoff test distance to represent "general received signal behavior" in the area affected by the ZoneCasting signal is preposterous. Lacking proper methodology, only a gridded study of D/U ratio-based interference would be acceptable.

[15] KSJO Technical Report, pg. 36.

The areas of interference shown in Figure 9 were determined using V-Soft Probe5, a widely-used engineering software tool, which calculates terrain-sensitive, grid-based D/U signal ratios as applied in numerous studies for the FCC. (The FCC also uses this software for certain studies.) Using the engineering specifications provided in the WRBJ Report, a receive height of 1.5 meters above ground was used. The resulting map shows that the ZoneCasting booster network pervades the primary service area of WRBJ-FM with interference. Their claim that interference occurs only the "transition region" and falls in "unpopulated areas" is wholly unsupported and inaccurate. For all of Roberson's efforts to show signal handoff next to back-to-back boosters, they provide no serious map of measured or predicted interference – only the abstract map of Figure 10. The data and mapping provided herein show entirely different and unacceptable interference condition with ZoneCasting.

Fundamental lack of understanding of multipath measurements used to assess transition areas. The report authors use an automatic instrument to report audio interference as the test vehicle drives through the zone handoff region. However, their report acknowledges that the instrument is designed for multipath interference indication.[16] In a misunderstanding of the instrument's operation, they state that multipath reception, which is indeed a "time-delayed" combination of the direct and reflected signals, is equivalent to the "two signals" transmitted by the primary and ZoneCasting transmitters: that is, multipath involves duplicates of signals that are different by only microseconds of time, which in simple terms causes FM detectors to distort the audio. They do not appear to realize that ZoneCasting involves an entirely different version of program audio from the host station's primary signal, which is properly called co-channel interference – not "multipath."

The instrument used by Roberson is designed around ITU-T Recommendation P.863, a telephony standard which is "a means of estimating listening speech quality by using reference and degraded speech samples" lasting between 3 and 6 seconds.[17] P.863 was developed for assessing quality of telephone networks. Table 9 of P.863 lists a number of "Factors not validated" with the algorithm described, including "Multiple simultaneous talkers," "Music as input to a codec" and "Listener echo." All of these factors are applicable to ZoneCasting and these exceptions are obviously concerning when attempting to measure artifacts in speech and music transmitted over FM signals experiencing co-

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16 WRBJ Report, p. 24

17 Recommendation P.863.1 (06/19), https://www.itu.int/rec/T-REC-P.863.1-201906-I/en

channel interference, causing hard switching (FM capture) between the primary and ZoneCasting audio, music programming and random noise bursts.

Roberson claims that the P.863 method is a "reliable and useful" indicator of "geo-targeted broadcast transition events" but provides no objective data that correlates real listener testing of ZoneCasting interference with the algorithm. The presence of data from controlled listener tests at NPR Labs, which GBS received in 2013, should supersede any automated device designed for testing telephone circuit quality. Of course, the NPR Labs data indicates that ZoneCasting interference is strongly disliked by human listeners.

Misrepresentation of use of NPR Labs data on ZoneCasting network design. GBS has cited the NPR Labs perceptual testing in its advertising literature, industry presentations and interviews.[18] In GBS' original Petition for Rulemaking to the FCC, it said:

> "In 2013, Geo contracted NPR labs and Dr. Ellyn Sheffield of Towson University to conduct subjective listening tests in much the same way that HD Radio proponents tested that technology with Dr. Sheffield prior to approval of HD Radio by the FCC. Lab simulations of MaxxCasting and ZoneCasting configurations were set up and 19,000 audio samples were evaluated by over eighty listeners. Design standards for acceptable interference thresholds were developed and for the first time provided objective and verifiable interference targets which could be used in the design of booster systems, both with the same and different program content."[19]

Despite GBS' references to NPR Labs research in marketing and FCC comments, the authors of the KSJO and WRBJ Reports did not rely on the NPR Labs interference criteria for ZoneCast network operation and testing. Indeed, no field tests were conducted across Jackson to support the claim with "high confidence that ZoneCasting will provide minimal impact on the user."[20]

Inconsistencies in ZoneCasting booster site data filed with the FCC. It was noted earlier that inconsistencies in the ZoneCasting booster site data available from FCC records made it difficult to verify the network design and test the reported performance claims. This was true of both site data and antennas used, particularly for the WRBJ-FM booster network, as detailed in Appendix 3. Technical facilities data were given in only two documents at the FCC:

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[18] GeoBroadcast Solutions blog, https://www.geobroadcastsolutions.com/castings/giving-boosters-their-best-shot, checked May 30, 2022.

[19] See Appendix C, page 5, *In the Matter of Amendment of Section 74.1231(i) of the Commission's Rules on FM Broadcast Booster Stations*, RM-11854, GeoBroadcast Systems, March 13, 2020.

[20] WRBJ Technical Report, pg. 40.

- File No. 20210604AAQ, a request for experimental facilities dated May 27, 2021
- File No. 20211129AAN, a request for extension and minor modification

These two requests list eight boosters in total, FM1 through FM8. However, the WRBJ Report lists boosters by names such as "Derrick" and "RiverSide," which are listed in Appendix 3. This inconsistency required an orderly naming to be set up, such as "A-SE" (meaning booster A, with a southeast antenna orientation). These are listed in the "Name Mod." Column.

Examination of the geographic coordinates found that only one of the boosters in the WRBJ Report was requested and authorized by the FCC: FM5. All of the other boosters have different coordinates, power, antenna height, type or orientation. It is unclear whether or not the boosters in the WRBJ Report were actually authorized, but documentation could not be found in FCC records.

No antenna specifications were provided in the WRBJ Report. There are tables giving cryptic names such as "Single log/dual log composite pattern" and that some antennas may be Jampro JAVA off-the-shelf models but no gain and relative field pattern data is provided for installations with special antenna rotation and stacking, where applied. Finding matches to the original engineering requests is particularly challenging because most of the antennas apparently used a slant linear polarization, which alters the horizontal-plane pattern data supplied by the manufacturer, and is dependent on factors such as vertical separation of two-bay arrays, which are not reported.

Considerable time was used to find and attempt a match to antennas in the engineering requests. Despite the lack of supplied antenna pattern data, the main beam power levels of many of the WRBJ-FM boosters result in maximum contour distances that do not match the maps in the Roberson report. The F(50,50) contour distance calculated at the specified beam-maximum ERP in the horizontal plane would be the same regardless of directionality of the antenna, which indicate errors in the report. Regardless of contour distance errors in the WRJB report, the magnitude of the errors is such that correction would have a minor effect on the results of studies for the booster network: the predicted interference to WRJB's service would remain almost unaffected from what is shown herein..

As a result of the missing or incomplete information, coverage predictions for the network were a 'best effort' exercise. However, as noted earlier, discrepancies in the antenna data would have a minor effect on the interference that was depicted for the WRBJ booster network during ZoneCasting operation.

Certification

This study of the ZoneCasting reports for KSJO(FM) and WRBJ-FM was prepared by the undersigned and is true and correct to the best of his knowledge and belief.

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Appendix 1

Behavior of Primary and Booster FM Signals in Mobile Receiver

Signal fading from the primary transmitter and booster are an unavoidable effect of signal propagation in the physical world. Reflections from the ground, structural clutter and terrain features form separate signal path lengths different from the direct signal path that may randomly reinforce, distort or cancel each other at the location of the listener's receiver. When a receiving antenna moves through space, as with mobile reception, signal fading occurs dynamically. The left side of Figure 11, below, shows the signal level variation over a one-minute period during a mobile measurement with time moving from left to right. It is apparent that FM signals vary widely and undergo sharp drops in level, along with occasional rounded peaks.

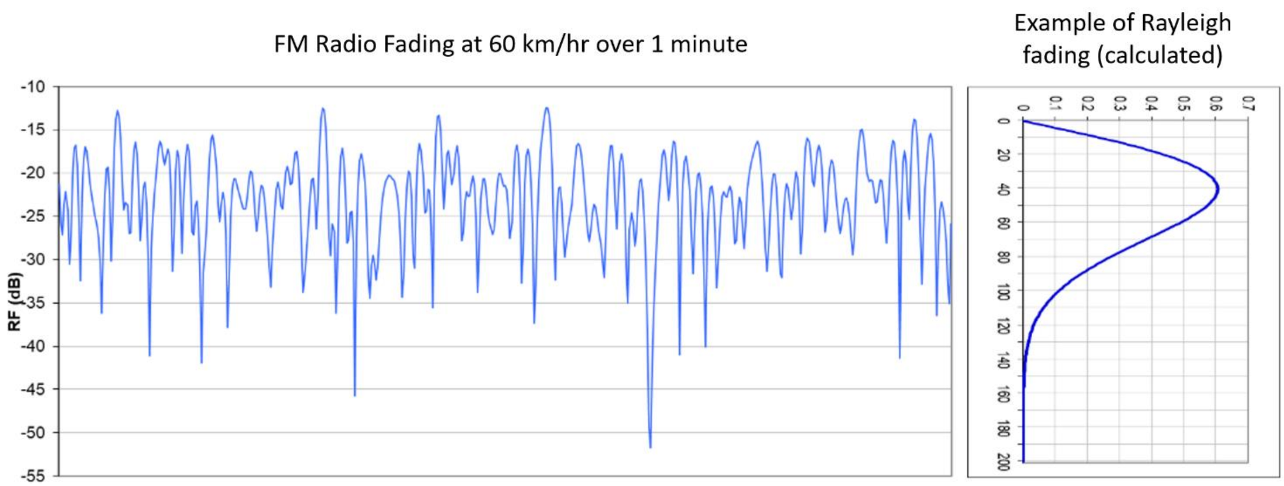

Figure 11. Signal variation over a one-minute period during a mobile measurement of FM radio.

Measurement data when normalized and represented as a probability distribution (showing the likelihood that a particular signal level is reached) assume a statistical distribution as similar to that shown on the right side of Figure 11. This plot of the distribution shows log-amplitude (normalized dB) versus probability of occurrence (1.0 would occur full-time) and its shape is characteristic of a Rayleigh distribution.[21] It can be seen that the most occurrences of the signal occur near the top (near the upper part of the measured signal) with the maximum likelihood approximately 20 dB below the maximum measured signal level. This distribution is asymmetrical, with the lower parts of the signal represented

21 A Rayleigh distribution occurs when a large number of vectors of random phase are combined. In this case, the vectors are the FM signals that reach the receiver through various propagation paths (reflections from clutter, terrain features, etc.)

by deep but less-frequent drops in signal level. Thus, when the desired FM signal drops sharply and there is another, co-channel FM signal present, signal replacement ("FM capture") occurs momentarily. That replacement is the same phenomenon that the listeners found most annoying in the NPR Labs tests of ZoneCasting.

The variability of FM signals in space (and time, when in motion) must be considered in estimating the occurrence of interference to service. When there are two signals originating at different transmitting sites (whether two different radio stations or an FM station and its ZoneCasting booster), the two signals propagate over separate paths, and produce two signals that fade independently of one another. Statistically, it can be said that the two signals combine with a joint probability at the receiver. Dealing with the mathematics of joint probability is complex but this phenomenon is addressed in the technical literature.[22] Appendix 2 derives a simple formula for converting jointly fading signals into a decrease in the protection between two independent signals.[23]

The amount by which a station's signal strength varies over some distance or time interval is described by the standard deviation of is signal strength probability distribution. When two stations (*e.g.*, a primary facility and a booster) are involved, the amount of variation is described by the standard deviation of the joint probability of their signal strength distributions. The standard deviation, σ_L, of field strength with respect to location is given as 8 to 12 dB in texts by Egli[24] and the ITU[25] (a lower value relating to populous areas and the higher to open environments). Applying the formula in Appendix 2 for an assumed standard deviation of 8 dB (2.51) for a 10 percent probability of interference, the desired-to-undesired signal strength ratio (F_d to F_u), R, is:

$$R = 0.1 \cdot \sqrt{2} \cdot 2.51 = 0.28 = -9.0dB$$

22 Wong, Harry K., A Computer Program for Calculating Effective Interference to TV Service, Federal Communications Commission, OST Technical Memorandum FCC/OST TM 82-2, July 1982.

23 Kean, John, Report to the CPB and FCC on the Advanced IBOC Coverage and Compatibility Study, National Public Radio, NPR Labs, November 24, 2009, pp. 78-79.

24 Egli, John J., Radio Propagation Above 40 MC Over Irregular Terrain, Proceedings of the I.R.E., Vol. 45, No. 10, October, 1957, pp. 1383-91.

25 Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz, Rec. ITU-R P.1546-6.

A good monophonic FM receiver can be expected to have a capture ratio of less than 2 dB, meaning the desired signal (“D”) must be at least 2 dB stronger than the undesired (“U”) to avoid co-channel interference. The above formula provides a reduction in interference discrimination; thus, the minimum required protection ratio as a result of joint independent fading is (9 + 2 =) 11 dB. It is assumed that a 10 percent probability results in a condition that correlates with the results of the listener study indicating a keep-on of 9 percent as acceptable. However, this is a low criterion that may need to satisfy a greater percentage of listeners, such as a ZoneCasting interference ratio closer to 18 dB.

Appendix 2

Joint Probability of Service and Interference [26]

Besides operation at lower average signal strengths than indoor reception, mobile reception has other differences from indoor listening. For one, received signals experience large fluctuations in magnitude as the location changes, referred to a Rayleigh fading (in cases where the propagation by line of sight is not dominant). This fluctuation occurs to both a desired and any interfering signals, and is usually uncorrelated due to the independent paths to the receiver. For a given percentage of time and other considerations, the probability of interference to reception can be determined as follows:[27]

Let

F_d= field strength of the desired signal, expressed in dB

F_u= field strength of the undesired signal, expressed in dB

F_s'= minimum value of the desired field strength level for acceptable service in the absence of interference for a given percentage of time

R = desired to undesired field strength ratio $(F_d - F_u)$, in dB, at which threshold interference occurs.

Assuming that F_d and F_u are independent, normally distributed variables with medians and standard deviations of (F_{dm}, σ_L) and (F_{um}, σ_L) respectively, the joint probability density function is[28]

$$f(F_d, F_u) = \frac{1}{2\pi\sigma^2} = exp\left\{\frac{-1}{2}\left[\left(\frac{F_d - F_{dm}}{\sigma_L}\right)^2 + \left(\frac{F_u - F_{um}}{\sigma_L}\right)^2\right]\right\}$$

The probability of interference to service is

$$P(F_d \geq F_s'; F_u \geq F_d - R) = \int_{F_d = F'}^{\infty} \int_{F_u = F_d - R}^{\infty} \quad .$$

[26] Advanced IBOC Coverage and Compatibility Report, submitted by NPR to the FCC November 4, 2009, In the Matter of Digital Audio Broadcasting Systems and Their Impact on the Terrestrial Radio Broadcast Service, ORDER, MM Docket No. 99-325

[27] A Computer Program for Calculating Effective Interference to TV Service, by Harry K. Wong, FCC OET Technical Memorandum 82-2, July 1982.

[28] Distributions in Statistics: Continuous Multivariate Distributions, by Norman L. Johnson and Samuel Kotz; A Wiley Publication in Applied Statistics; John Wiley & Sons, Inc., 1972.

In the presence of an undesired signal, the probability of perceptible interference, P_I, for a given percentage of time (time factor) can be derived from

$$k(P_I) = \frac{F_{um} - F_{dm} - time\ \ factor + R}{\sqrt{2} \cdot \sigma_L}.$$

The *time factor* relates to atmospheric signal propagation, which is small in relation to the fading interval of VHF mobile reception. Time variability can be removed from the equation for simplicity. Within local areas, wherein the pathloss is relatively stable for the desired and undesired signals, one can solve for the desired-to-undesired signal strength ratio due to Rayleigh fading, resulting from a given probability of interference:

$$R = k(P_I) \cdot \sqrt{2} \cdot \sigma_L - F_u + F_d$$

For a standard deviation of 6 dB, which is a common value in propagation studies,[29] and a 10% probability of interference the signal strength ratio of F_d and F_u is

$$R = 0.1 \cdot \sqrt{2} \cdot 2 = 0.28 = 11dB$$

The ratio *R*, is the effective de*crease* in protection relative to the median ratio for threshold interference. Thus, the interference under mobile fading can be substantially worse in the short term than the median conditions.

[29] Prediction of Urban Propagation Loss, Ranier Grosskopf, *IEEE Transactions on Antennas and Propagation, Vol. 42, No. 5*, May, 1994. This paper summarizes the literature on standard deviation

Appendix 3

Table of Experimental Facilities Filed for WRBJ-FM And reported by Roberson Technical Report

	Reported Name	Site Name	Structure Type	Lat. NAD83	Lon. NAD83	Max. ERP (H&V)	AGL (m)	AMSL (m)	Azimuth (°)	Stated Antenna
Original Request for EA, May 27, 2021	Node FM1		Existing Tower	32.276583	90.165083	210	20	101	305	Kathrein BCA CL-FM/RM log periodic
	Node FM2		Existing Tower	32.276583	90.165083	210	20	101	130	Kathrein BCA CL-FM/RM log periodic
	Node FM3		Existing Tower	32.316889	90.117639	170	20	102.6	322.5	Kathrein BCA CL-FM/RM log periodic
	Node FM4		Existing Tower	32.274361	90.204056	20	40	134.7	260	Shively 6025-2
	Node FM5	F	Existing Tower	32.343667	90.123472	30	55	138	345	Aldena ALP.08.02.712 (2x2)
Extension Request and Modification Nov. 29, 2021	Location FM5 (NW)		Portable tower	32.332333	90.126222	80	24.4	107	305	Log-periodic (Jampro or Scala)
	Location FM6 (SE)		Portable tower	32.332333	90.126222	80	24.4	107	125	Log-periodic (Jampro or Scala)
	Location FM7		Existing Tower	32.322583	90.156972	15	36	135	300	Log-periodic (Jampro or Scala)
	Location FM8		NA	32.239160	90.214722	175	30	112	200	Dual Scala Log-periodic
TECHNICAL REPORT Hwy. 25 Test	Derrick	A-SE	Tower	32.27663	-90.16511	240	24	-	135	Single log/single log pattern
	Derrick	A-NW	Tower	32.27663	-90.16511	240	24	-	315	Single log/single log pattern
	Jackson S.	B-SW	Tower	32.27389	-90.20500	200	45	-	210	Single log/dual log composite. pattern
	Jackson S.	B-W	Tower	32.27389	-90.20500	200	45	-	260	Single log/dual log composite pattern
	Savannah	C	Tower	32.23917	-90.21472	100	45	-	215	Dual Log pattern
	RiverSide	D	Tower	32.32289	-90.15744	30	45	-	300	Dual Log pattern
	Route 25	E-NW	COW	32.33213	-90.13548	65	21.5	-	310	Single log/single log pattern
	Route 25	E-SE	COW	32.33213	-90.13548	65	21.5	-	130	Single log/single log pattern
	Jackson N.	F	Monopole	32.34367	-90.12347	55	39.5	-	350	Dual Log pattern

Appendix 3 (cont'd)

Table of Experimental Facilities Filed for WRBJ-FM
And reported by Roberson Technical Report

	Reported Name	Site Name	Structure Type	Lat. NAD83	Lon. NAD83	Max. ERP (H&V)	AGL (m)	AMSL (m)	Azimuth (°)	Stated Antenna
TECHNICAL REPORT I-20 and Hwy. 80 Test	Derrick	A-SE	Tower	32.27663	-90.16511	240	24		135	Single log/single log pattern
	Derrick	A-NW	Tower	32.27663	-90.16511	240	24		315	Single log/single log pattern
	Jackson S.	B-SW	Tower	32.27389	-90.20500	200	45		210	Single log/dual log composite pattern
	Jackson S.	B-W	Tower	32.27389	-90.20500	200	45		260	Single log/dual log composite pattern
	Savannah	C	Tower	32.23917	-90.21472	100	45		215	Dual Log pattern
	RiverSide	D	Tower	32.32289	-90.15744	30	45		300	Dual Log pattern
	Jackson N.	F	Monopole	32.34367	-90.12347	55	39.5		350	Dual Log pattern
	Hwy. 80	G-NW	COW	32.27839	-90.16344	200	20		315	Single log/single log pattern
	Hwy. 80	H-SE	COW	32.27839	-90.16344	200	20		135	Single log/single log pattern