NTIA Technical Memorandum TM-18-534

Further Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices

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technical memorandum

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration

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U.S. DEPARTMENT OF COMMERCE

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ABBREVIATIONS AND SYMBOLS

$\boldsymbol{B_c}$	chirp bandwidth of a NLFM radar pulse
CBSD	Citizens Broadband Radio Service Device
dBm	decibels relative to a milliwatt
DPA	dynamic protection area
ESC	environmental sensing capability
FCC	Federal Communications Commission
GHz	gigahertz
GN	Gaussian noise
ITS	Institute for Telecommunication Sciences
LFM	linear frequency modulation
MHz	megahertz
n	**noise power**
NLFM	non-linear frequency modulation
NTIA	National Telecommunications and Information Administration
OoB	out of band
PRR	pulse repetition rate
RMS	root mean square
RF	radio frequency
s	signal power
SAS	spectrum access system
t	time within an NLFM radar pulse
$\boldsymbol{\tau}$	pulse width of NLFM radar pulse
TM	Technical Memorandum
VSA	vector signal analyzer
VSG	vector signal generator

EXECUTIVE SUMMARY

NTIA Technical Memorandum TM-18-527 describes procedures for testing the functionality of Environmental Sensing Capability (ESC) sensors that will detect 3.5 GHz radar signals for future spectrum sharing systems. The present document describes additional ESC certification test tasking identified since TM-18-527 was published.

The first addition to ESC test procedures is three-fold, all related to the behavior of ESC sensors in the presence of high-power radar pulses. These three items are: (a) examination of ESC behavior in the presence of high-power radar pulses; (b) examination of ESC behavior in the presence of out-of-band radar pulses that coincide in time and frequency with in-band 3.5 GHz radar pulses; and (c) examination of radio frequency (RF) front end filtering characteristics of ESCs. These three observations, which were already included in pre-certification testing, will now be repeated in certification testing so that their results can be included in each ESC's final certification test report.

The second addition is the use of non-linear frequency modulation (NLFM) chirping in lieu of linear chirping for a subset of pulses in Radar Waveform Bins 3 through 5. NLFM chirping has been added to make some of the pulses in those bins more closely resemble pulses that are expected to be used by some future 3.5 GHz radars.

The third addition is observation of ESC behavior in the presence of high background noise levels (at or above -89 dBm per megahertz, average detected) in ESC detection channels. This new task is being added because, although future 3.5 GHz spectrum access systems (SASs) are supposed to ensure that background power levels that might be produced by 3.5 GHz base stations will not exceed certain thresholds at ESC radio frequency (RF) sensor locations, there is no way to be absolutely certain that such high background levels will in fact never occur. Therefore, ESC RF sensors will be checked for their responses to high background noise levels in their detection channels as part of additional ESC test tasking.

All of these new tasks will be included as part of each ESC's pre-certification testing, and will be repeated a second time in each ESC's certification testing. The results of the tests in the certification testing will be included in each ESC applicant's final report of test results.

FURTHER PROCEDURES FOR LABORATORY TESTING OF ENVIRONMENTAL SENSING CAPABILITY SENSOR DEVICES

Frank H. Sanders,[1] Robert L. Sole,[2] Geoffrey A. Sanders[1] and John E. Carroll[1]

NTIA Technical Memorandum TM-18-527 describes procedures for testing the functionality of Environmental Sensing Capability (ESC) sensors that will detect 3.5 GHz radar signals for future spectrum sharing systems. The present document describes additional ESC certification test tasking. The first addition involves (a) examination of ESC behavior in the presence of high-power radar pulses; (b) examination of ESC behavior in the presence of out-of-band radar pulses that coincide in time and frequency with in-band 3.5 GHz radar pulses; and (c) examination of radio frequency (RF) front end filtering characteristics of ESCs. These three observations, which were already included in pre-certification testing, will now be repeated in certification testing so that their results can be included in each ESC's final certification test report. The second addition is the use of non-linear frequency modulation (NLFM) chirping in lieu of linear chirping for a subset of pulses in Radar Waveform Bins 3 through 5. NLFM chirping has been added to make some of the pulses in those bins more closely resemble pulses that are expected to be used by some future 3.5 GHz radars. The third addition is observation of ESC behavior in the presence of high background noise levels in ESC detection channels.

Keywords: Dynamic Protection Area (DPA); Environmental Sensing Capability (ESC); chirping; non-linear frequency modulation (NLFM); radar; radar pulses; Spectrum Access System (SAS); spectrum sharing

1. BACKGROUND AND INTRODUCTION

Tasking has been added to the previously published procedures [1] for certification testing of Environmental Sensing Capability (ESC) radar pulse detection and declaration performance. The first change is that some procedures and tests that will be performed in the ESC pre-certification phase will be repeated in the certification phase, as only the certification-testing results will be included in ESC test reports that will be shared with the FCC. The second change is in the technical details of some of the chirped pulses in Radar Waveform Bins 3 through 5. A sub-set of the pulses in those bins will be modified to make them more closely resemble pulses that are expected from some future 3.5 GHz radars. A third change is the addition of an observation on ESC behavior in the presence of a high background noise level in one or more of its 10 MHz detection channels.

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Some of the new observations that are being added to the certification work are focused on the performance of ESCs in the presence of high-power levels of radar pulse inputs. These added observations will be of limited scope, to build confidence that ESCs perform well in high-power pulse-input environments. They will not be extensive enough to show 99% detection-declaration performance with a 1% standard error. Instead, they will show whether there are obvious failures of ESCs to perform well (or at all) when they are injected with high power pulsed energy under a variety of circumstances.

The observations that are being added to the certification testing are:

- Observation of ESC performance when representative pulses from Bins 1 through 5 are injected at power levels consistent with those of [2] when 3.5 GHz ship radars are 10 km offshore.

- Observation of ESC behavior and performance when pulses that are supposed be detected by the ESC are injected coincident in time and frequency with a second set of pulses that represent OoB emissions from a radar (called Radar 3) that operates in an adjacent band, below the lower edge of the 3.5 GHz sharing band. (That is, the OoB pulses from the adjacent band radar are co-channel with the injected pulses that are supposed to be detected by the ESC.)

- Examination of the ESC radio frequency (RF) front end filtering for rejection characteristics in spectrum adjacent to the 3.5 GHz sharing band. This examination is especially focused on filter rejection at frequencies below the lower edge of the sharing band.

- Substitution of nonlinear frequency modulation (NLFM) for linear frequency modulation (LFM) in a subset of pulses in Radar Waveform Bins 3 through 5.[3] This substitution of NLFM for LFM chirping in some of those bins' pulses reflects an increased recognition that some future 3.5 GHz radars will use NLFM pulses.

- Observation of the behavior of ESCs when a high level of background noise is injected into one or more of the 10 MHz-wide ESC radar detection channels. This observation is being added in recognition that, although such high noise levels are not supposed to occur in future 3.5 GHz spectrum sharing systems, the government needs to know how ESCs will respond if such noise levels were to nevertheless occur at deployed ESC RF sensor sites.

These additions to the certification phase of the ESC work are of limited scope and must be accomplished within a strictly limited amount of time in order to meet overall requirements for completing ESC certification testing within existing time and budgetary constraints.

[3] Frequency modulation within pulses is commonly called chirping.

2. OBSERVATION OF ESC PERFORMANCE WHEN RADAR PULSES ARE INJECTED AT HIGH PEAK POWER LEVELS

This tasking is intended to verify that ESCs perform properly when they are subjected to high power radar pulse inputs, consistent with the levels found in [2] for naval radars located 10 km from shore. The basic approach will be to select a single frequency (or center frequency for chirped pulses) at which high power pulses will be injected into an ESC RF sensor, and to then inject sets of such pulses into the ESC while watching for appropriate ESC detections or declarations. Within each group of pulses, some will be at the high power drawn from [2], while others will be injected at lower power levels. The high-power and low-power pulses will approximate the antenna pattern of a radar. Each antenna pattern set of pulses will last for a specified amount of time ranging from 4 seconds to 10 seconds. Referring to one such interval as a radar scan pattern, a set of five such patterns will be injected into each ESC, one for each of the five radar waveform testing bins. This procedure is described in more detail below.

In this set of observations, the radar pulses will always exceed the -89 dBm/MHz detection threshold of [1]. ESC designs that would require radar power levels to *cross* this power threshold for detection or declaration might therefore experience difficulties under this circumstance.

2.1 Radar Waveform Parameters and Power Levels for High-Power Observations

From each of the five radar test waveform bins, one waveform will be generated via a vector signal generator (VSG), and will be injected into the ESC sensor at high power. There will be five detection-declaration trials per waveform, for a total of (5 waveforms) × (5 trials per waveform) = 25 high-power trials across all bins. ESC behavior is expected to be the same as when the injected power levels are at -89 dBm/MHz. That is, the ESC should detect and declare each radar waveform, even if the waveform power has saturated the ESC receiver's dynamic range. The ESC should indicate via its data/message stream that its corresponding dynamic protection area (DPA) is to be activated, and which 3.5 GHz spectrum sharing channel or channels have shown radar activity. If the ESC does not behave in the same way for the high power test as for the low-power tests with the same waveforms, such discrepancy will be noted and recorded into the test logbook for each vendor's ESC device.

The Bin 1 waveform will be coded to replicate Radar 1 parameters in pulse width, pulse repetition rate (PRR), pulses per burst. Bin 1 power levels at the ESC input will be set to a level from [2] that simulates a single Radar 1 transmitter located 10 km offshore using peak detection in a 1 MHz resolution bandwidth on the spectrum analyzer. (The analyzer's video bandwidth will be set to 3 MHz.) The power value to be used is taken from [2], Table 9; this is -5.4 dBm in a 1 MHz bandwidth.

The Bin 2 through 5 waveforms will use the median value for the waveform parameters from [1]. The pulse width, chirp, PRR, and number of pulses per burst will be at the median of the range of available values for each waveform. The power levels at the ESC input will be set to a level from [2] that simulates a Radar 3 transmitter located 10 km offshore using peak detection in a 1 MHz resolution bandwidth on the spectrum analyzer. (The video bandwidth will be set to 3 MHz.) The power value to be used is taken from [2], Table 9; it is +10.6 dBm in a 1 MHz bandwidth.

2.2 Radar Antenna Patterns for High-Power Observations

The VSG output will simulate the mainbeam, sidelobe, and backlobe of a radar antenna as it would sweep across an ESC antenna. One type of antenna pattern will be used for Bin 1 pulses and a qualitatively different antenna pattern will be used for pulses of Bins 2 through 5. The first type of pattern is consistent with Radar 1, which uses a modified parabolic antenna that rotates in the horizontal plane. The second type is used for Bins 2 through 5, which will simulate an active or passive electronically scanned array type of antenna.

2.2.1 Bin 1 Antenna Pattern for High-Power Observations

The Bin 1 pattern will radiate for 4 seconds. It will emulate a parabolic type antenna rotating azimuthally, similar to Radar 1. The pattern will radiate 19 pulses at the radar's highest power level to simulate mainbeam, and will then drop to lower levels to replicate sidelobes and backlobes. Pattern generation will be implemented via the Keysight© Signal Studios for Pulse Building software in which radar antenna pattern beam width, rotation time, pulse repetition rate, and front-to-back ratio are specified and the pattern is automatically constructed from those inputs.

2.2.2 Bin 2 through Bin 5 Antenna Pattern for High-Power Observations

The Bin 2 through 5 pattern will radiate for 10 seconds. It will emulate the pencil beam type scanning pattern of an active array or electronically steered antenna. The pattern will radiate the same number of pulses at the highest power level as specified for the corresponding bins in [1]. This pattern will be generated by replicating the single burst at variable[4] intervals over the course of the 10 second transmission.

2.3 Additional Considerations for High-Power Pulse Generation

We note that the VSG may need to be fitted with an external power amplifier to generate these power levels. Such power levels create concerns about power reflections coming back into the VSG and damaging it. Safe generation of the required power levels may require a network of isolators and circulators so that the reflected power is limited to what the VSG can withstand at its output port. This tasking will be the responsibility of ITS, not the applicants.

2.4 Expected ESC Behavior and Data Records for High-Power Observations

The test log book will contain data on the radar waveforms that were generated and the outputs of the ESC data stream to the control computer. The ESC should detect and then send out the same messages[5] that it does under the -89 dBm test conditions denoting which DPA was active

[4] Essentially the main burst will be repeated at varying power levels with dead times inserted in between sets of lower power bursts. The lower-power bursts will be radiated at, e.g., -10 dB, -20 dB, and -30 dB relative to the maximum power to be injected.

[5] A representative sampling of ESC message strings will be documented and recorded for inclusion in the certification packages that the FCC receives for each device. The FCC will determine the extent to which these

and which channel or channels show radar activity. The logbook will note any erratic ESC behavior such as failure to operate or recover from any error condition brought on by these tests.

messages' structure and content meet FCC certification requirements for ESCs under Part 96 of the FCC's rules, 96 C.F.R. § 96 *et.seq*., and the WInnForum WINNF-TS-0112 requirements [3], including R2-ESC-12.

3. OBSERVATION OF ESC BEHAVIOR WHEN BIN 1 THROUGH 5 PULSES ARE INJECTED COINCIDENT IN TIME AND FREQUENCY WITH PULSES REPRESENTING OOB EMISSIONS FROM AN ADJACENT BAND RADAR

As noted above, the observation of two types of radar pulses overlaid one atop another in time addresses a condition that will occur when a radar that operates in an adjacent band, below the lower edge of the 3.5 GHz sharing band, is in proximity to an ESC at the same time that a different radar in the 3.5 GHz sharing band is operating. Under this condition, the ESC will see some OoB pulses from the adjacent-band radar on the same frequencies, and at the same time as, pulses arriving from the sharing-band radar. Five of these observations will be performed for each of the five radar waveform bins, for a total of 25 total observations.

We stress that the problem that this observation addresses is unbounded and is not by any means fully addressable by laboratory work. The problems include variation in OoB pulses from Radar 3 in time and with frequency, the large variation in time and with frequency of those OoB pulses, and the infinite number of ways that those OoB pulses may interleave in time with in-band radar pulses. *The only way to fully replicate this problematically unbounded real-world condition is to build an ESC at a shore location and then operate two radars on two ships, one in the sharing band and one in the adjacent band (i.e., a ship with Radar 1 and another ship with Radar 3) while the ESC operates.* The proper operation of the ESC would need to be verified with the two radars operating simultaneously in its proximity. The observation described below will only weakly replicate this condition. It is the best solution that can be implemented within the externally imposed time and funding constraints of ESC laboratory certification testing.

3.1 Radar Waveform Parameters and Power Levels for OoB Observations

Each observation will be done with a set of "desired" radar pulses from Bins 1 through 5 interleaved in time with one or several OoB pulses from the adjacent-band radar. The Bin 1 through 5 pulse parameters will have the median values for pulse width and PRR from [1]. Those pulses will be fired in burst groups that will have the same numbers of pulses per group as the median values from [1]. The OoB pulse waveforms will be generated from recordings of some OoB pulses of Radar 3. Five of those pulses will be generated with each group of Bin 1 through 5 pulses, at an average pulse repetition interval of 1 millisecond.

Two VSGs will be required to perform these observations, one to generate Bin 1 through 5 pulses and another to generate the Radar 3 OoB pulses. The two VSGs will be triggered to generate their pulses coincidentally in time. All testing will be performed on a single frequency, for example, 3600 MHz.

The Bin1 through 5 pulses will be generated at -89 dBm/MHz. The Radar 3 OoB pulses will be generated at a peak-detected power level of +10.6 dBm, consistent with OoB levels generated by Radar 3 when it is 10 km offshore.[6]

[6] The intentionally radiated pulse power level from Radar 3 in the adjacent band would be about 30 dB higher than the OoB level to be generated in these observations.

3.2 Expected ESC Behavior and Data Records for OoB Observations

The test log book will contain data on the radar waveforms that were generated and the outputs of the ESC data stream to the control computer. The ESC should detect and then send out the same messages that it does under non-OoB pulse-test conditions denoting which DPA was active and which channel or channels show radar activity.[7] The logbook will note any erratic ESC behavior such as failure to operate or recover from any error condition brought on by these tests.

3.3 Time Resource for OoB Pulse Observations

The amount of time that will be available for ESC tests is strictly limited, as described in [1]. The OoB pulse observations will be done *after* the regular Bin 1 through 5 low-power certifications tests, and only if the ESC has passed the lower power testing.

[7] *See* footnote 4, *supra*.

4. EXAMINATION OF ESC RF FRONT END FILTERING

ESC RF front ends are supposed to incorporate RF filtering that meets the requirements of **Error! Reference source not found.**.[8] This filtering requirement seems to be written more for spectrum compatibility with systems above the sharing band than for systems below the sharing band. The ESC front end RF filtering will be examined for each ESC via either of the following options: Submission of a filter frequency-response curve with at least 60 dB of dynamic range from each applicant, or else measurement of the RF filter response in the ITS laboratory with an ITS swept carrier-wave source.

If the second option is exercised, the applicant will be required to bring a stand-alone ESC RF filter to the laboratory during certification testing. This filter will be swept for its frequency response (power response only, not vector network parameters S_{11}, etc.) in parallel with the other testing being performed on the ESC during the certification work. In either case, the ESC RF filter frequency response will be recorded and will be included as part of the final ESC certification report provided from ITS to each ESC applicant.

In any event, the characteristics of the ESC front-end RF filtering will be documented and recorded. That information will be included in the final certification package that the FCC will receive for each ESC; the FCC will be able to use that information to judge the adequacy of the ESC RF front end filtering for mitigation of interference from adjacent band radars.

[8] The pertinent text in that reference is found in Section R2-SGN-25: SAS ESC Sensor Protection, sub-part b: “For initial certification, the SAS shall treat Category B CBSDs operating within the frequency range 3650-3680 MHz, and Category A CBSDs operating within the frequency range 3650-3660 MHz, as co-channel to ESCs and apply the same protection described above, after assuming a straight line 1 dB per MHz ESC reference filter roll-off from 3650-3680 MHz.”

5. NON-LINEAR FREQUENCY MODULATION IN SOME RADAR TEST PULSES

5.1 NLFM Pulse Technical Parameters

As already described in [1], Bins 3–5 use pulses that have frequency modulation (chirping). The chirps can go either up or down in frequency as a function of time. The type of time-dependent ramp function (linear *vs.* non-linear) is not defined in [1]. Operationally, some chirped radars use linear FM (LFM) ramp functions and some use non-linear FM (NLFM) ramp functions.[9] We note that solid-state radar designs especially seem to be moving toward the use of NLFM pulses. This may be because NLFM functions are easier to implement for solid state waveform generators and amplifiers than for conventional tube designs. In any event, NLFM pulses need to be utilized in some of the ESC testing if the test pulses are to have a credible amount of fidelity with future deployed radar designs at 3.5 GHz.

Figure 1 shows an NLFM pulse in a time-frequency plot (from an actual, measured radar pulse) superimposed on an LFM pulse of the same chirp width and pulse width.

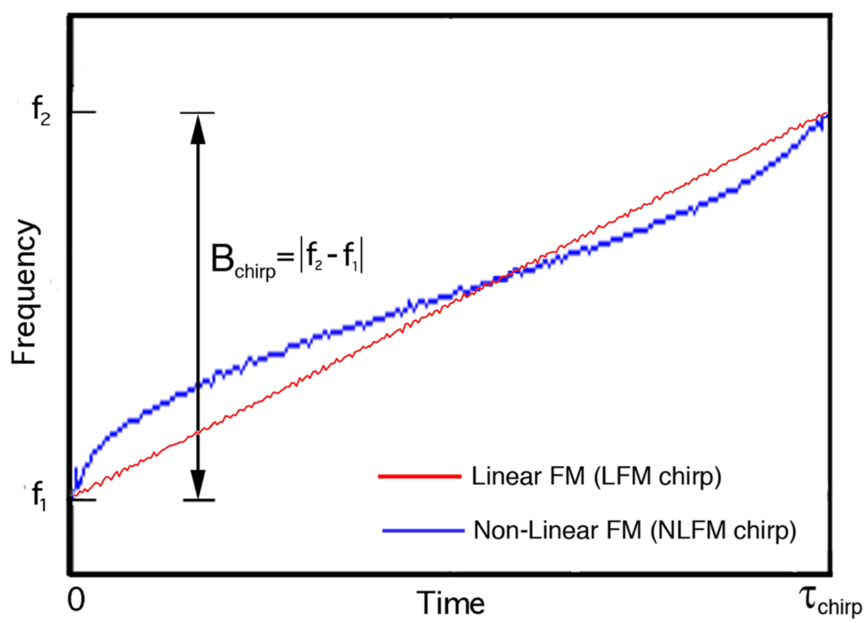

Figure 1. Comparative time-frequency curves for NLFM and LFM pulses. Both curves are from the authors' vector signal analyzer (VSA) measurements of operational radar pulses. The chirp width and pulse width are identical for the two pulses. It is the *shape* of the NLFM ramp function through time and frequency that differs from the LFM ramp function.

[9] LFM pulses are easier to generate than NLFM pulses in radar transmitters, but introduce problems with range determination and resolution of Doppler ambiguities for targets of otherwise unknown or badly estimated range. Weighting factors have to be introduced to reduce range sidelobes in LFM receivers. NLFM pulses are more difficult to generate, but they reduce the operational problems with radar range estimation and Doppler ambiguity. Range sidelobes have good performance without any need to resort to weighting factors in NLFM receivers. Because of this, the design trend for future high-performance chirped radars is believed to be NLFM.

Here, we describe the functionality of the non-linear chirp-ramp function that will be used in ESC testing. The majority (90 out of 100, or 90 %) of the waveforms in Bins 3–5 will use LFM chirping. The remaining 10 out of 100, or 10 %, of pulses in Bins 3–5 will use NLFM ramp functions. None of the parameters given for pulse width and chirp width in [1] will change; the chirp-ramp functions for all waveforms in Bins 3–5 will be unchanged from those given in [1]. But the selected 10 % of waveforms in Bins 3–5 will use NLFM chirping in lieu of linear chirping.

The procedure for making some waveforms in Bins 3–5 use NLFM ramp functions will be as follows:

1) For each of Bins 3, 4 and 5, ITS engineers will pick at random ten percent of the waveform files for conversion from linear FM (LFM) to NLFM. That is, ten waveforms for each of those three Bins will be converted to NLFM.

2) Each of the selected LFM waveforms will be converted to NLFM by retaining their original chirp width and pulse width while replacing the original linear FM ramp with a non-linear ramp function scaled from a tactical radar's NLFM pulses that were previously measured by ITS engineers. (The ramp function from the original, measured radar pulses will be scaled linearly for the desired chirp width and pulse width for each waveform.) This conversion from LFM to NLFM is seen graphically in Figure 1.

3) ESC testing will be performed with those converted waveforms for Bins 3–5 in lieu of the original linear-ramp forms for those entries in the original Bin Table of [1].

4) These NLFM waveforms will be used in both the pre-certification testing and the later certification testing. Other than substituting the NLFM for the LFM ramp functions in those waveforms in Bins 3–5, there will be no difference in testing procedures or pass-fail criteria.

5) NTIA will share with the applicants, in advance of ESC pre-certification testing, the waveform generation file (MATLAB® format) that will later be used for the VSG in ESC pre-certification and certification tests at the ITS Boulder lab.

The basic ramp function is a fifth-degree polynomial taken from a chirped-pulse measurement of an operational tactical radar. For the ESC tests, this radar's NLFM polynomial has been scaled to a reference chirp bandwidth of 1 MHz and a pulse width of 1 microsecond. This scaled polynomial for pulse frequency, f, as a function of time, t, is:

$$f(t) = at^5 + bt^4 + ct^3 + dt^2 + et.$$

This non-linear polynomial defines a ramp for a pulse that begins at time $t = -\tau/2$ and proceeds through $t = 0$ to ending time $t = \tau/2$, where τ is the pulse width. To change the direction to a decreasing chirp frequency over time, the coefficients' signs are reversed.

The values for the baseline NLFM coefficients are:

a = 6.3029E36; b = -1.9259E29; c = -2.276E23; d = 2.1885E16; and e = 6.5655E11.

The NLFM curve is programmed at baseband; the radio frequency (RF) of the pulse is not part of the equation. The VSG will produce the pulse at baseband with this polynomial; test pulses will be tuned to RF as a second step in the process. Note that the baseband frequency is centered at zero hertz, in the center of the pulse's FM range.

These coefficients are scaled to any desired chirp width, B_c (relative to 1 MHz) and time within a pulse, t (relative to 1 MHz and 1 microsecond) as follows:

$$\text{Frequency} = B_c \times \text{coefficient} \times (t^n)$$

where n is the power to which t is raised for the given coefficient (a,…, e) in the baseline polynomial. For coefficient a in the baseline polynomial, for example, the value of n would be 5.

Figure 2 shows the pulse from which all scaling will be performed. This pulse is 1 microsecond long and chirps across 1 MHz.

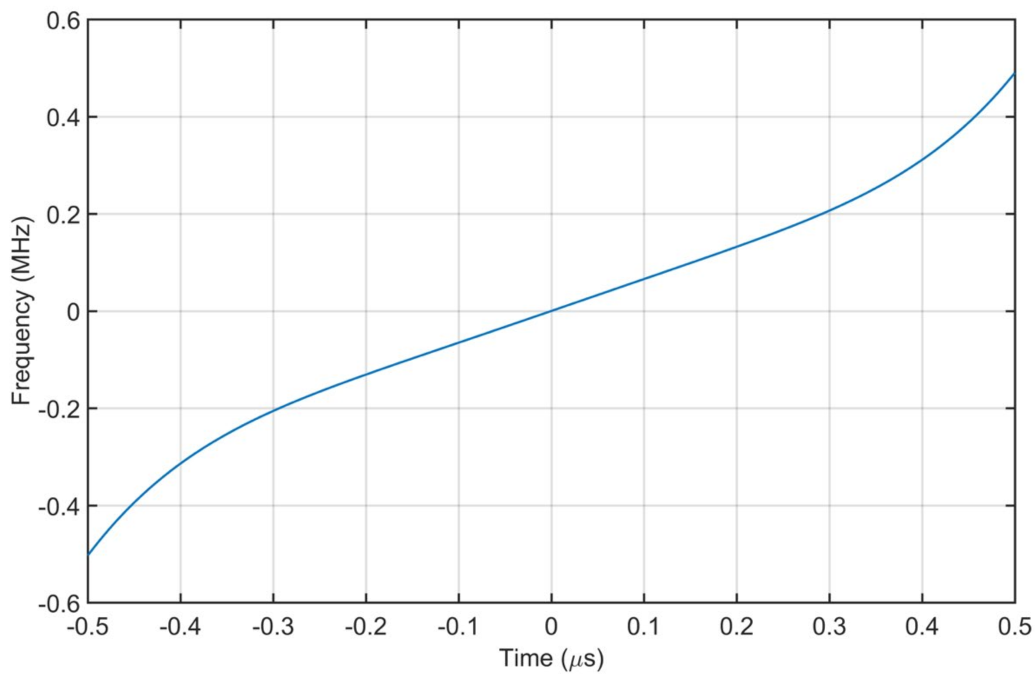

Figure 2. Baseline NLFM pulse from which testing pulses will be scaled for NLFM ESC tests.

5.2 Use of NLFM Pulses in Pre-Certification and Certification Tests

In pre-certification testing, each ESC will be exposed to NLFM chirped pulses under an administrative condition which has already been defined as being reportable only to each individual applicant. Thus the pre-certification results will allow both the applicant engineers and the ITS engineers to observe ESC performance with such pulses without any outside reporting. ESC designs may be modified after pre-certification tests, at the option and discretion of the applicants, to take advantage of what is learned from the pre-certification results.

In certification testing, the ESCs will again be exposed to the set of NLFM chirped pulses. This time, the results will be incorporated into the final report that ITS gives to each applicant, and which each applicant will in turn determine whether to provide to the FCC. However, the NLFM-pulse detection results will be tabulated separately from the LFM chirped and non-chirped pulse detection results in that report. The FCC will determine what to do with those results as regards final ESC certifications.

6. EXCESS BACKGROUND NOISE IN ESC CHANNELS

In the pre-certification and certification procedures of [1], Gaussian noise (GN) will be injected into ESC channels at an RMS average power level of -109 dBm/MHz (with a peak level of about -99 dBm/MHz) while radar pulses are injected at a peak power level of -89 dBm/MHz. Detection and declaration statistics will be determined for radar pulses under this injected noise condition. Deployed SAS networks are supposed to keep ambient, background noise generated by CBSD base stations at or below this noise level at ESC sensor locations.

A second noise topic needs to be addressed: How well, or whether, ESC RF sensors will recognize the presence of substantially higher noise levels than the -109 dBm/MHz background level generated by CBSD operation near ESC sensor locations that is supposed to be maintained by SAS networks. Applicants have agreed that they can detect radar pulses at the required 99 per cent performance criterion in the presence of -109 dBm/MHz noise, but that they cannot guarantee such performance at higher background levels of noise. The -109 dBm/MHz power level has been accordingly set by the WInnForum, and agreed to by the government, as the upper limit expected for pulse-detection testing. According to WInnForum documents, the SASs associated with each ESC will compute the mean aggregate CBSD power expected to be generated at each ESC sensor, and SAS management is supposed to always maintain the mean aggregate CBSD background power level at or below the -109 dBm/MHz average power level in each ESC channel.[10]

The proposed way forward is to generate excess noise at a specified level in ESC detection channels, and then see what, if anything, each ESC does in response.[11] The proposed excess Gaussian noise (GN) power level for this additional observation[12] in ESC channel(s) is -89 dBm/MHz root mean square (RMS) average, which will generate peak noise of -79 dBm/MHz. This proposed GN power is 20 dB higher than the background level at which the radar pulse detection capability of ESCs will generally be tested. This ESC excess noise observation will be performed once in pre-certification testing, for the benefit of applicants and ITS engineers, and then it will be performed a second time in certification testing, with possible interim ESC modification based on precertification results.

When the +20 dB GN level (i.e., 20 dB higher than the -109 dBm/MHz average RMS level) is introduced into one or more ESC channels for the laboratory observation, it will be maintained for 15 minutes. During that time, the ESC messages sent to the SAS or any cloud-based decision

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[10] *See* [3] at R2-SGN-25, sub-part a: "SASs shall manage CBRS interference for all ESC sensors that require protection such that the aggregate mean interference at the reference ESC filter output of the protected sensor in 3550-3700 MHz does not excel [sic] -109 dBm/MHz."

[11] The idea here is *not* to determine ESC radar pulse detection and declaration performance in the presence of this high noise level. The applicants have already stipulated that they can only be expected to meet radar pulse-detection performance signal (s) to noise (n) requirements of $10\log\left(\frac{s}{n}\right) = 10\ dB$ (pulses detected at peak-power threshold of -89 dBm/MHz in the presence of a Gaussian noise level) of -109 dBm/MHz average (-99 dBm/MHz peak); the applicants and the government have already agreed that the pulse-detection testing level for background noise will in fact be this noise power level. This new noise-monitoring test will not re-visit the topic of pulse detection at higher background noise levels than have already been agreed by all parties.

[12] This will be an observation, not a test, because there is no currently defined test criterion and there is no pass-fail condition for the ESC's response to excess GN in one or more of its detection channels.

messages to the SAS, will be monitored and recorded to determine whether or not the ESC is reporting this noise condition, and/or how the ESC is handling the noise condition. The ESC's fault or heartbeat messages in the presence of +20 dB GN will be noted and recorded by ITS engineers in each applicant's precertification results and in each ESC's final certification report.

7. REFERENCES

[1] Sanders, F. H., J. E. Carroll, G. A. Sanders; R. L. Sole; J. S. Devereux and E. F. Drocella Jr., "Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices," NTIA Technical Memo TM-18-527, U.S. Department of Commerce, Nov. 2017. https://www.its.bldrdoc.gov/publications/3184.aspx.

[2] Carroll, J. E., G. A. Sanders, F. H. Sanders, R. L. Sole; J. S. Devereux and E. F. Drocella Jr. "Non-Linear Effects Testing of High Power Radar Pulses on 3.5 GHz Low-Noise Amplifiers," NTIA Technical Report TR-17-525, U.S. Department of Commerce, Jun. 2017. https://www.its.bldrdoc.gov/publications/3173.aspx.

[3] Wireless Innovation Forum, "Requirements for Commercial Operation in the U.S. 3550-3700 MHz Citizens Broadband Radio Service Band," Working Document WINNF-TS-0112, Version V1.5.0. Section R2-SGN-25: SAS ESC Sensor Protection, sub-part a, pg. 25, sub-part b, pg. 26; Section R2-ESC-12: Federal Incumbent Detection Event, pg. 64, . May 1, 2018. https://workspace.winnforum.org/higherlogic/ws/public/download/6531/WINNF-TS-0112-V1.5.0%20CBRS%20Operational%20and%20Functional%20Requirements.pdf.

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14. SUPPLEMENTARY NOTES

15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

NTIA Technical Memorandum TM-18-527 describes procedures for testing the functionality of Environmental Sensing Capability (ESC) sensors that will detect 3.5 GHz radar signals for future spectrum sharing systems. The present document describes additional ESC certification test tasking. The first addition involves (a) examination of ESC behavior in the presence of high-power radar pulses; (b) examination of ESC behavior in the presence of out-of-band radar pulses that coincide in time and frequency with in-band 3.5 GHz radar pulses; and (c) examination of radio frequency (RF) front end filtering characteristics of ESCs. These three observations, which were already included in pre-certification testing, will now be repeated in certification testing so that their results can be included in each ESC's final certification test report. The second addition is the use of non-linear frequency modulation (NLFM) chirping in lieu of linear chirping for a subset of pulses in Radar Waveform Bins 3 through 5. NLFM chirping has been added to make some of the pulses in those bins more closely resemble pulses that are expected to be used by some future 3.5 GHz radars. The third addition is observation of ESC behavior in the presence of high background noise levels in ESC detection channels.

16. Key Words (Alphabetical order, separated by semicolons)

Dynamic Protection Area (DPA); Environmental Sensing Capability (ESC); chirping; non-linear frequency modulation (NLFM); radar; radar pulses; Spectrum Access System (SAS); spectrum sharing

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