Annex M

Measurement Methods

M.1 GENERAL

M.1.1 Introduction

Chapter 5 of this Manual contains Radio Frequency Spectrum Standards applicable to federal radio stations and systems. This Annex supplements Chapter 5 with the measurement methods appropriately referenced from the various sections of Chapter 5. A measurement method, in turn, is referenced back to Chapter 5. Cross-references to the FCC 47 CFRfixed and/or other measurement method procedures are also provided in this annex. It consists of two sections, one for measuring systems to NTIA and other relevant standards, and the other section to provide guidance on measurement procedures for interference investigations.

M.1.2 Measurement Methods

Measurement methods included or referenced in this annex are provided only for clarification and uniform interpretation of the standards. In cases of harmful interference, the agencies involved are expected to utilize these or equivalent, mutually agreed upon, methods of measurement for resolution of any disagreement concerning compliance with the standards. Agencies may, at their discretion, use these measurement methods as minimum qualification test procedures, e.g., as part of factory test procedures.

M.1.3 Resolution Bandwidth

Resolution bandwidth is the 3 dB bandwidth of the measurement system used, e.g., in power spectral density measurements. The appropriate resolution bandwidth of the measurement system varies depending on the modulation type and frequency band but should not be greater than the necessary bandwidth of the transmitter being measured.

M.2 MEASUREMENT METHODS

M.2.1 Fixed and Mobile Services

M.2.1.1 Fixed and Mobile Single Sideband and Independent Sideband Equipment (2-29.7 MHz)

This measurement method is referenced from Section 5.3.1. For HF single sideband transmitters, the transmitter without a device to limit modulation or peak envelope power shall be modulated as follows. The input level of the modulating signal shall be that necessary to produce rated peak envelope power. HF single sideband transmitters in A3A or A3J emission modes shall be modulated by two tones at frequencies on 400 Hz and 1800 Hz (for 3.0 kHz authorized bandwidth), applied simultaneously. The input levels of the tones shall be so adjusted that the two principal frequency components of the radio frequency signal produced are equal in magnitude and 3 dB below the maximum received signal level (RSL) as indicated in Figure 5.3.1 of Chapter 5. The plot of the spectrum shall have a span of 21.1 kHz or that necessary to identify intermodulation products up through the 13th and a resolution bandwidth of 100 Hz. This measurement method is also contained in Title 47 CFR Section 2.1049 (d)(2).

M.2.1.2 Maritime Mobile, FM Operation (150.8 - 162.0125 MHz)

This measurement method is referenced from Section 5.2.1, see Note (q). The measurement method for frequency tolerances to be used is as given in the Electronic Industries Association (EIA) Standard TIA/EIA-603, Land Mobile FM or PM Communications Equipment Measurement and Performance Standards (ANSI/TIA/EIA-603-E(2016), Chapters 2, 3 and 4, or equivalent

M.2.1.3 Fixed Services (406.1 - 420 MHz, 932 - 935/941 - 944 MHz, and 1.71 - 15.35 GHz)

1. Transmitter Standards

a. Measurement Method for Frequency Tolerance of Transmitter (referenced from Section 5.2.1, see Note (u)): A sample of the unmodulated carrier at the center frequency should be measured with equipment having an accuracy of at least five times that of the minimum to be measured.

b. Measurement Method for Unwanted Emissions of Transmitters Employing Digital Modulation Techniques (referenced from Section 5.5.3): A sample of the transmitter output at the interface point with the antenna transmission line shall be measured using a measurement system with 4 kHz resolution bandwidth. The full unmodulated carrier power output is used as the transmitter average output reference.

c. Measurement of the unwanted emissions shall be made from the lowest radio frequency generated by the equipment to the third harmonic of the carrier with the transmitter modulated as follows:

(1) Analog-white noise generator in accordance with EIA RS-252A recommended loading levels.

(2) Digital-pseudorandom code generator with appropriate loading levels and format.

2. Receiver Standards

a. Receiver Unwanted Signals Measurement Method, (referenced from Section 5.3.3): Couple two signal generators to the input of the receiver and connect a spectrum analyzer to the baseband output. The unmodulated output of one signal generator (desired signal) on the assigned frequency shall be adjusted to reduce the baseband noise by 3 dB as observed on the spectrum analyzer. The unmodulated output of the second signal generator (unwanted signals) shall be adjusted to 70 dB above that of the desired signal. The output frequency of the unwanted signals shall be varied over a range of ±1 percent of the assigned frequency excluding frequencies within the receiver 60 dB selectivity bandwidth.

b. At each receiver response of the unwanted frequency, adjust the output of the unwanted signal generator for a 3 dB reduction in baseband noise. The difference, expressed in dB, in the output levels of the two signal generators is the unwanted signal attenuation.

M.2.1.4 Land Mobile, Single Channel Narrowband Operations (220 - 222 MHz)

1. This measurement method is referenced from 5.3.4. A sample of the unmodulated carrier at the center frequency should be measured with equipment having an accuracy of at least five times that of the minimum to be measured.
2. Measurement Method for Resolution Bandwidth. The resolution bandwidth of the instrumentation used to measure the emission power shall be 100 Hz for measuring emissions up to and including 250 kHz from the edge of the authorized bandwidth, and 10 kHz for measuring emissions more than 250 kHz from the edge of the authorized bandwidth. If a video filter is used, its bandwidth shall not be less than the resolution bandwidth. The power level of the highest emission within the channel to which the attenuation is referenced shall be remeasured for each change in resolution bandwidth.
3. Additional guidelines may be obtained from the latest revision of Electronic Industries Association (EIA) TSB-57, Sideband Spectrum Measurement Procedure for Transmitters Intended for Use in the 220-222 MHz Band. Modulation is referenced to FCC regulations (CFR 47 2.1047).

M.2.1.5 Analog or Digital FM/PM Operations

1. Wideband (29.7 - 50, 162 - 174, and 406.1 - 420 MHz)

a. Measurement Methods for Transmitter Frequency Deviation and Receiver Conducted Spurious Emissions, All Station Classes and Bands, (referenced from Section 5.3.6): The prescribed measurement methods to be used are given in the latest revision of Electronic Industries Association (EIA) Standard TIA/EIA-603, Land Mobile FM or PM Communications Equipment Measurement and Performance Standards (ANSI/TIA/EIA-603-E/(2016), Chapters 2, 3 and 4.

The present EIA measurement methods were written for analog systems. Some of these methods are not appropriate for digital systems. Appropriate analog to digital or digital to analog test sets will have to be used.

b. Measurement Method for Frequency Tolerance, (referenced from Section 5.2.1, see Note (i)): An unmodulated standard input signal source, adjusted to the standard input frequency as specified in the latest revision of Electronic Industries Association (EIA) Standard RS-204, Minimum Standards for Land Mobile Communications FM or PM Transmitter, 25 - 866 MHz shall be connected to the receiver under test and adjusted for an output of 20 dB above the receiver sensitivity. The center frequency of the IF passband shall be measured with equipment having a degree of accuracy of at least five times the minimum tolerance to be measured.

2. Narrowband (138 - 150.8, 162 - 174, and 406.1 - 420 MHz Bands)

a. Transmitter and Receiver Measurement Methods (referenced from Section 5.3.7): The measurement methods to be used are as given in the Telecommunications Industries Association standard TIA/EIA-603-E(2016) for narrowband analog equipment, and TIA-102.CAAA-E(2016) for narrowband digital equipment. Where these methods are not specified for a particular system type, appropriate test procedures should be applied.

3. Digital 6.25 kHz Channel Equipment in the 406.1-420 MHz band.

a. Transmitter and Receiver Measurement Methods (referenced from Section 5.3.11): The reference level for showing compliance with the equipment emission mask shall be established using a resolution bandwidth sufficiently wide (usually two or three times the channel bandwidth) to capture the true peak emission of the equipment under test. In order to show compliance with the emission mask up to and including 50 kHz removed from the edge of the authorized bandwidth, adjust the resolution bandwidth to 100 Hz with the measuring instrument in a peak hold mode. A sufficient number of sweeps must be measured to ensure that the emission profile is developed. If video filtering is used, its bandwidth must not be less than the instrument resolution bandwidth. For frequencies more than 50 kHz removed from the edge of the authorized bandwidth a resolution of at least 100 kHz must be used for frequencies below 1000 MHz. Above 1000 MHz the resolution bandwidth of the instrumentation must be at least 1 MHz.

b. The measurement method to be used for the receiver standards are as given in the Telecommunications Industry Association standard TIA-102.CAAA-B for narrowband digital equipment.

c. Where these methods are not specified for a particular system type, appropriate test procedures should be applied.

M.2.1.6 Telemetry, Terrestrial Operations (1435-1525, 2200-2290, 2310-2320, 2345-2395, 4400-4940, and 5091-5150 MHz Bands)

The bandwidth measurements are performed using a spectrum analyzer (or equivalent device) with the following settings: 30-kHz resolution bandwidth, 300-Hz video bandwidth, and no max hold detector or averaging. These settings are different than those in earlier versions of the Telemetry Standards. The settings were changed to get more consistent results across a variety of bit rates, modulation methods, and spectrum analyzers. This measurement method is referenced in Appendix A.5.2 of Chapter 2 in IRIG-106-17.

M.2.1.7 Wideband and Narrowband Emission Level and Temporal Measurements in the Navstar Global Positioning System Bands

1. The wideband and narrowband radiated equivalent isotropically radiated power (EIRP) levels in the 1164-1240 MHz and 1559-1610 MHz frequency bands are to be measured for systems operating in the frequency bands: 390-413 MHz, and 960-1710 MHz. The following guidelines are to be used in measuring the wideband and narrowband EIRP levels:

a. The radiated EIRP levels in these frequency bands are to be measured using a root mean square (RMS) spectrum analyzer detector function.

b. The wideband emission levels are to be measured using a 1 MHz resolution bandwidth.

c. The narrowband emission levels are to be measured using a 1 kHz resolution bandwidth.

d. For the wideband emission measurement, the RMS levels are to be measured using a 2 millisecond averaging time over each 1 MHz segment.

e. The video bandwidth of the spectrum analyzer should not be less than the resolution bandwidth.

f. The measurement system must have a noise floor of approximately -141 dBW as measured in a 1 MHz resolution bandwidth.

2. The following guidelines are to be used in measuring the temporal characteristics of the emissions in the 1164.45-1188.45 MHz, 1215.6-1239.6 MHz, and 1563.42-1587.42 MHz bands:

a. The system under test should be tuned to its assignable channel that is closest to the GPS frequency band under consideration.

b. A time-domain measurement of the waveform envelope in a 20 MHz bandwidth can be measured using an antenna with appropriate gain and frequency response characteristics connected to either a notch filter or a bandstop filter. The filter is connected to a low noise amplifier (LNA) that operates across the frequency range of at least 1100-1600 MHz. The LNA is connected to a vector signal analyzer (VSA).

c. Tune the VSA sequentially to the 1164.45-1188.45 MHz, 1215.6-1239.6 MHz, and 1563.42-1587.42 MHz bands and perform time-domain measurements using the full VSA bandwidth of 36 MHz.

d. Subsequent to the data capture, the time-domain waveform envelopes are processed in a 20 MHz bandwidth.

e. Alternative techniques to perform these measurements should be provided to NTIA for review.

M.2.2 Radar Spectrum Engineering Criteria (RSEC)

M.2.2.1 General including RSEC-A

This measurement method is referenced from Section 5.5.1. NTIA Technical Report TR-05-420 titled "*Measurement procedures for the radar spectrum engineering criteria (RSEC)*" should be used for radar emission measurements by federal agencies or other parties seeking system certification by NTIA. It describes techniques for measuring radar spectrum-related parameters and characteristics for compliance with the RSEC. Measurements for both conventional and advanced radar types are addressed. The report can be downloaded at: http://www.its.bldrdoc.gov/publications/2450.aspx.

M.2.2.2 RSEC B

This measurement method is referenced from Section 5.5.2. In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of 1 ppm is desirable, although, for most radars 100 ppm is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, each Federal agency shall have access to the instrumentation necessary to make a frequency measurement to at least 100 ppm to measure time and frequency parameters necessary to determine conformance with these criteria. For fast rise devices, such as magnetrons, measurement equipment resolution bandwidths of at least 50 MHz should be used.

M.2.2.3 RSEC C and RSEC D

This measurement method is referenced from Sections 5.5.3 and 5.5.4. In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of 100 ppm is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy.

Accordingly, each federal agency shall have access to the instrumentation necessary to make a frequency measurement to at least 100 ppm to measure time and frequency parameters necessary to determine conformance with these criteria. For fast rise devices, such as magnetrons, measurement equipment with resolution bandwidths of at least 50 MHz should be used.

M.2.2.4 RSEC E

This measurement method is referenced from Section 5.5.5. In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of 1 ppm is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, each federal agency shall use the measurement equipment necessary to make a frequency measurement to at least 1 ppm and be able to measure time and frequency parameters necessary to determine conformance with these criteria. Measurement equipment shall have resolution bandwidths of at least 10 kHz to measure close in bandwidth limits, and otherwise 100 kHz bandwidth below 1 GHz and 1 MHz bandwidth at and above 1 GHz should be used.

M.2.3 Measurement Methods for Interference Investigations

NTIA has a long history of performing investigations of interference both to and from federal systems, including radars, satellite, and land mobile systems. Many of the investigations have included both on-site investigations and later field and laboratory tests. The investigations have often been performed by combined teams from the Office of Spectrum Management (OSM) working with engineers at the Institute for Telecommunication Sciences (ITS) and the FCC Enforcement Bureau. They typically begin their work with a detailed review of pertinent GMF records, system certification documents, FAS and IRAC documents. Then they follow up with field work. ITS uses ITS their test and measurement equipment to document and record necessary data and draw conclusions. Using the past interference investigations as examples, NTIA has developed general guidelines, methods, and procedures that agencies can use on their own to assist NTIA on new and future cases. The following steps, with additional details, can be used by the agencies to accomplish that task. If more information or guidance is required on methods and procedures for interference investigations, agencies should contact The Office of Spectrum Management.

The following steps addresses the series of events that need to be done to investigate and resolve, and hopefully mitigate the interference problem. The steps are as follows:

Step 1 Gather information about the interference event

The first step is to gather information and data about the interference problem, and make some sort of initial report. It should give a good description of the problem along with how the data was obtained, who obtained it, and when/where it was gathered. This could be a written report of some sort, phone calls, emails, spectrum analyzer recordings, or other form of media. Many times the reports are taken at the field levels and passed up the agency's command chain, so that the person giving the information to NTIA in the IRAC or TSC is not the person that did the investigation or obtained the field level data.

NTIA has developed as PDF form that agencies can use to fill out and send back to NTIA with fields that allow them to fully document the interference problem. The agencies should use the interference form as best they can to provide when the event, noting how often it happens, what system is being affected, how it affects mission objectives and other fields. It can be helpful if NTIA and ITS engineers talk directly to the field office personnel about the interference problem, so details about the situation are not lost in translation. Of course this is only with the agency's permission to contact the field level engineers. Section 8.2.30 of the NTIA Manual provides guidance on the use of the interference reporting form and how to submit it to NTIA.

Gathering information from industry can also be important since key data parts of their systems are not published or available from the FCC. Typically, OSM management contacts the public affairs or government liaison office about any interference problems and then they in turn will supply local contact names and phone numbers of the right personnel to work with.

Step 2 Review the data and meet with agencies to discuss their findings

In Step 2 a thorough review of the information and data obtained by the agencies by NTIA and ITS personnel, including management and technical review is performed prior to deploying a team for field investigations. If not taken properly or if misinterpreted, the data obtained by the agencies can lead to the wrong conclusions and the wrong decisions. This is especially true when a new type of interference problem arises. In some cases the initial spectrum analyzer recordings of the interference and misinterpreted the problem as being due to other federal systems and it had also misidentified the interference mechanism, which led to more confusion. The best approach is for field engineers to review and discuss the material, make notes or develop questions, and then meet face to face with NTIA or industry representatives to discuss the issues. They can aslo reads through the various reports that NTIA and ITS have published that cover the gamut of federal systems and the types of interference events that they document.

Step 3 Review GMF assignments, system certification files and Initial analyses

When interference problems arise, especially in federal bands, the first thought should be to review the GMF assignments for that band for possible interference sources. A GMF cull needs to be done within some radius of the interference location to obtain the names of the systems and their assignment serial numbers that might be the source of the interference. For fixed terrestrial systems, the radius cull should be within the radio horizon as determined by the antenna height above ground; for airborne systems and terrestrial mobile systems, the area should be at least as large as the operating area. Once all the systems with assigned frequencies are identified, they need to be carefully reviewed to see if they might be a problem or have been a problem in the past. This would entail reviewing the transmitter power levels of suspect systems and any relevant notes for that assignment such as operating hours/locations and perhaps antenna sector blanking.

If the in-band cull yields no results for a possible source of interference, then the systems in the adjacent bands need to be researched as well, which may or may not include non-federal bands or shared bands. If the adjacent band is non-federal, then it can be problem identifying the tower sites or transmitters as the FCC does not require them to be listed in their license grants that are available online. At that point, the FCC is consulted to see what entities have licenses in the band of interest and the investigation progresses from there. Another consideration is the harmonics of another system causing the interference. A harmonic analyses is much more involved, but can be done by very carefully noting the exact frequency the interference appears on, and then reviewing the GMF assignments in lower bands for a multiplication factor of 2 or 3 that might occur on the cannel getting the interference.

Step 4 Perform on-site investigations

The onsite investigation is crucial. If possible, the best procedure is to follow the interference signal in the victim receiver through its entire chain. That means taking spectrum analyzer measurements in the time and frequency domains of the interfering signal after the antenna, LNA, RF filter and finally the IF filter, before the signal goes to the detector or digitizer. It is also a good idea to do a spectrum survey of the environment to see what signals are present and their location in relationship to the system getting interference. This technique can be used to pinpoint the interference sources and save time during the field investigation. If possible the systems own antenna can be used to help find the azimuth or direction the interference is coming from.

Taking the measurements at these locations in the time and frequency domains lets the engineers see in detail the interference signal's true nature. Is it from receiver front-end saturation, or perhaps a small signal effect or an intermodulation problem? In many cases the experience of the engineer on-site is a key element of the investigation. In previous investigations, ITS engineers recorded the time domain signals of the interfering signal as part of their on-site work, and once they looked at them on a plot, it was easily identified them as a broadband OFDM signals, because they had measured them at the ITS laboratory for previous tasks.

On-site investigations need to be done in an expedited manner. Many times the federal agency uses the system to complete their mission objectives. The system must be taken out of the network and off-line while ITS engineers perform the investigation and do tests. Afterwards, the system must be re-certified for operations before rejoining the network. This is especially true in the case of the weather and air surveillance radar systems. In the case of a non-federal system being involved, removing a tower from a broadband network costs lost revenue and perhaps angry customers wondering why their phone is not working. So the on-site work must be planned out with clear objectives in mind to minimize the down time. Often time it must be done late at night once air traffic has ceased operations and broadband traffic is lower as well.

Step 5 Consult with industry (if required)

For interference cases that involve non-federal entities, industry representatives need to be involved in the process as soon as it is apparent that the interference is not just between federal systems. It is important to use industry expertise regarding its own systems. Typically this involves meeting with management of the company and then getting the contacts in the local area where the problem exists. NTIA used this approach in past investigations that involved Broadband providers as their management was first contacted about the potential problem and then ITS and SEAD engineers worked with the local network operators in to perform the initial measurement and verify that the macro base stations were indeed the cause of the problem. It was crucial to resolving the matter that the service provider's own engineers verified the problem and could tell their management that the problem was real and it was from their system, When Industry is a part of the whole process it is more cooperative.

Step 6 Identify the interference mechanism and the mitigation path

There are many kinds of RF interference; before a mitigation solution can be identified, you first have to be able to identify the type of interference. The various types of interference can generally be grouped into three categories: High-power effects, small-signal effects, and non-linear effects. Once all of the data has been gathered by ITS and NTIA and the Federal agency, it needs to be carefully reviewed so that the correct mechanism is identified. Mistakes can lead to more confusion and a wrong (and therefore ineffective) interference mitigation option being chosen. A brief discussion of each type of interference is discussed and mitigation options are provided.

High-Power effect

In a high-power effect, the interfering signal is strong enough to either burn out the components in the receiver or at the least cause a receiver LNA to saturate and/or ring causing system performance degradation or unavailability. This type of interference has been documented many times before as being a problem both to and from federal systems. It can be mitigated by reducing the power levels of the incoming interfering signal, with filter on the receiver input, to a level where the LNA does not get saturate. That exact level is not always known and it may take experimentation in the laboratory or field to obtain it. Note that care must be taken in how these solutions are used. For example in a radar receiver, initially its front end was configured with (in order): antenna, limiter, bandpass filter and amplifier. This configuration produced interference via the limiter-filter interface. But when the order of the limiter and bandpass filter was reversed (the front end order of components then being antenna, bandpass filter, limiter and amplifier) the problem ceased.

Small-Signal effect

In a small-signal effect the interfering signal is *not strong enough* to cause the receiver's LNA to go into gain compression, bit its strong enough so that the receiver's bit error rate, block rate, probability of target detection is reduced or some other performance metric is negatively affected. It may be reduced below some specified level of performance. It can be mitigated by adding frequency separation between the interferer and the receiver or additional filtering on the transmitter's emissions. Other options are to change the antenna orientations such that the antenna patterns of the systems (the victim and/or the interferer) are used to reduce the interference power. Many times, more than one mitigation option can be used at the same time so that extremes are not needed in any one solution to get rid of the interference. A combination of off-tuning, increasing horizontal and/or vertical antenna separation, and antenna downtilt can be used to mitigate interference. These effectiveness of these methods can be obtained either through field trails and/or simulations.

Non-Linear Effects

In a non-linear effect, the interference causes an intermodulation effect in the receiver or a nearby structure. An intermodulation is the result of two or more signals mixing in the receiver, such that another signal is generated that causes the system to lose capacity or become inoperable. These types of signals are difficult to diagnose and define. They best way is to first do an analyses of the signals in the area, via a GMF search, to see if any combination of them added and subtracted might place a signal on a desired channel. Computer programs are available that will produce the various orders of the intermodulation frequencies given a set of input frequencies. In some cases, by reducing the power of one of the signals with an attenuator or some other means, the intermodulation effect will go away, as it's a function of the multiplication of the power.

For non-linear effects that are not generated in the receiver, but nearby from some structure, is an effect called rusty bolts. The only way to mitigate this type of interference is to move at least one of the systems off the frequency that is getting the interference or reduce the power of them such that the intermodulation no longer occurs. Finally if one of them is simply turned off, the problem will go away, such as the case of a federal earth station receiver that was getting a rusty bolts effect from a nearby tower that was generating a signal from being illuminated by a local TV station's tower. When the analog TV station ceased transmitting and transitioned to a digital signal on another frequency, the interference ceased.

Step 7 Post analyses of interference

The post analyses address what OSM and ITS management and engineers do after the interference problem has been investigated on-site and after the initial analyses had been completed. The post analyses uses the data that was gathered in the field or laboratory work to develop a mitigation solution after the interference mechanism was identified. This could be a number of things, from making a computer model to develop frequency and distance separation curves to developing the specifications of a filter, or using other techniques as well. It might also include developing exclusion zones or antenna sector blanking.

Post analyses can also show that a regulatory change is required at times when the technical options can't solve all of the problems. For systems that use cognizant behavior to detect and avoid federal systems, a thorough review of the test certification waveforms may be warranted and changes might have to be made to them. Regulatory solutions can take a long time to be set in place as they must go through technical review and consultation with industry before the FCC can change its rules.

Step 8 Resolution of Interference

The resolution addresses how the interference investigation was solved and tells which steps were taken to mitigate the interference. The goal of any interference case is to resolve it in some manner, to either show that it was real or not, and if it was to do something that is acceptable to all parties. The resolution can be a technical solution, administrative/regulatory, or political. In some cases it can be a combination of all three approaches.

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