



# Dynamic Frequency Selection (DFS)

*An overview of radar detection requirements for wireless devices operating in certain 5 GHz bands*



# Topics Covered in this Presentation

- Definition of Dynamic Frequency Selection (DFS)
- Origins of DFS Requirements in USA and EU
- Overview of Current Standards in USA, EU
- Affected Product Types and Device Classifications
- Basic DFS Testing Requirements & Terminology
- Using Test Labs and TCBs for DFS Compliance
- FCC submittal process
- Q&A Session



# Dynamic Frequency Selection (DFS)

*“A channel allocation scheme that dynamically selects and/or changes the operating frequency to avoid interfering with (or interference from) other systems.”*

For this presentation

- Evaluation of DFS capabilities of 5GHz WLAN devices
- Primarily concerned with avoiding causing interference to other systems
- Does not address Transmit Power Control or Uniform Channel Loading requirements

# Background History

- Worldwide, the frequency bands 5250 – 5350 and 5470 – 5725 MHz are used by radar systems
- The same frequency bands (or subset(s) thereof) were allocated to unlicensed WLAN devices
- The European Union addressed potential interference issues to existing radar systems in the standard EN 301 893 V1.2.3 by requiring DFS
  - The evaluation of DFS was based on the ability for a system to be capable of detecting three radar types
  - Became a harmonized standard in
  - The latest version (EN 301 893 V2.0.7) has additional radar types

# Background History (US)

- The FCC allocated 5150 – 5350 MHz for unlicensed devices (U-NII, FCC Part 15 Subpart E)
- Pressure to open up 5470 – 5725 MHz spectrum to match that being opened in other geographies for 802.11a
  - Band already assigned to the Department of Defense (DoD) for radar systems
  - DoD would only permit the allocation of the band if the systems employed DFS
  - DFS evaluation had to demonstrate that systems would be capable of responding to all of DoD radar systems
  - DFS requirements extended into the previously non-DFS 5250 – 5350 MHz sub-band



# Background History (US)

- Project Team established to develop test requirements and methods
- Comprised of representatives from
  - DoD
  - FCC
  - Wireless manufacturing industry (predominantly 802.11a)
  - Testing laboratories



# Background History (US)

- Problems with defining the different radar types to be used during the evaluations
  - DoD had a need to keep the actual radar signatures confidential
  - Made it difficult to determine what would be “representative”
  - Did not want devices to detect specific patterns, rather be capable of responding to a wide variety of signals
    - ✓ Addressed by incorporating a randomizing element into the various radar types



# Background History (US)

- Problems with defining the different radar types to be used during the evaluations
  - Expanded the 1us and 2us pulse width of the EN 301 893 V1.2.3 standard to widths exceeding 20us
    - ✓ The  $> 20\mu\text{s}$  pulse width caused concerns with industry because of the similarity to the width of 802.11 packets
    - ✓ After working on detection algorithms agreement reached
  - Requirement for simulation of frequency-hopping radar
    - ✓ Cost of test equipment became an issue
    - ✓ Worked on alternate simulation methods



# Background History (US)

- Bench tests by the NTIA and NIST evaluated the test methods on several sample systems
- DoD did live trials on the same systems with real radar
- Results of both tests gave confidence in the proposed requirements and methods
- FCC released original requirements and methods in the second quarter of 2006
  - Report and order FCC-06-96A1
  - FCC Part 15.37 (I)



# Background History

- Other countries are including DFS requirements into their rules for WLANs in the 5250 – 5350 / 5470 – 5725 MHz bands
  - Japan (5250 – 5350 MHz allocation)
  - Australian standard AS/NZS 4268
  - Canada RSS 247
  - Canadian rules state to follow FCC procedures for the testing
- DFS requirements expanded to other frequency bands
  - EN 302 502 standard for licensed devices operating in the 5725 to 5850 MHz band (not harmonized)

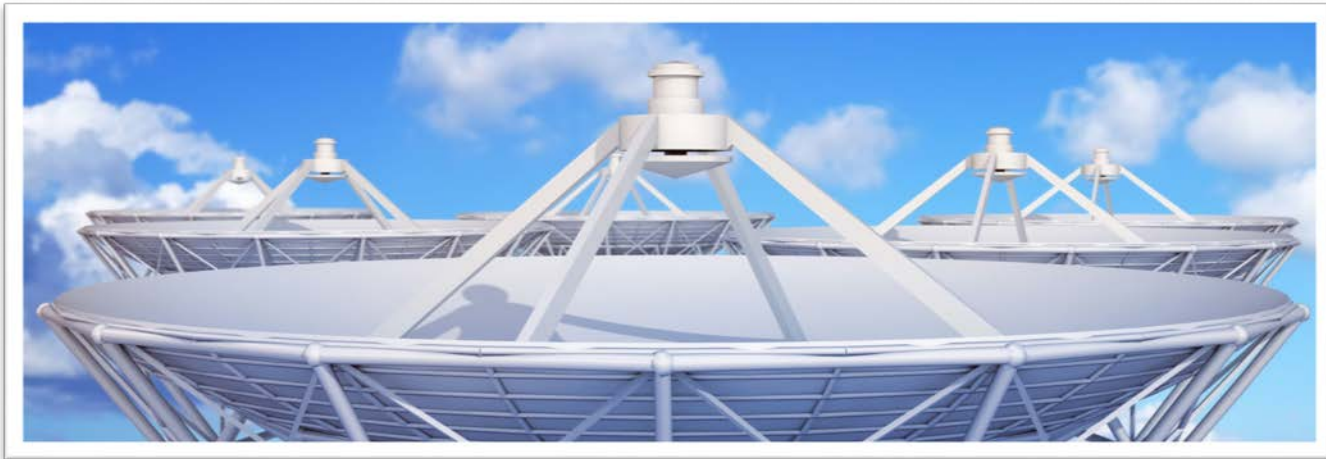
# What does DFS Require ?

- A system that requires DFS needs to be capable of avoiding interfering with radar systems by
  - Verifying a channel is free of radar before using it
  - Monitoring for radar once a channel is in use and vacating the channel if radar is detected
  - Remaining off of a “radar” channel
  - Loading channels equally (Uniform Loading)
  - Transmitting only the power required (**T**ransmit **P**ower **C**ontrol) for successful communications



# How is DFS Implemented ?

- Non-Occupancy Period
  - If radar is detected on a channel the system cannot use the channel for the non-occupancy period
- Radar Detection Bandwidth
  - System shall be capable of detecting radar across the same bandwidth as the system's transmitted signal bandwidth





# How is DFS Implemented ?

- Channel Availability Check (CAC)
  - System selects a channel to use
  - Cannot transmit on the channel until it has been monitored for the *channel availability check time* to verify no radar devices are present (above the threshold level)
  - If radar is detected:
    - ✓ Do not use the channel
    - ✓ Avoid using/selecting the channel for the non-occupancy period
    - ✓ Select another channel and start again

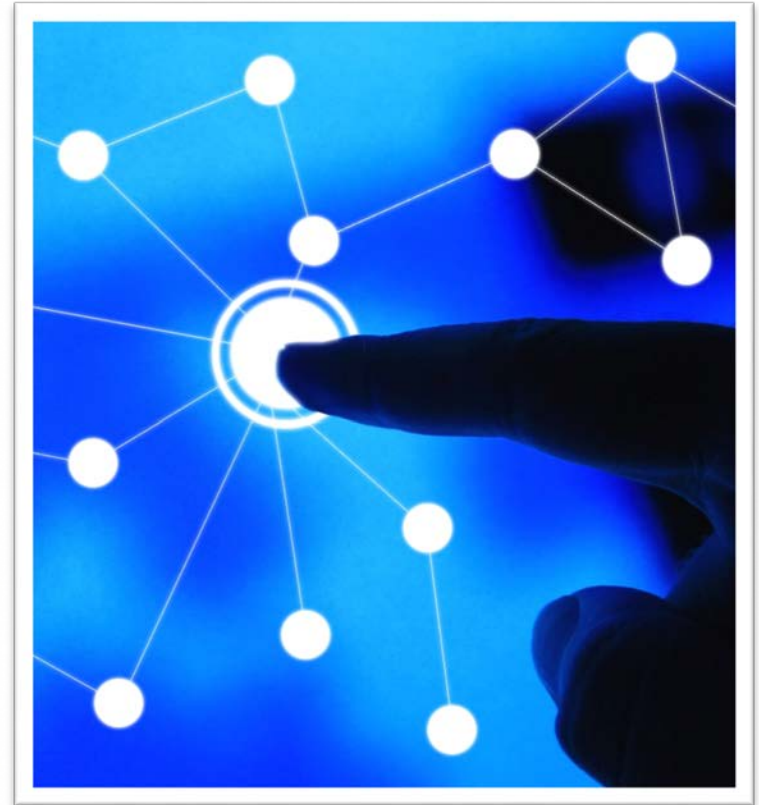


# How is DFS Implemented ?

- In service monitoring
  - Monitor the channel being used
  - If radar is present above the threshold level
  - Vacate the channel within the *channel move time*
  - During the channel move time, limit total duration of transmissions to less than the *channel closing transmission time*
  - Not use the channel for the non-occupancy period

# Typical System

- A typical system, such as an 802.11 network, consists of:
  - Master device
  - Client device(s)
  - Some “Client” devices have “Ad Hoc” capabilities
- Other systems may use a different topology

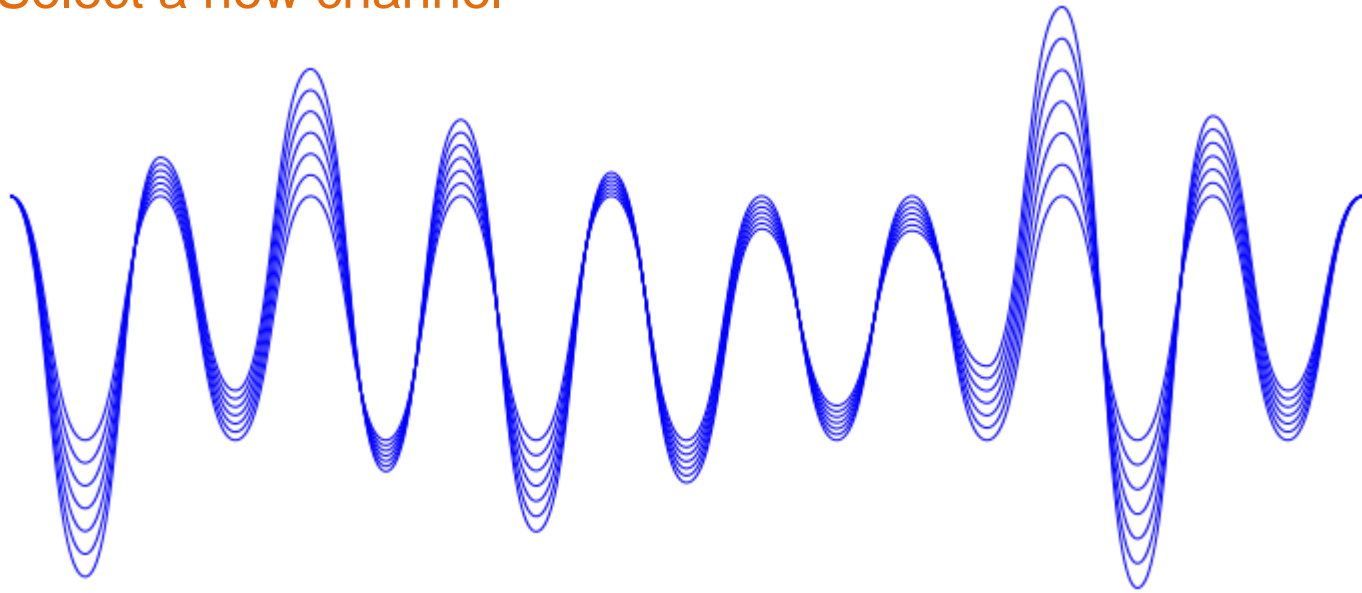


# DFS Device Classifications

- Master Device
  - Device that controls a network
    - ✓ Devices under its control (client, aka station) cannot transmit unless authorized by the master
    - ✓ Clients associate with a master device
  - Must be able to detect radar
    - ✓ Prior to starting on a frequency (channel start-up)
    - ✓ While communicating (in-service)
  - Maintains a database of “radar channels”
    - ✓ Cannot use those channels for the non-occupancy period

# DFS Device Classifications

- Master Device
  - On detecting radar must
  - Tell all associated clients to stop within the channel move time
  - Select a new channel



# DFS Device Classifications

- Client Device (Infrastructure Mode)
  - Cannot initiate communication, can only transmit when authorized by a master
  - Must be able to clear a channel when commanded by a master device
  - Active scanning not allowed – passive scanning only
- Ad Hoc mode
  - Mode that supports client-client initiated communication
  - Requires devices that support this mode to have the same attributes as a master device



# DFS Device Tests

| Test                                     | Master | Client |
|--|--------|--------|
| Non-occupancy period                     | √      | -      |
| Detection probability / threshold        | √      | -      |
| Channel Availability Check               | √      | -      |
| Detection Bandwidth                      | √      | -      |
| Channel move / closing transmission time | √      | √      |

# DFS – Simulated Radar Signals

- To evaluate DFS a system is subjected to a simulated radar signal
- The radar signal consists of a series (burst) of pulses
- The main parameters for the signals are
  - Width of each pulse
  - Time between each pulse (pulse repetition interval, pri)
  - The total number of pulses
  - The amplitude of the pulse
  - The modulation of each pulse, if any

# FCC Simulated Radar Signals

- The FCC evaluation of DFS includes a total of 6 different radar signals
- The detection of the radar signals is evaluated over a number of trials (minimum of 30 for each radar type)
  - The “probability” of detection is calculated by dividing the number of successful detections by the total number of trials
- Apart from radar types 1 and 6, the pulse width, number of pulses and pri are listed as a range
  - The test is performed by selecting, at random, a value within the range (step intervals of 0.1us for width; 1us for interval; 1MHz for FM chirp and 1 for number of pulses)
  - For parameters with a range, each trial uses a different signal

# FCC Simulated Radar Signals

Radar signals 0 through 4

| Fixed Frequency Radar Type                    | Pulse Width (μsec) | PRI (μsec) | Number of Pulses per burst | Minimum Probability of detection for the U-NII Device |
|---|--------------------|------------|----------------------------|---|
| 0   | 1                  | 1428       | 18                         | N/A   |
| 1   | 1                  | 518-3,066  | 18 - 102                   | 60%   |
| 2   | 1-5                | 150-230    | 23-29                      | 60%   |
| 3   | 6-10               | 200-500    | 16-18                      | 60%   |
| 4   | 11-20              | 200-500    | 12-16                      | 60%   |
| Average detection probability for types 1 - 4 |                    |            |                            | 80%   |

# FCC Simulated Radar Signals

## Radar Signal 5

(Long Pulse Radar Test Waveform)

- This consists of a 12 second-long waveform with multiple different bursts.

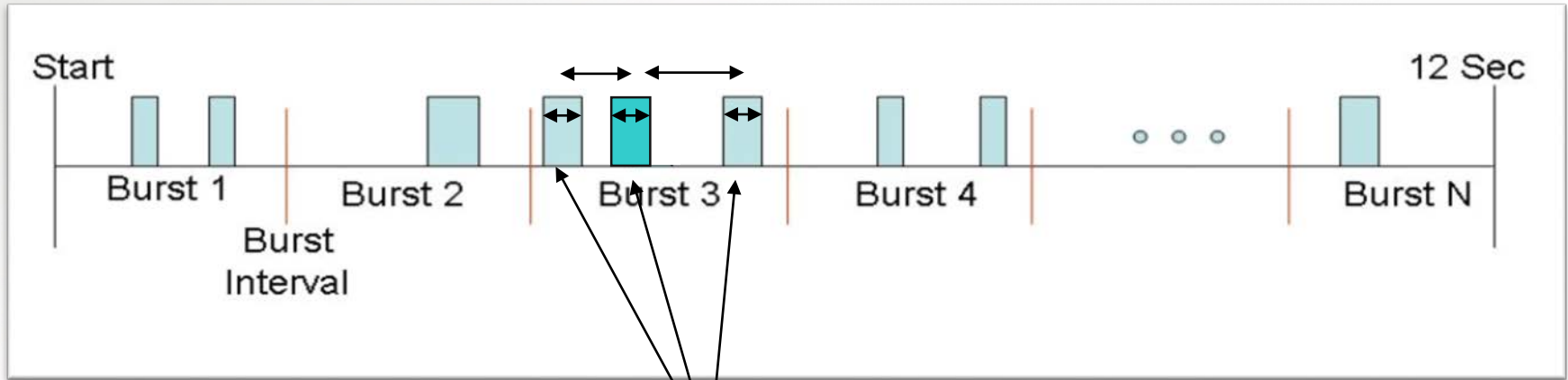
| <b>Pulse Width<br/>(<math>\mu</math>sec)</b> | <b>PRI<br/>(<math>\mu</math>sec)</b> | <b>Chirp Width<br/>(MHz)</b> | <b>Number<br/>of Pulses<br/>per burst</b> | <b>Number<br/>of<br/>Bursts</b> | <b>Minimum<br/>Probability of<br/>detection</b> |
|--|--------------------------------------|------------------------------|---|---------------------------------|---|
| 50 - 100                                     | 1,000 –<br>2,000                     | 5 - 20                       | 1 - 3                                     | 8 - 20                          | 80  |



# FCC Long Duration Waveform

- The 12-second waveform is split into  $n$  equal intervals, where  $n$  is the number of bursts.
  - For 10 bursts, the interval is 1.2s
- Each burst is located within each interval
- Within a burst the pulses have the same width and modulation, but not pri
- Chirp width is the same for all pulses
- The first pulse in the burst appears at a random time in the burst's interval
- Each burst is contained within its interval

# FCC Long Duration Waveform Example



- Burst 3 has 3 pulses
- Each pulse has the same width
- The interval between from pulse 1 to 2 is not the same as pulse 2 to pulse 3

# FCC- Frequency Hopping Radar

| Pulse Width (μs) | Pulse Repetition Interval (pri) (μs) | #Pulses per Frequency Hop | Hopping Sequence Length ms | Hopping rate | Minimum Probability of detection |
|------------------|--------------------------------------|---------------------------|----------------------------|--------------|----------------------------------|
| 1                | 333                                  | 9                         | 300                        | 333 Hz       | 70%                              |

- Radar hops over the entire frequency range 5250 – 5724 MHz (475 channels)
- The radar hops across 475 channels in a random manner without using the same channel twice
- A 100 channel sequence is defined and applied ONLY if the sequence includes one or more frequencies that fall in the detection bandwidth of the device under test

# EN 301 893 Simulated Radar Signals

- The EN 301 893 v2.0.7 includes 6 different radar signals
- The detection of the radar signals is evaluated over a number of trials (minimum of 20 for each radar type)
  - The “probability” of detection is calculated by dividing the number of successful detections by the total number of trials
  - The standard requires probability to be evaluated during in-service monitoring AND CAC tests
- Ranges for pulse widths and repetition rates are listed for each type
  - One value for each parameter is selected at random for each trial
  - Types 5 and 6 use staggered PRF signals using 2-3 different values

# EN 301 893 Simulated Radar Signals

| Fixed Frequency Radar Type | Pulse Width (µsec) | PRF (pps)     | Number of Pulses per burst | Minimum Probability of detection |
|----------------------------|--------------------|---------------|----------------------------|----------------------------------|
| 1                          | 0.5 - 5            | 200 – 1,000   | 10                         | 60%                              |
| 2                          | 0.5 - 15           | 200 – 1,600   | 15                         | 60%                              |
| 3                          | 0.5 - 15           | 2,300 – 4,000 | 25                         | 60%                              |
| 4                          | 20 - 30            | 2,000 – 4,000 | 20                         | 60%                              |
| 5                          | 0.5 – 2            | 300 - 400     | 10                         | 60%                              |
| 6                          | 0.5 – 2            | 400 – 1,200   | 15                         | 60%                              |



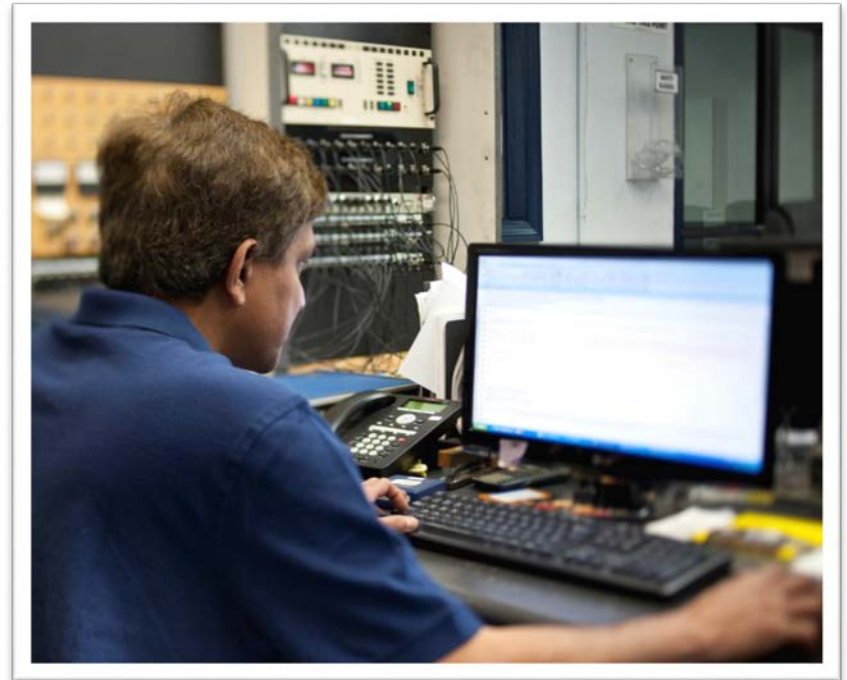
# Other DFS Requirements

| Parameter                         | FCC   | EN 301 893                             |
|-----------------------------------|---|--|
| Non Occupancy Period              | $\geq 30$ minutes   | $\geq 30$ minutes                      |
| Channel Availability Check Time   | $\geq 60$ seconds   | $\geq 60$ seconds                      |
| Channel Move Time                 | $\leq 10$ seconds   | $\leq 10$ seconds                      |
| Channel Closing Transmission Time | 200ms at the start of the channel move time, $\leq 60$ ms during the remaining 9.8s | $\leq 1$ s                             |
| Radar Detection Bandwidth         | $\geq 100\%$ of the 99% signal bandwidth  | No requirement                         |
| Detection Threshold               | -62dBm / -64dBm   | -62dBm / -64dBm                        |
| Traffic during testing            | Typical data but must be random (~17% channel loading)                              | Any type of data (30% channel loading) |

\* For FCC the CAC must be performed immediately before the channel is used, Off-channel CAC allowed for EN 301 893

# DFS Testing

- Evaluation of the DFS performance is performed on a system with a master and a client device
- Channel availability check is performed with just a master device (radar detection device)
- In service monitoring and the associated measurements for channel move, channel closing and non-occupancy are performed on the combination



# DFS Tests – Basic Configuration

- The basic elements of the test system are
  - Radar generator
  - Capable of reproducing the various radar waveforms required to evaluate DFS performance
  - Field monitoring system
  - Capable of measuring radar signal level at EUT
  - Frequency selective
  - Capable of providing timing information relative to the radar burst
    - ✓ Ideally timing resolution can resolve a single transmitted packet over a 20-second period
    - ✓ Capable of measuring over periods up to 30 minutes

# DFS Tests – Basic Configuration

- Radar generator
  - Basic rf generator with pulse modulator and pulse generator for most radar types
  - High performance generator required for modulated and long duration waveform
  - Frequency hopping capability
- Field monitoring system
  - Spectrum / Vector analyzer may work
  - Can use a oscilloscope connected to the IF output of the analyzer to increase resolution



# DFS Tests – Basic Configuration

- Software (or manual programming)
  - Generates the random patterns
  - Programs test equipment
  - Performs/facilitates timing measurements
  - Records the results for each test
    - ✓ Radar parameters
    - ✓ Radar signal level
    - ✓ Detection (yes/no)

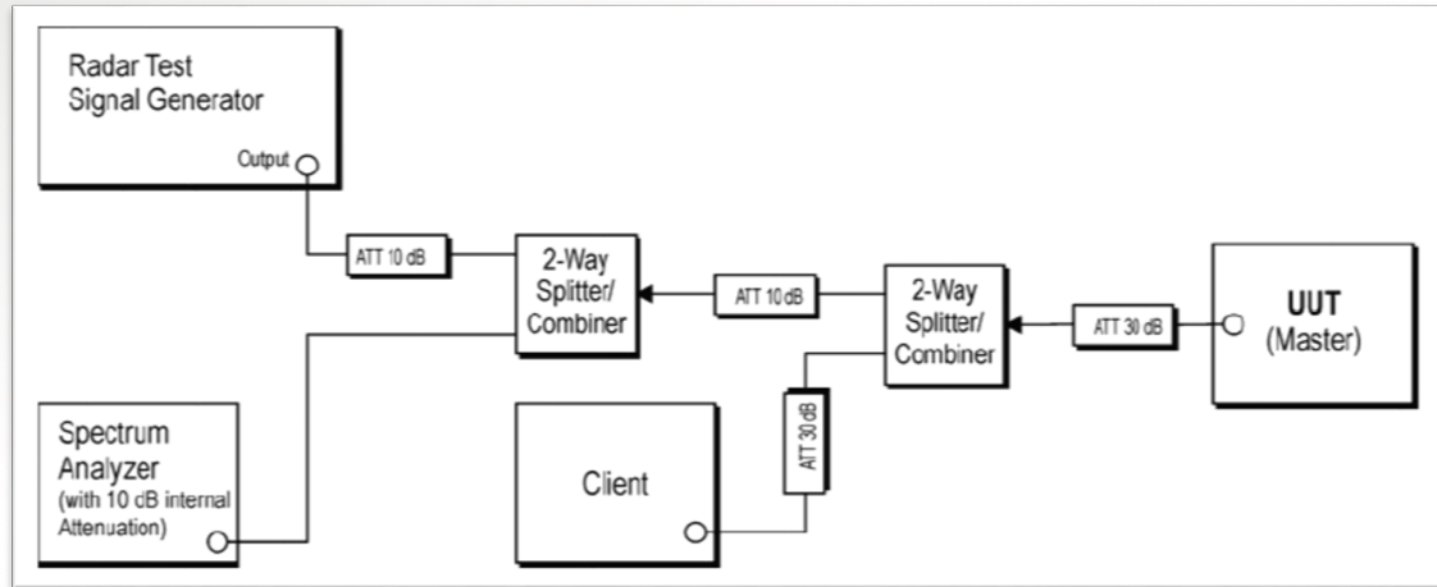




# DFS Tests – Basic Configuration

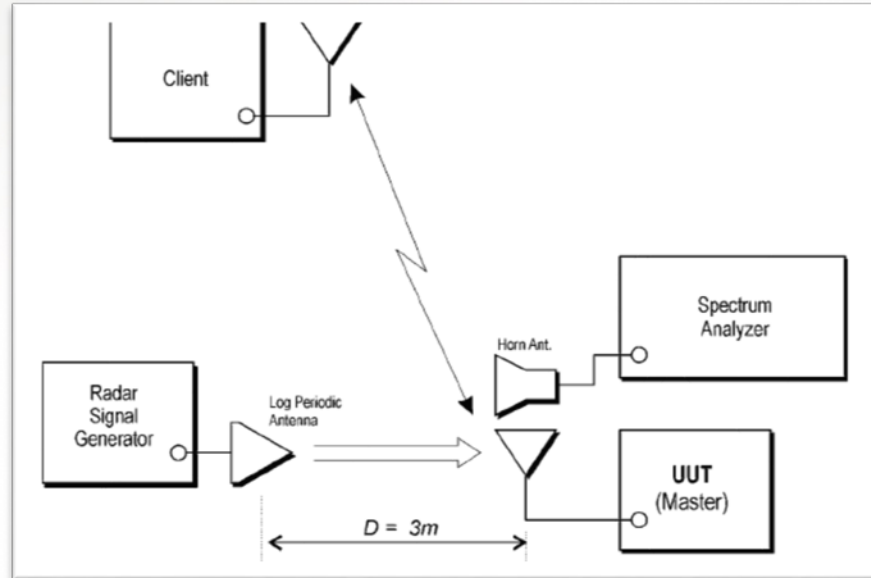
- To perform a test the simulated radar signals are applied to the master device
  - Signals can be radiated
    - ✓ Master device is configured with its lowest gain antenna
    - ✓ Client device is configured with an antenna
  - or conducted
    - ✓ Master and client are connected to test system via couplers
    - ✓ Master and client need to have co-axial adapters on their rf ports to connect to the test equipment

# DFS Conducted Test Method



- Attenuator values may be modified to improve signal levels at the analyzer
- Splitters / combiners could be replaced with directional couplers

# DFS Radiated Test Method



- Play with location of monitoring antenna to obtain best signal levels for CAC and In-Service monitoring

# CAC Tests

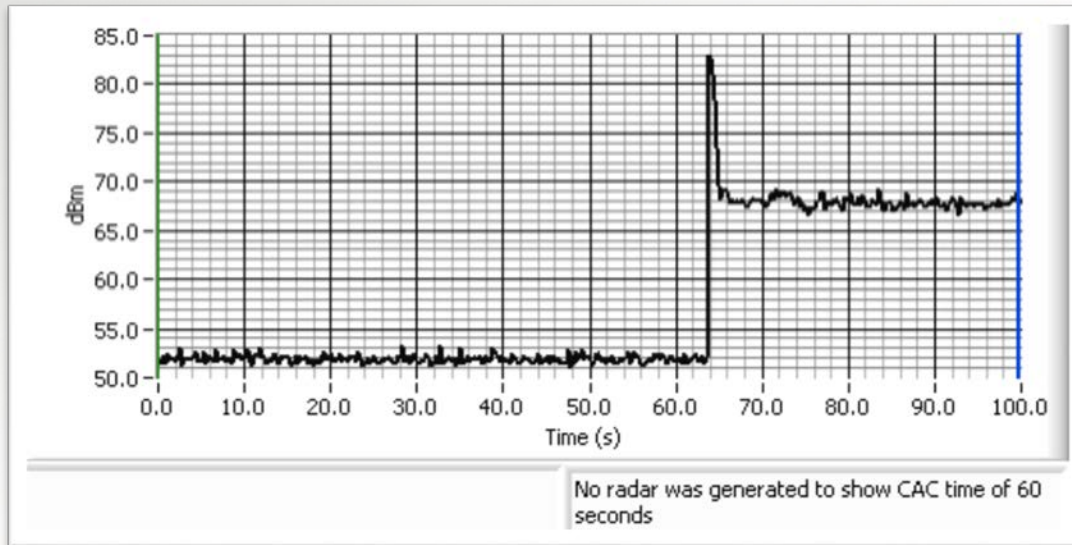
- A plot is made showing the channel from the point the system is powered on to the just after the first transmission
- The test is repeated with a radar signal applied within the first 6(2) seconds of the start of the CAC
  - If the system cannot report the start of the CAC then the start of CAC is assumed to be 60 seconds before the first transmission
  - Plot should show the radar signal and no transmissions from the device

# CAC Tests

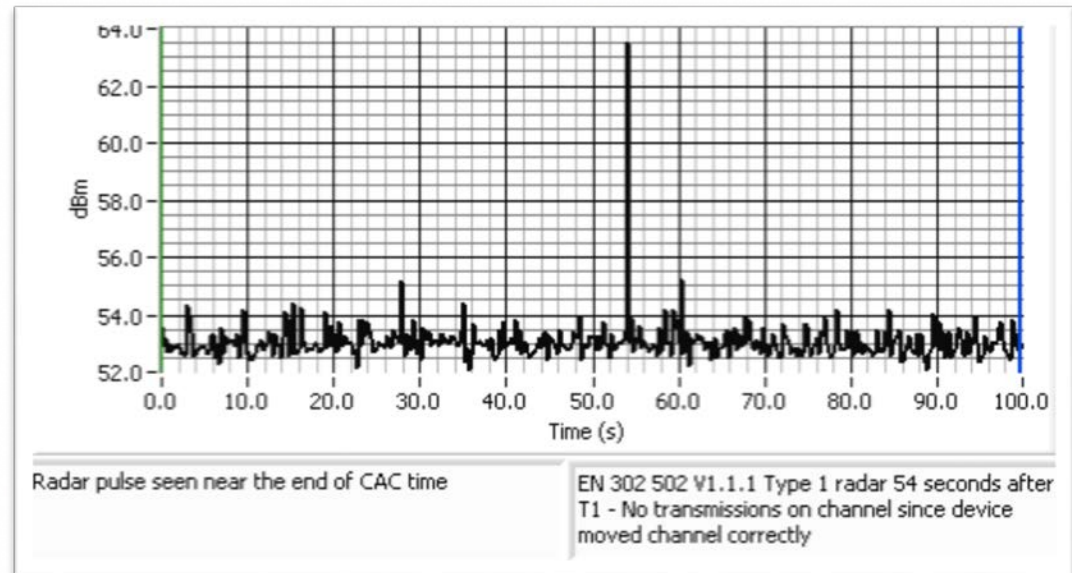
- The test is repeated with a radar signal applied in the last 6(2) seconds of the CAC
  - If the system cannot report the start of the CAC then the start of CAC is assumed to be 60 seconds before the first transmission
  - Plot should show the radar signal and no transmissions from the device
- Radar Waveforms:
  - FCC test method uses one of the types 0-4 waveforms (assumes same algorithm used for CAC and In-Service monitoring)
  - EN 301 893 specifies CAC to be evaluated with the reference radar waveform and probability of detection during CAC performed with types 1, 2, 5 and 6



Plot showing system  
starting 60 seconds  
after start of CAC



Plot showing no system  
transmissions with  
radar signal in last 5  
seconds of CAC



# Detection Bandwidth Tests

- Only required by the FCC
  - Only uses one of the types 0-4 waveforms
  - Has to be performed on the same channel
  - Has to be performed for all channel bandwidth settings of the EUT
- The master device is operational but with no associated client devices
- Radar is applied at the center frequency ( $f_c$ ) of the channel in use ten times at (or below) the threshold level
  - Device is expected to detect 90% (9 of 10)

# Detection Bandwidth Tests

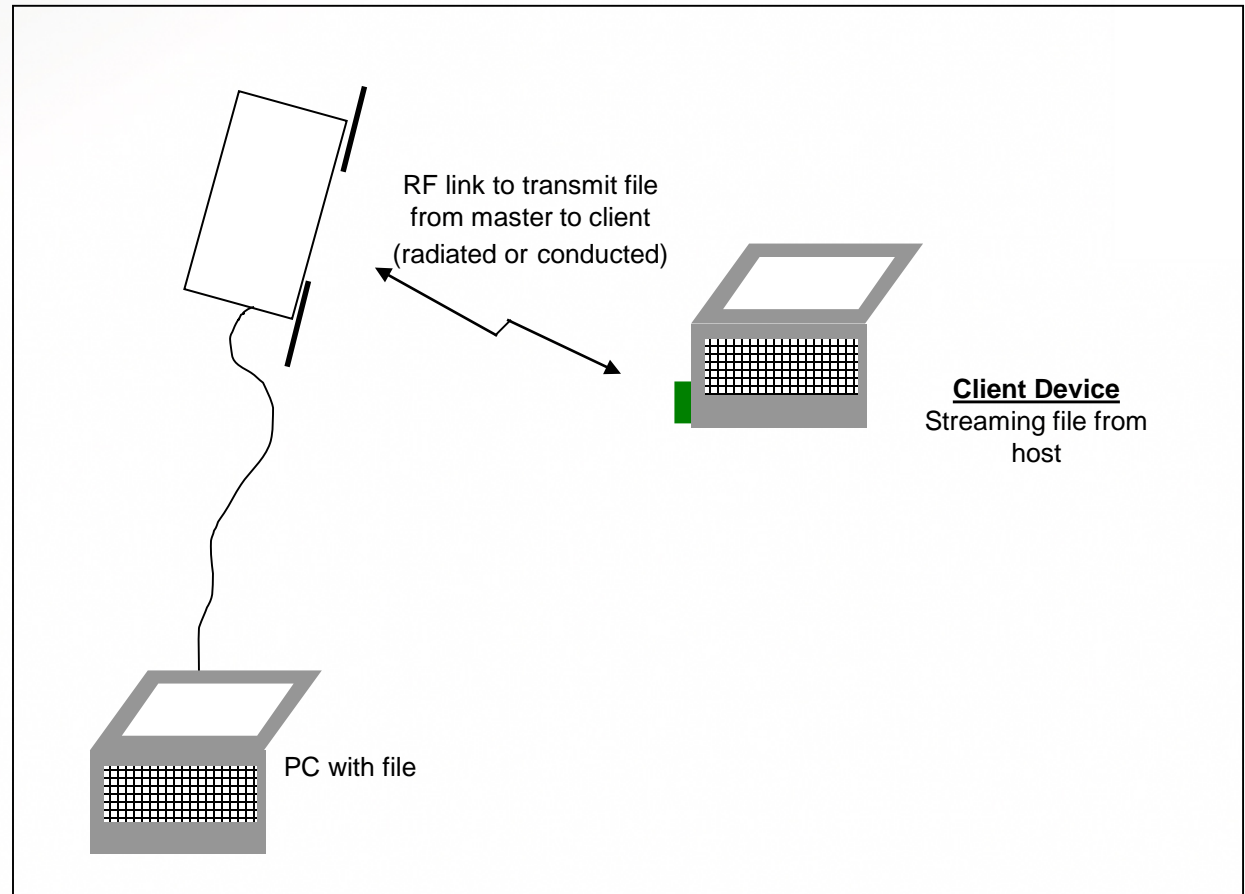
- Frequency of the radar is incremented by 5MHz and test repeated until device fails to detect 90%
- Frequency is the decremented from  $f_c$  in 5MHz steps until device fails to detect 90%
- In the last 5 MHz step, frequency is incremented by 1 MHz steps
- The frequency range over which 90% of the radar signals are detected is the radar detection bandwidth
- Has to be greater than 1000% of the 99% power bandwidth of the EUT's transmitted signal

# In-Service Monitoring Tests

- Tests performed with master device associated with a client device
  - EN 301 893 requires transmissions from master to client to occupy the channel at least 30% of the time
  - FCC method uses a typical file that is streamed from master to client device
    - ✓ Can use ping but must be random
    - ✓ Load the channel at least 17% of the time
  - FCC require the use of an **FCC-approved** master device when evaluating a client device
- Two tests are performed – probability of detection and channel close and move

# In-Service Monitoring Tests

- Master- client configuration





# In-Service Monitoring Tests

- What if I cannot use file transfer?
  - Client device or complete system may not support streaming
  - Need to use a method of data transfer to load the channel  
~17% of the time
    - ✓ If your system does not support that level of activity you will need to justify using a lower occupancy
    - ✓ Generate an even channel utilization
    - ✓ Avoid using transfers that can buffer data – this can lead to high- and low- traffic patterns
- Need to have the proposed data transfer reviewed and okayed by the FCC

# In-Service Monitoring Tests

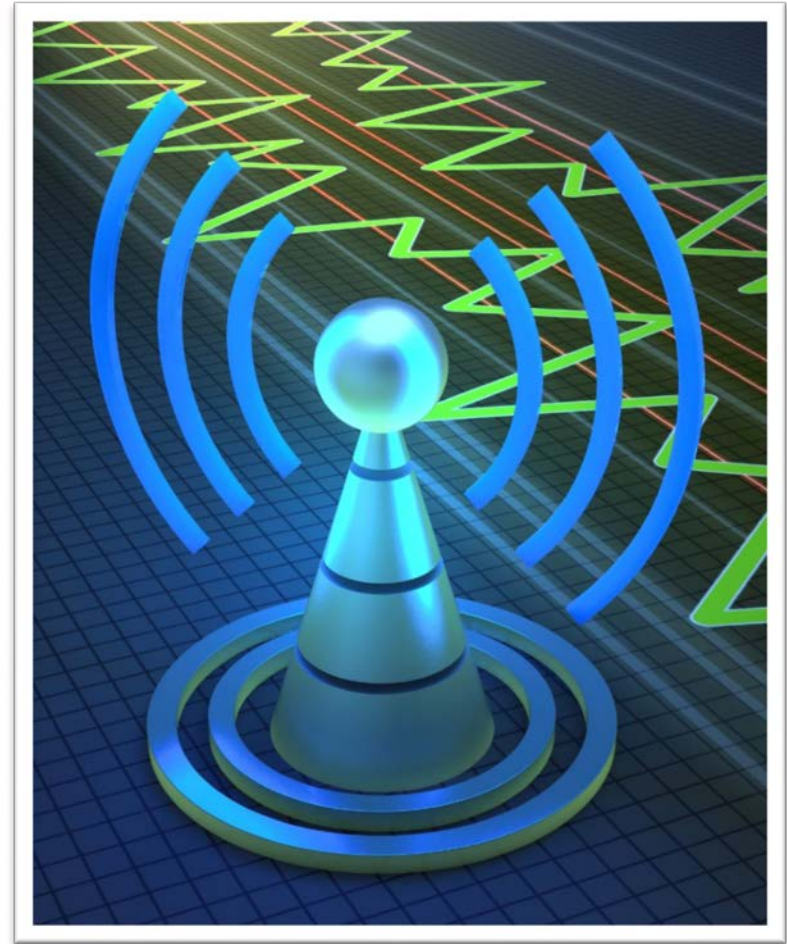
- Probability of detection
  - Each radar type is applied at (or below) the threshold level
  - 20 times (for EN 301 893)
  - 30 times (FCC)
  - Probability is calculated by dividing number of detections by number of trials
  - Test mode recommended (see later slide)
  - Typically performed in one of the bands with spot checks for threshold in the other band(s)
    - ✓ Assumes same detection algorithm used in all bands

# In-Service Monitoring Tests

- Channel move time / channel closing transmission time
  - For FCC measurements are made for one of the radar types 0-4
  - For EN 301 893 measurements are made with the reference radar signal
  - The master device is configured to operate in its normal mode
  - After traffic has been established at the required load on the channel the radar signal is applied
  - The monitoring system captures the radar signal and the channel traffic

# In-Service Monitoring Tests

- Channel move time/  
channel closing  
transmission time
  - Channel move time is measured from the end of the radar signal (noted as  $T_1$ ) to the end of transmissions on the channel
  - Should be less than 10 seconds

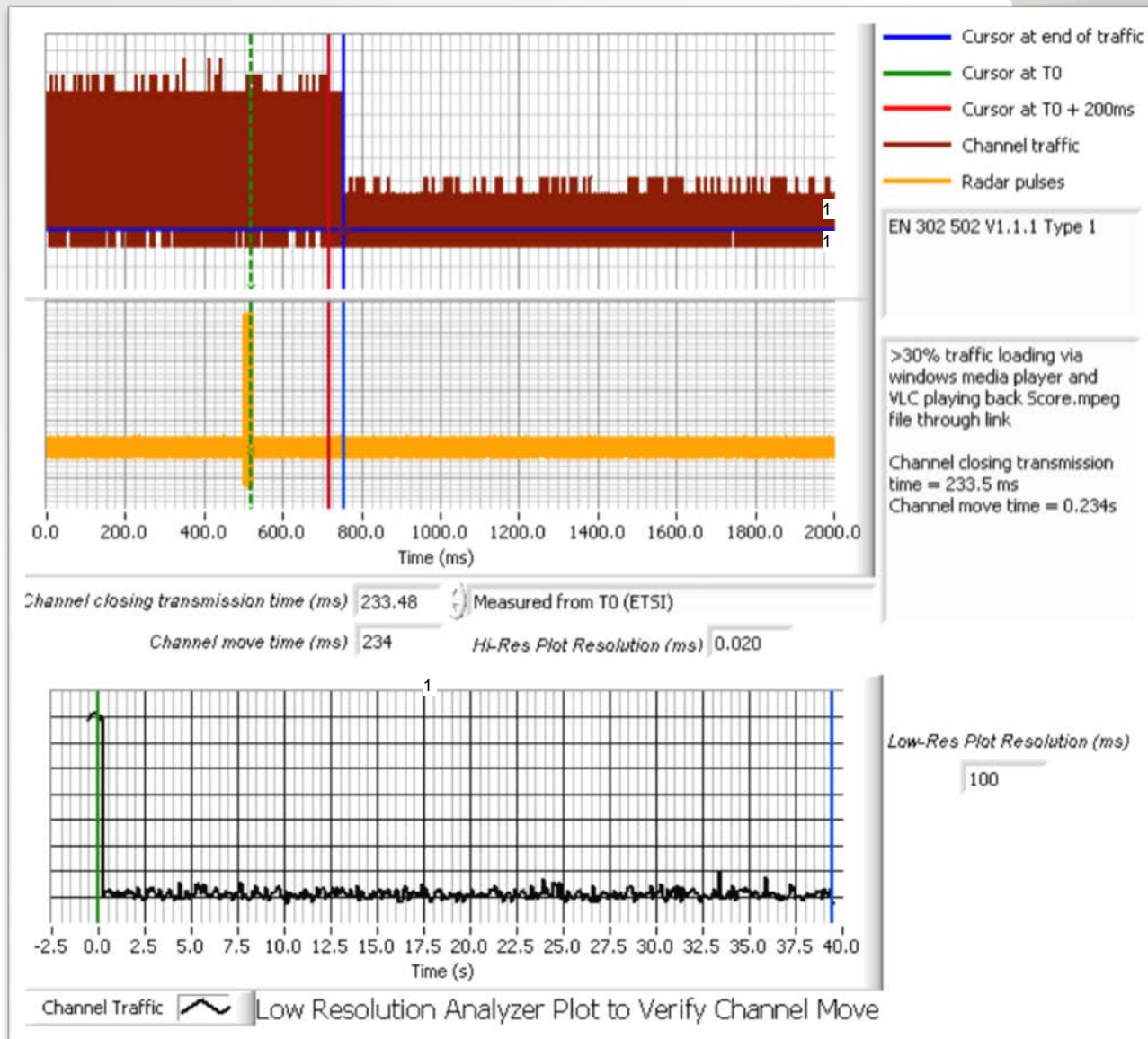


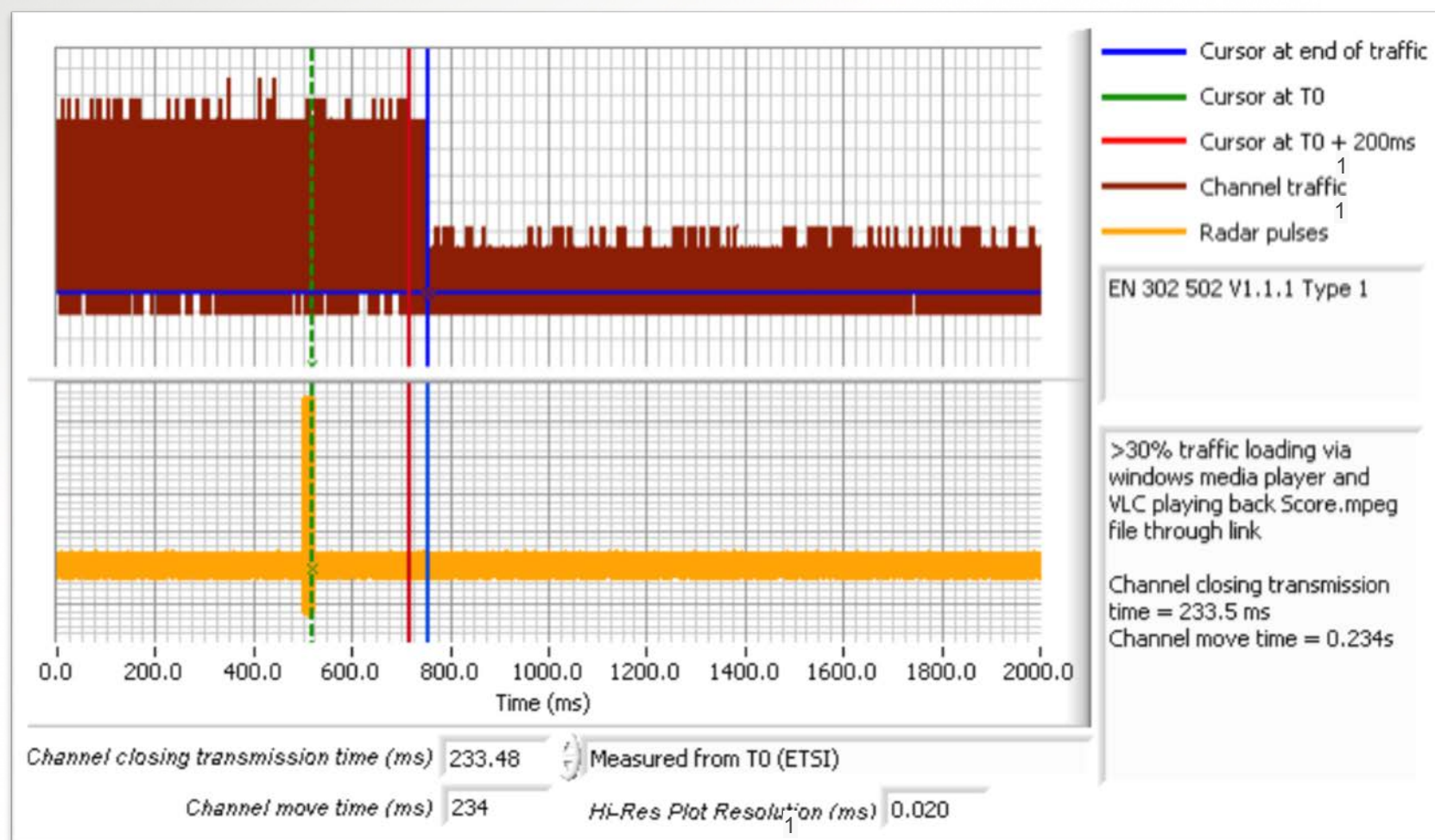


# In-Service Monitoring Tests

- Channel move time / channel closing transmission time
  - Channel closing transmission time - FCC:
    - Total transmission time from  $T_1 + 200\text{ms}$  to the end of the channel move time
    - Should be less than 60ms
  - Channel closing transmission time - EN:
    - Total transmission time from  $T_1$  to the end of the channel move time
    - Should be less than 1s







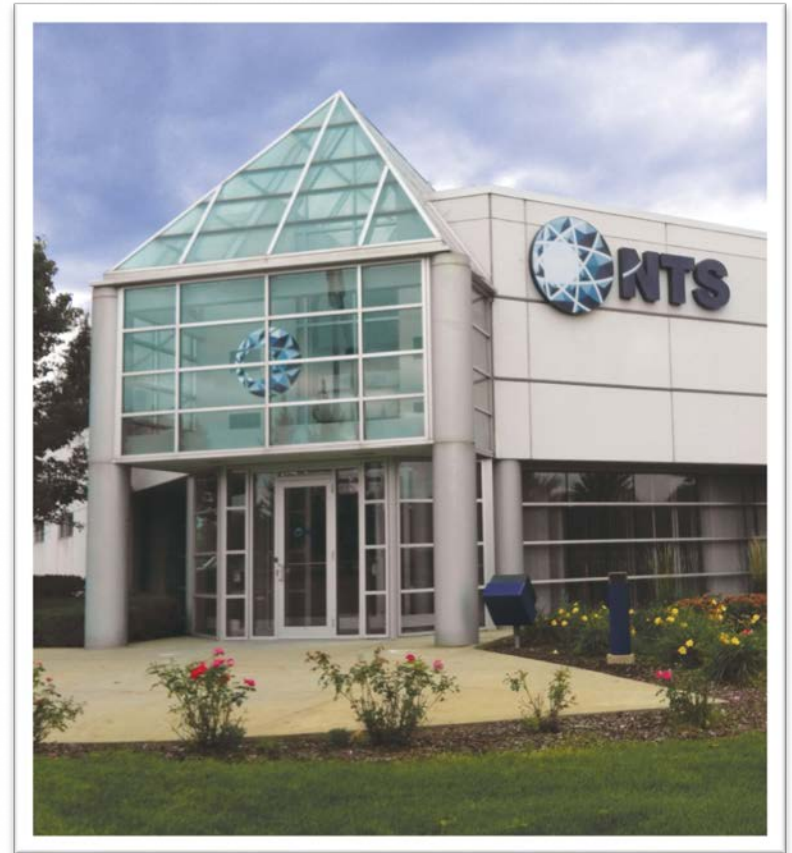
# EUT Test Modes

- Master device features for rapid testing:
  - Ability to report start of CAC
  - Test mode for the probability of detection test and detection bandwidth tests
    - ✓ Inhibits channel move when radar is detected
    - ✓ Channel move replaced by reporting radar detected via serial/Ethernet interface
    - ✓ Mode cannot be available to end-users
    - ✓ For FCC there are 180 trials for each supported bandwidth for in-service monitoring and more for detection bandwidth
    - ✓ For EN 301 893 there are 120 trials for each band and both the lowest and highest supported bandwidths



# Working with Test Labs and TCBs

- Test Labs can assist with:
  - Testing to evaluate algorithms for DFS compliance
  - DFS Testing and Report Development
  - Submittals to TCB
  - Approvals
  - Permissive Changes
- NTS offers all of the services offered above!



# NTS DFS Services

If you are interested in working with NTS for DFS compliance you should:

- 1) Contact your assigned **Sales Representative**
  - **If you don't have one contact NTS for more info**
- 2) Explain your specific DFS objectives
  - **Be prepared to specify your device type(s) and the markets that you would like to certify your device(s) for (i.e. US, EU, or both)**
- 3) Request a project proposal and be prepared to provide samples of your equipment to NTS
- 4) Given the likelihood that your product will fail to meet the DFS requirements on the first pass, please have your firmware engineers prepared to participate in the debugging process if necessary





# What information should I provide prior to testing?

Questions your lab may ask:

- Is the EUT a master device, client device or both?
- Will you bring your own master/client to support the testing?
- What are the operating frequencies for the device?
- What is the lowest antenna gain for your master device?
- What are the operating modes your device supports (e.g. 802.11a/n/ac, 20, 40, 80 and 160 MHz channels)?



# What do I need to bring to the test?

- Ideally bring both master and client devices
  - SSIDs, IP settings, streaming file and media player pre-configured
  - If using test lab master device, ask for these settings/software so you can configure the client
  - If using test lab client device, provide settings ahead of time
  - Significant time can be spent just getting master and client to associate



# What do I need to bring to the test?

- Test modes installed
  - If master does not have sufficient memory for both test mode and normal mode bring two samples
- Coaxial adapters to facilitate connection of a standard N- or SMA-coaxial connector to your master device antenna port
- Lowest gain antenna you anticipate using with the master device



# The FCC Submittal Process

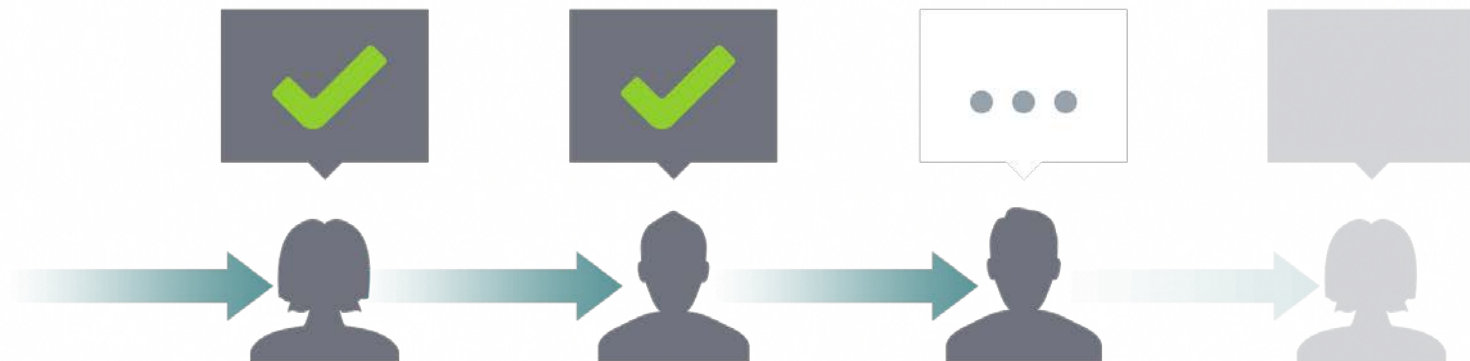
- Devices with radar detection DFS capabilities (master /ad-hoc) have to be tested by the FCC
  - Approval time >> 6 weeks ....
  - Pre-certification sample request and test by FCC will be performed for the foreseeable future
  - Provide detailed operating instructions for the FCC test engineers so they understand how to run the system
  - Usually will attend FCC testing





# The FCC Submittal Process

- Devices without radar detection DFS capabilities (client)
  - Approval time 1 - 2 weeks if approved master device supported the DFS tests
  - If FCC-approved master device was not used, approval will be held up until the master device is approved





# FCC Submittal Documents

- List of all antennas and their gains, with data to support the high and low gain specifications.
  - Gains should account for any feed-cable loss.
- Statement that the test modes used during testing are not available to the general public



# FCC Submittal Documents Client Device

- FCC ID or proposed FCC ID for the Master Device
- Statement declaring that the device is not capable of operating in an ad-hoc mode, or any mode that would allow it to initiate communication in the 5GHz band.



# Next Steps

Please contact NTS for more information about how we can help you with your DFS requirements

[sales@nts.com](mailto:sales@nts.com) or 800-270-2516

