FIRST CONSULTING CASE STUDY | RF VERIFICATION & SPECTRUM COMPLIANCE

# Radiated Spectral Characterization of a Highly Configurable RF Transmit System

PART 1

## The Engagement at a Glance

### Executive Summary

A defense-sector developer of configurable RF systems engaged First Consulting to plan and execute the spectral characterization its government customer requires before the system can be fielded. The system pairs a multi-channel radio/exciter and a 20 W external power amplifier with six interchangeable transmit antennas. Each antenna configuration must be characterized from 20 MHz to 18 GHz under the published measurement rules of an allied government's defense spectrum authority, which uses the data to model interference risk before authorizing the system for use.

First Consulting owns the effort end to end: interpreting the authority's requirements for a radiated measurement, writing the test plan, specifying the chamber and measurement equipment, running the measurements, and producing the datasets, traceability records, and equipment-registration packages the authority reviews.

To deliver on a schedule of roughly ten weeks from award, First Consulting's plan reduces the work to one transmit chain and six configurations that differ only by antenna and mission fill, defines how the authority's power threshold applies to a radiated measurement, and builds measurement-integrity checks and traceability records into every sweep.

### Background and Context

#### The client

The client is a defense-sector developer of highly configurable RF systems, delivering a fielded system as prime contractor to an allied government's defense organization. Unlike conventional radios that operate on fixed channels, systems of this kind are reprogrammed through loadable mission fills, so their emissions change with every hardware and software configuration.

## The system under test

The system combines a multi-channel radio/exciter with an external power amplifier rated at 20 W across 30 MHz to 6 GHz. The radio is configured by a mission fill and drives the amplifier, which feeds one of six transmit antennas depending on the mission:

| Antenna | Frequency range | Characteristics |
|---|---|---|
| Low-band omnidirectional | 20–1000 MHz | Monopole, vertical polarization, 360° azimuth |
| High-band omnidirectional | 800–6000 MHz | Gooseneck, near-omnidirectional, 0 dBi |
| Low-band directional | 30–1000 MHz | Log-periodic |
| Mid-band directional | 500–2500 MHz | Log-periodic, 7 dBi, 77° azimuth beamwidth |
| High-band directional | 2000–6000 MHz | Directional, 7–8 dBi, 70° azimuth beamwidth |
| Wi-Fi survey | 2.4 GHz and 5 GHz | Linear polarization, 4–5 dBi peak |

*The six transmit antennas, each requiring its own characterization dataset.*

## Why characterization was needed

Before the system can be fielded, the defense spectrum authority must authorize its use. To do that, the authority models the interference risk the system poses to neighboring civilian and defense users of the spectrum, which requires an accurate picture of everything the system emits. That includes both intended emissions (the signals a mission fill is programmed to produce) and unintended emissions such as harmonics, clock feed-through, and intermodulation products. The same data also supports the client's radiation hazard (RADHAZ) safety documentation.

## The regulatory driver

The authority publishes specific measurement requirements for highly configurable systems, and data that does not follow them cannot be used. The key requirements are:

- **Frequency range:** from 20 MHz to three times the equipment's highest operating frequency, regardless of what the loaded mission fill uses; for a 6 GHz system, that means 20 MHz to 18 GHz
- **Two measurement sets:** contiguous sweeps across the full range to locate every emission at or above 0 dBm, then targeted sweeps on each of those emissions to measure peak level and emission bandwidth
- **Prescribed settings:** fixed resolution bandwidths above and below 1215 MHz, peak detector, max-hold trace, and a displayed noise floor at least 10 dB below the equipment's own noise
- **Bandwidth definition:** the width at 20 dB below peak, with a 10 dB fallback or an "unidentifiable" result where 20 dB cannot be determined reliably

- **A dataset per configuration:** a new set of measurements for every hardware change and every new mission fill
- **Data format:** one CSV file per sweep, containing analyzer settings and frequency/level pairs, named to a defined convention so each file can be traced to its equipment and mission fill

Results are also recorded on the authority's equipment-registration form, one per transmitting antenna. Final acceptance of the work rests with the government customer, not the client.

## Scope of the engagement

- **Requirements interpretation:** applying the authority's rules to this system and defining each configuration to be measured
- **Planning:** a test plan, a schedule including anechoic chamber time, and a specification of the facility and measurement equipment
- **Execution:** radiated contiguous and targeted measurements for all six antenna configurations
- **Reporting:** CSV datasets, test-run and emission records, equipment-registration packages, and a test report with supporting evidence
- **Review support:** answering the authority's questions by email or phone during its review period

## Constraints

- **Schedule:** test plan due three weeks from award, chamber time confirmed by week four, and the test report and evidence due two to two and a half months from award
- **Client-furnished hardware:** the client supplies the system hardware, antennas, and a support engineer for setup and configuration; the test facility and measurement equipment are supplied to First Consulting's specification
- **Export control:** the subject matter is controlled under the International Traffic in Arms Regulations (ITAR), which governs who can work on it and how technical data is handled
- **Deliverable process:** every deliverable is submitted in draft for client review, with final versions due within five working days of receiving comments, and any potential delay reported in writing within three working days
- **Long review window:** the government customer allows up to six months to review the report and data

## Contract structure

The work is performed under a subcontract statement of work that makes First Consulting responsible for planning and executing the full effort.

## Key Challenges

- **A threshold built for a different measurement:** the authority's 0 dBm threshold is defined at the equipment output, so it had to be applied defensibly to an over-the-air measurement made through the antenna
- **Wide coverage, six times over:** covering 20 MHz to 18 GHz at the prescribed settings takes 29 sweeps and three measurement antennas per configuration, or at least 174 contiguous datasets in all
- **Defining a configuration:** operational mission fills vary too widely to measure directly, so each antenna configuration needed a representative, repeatable, and defensible way to be characterized
- **Proving the measurement:** analyzer-generated products can look like real emissions, the noise-floor rule cannot always be applied as written, and low frequencies add chamber uncertainty
- **A compressed schedule:** planning, facility arrangements, chamber testing, and reporting all had to fit within about ten weeks of award
- **Little room for a second attempt:** a problem found during the government's review of up to six months would mean re-booking the chamber and repeating measurements long after testing ended
- **What was at stake:** without accepted data, the system cannot be authorized or fielded, and the client's safety documentation and delivery to its customer would slip

## Is This Relevant to You?

First Consulting's approach fits organizations facing any of the following:

- A configurable or software-defined RF system that needs spectral data before it can be fielded
- Regulator measurement requirements that need interpreting for a specific system or radiated test setup
- Test facilities and hardware already in hand, but no test plan or dedicated team to run them
- A fixed delivery date that leaves no room to repeat chamber testing

**To discuss an RF characterization or spectrum compliance program, contact First Consulting.**

> **Continue to Part 2 for the details.** Part 2 covers the challenges the effort had to overcome, the V&V objectives and acceptance criteria, the team structure and phased methodology behind the work, and why this approach matters.

PART 2

# Inside the Engagement

This part goes deeper into the effort: what made it difficult, what the team set out to verify and validate, how the work is staffed and sequenced, and how every measurement is kept valid and traceable.

## The Challenge

The authority's requirements are precise, but they are written to cover a wide range of equipment and measurement setups. Turning them into a plan that would produce acceptable data for this system, on a short schedule and with little room for a second attempt, raised several problems.

### A threshold defined at the equipment output, applied to a radiated measurement

The authority's 0 dBm threshold is defined as the level at the output of the system under test. When the system includes its antenna and the measurement is made over the air, that definition needs interpretation: the level arriving at the analyzer depends on the test distance, the measurement antenna's gain, and the losses in the receive path. Without a clear, defensible definition, the team could not decide which emissions qualify for targeted measurement, and the authority could not compare the results across configurations.

### 20 MHz to 18 GHz, six times over

Covering the full range at the prescribed resolution bandwidths takes 29 contiguous sweep spans per configuration and three different measurement antennas. Across six configurations, that is at least 174 contiguous datasets before a single targeted measurement, and every one needs its own noise-floor baseline and record.

| Measurement | Resolution bandwidth | Span width | Spans per config | Measurement antenna |
|---|---|---|---|---|
| Contiguous, 20–1215 MHz | 100 kHz | 100 MHz | 12 | Biconical (20–120 MHz), hybrid log-periodic (120–1215 MHz) |
| Contiguous, 1215–18,000 MHz | 1 MHz | 1000 MHz | 17 | Double-ridged waveguide horn |
| Targeted, below 1215 MHz | 10 kHz | As needed | Per flagged emission | As above |
| Targeted, above 1215 MHz | 100 kHz | As needed | Per flagged emission | As above |

*Measurement structure for each of the six antenna configurations.*

## Defining what counts as a configuration

The authority requires a new dataset for every combination of hardware and mission fill. Operational mission fills vary widely in frequency, waveform, and timing, so measuring them directly would be open-ended and hard to repeat. The team needed a way to characterize each antenna configuration that was representative, repeatable, and defensible to the authority.

## Proving the measurement, not just the emission

A spectrum analyzer driven too hard can generate its own intermodulation products, which look exactly like the system's unintended emissions. The noise-floor rule raised a second problem: it requires the floor to sit at least 10 dB below the equipment's own noise, but in many spans a well-behaved transmitter produces no measurable noise at all, leaving nothing to compare against. And below about 300 MHz, test distances in a typical chamber put the antennas in each other's near field while absorber performance falls off, adding measurement uncertainty near the bottom of the range.

## A compressed schedule

Planning, facility arrangements, execution, and reporting all had to fit within about ten weeks of award:

| Time from award | Milestone |
|---|---|
| Week 3 | Test plan delivered |
| Week 4 | Anechoic chamber time confirmed |
| Weeks 8–10 | Test report and supporting evidence submitted |
| Up to 6 months after submission | Government review, with First Consulting answering queries |

*Contractual schedule, shown relative to award.*

## Little room for a second attempt

The work is not accepted until the government customer accepts the data, and its review can take up to six months. A gap in coverage, a measurement artifact, or a formatting problem found late in that window would mean re-booking the chamber, reassembling the system, and repeating measurements months after the team had moved on.

## What was at stake

Without accepted spectral data, the system cannot be authorized for use or fielded, and the client cannot complete its safety documentation. Delays or rejected data would push back the client's delivery to its customer.

## V&V Objectives

This effort verifies the system's emissions against the authority's measurement requirements, and validates that the resulting data is fit for its purpose: the authority's interference modeling and authorization decision.

### Verification objectives

- **Complete coverage:** every configuration measured from 20 MHz to 18 GHz with no gaps between spans
- **Every qualifying emission characterized:** peak level and emission bandwidth recorded for each emission at or above 0 dBm, with the basis (20 dB, 10 dB, or unidentifiable) documented
- **Valid measurements:** prescribed analyzer settings, a confirmed noise-floor margin in every span, and a check that no emission was generated by the measurement system
- **Traceable records:** each data file linked to its configuration, test-run record, and registration package

### Validation objectives

Data the authority cannot use has no value, however accurate it is. The team therefore validates the output against the authority's needs: files in the required format and naming convention, levels reported on a consistent basis across configurations, registration entries that agree with the measured data, and clear annotation of any emission whose bandwidth could not be identified.

### Program objectives

Alongside the technical goals, the statement of work and test plan set the delivery commitments and acceptance criteria that define success:

| Objective | Measure | Target |
|---|---|---|
| Test plan | Time from award | 3 weeks |
| Facility | Chamber time confirmed | 4 weeks from award |
| Test report and evidence | Time from award | 2–2.5 months |
| Responsiveness to review | Comments incorporated into final deliverables | Within 5 working days |
| Schedule transparency | Written notice of potential delays | Within 3 working days |
| Frequency coverage | Per configuration | 20 MHz–18 GHz, no gaps |
| Noise-floor margin | Per measurement span | 10 dB or more |
| Measurement linearity | Level change with 10 dB added attenuation | Within ±1 dB |

*Delivery commitments and measurement acceptance criteria.*

## Approach and Methodology

First Consulting's approach is to make a complex requirement simple to execute: one transmit chain, one test geometry, and one record structure, repeated for each of the six configurations. Keeping the plan simple shortens chamber time, reduces the chance of error, and makes the results easy for the authority to review.

### Team structure

| Role | Focus |
|---|---|
| RF Test Lead | Requirements interpretation, test plan authorship, technical point of contact for the client, execution oversight, and report sign-off |
| RF Test Engineer | Chamber setup, receive-path characterization, measurements, and test records |
| Client support engineer | Provided by the client to set up and configure the system and load mission fills |

*Team composition.*

### A phased methodology

| Phase | Timing | Key activities |
|---|---|---|
| 1. Requirements analysis | Weeks 1–3 | Interpret the authority's rules for a radiated measurement; define the system under test and threshold basis; define the configurations |
| 2. Test planning | By week 3 | Test plan covering equipment, configurations, setup, geometry, step-by-step procedures, and record templates; client review |
| 3. Facility and equipment | By week 4 | Specify chamber, measurement antennas, analyzer, attenuator, and cabling; confirm chamber time |
| 4. Setup and verification | During chamber time | Assemble the system as fielded; characterize receive-path losses; load antenna correction tables; capture equipment-off baselines |
| 5. Contiguous sweeps | During chamber time | 29 spans per configuration; flag every emission at or above 0 dBm |
| 6. Targeted sweeps | During chamber time | Measure peak level and emission bandwidth of each flagged emission |
| 7. Reporting and registration | By weeks 8–10 | CSV datasets, test records, registration package per antenna, test report |
| 8. Review support | Up to 6 months after submission | Answer the authority's questions during its review |

*Program phases and timing relative to award.*

## Measuring what the authority actually needs

To resolve the threshold question, the test plan defines the system under test as the complete transmit configuration: radio/exciter, power amplifier, interconnects, and antenna. Its output is therefore the radiated emission, expressed as effective isotropic radiated power (EIRP). A calibrated measurement antenna receives each emission, and a correction table loaded into the analyzer converts the reading to EIRP, accounting for cable loss, attenuator loss, measurement-antenna gain, and test distance. The 0 dBm threshold is applied to that corrected value, giving the authority one consistent basis for every emission in every configuration.

## Purpose-built characterization mission fills

Instead of measuring open-ended operational mission fills, the test plan defines one characterization fill per configuration. Each transmits at full rated output on three fixed frequencies near the bottom, middle, and top of the antenna's usable range, using the radio's narrowest waveform and cycling through the frequencies in turn. Because each transmission occupies only a narrow slice of spectrum, it does not mask spurious emissions elsewhere in a span. The fills contain no reactive (detect-and-respond) modes, so the authority's additional reactive-mode measurements do not apply.

| Configuration | Antenna | Characterization frequencies |
|---|---|---|
| CFG-01 | Low-band omnidirectional | 40, 500, and 980 MHz |
| CFG-02 | High-band omnidirectional | 850, 3400, and 5900 MHz |
| CFG-03 | Low-band directional | 170, 580, and 990 MHz |
| CFG-04 | Mid-band directional | 520, 1500, and 2450 MHz |
| CFG-05 | High-band directional | 2100, 4000, and 5900 MHz |
| CFG-06 | Wi-Fi survey | 2450, 5200, and 5800 MHz |

*Test configurations. All six share the same radio/exciter and power amplifier.*

## A simple, fixed test geometry

The full system is installed in an anechoic chamber and arranged as fielded. The test and measurement antennas sit at the same height, 3 m apart (10 m where the chamber allows), both vertically polarized, with directional antennas pointed at the measurement antenna. The radio is controlled through a wired link and filtered feedthrough, and all wireless links are disabled so they cannot appear in the data. The plan also covers practical safety: battery or filtered chamber power, cool-down periods to keep the amplifier within limits, and confirmation that the chamber is clear before the transmitter is keyed.

## Measurement integrity built into every span

- **Matched baselines:** an equipment-off noise-floor capture before every span, using exactly the settings of the active measurement

- **A workable noise-floor rule:** where the transmitter produces no measurable noise in a span, the floor is instead required to sit at least 10 dB below the 0 dBm threshold, declared openly in the plan as a deviation rather than left to interpretation
- **Artifact check:** for every emission at or above 0 dBm, 10 dB of analyzer attenuation is added; a real emission stays within ±1 dB, while an analyzer-generated one drops or disappears and triggers a repeat
- **Full exercise of the system:** max-hold captures continue until the mission fill completes at least two full cycles, so every programmed frequency and its harmonics are captured
- **Calibrated settings:** peak detector, max-hold trace, 1001 trace points for contiguous sweeps, and video bandwidth and sweep time kept in calibrated ranges
- **Visual review:** each trace inspected for coverage gaps, overload, clipping, and artifacts before it is saved

### Traceability from sweep to submission

Every configuration carries an ID that ties together its equipment, data, and paperwork. Each contiguous-sweep file gets a test-run record listing configuration, sweep range, operator and verifier, equipment serial numbers, analyzer settings, and noise-floor result. Each flagged emission gets its own record linking the contiguous sweep that found it to the targeted sweeps that characterize it. These records feed the registration package for each antenna, which is cross-checked so that serial numbers, mission-fill IDs, and filenames agree everywhere. Data from one configuration is never used to complete another's package, and a checklist at the end of each configuration confirms full coverage and a record for every file and emission before the antenna is changed.

### Data in the authority's format

Every sweep is exported as its own CSV file containing the analyzer configuration and frequency/level pairs, with levels already corrected to EIRP. Filenames follow the authority's convention of frequency range, equipment, configuration, and mission fill, using underscores in place of spaces and decimal points so the files load cleanly into the authority's tools. Any emission whose bandwidth cannot be identified is listed with its filename in the transmittal that accompanies the data.

### Governance and communication

Regular weekly or bi-weekly meetings with the client track open questions and actions. Each deliverable goes to the client as a draft, and final versions follow within five working days of comments. Potential delays are reported in writing within three working days with their cause, impact, and a revised date, and any safety concern during chamber work stops testing until both parties agree it is safe to continue.

## Why It Matters

Spectrum authorities ask for detailed, tightly specified data before they will authorize configurable RF systems, and the review that follows is slow. Submissions tend to fail in predictable ways: coverage gaps, measurement artifacts mistaken for emissions, and data the authority cannot use. First Consulting designed this engagement to avoid all three.

### What this demonstrates

- **Regulatory interpretation:** turning a regulator's general requirements into specific, defensible decisions for a particular system and test method, and documenting them openly
- **RF measurement discipline:** radiated characterization from 20 MHz to 18 GHz with calibrated corrections, matched noise-floor baselines, and built-in artifact checks
- **End-to-end ownership:** one team accountable from requirements to delivered data, working with client-furnished hardware and facilities
- **Verification across regulated industries:** the same structured planning, traceability, and evidence standards First Consulting applies to medical-device software verification