Technology Transfer Award

For research that resulted in a technological solution with widespread and/or significantly measurable societal utilization, with related impact on a global challenge or issue.

Radiofrequency Measurements to Address Electromagnetic Compatibility between Radar Altimeters and 5G Base Stations

NOMINATION ABSTRACT:

This team of researchers from the Institute for Telecommunication Sciences (ITS) rapidly and effectively responded to concerns about coexistence between new C-Band 5G base stations and existing safety-of-life airborne radar altimeters by designing and performing measurements and technical analyses to assess whether 5G might interfere with the altimeter receivers. They worked with a multi-stakeholder group including over 100 representatives of the NTIA, FCC, FAA, and eight other federal agencies; three cellular carriers; three airlines; and four aircraft and radalt manufacturers. With open peer review by all stakeholders, ITS researchers designed, built, tested, and flew a novel airborne 5G radiation measurement system that exhaustively explored, through calibrated radiated measurements, the three-dimensional aerial radiation patterns and emission spectra of 5G base station transmitters then being commercially deployed in the United States. The group's work demonstrated that 5G transmissions should not interfere with radar altimeters that incorporate suitable altimeter receiver filters and suppression of 5G-base stations' out-of-band and skyward emissions. The data publicly released by this team was instrumental in resolving the grave concerns that 5G transmissions near airports might interfere with radio altimeters that had delayed full commercial deployment of 5G commercial services. Cellular operators had collectively paid $80B in an FCC auction that concluded in spring of 2021 for licenses to transmit in frequency bands adjacent to those assigned to radio altimeters, but FAA concerns about potential interference into radio altimeters led to a delay in the cellular operators' ability to fully utilize the spectrum. The data provided by ITS's research were a major contributor to resolving the issue. Detailed engineering analysis of both systems provided objective and quantifiable characteristics of out-of-band and in-band signals and yielded interference protection criteria of radalts which were submitted to the FCC on March 31, 2023. ITS also collaborated with the FAA to develop mitigation methods and issue new airworthiness directives so 5G base stations and radalts could safely co-exist. On July 1, 2023, cellular operators were able to complete full-power deployments across the C-Band and take full advantage of their multi-billion dollar investment in spectrum licenses.

THE BACKGROUND CONTEXT SHAPING THE NEED AND INTEREST IN THIS RESEARCH.

In early 2022, AT&T and Verizon were preparing to commission 5G base stations throughout the U.S. using newly purchased licenses in the range 3.7-3.98 GHz (part of the C Band). Aviation authorities and airlines raised grave concerns that 5G transmissions near airports might interfere with radio altimeters (radalts) that operate in the range 4.2-4.4 GHz and lead to aircraft crashes, so full 5G commercial deployment in the C Band was delayed. Between them, these two carriers had paid about $69B of the $80B in total proceeds generated by the Federal Communications Commission's (FCC) recent auction of licenses to transmit in the C Band and they were anxious to begin realizing the benefit of their investment.

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THE BACKGROUND CONTEXT SHAPING THE NEED AND INTEREST IN THIS RESEARCH. (CONTINUED)

However, the Federal Aviation Administration (FAA) had issued an airworthiness bulletin warning of potential adverse effects on radio altimeters from 5G transmissions. This warning played a role in causing significant disruptions for aviation operations in the U.S.; in fact, some airlines began canceling flights. Major news outlets carried the story which resulted in headlines that caught the attention of policymakers at the local, state, and federal levels. Negotiations between the FAA and cellular operators led to a compromise solution under which C Band auction winners agreed to postpone initial launch until they could come to agreement with the FCC on establishing operational parameters to ensure safe co-existence. The initial agreement reached some months later allowed telecom operators to launch with restrictions around airports.

In the meantime, the Department of Defense (DoD) had its own concerns about possible interference between 5G and radalts. DoD was researching spectrum co-existence solutions between 5G networks and airborne radars operating in the same bands at bases with military airports. The DoD's Hill Air Force Base (AFB) deployed a private 5G cellular network and began experiments around spectrum sharing between commercial networks and highly sensitive DoD assets, including radalts as well as several other types of radars. In support of this project, DoD had an agreement in place with the Institute for Telecommunication Sciences (ITS) to obtain subject matter expertise to design appropriate co-existence testing.

To speed resolution of the disagreement between the FAA and cellular operators on how to reach interference-free coexistence, Hill AFB organized a Joint Interagency Fifth Generation Radar Altimeter Interference (JI-FRAI) multi-stakeholder group to agree on a test design that would provide trusted ground truth data to guide the negotiations, and re-scoped its agreement with ITS to put ITS in charge of the testing. The NTIA, FCC, and FAA, and eight other federal agencies; three cellular carriers; three airlines; and four aircraft and radalt manufacturers were among those who substantively participated in the JI-FRAI Program.

THE COMPELLING FACETS OF THE, OR THIS TEAM/PERSON'S, RESEARCH AND WHAT WAS THE ULTIMATE KNOWLEDGE AND INSIGHT DISCOVERED.

The researchers named in this nomination planned and implemented first-of-their-kind quick-reaction over-the-air 5G transmitter measurements and analyses, working in collaboration and in parallel with other researchers to ensure full transparency and the most efficient use of resources. The JI-FRAI program test design comprised four major phases of testing: (1) bench testing with hardline-injected 5G interference signals; (2) in-flight radalt performance testing in the presence of 5G radiated signals; (3) EIRP measurements of on-the-ground radalt emissions from taxiing aircraft at civilian and military airfields; and (4) controlled, calibrated measurements of emission spectra and three-dimensional radiated field strength patterns around 5G base station transmitters deployed in 3700–3980 MHz in the US.

Over 100 JI-FRAI participants previewed the test plans and results, which ITS also shared internationally with other spectrum regulators. This full transparency inspired trust in the results and led to consensus on a technical solution to coexistence that was accepted by all parties.

MITRE, already under contract with Hill AFB, organized bench testing, in which radalt units were operated in a laboratory setting with nominal transmissions and ground-bounce echo returns running in hardline (closed) loops between the transmitter and receiver sections. Then 5G radio interference was introduced into those loops, its power level being adjusted to cause degradation to the radalt receivers. This bench testing identified power thresholds for interference within radalt receiver circuits and provided information on underlying physical interference mechanisms.

Building on this work and on ITS's decades long expertise in electromagnetic compatibility studies involving radars, ITS led the remaining three phases involving over-the-air testing in realistic conditions. ITS designed in-flight Joint Test and Evaluation (JT&E) of radalt performance in the presence of radiated high C band 5G base station signals under controlled conditions (phase 2). Selected aircraft carrying representative examples of a wide variety of radalts (mostly military but some civilian and some dual-use) were used for JT&E at Hill AFB in Utah (near Salt Lake City) and at Majors Airfield at Greenville, Texas (near Dallas). In these flight tests, aircraft with radalts were repetitively flown in closed-loop routes, such as traffic patterns. Each route was first flown while nearby 5G base station transmitters were turned on and then flown again with them turned off, and radalt performance was assessed in 5G base station transmitter-on versus transmitter-off conditions.

THE COMPELLING FACETS OF THE, OR THIS TEAM/PERSON'S, RESEARCH AND WHAT WAS THE ULTIMATE KNOWLEDGE AND INSIGHT DISCOVERED. (CONTINUED)

The third phase of the JI-FRAI test design measured emitted radalt power radiated from aircraft on the ground while the aircraft were sitting in gate areas and taxiing at a major airport (for civilian airliners) and at a military airfield (for military aircraft). These emissions were needed for comparison to predictions of such emissions that had been produced in separate work projects by other groups, some of which tried to take into account stray or background radalt-to-radalt radiation emanating from planes on the ground and coupled into nearby planes that are in-flight, landing at airports to determine radalt interference thresholds. For this testing, the ITS researchers measured on-the-ground emissions from airliners at Denver International Airport (DIA) and from F-16 jet fighters at Buckley Space Force Base (SFB). The raw data taken in those environments were converted to effective isotropic radiated power (EIRP) levels radiating from underneath the on-the-ground aircraft bellies.

The fourth phase of the JI-FRAI test design was the characterization, via carefully calibrated radiated measurements, of (a) the three-dimensional aerial radiation patterns; and (b) the emission spectra of 5G base station transmitters that are being built and sold by the three known manufacturers of US 5G n77 band equipment then under deployment in the United States. The task of measuring spatial radiation patterns and emission spectra and establishing the validity of independent height-above-ground equipment was led and accomplished by ITS.

Between January and June 2022, and working with the support of the U.S. Army, Verizon, and AT&T, and in collaboration with the FAA and the FCC, ITS engineers performed detailed, precision measurements of aerial radiation patterns of low C band (3300 3600 MHz) and high C band (3700 3980 MHz) multiple input multiple output (MIMO) transmitter arrays incorporated in the four radio models produced by the three known manufacturers of U.S. n77 band (3300 3980 MHz) 5G transmitter equipment being deployed in the United States.

All the measurements were performed via radiated 5G base station emissions at the U.S. Department of Commerce (DoC) Table Mountain Radio Quiet Zone (Table Mountain) north of Boulder, Colorado. ITS engineers rapidly tailored an innovative computer-controlled measurement system to measure 5G ground and skyward emissions for all types of 5G base stations being deployed in the U.S. Army helicopters were coordinated and specially equipped for this purpose and ITS engineers operated the measurement system in the back seats of these helicopters as they flew above, below, around, and over the tops of every manufacturer's 5G tower.

Results showing insignificant unwanted emissions and skyward transmissions up to 1000× less than those on the ground gave confidence that 5G can coexist with radalts equipped with suitable receive filters, and thus that 5G base stations as currently built would not cause interference in the radalts' band.

"The Institute for Telecommunication Sciences in Boulder exemplifies the evidence-based policymaking that is NTIA's hallmark," said Alan Davidson, Assistant Secretary of Commerce for Communications and Information and NTIA Administrator. "By producing objective data that the public can trust, ITS aided federal agencies working to ensure airline safety while also promoting new 5G wireless deployments. Thank you to CO-LABS for recognizing the terrific efforts of NTIA's Colorado colleagues."

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Technology Transfer

ITS Institute for Telecommunication Sciences

Boulder, Colorado

HOW THIS RESEARCH HAS BEEN APPLIED, UTILIZED, COMMERCIALIZED OR OTHERWISE ADOPTED OUTSIDE THE LAB

A summary of the research findings was published in NTIA Technical Report TR-22-562, "Measurements of 5G New Radio Spectral and Spatial Power Emissions for Radar Altimeter Interference Analysis," (available at https://its.ntia.gov/publications/3289.aspx) in October of 2022, as was the data underlying the report. Detailed engineering analysis of both systems provided objective and quantifiable characteristics of out-of-band and in-band signals and yielded interference protection criteria of radalts which were submitted to the FCC on March 31, 2023. ITS also collaborated with the FAA to develop mitigation methods so 5G base stations and radalts could safely co-exist.

In early 2023, the FAA issued an airworthiness directive mandating that all planes used in scheduled passenger or cargo flight operations have 5G C-Band-tolerant radio altimeters, or otherwise install an acceptable radio frequency filter. The collaboration between the FAA, the FCC, ITS, wireless companies, aviation stakeholders and other federal agencies, in which ITS played a central role, produced the data required to resolve concerns about coexistence between 5G and radio altimeters.

On July 1, 2023, cellular operators were able to complete full-power deployments across the C-Band and take full advantage of their multi-billion dollar investment in spectrum licenses.

The novel airborne 5G radiation measurement system designed, built, tested, and flown for this effort was deliberately engineered for use by future spectrum coexistence studies. The core measurement system design and capability, suitable for future implementation with uncrewed drones rather than helicopters, represents an important advancement in the state of the art for effective spectrum coexistence engineering measurements, studies, and analyses.

Due to increasing regulatory pressure for disparate systems to share spectrum to fully utilize this limited resource, many more such studies will be required. It is critical that these studies be both fast and accurate to provide decision makers reliable and actionable data to inform rulemaking. A detailed description of the measurement system and its parameters and the methodology used to collect accurate and repeatable measurements was published in the TR-22-562, allowing other researchers to replicate the rigor of this data collection in future. Test design, execution, and analysis of the results took place under conditions of unprecedented transparency, with over 100 stakeholder representatives invited to peer review the entire study, from initial ideation through experiment design and publication of results.