Section 1

Limitations of Current Electromagnetic Instrumentation: What Today's Instruments Miss in Urban Environments, and the Measurement Capabilities Needed

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Scope: instruments and methods for measuring radiofrequency and microwave fields in the environment (broadband probes, body-worn exposimeters, frequency-selective analyzers, fixed sensors), and the low-frequency gaps that affect the monitoring program in Section 2 (T11); device SAR testing is in Section 6. **RFI questions answered:** 4(l), 5(n), 5(o), 5(p), 7, 8, 13(a), 13(c), 16 and 17, each tagged in brackets where answered.

OUR PROPOSAL

EFEIA proposes to define the measurement requirements that radiofrequency and microwave instruments must meet in urban environments, and to evaluate, with NIST and accredited laboratories, which current instruments meet them.

From that evaluation, instruments and methods should be developed or adapted, validated in the field and turned into a measurement and reporting standard that can be applied nationwide.

1 SUMMARY OF THE ISSUE [Q7, Q8]

Characterizing environmental exposure depends directly on what instruments can measure. Their frequency range, sensitivity, resolution, time response and acquisition methods limit what a field assessment obtains, above all in cities, where many emitters and technologies combine into complex, variable exposure.

1. Instruments are limited on several fronts, not only at millimeter waves (Table 1). Personal exposimeters measure a fixed list of bands up to about 6 GHz [1,2], and a broadband probe that reaches 90 GHz cannot detect fields below 0.7 V/m [3], the order of the median measured across New York City [1]. At low frequencies, spot readings miss time-averaged exposure and 2-150 kHz has no exposure metric (T11).

2. What an instrument cannot capture is missing from the data. At the same site, broadband and frequency-selective instruments differed by up to 12.28 dB with no active user [4], and idle and fully loaded 5G beams by 13 to 43 dB in line of sight [5], against the ±3 dB uncertainty most studies state [4-6]. Values below a floor become zero, values above a ceiling are clipped, peaks are averaged away, and modulation and polarization are not recorded.

3. The requirements can be specified now. No commercial personal exposimeter or monitoring node is designed for 5G millimeter-wave bands, and the European uncertainty requirement stops at 6 GHz [3]. Design can close gaps: a four-node distributed exposimeter narrowed the 50% prediction interval of body-worn readings from 12 dB to 3.1-3.7 dB [7].

EFEIA's role. EFEIA offers its field experience to define the requirements, test current instruments and validate improvements with its partners, and submits a 24-month plan for a modular family of instruments that retains short events, measures electric and magnetic fields separately and reports its own detection limits (Exhibit 1A) [8]. It has not developed or validated a new instrument and does not claim one; the plan's figures are preliminary engineering targets (Parts 5 and 7).

Designed for compliance, not characterization. Current instruments and protocols were built to check limits averaged over 6 or 30 minutes [9,10]. A value below the limit shows distance from a heating threshold; it does not show that the exposure has been characterized or is under control. Compliance is not protection.

2 WHY IT MATTERS

Every exposure figure inherits the limits of the instrument that produced it. If a band is not covered, a low field not detected, a high one clipped or a burst averaged away, that part of the exposure is absent from every analysis built on it, and results from different instruments cannot be pooled.

Cities are where the limits bite. Broadcast, mobile downlink, the uplink of nearby phones and Wi-Fi share the same streets, and their levels change with traffic, beam direction and position [1,2,4].

The federal questions require it. The D.C. Circuit remand covers testing procedures and technological developments [11], the FCC is taking comment [12], and this RFI asks which methods characterize exposure and what assessment needs [13]. A national monitoring program, such as the one proposed in Section 2, can only be as good as its instruments.

3 CURRENT LIMITATION OR GAP [Q5(o), Q8]

Table 1. Instrument limitations, the information they leave out, and proposed requirements (EFEIA proposal, for review with NIST, EPA and the program partners). Values as printed in each source.

Capability	Current limitation, with evidence	Information left out	Proposed requirement
T1. Frequency coverage [Q13(a), Q13(c)]	Fixed band lists: 88 MHz to 5.925 GHz in New York [1], 87.5 MHz to 6 GHz in GOLIAT [2]; no commercial exposimeter or node designed for 5G FR2; EU 4 dB uncertainty requirement only to 6 GHz [3]	6 GHz Wi-Fi (5.925-7.125 GHz) [14], millimeter-wave 5G, later allocations	Continuous coverage from 88 MHz to at least 40 GHz; bands defined in software
T2. Detection floor	A 100 MHz to 90 GHz probe detects nothing below 0.7 V/m [3]; in France significance starts at 0.3 V/m and every no-download mean and median fell below it [15]	Low ambient levels, such as residential background	Floor stated per band, at least ten times below the lowest median reported (urban medians about 0.2 to 0.7 V/m)
T3. Upper range and censoring	EME Spy saturates at 6 V/m, exceeded repeatedly on one Columbia street; readings at its floor set to zero [16]	Clipped hotspots; biased means and percentiles	Range above street-level maxima (13.33 V/m in New York [1]); out-of-range values flagged, never zeroed or clipped
T4. Frequency selectivity	Broadband and selective instruments differed 0.14 to 12.28 dB (mean 2.63) with no active user, up to 21.15 dB beyond 700 m [4]	Which source; downlink versus uplink	Per-band values by source class, downlink and uplink separable
T5. Detector and time response	Log detectors respond to the peak-to-average ratio [17]; diode probes overestimate 5G FR1 fields by tens of percent [3]; compliance metrics average over 6 or 30 min [9,10], although ICNIRP 2020 adds restrictions for brief exposures [9]	Peaks, bursts, duty cycle (TDD downlink 0.74 [5,18])	RMS and peak detection with stated time constants; time-stamped samples; duty cycle and crest factor beside averages
T6. Signal state	Idle and fully loaded beams differ 13 to 43 dB in line of sight [5]; a download raised mean power density 1.0 to 1.9 dB [6]; other active users lowered the field 2.3 to 5.4 dB [4]	Comparability of values from one site	Traffic state and number of active users recorded with each value
T7. Maximum extrapolation	IEC 62232:2025 methods [19] depend on beam-gain assumptions [20] and height: readings varied 70% on average across three heights [21]; extrapolated maxima deviated up to 3.5 dB in line of sight and 9 dB out of it [5]	The error in estimated maximum exposure	Extrapolation factor, height and their uncertainty stated
T8. Placement on the body	Single body-worn meters read 1.6 to 20.6 times lower than a distributed meter [17,22]; body-correction uncertainty 5.3 to 12.2 dB [3]	Personal, body-contact and bedside exposure	Height and distance recorded; off-body or distributed placement; any correction and its uncertainty stated
T9. Signal properties	Isotropic probes combine three axes; none of the instruments or protocols reviewed records modulation or polarization	Descriptors for non-thermal research	Per-axis values kept; modulation identified where decodable

T10. Uncertainty and procedure	Most studies state ±3 dB [4-6]; one 5G methodology paper reports none [20]; OET Bulletin 65 sets no mandatory procedure [10]	Reliable pooling across studies	Expanded uncertainty per band, below and above 6 GHz; NIST-traceable calibration; open raw data
T11. Low frequencies [Q8]	Spot readings, although one residential study added a 24-hour bedroom recording to its spot measurements to estimate the 24-hour mean [23]; whether repeated 200 V/m maxima in Doral reflect a display limit is not established [24]. For 2 to 150 kHz, IEC 61000-2-2 and IEC 61000-4-30 protect equipment, not people [25]; EV charging sites reached 100 to 114 dBµV within normative limits [26]; the Graham-Stetzer meter reads about 4,250 GS on a clean supply, against a 50 GS threshold with no demonstrated basis [27]	Time-averaged exposure; values above range; a human-exposure quantity for 2-150 kHz	24-hour magnetic-field logging; electric-field range stated (T3); a NIST-traceable 2-150 kHz metric, with consumer meters calibrated against it

4 EXISTING EVIDENCE [Q7]

Table 2. Same site, different result. Values as printed in each source, except the ratio marked calculated.

What changes	Study (grade)	Result
Instrument class	Deprez 2022 [4] (a)	Broadband against frequency-selective: 0.14-12.28 dB (mean 2.63) with no active user; up to 21.15 dB beyond 700 m
Traffic state	Aerts 2021 [5] (a)‡	Bern, massive MIMO, 3.6 GHz: idle against full downlink, +13 to +43 dB in line of sight (mean 28 dB)
Traffic state	Wang 2025 [28] (a)	11 locations, 3,500 MHz: 0.02-0.59 V/m idle, 0.1-9.75 V/m during download
Traffic and extrapolation	Calderón 2025 [21] (a)	UK, 56 base stations: 5G channel power density 0.5 background, 0.7 streaming, 15 speed test, 64 mW/m² extrapolated maximum
Capture mode	Machado 2026 [29] (b)	Brickell, Miami, September 2026: maximum-hold windows averaged about 5.4 times the live-display readings of the same survey (ratio of mean power densities, calculated)

‡ Funded by the Mobile & Wireless Forum; two authors at Ericsson Research (noted, not downgraded).

F1. Measurement choices change the number by more than the stated uncertainty (well established): up to 43 dB in Table 2, against the ±3 dB most studies state [4-6]. **F2. Methods agree on town-wide medians, not at the point (well established for medians):** four methods in one French town gave medians of 0.3 to 0.5 V/m but diverged at individual positions and under load [28]. **F3. Better design closes specific gaps (one design):** a four-node distributed exposimeter cut the 50% prediction interval from 12 dB to 3.1-3.7 dB [7], although too few studies exist to standardize body corrections [22]. **F4. 5G extrapolation is standardized but assumption-dependent (well established):** outputs depend on beam data, height and other users, and can fall below a measured value [19,20].

5 WHAT EFEIA CAN CONTRIBUTE [Q4(l), Q17]

EFEIA works with broadband probes, body-worn exposimeters and frequency-selective analyzers in dense urban settings, including Brickell, 2020 to 2026, where simultaneous live-display and maximum-hold readings showed how capture mode changes the result [29]. It offers technical definition, testing and validation, not a finished instrument: drafting the requirements (Table 1; Stage 1); instrument-comparison experiments at one point and time, with paired differences in dB (Stage 2); time-domain captures of duty cycle and bursts (T5); a traffic-state protocol (T6); 24 to 40 GHz observations (T1, T2; calibration to 40 GHz required); field validation through its professional network (Stages 2 and 4); a draft minimum reporting standard (P5); and a development plan for next-generation instruments (Exhibit 1A; P8). The plan notes that real-time analyzers already capture many transients and proposes a calibrated, exposure-focused integration of those capabilities with field probes, spatial data, event retention and independent testing; any claim of novelty would need separate review [8].

[Q4(l)] Each dataset EFEIA produces for the program will record instrument model and serial number, calibration and traceability, coverage, detector, sampling rate, averaging time, height, traffic state, statistics and

expanded uncertainty following IEEE C95.3-2021 [30], in V/m and mW/m^2.

6 ADDITIONAL RESEARCH NEEDED [Q5(o), Q8, Q16]

R1. A U.S. fixed-site inter-comparison of all instrument classes under declared traffic states, with paired differences and full uncertainty budgets [4,28,30]. **R2.** The floors and ranges needed in residential, commercial and near-antenna settings, and how censored values bias statistics (T2, T3). **R3.** Probes and personal meters for the 6 GHz and millimeter-wave bands, with an uncertainty requirement above 6 GHz [3]. **R4.** Standard field definitions of peak, duty cycle, crest factor and bursts; EFEIA's plan treats a micro-peak as an event descriptor defined by quantity, bandwidth, window, threshold and minimum duration, not as a health endpoint [8]. **R5.** On-body validation of distributed exposimeters in 5G bands [7], and protocols for bedrooms, classrooms and body contact. **R6.** Whether spectrum-monitoring sensors [31] can be calibrated for field strength, to lower the cost of dense networks. **R7.** A traceable 2-150 kHz metric, cross-calibrated against Graham-Stetzer readings, then blinded exposure studies [25,27].

7 NEXT STEPS: FROM REQUIREMENTS TO STANDARD [Q5(n), Q5(p), Q8, Q16, Q17]

[Q8] **P1. Adopt a measurement requirements specification** built from the last column of Table 1, after review with NIST, EPA and the program partners.

P2. Follow a five-stage path from specification to standard (Table 3), run alongside the pilot of the national monitoring program proposed in Section 2, which supplies the field sites.

Table 3. From requirements to standard.

Stage	Work	EFEIA role	Partners	Output
1. Specify (months 1-4)	Finalize the requirements with the users of the data	Drafts the specification	NIST, EPA, NIEHS, universities	Published specification
2. Test what exists (3-12)	Bench tests and a field inter-comparison at the monitoring pilot sites under declared traffic states [4,28]	Protocol, paired measurements, analysis	Accredited laboratories, universities	Which instrument meets which requirement
3. Develop or adapt (year 2)	Close the gaps: 6 GHz and millimeter-wave probes with adequate floors, time-resolved detectors, per-axis output; calibration of spectrum-monitoring sensors [31]	Test criteria; field trials; development program (P8)	NIST, NTIA ITS, manufacturers	Candidate instruments and methods
4. Validate (years 2-3)	Test candidates against reference instruments in several cities	Validation through its network	Program partners	Validation reports with uncertainty
5. Standardize (year 3)	Submit methods to the IEEE C95.3 and IEC 62232 committees; align sensors with ITU-T K.83 [19,30,32]	Drafts the reporting standard (P5)	Standards bodies, FCC, HHS	Reporting standard; updated methods

P3. Fund the inter-comparison with the monitoring pilot, which supplies cities and sites; EFEIA contributes protocol, field teams and data. [Q17] **P4. Assign the metrology to NIST** (calibration traceability, 6 GHz and millimeter-wave metrology) **and the sensor platform to NTIA's Institute for Telecommunication Sciences** [31]. **P5. Adopt a minimum reporting standard** for federally funded RF exposure studies, with the metadata in Part 5 and time structure and descriptors reported beside 6- and 30-minute averages.

[Q5(p)] **P6. Classify exposure by descriptors, not by one compliance percentage.** Every exposure is recorded by proximity class (contact; near, within 20 cm, the FCC boundary for portable devices [33]; room, with the bedroom recorded separately; ambient) and by the descriptors in Table 4, each source and band separately rather than summed as fractions of a limit [9].

Table 4. Descriptors a classification system should record (Q5(p)).

Characteristic	What to record	Why it matters
Operating frequency	Each band, with center frequency and bandwidth	Sets the dosimetric quantity: SAR to 6 GHz, absorbed power density above [9]

Field strength, power density	Per-band V/m, A/m, mW/m², stating any conversion	Near a source, E and H are not related by 377 Ω
Specific absorption rate	1 g, 10 g and whole-body values, including at body contact	Most phones would exceed the ICNIRP 10 g limit 1.6 to 3.7 times at contact [34]
Modulation, pulses, duty cycle	Scheme, peak-to-average ratio, crest factor, duty cycle, burst repetition	Averages discard time structure (T5)
Beamforming	Traffic state; measured or extrapolated; beam-gain factor	Idle and fully loaded beams differ 13 to 43 dB [5]
Multiple frequencies	Contribution of each band and source, and the total	At most 5 to 7% of health studies address combined exposure [35]
Duration, distance, proximity	Proximity class, distance, hours per day, night-time hours	The user's own device dominates: maximum-uplink mean 26.32 against 1.10 mW/m² as a non-user [2]
Cumulative exposure	Daily and yearly record by proximity class	FCC and ICNIRP rules have no cumulative metric [9,10]

P7. Enter method-comparison evidence in the FCC remand record (ET Docket No. 13-84, comments due 22 October 2026) [12].

P8. Fund EFEIA's 24-month instrument development program, run in parallel with Stages 1 to 4 (Exhibit 1A; Table 5) [8]. It uses characterized commercial receivers and digitizers where they meet the requirements and releases funding by milestone: requirements and a benchmark of current tools (months 1-3), bench integration (4-6), alpha units (7-12), beta units and high-GHz and vector decisions (13-18), independent laboratory tests (19-21) and an engineering report with validated performance and limits (22-24). Uncertainty follows the JCGM guide [36] and a second laboratory repeats selected tests. The monitoring program uses calibrated existing equipment until a module passes its gate, and data from different instrument generations are not pooled without comparability tests. The platform is a research instrument, not a diagnostic or compliance device [8].

Table 5. Development modules and preliminary targets, not demonstrated performance or health thresholds (Exhibit 1A) [8].

Module	Gaps	Preliminary target
A. Low frequency	T11	1 Hz to 100 kHz; separate triaxial E and H sensors; at least 500 kS/s per channel
B. RF survey	T1-T4	9 kHz to 6 GHz; preselection, dual-gain inputs; at least 60 dB usable dynamic range
C. Event recorder	T5	At least 200 MHz instantaneous bandwidth; 1 µs reference burst retained with at least 99% probability of intercept (one-sided 95% lower bound), amplitude within 1 dB
D. High-GHz heads	T1, T2	6-18 and 18-40 GHz; 40-110 GHz in validated sub-bands only
E. Vector research	T9	Six coherent field components in one sub-band of about 0.7-6 GHz; phase error within 5°
F. Spatial and timing	T7, T8	Position, orientation and sensing volume; timestamps across sites within 100 ns
G. Data software	T10	Calibration registry; expanded uncertainty goal ≤3 dB in core bands; raw samples kept

[Q17] P9. Define a traceable 2-150 kHz exposure metric. Ask NIST, with the IEEE and IEC committees, to define a human-exposure metric for 2 to 150 kHz and to calibrate consumer meters against it (T11).

Related: Sections 2 (monitoring program) and 6 (assumptions behind the limits).

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