Project: **SEAWave**

DEVIN Device

Work Package: WP1

Deliverable: D1.4

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Abstract

This report describes the functions, performance, and a user manual of the DEVIN5G, an Up-Link EM exposimeter fully developed in the SEAWave project. As the DEVIN5G devices are made available for use by SEAWave partners, this report explains the Tx power acquisition chain and its settings.

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Acronyms List

ADC	Analog to Digital Converter
DL	Down Link
EM	Electro-Magnetic
EMF	Electro-Magnetic Field
FR1	5G sub6GHz frequency bands
FTP	File Transfer Protocol
PTx	Transmitted Power
PCB	Printed Circuit Board
RF	Radio Frequency
RMS	Root Mean Square
SAW	Surface Acoustic Wave
SAR	Specific Absorption Rate
TAS	Time Averaging SAR
TDD	Time Division Duplexing
Tx	Transmission
UL	Up-Link

Introduction and technical problematic

Specific Absorption Rate (SAR) certification is ensuring that ‘worst case’ Transmission (Tx) RF power does not exceed maximum exposure ICNIRP limits for a couple of spacing scenarios between the source and a human body phantom. However, up to now, there were limited solutions to assess the wide diversity of user’s mobile exposure during its daily and operational usage. This is particularly relevant because the UL exposure (radiation from the mobile) is still considered as the dominant part compared to Down-Link one for standard mobile usages once the access point is not very close from users.

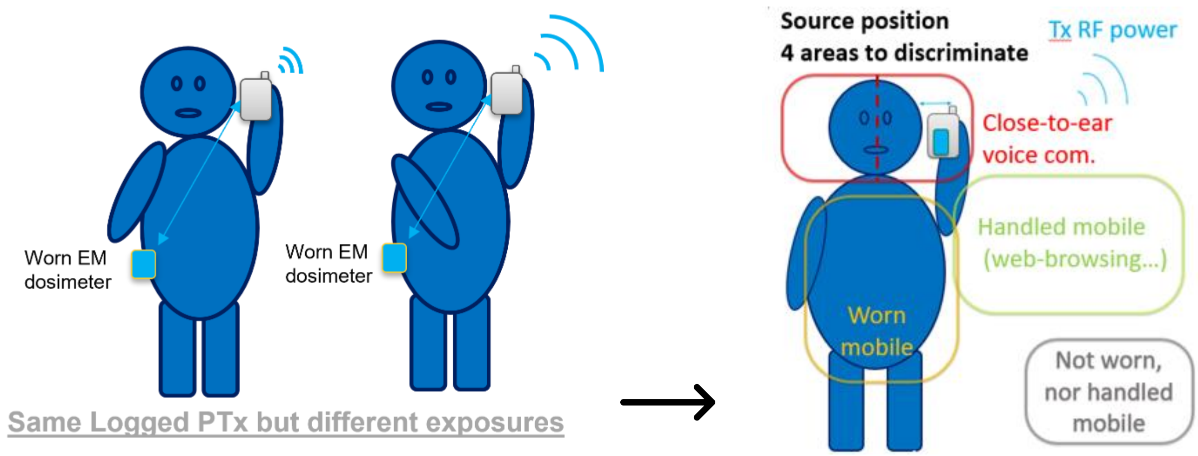

Figure 1. Body screening ambiguity with worn EM dosimeter (left) and DEVIN exposimeter solution fixed on the mobile cover (right). Mobile position detection regarding user’body with additional sensors on the DEVIN.

Ten years ago, an innovative concept of personal electromagnetic (EM) exposimeter, namely DEVIN, was proposed by CEA [1]. Its initial purpose was to assess the long-term evolution and the wide diversity of the population EMF exposure resulting from mobile device use. For instance, it has been deployed over 300 volunteers in French exposure epidemiological campaign in the ANSES-CORIOLIS project. The DEVIN novelty lies in its sufficient miniaturization so it can be fixed on the mobile cover without perturbing the daily usage, (see Figure 1). This few millimeters fixed position between the mobile antennas and the instrument is the main advantage of DEVIN, by fixing the RF power transfer function that varies largely when using worn EM dosimeter, and by avoiding RF amplification components that would require a much larger battery. The exposimeter is able to log two metrics that govern the user UL exposure: the relative position of the EMF source with respect to the human body, known as the mobile phone usage, and the Tx power emitted by the monitored source over cellular and Wi-Fi frequency bands. This is accomplished through proximity sensors and accelerometer for the former and through EM coupling with a near-field probe for the latter.

DEVIN is a user-friendly instrument that remains independent of the wireless device itself and its operating system version, unlike legacy tools such as software applications and Trace Mobile middleware chipset-based logging tools [2]. Thus, the comprehensive measured RF power metric ensures a long-term comparison even if PHY layer evolves with new radio releases.

Figure 2. 85 x 55 x 10 mm3 DEVIN5G instrument mounted on a mobile cover

In SEAWave project, the 5G specificities (TDD multiplexing), new Wi-Fi 6E standard, and new Tx schemes implemented to mitigate SAR limit constraints, are considered with an UL exposure assessment viewpoint. First, new FR1 and 6 GHz frequency bands are supported. Secondly, recent terminals (smartphone, tablet, laptop) are incorporating new Tx schemes (multi-band simultaneous Tx from the same antenna, multi-antenna simultaneous Tx on the same band) and Time Averaging SAR (TAS) [3]. A dynamic antenna switching allows for the selection of the active antenna based on various factors, ultimately enhancing connectivity and overall performance. However, these novel features necessitate a comprehensive assessment of their impact on EMF exposure. These features motivate the development of a new version of the exposimeter, namely DEVIN5G, (Figure 2).

1 DEVIN5G Design

1.1 Global Instrument Architecture

The DEVIN5G architecture is centered on the ultra-low power micro-controller STM32U5® which controls all the different functions and sensors of the exposimeter. Most of the electronic components are mounted on a single face Printed Circuit Board (PCB) (size 85 x 55 mm^2) except the two proximeters which are shifted beyond the upper edge of the mobile in order to ‘view’ both front and back sides for usage assessment, (Figure 3).

The STM32 chip manages all the basic functions (Programming, data logging, Real Time Clock, Battery reloading, User Interface) but also the two specific functions of an EM exposimeter:

Usage assessment (yellow rectangle in Figure 3) and RF Measurements (pink rectangle in Figure 3).

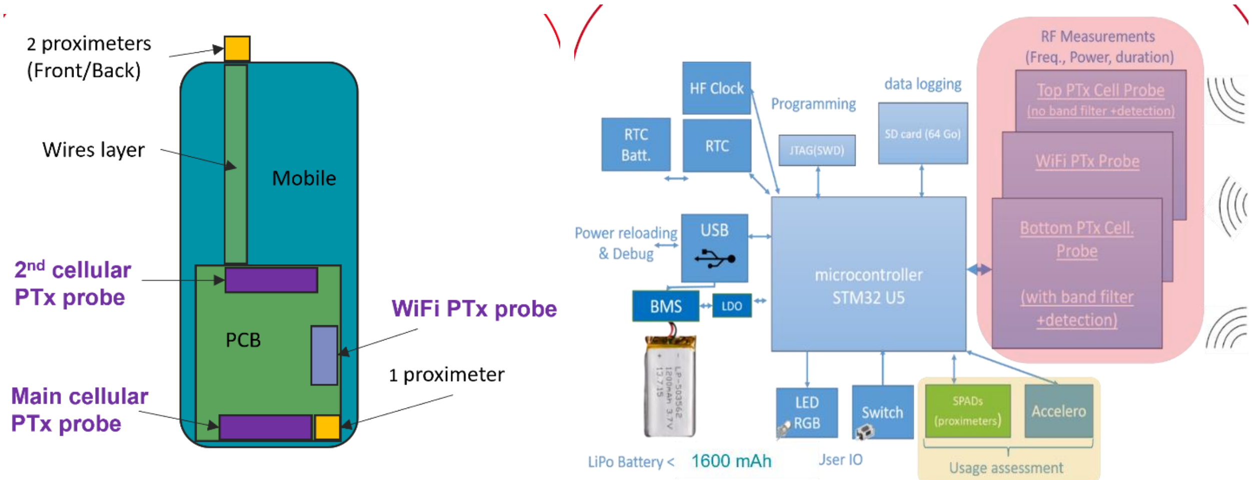

Figure 3. DEVIN5G Mechanical scheme (left) and Software architecture (right)

1.2 RF Measurements acquisition chains

The RF Measurements architecture consists of three separate RF power acquisition chains: two dedicated for all the FR1 cellular frequency bands and one for the three Wi-Fi frequency bands, as illustrated in magenta and blue area in the electronic layout in Figure 4. Each chain is connected to a dedicated EM probe.

For the main cellular chain, a miniature (50 mm) balanced dipole (with no impedance matching) aims to couple between -30 dB and -20 dB from the mobile Tx antenna. This EM coupling varies with regard to frequency bands and with the mobile model and so should be calibrated. This coupling remains constant even when the mobile is handled due to less than 1 mm separation between mobile antenna and the probe. Nevertheless, different handling experiments show that severe perturbations could happen to the mobile antenna due to its input impedance mismatching.

The main cellular chain is composed of a bank of 8 band-pass filters whose band is selected via a pair of RF switches (SP8T), an RMS detector, and an analogue to digital converter (ADC) in the microcontroller. This low consumption micro-controller (STM32 U5®) is orchestrating all these sensors and functions with up to 500 Hz sampling and data logging in a SD card. All (6) European cellular operational UL frequency bands are supported between 717 MHz and 3500 MHz (full list hereafter).

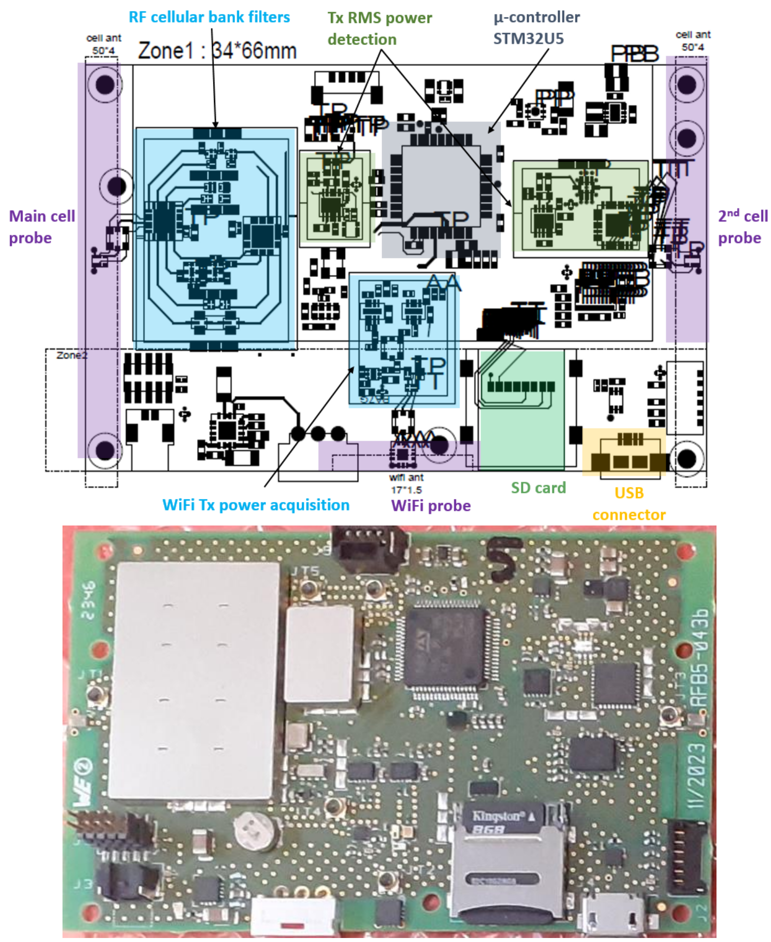

Figure 4. DEVIN5G PCB top layer with its main functions in colours (up), and PCB picture with mounted components and EMC shieldings (down)

To detect antenna switching, simultaneous Tx, and to identify the active Tx antenna, a second EM probe is added on the top edge of the board and connected to a single wideband filter, an RMS detector, and an ADC that can sample simultaneously with the first (main) chain. This choice is clarified according to the following analysis. If the mobile bottom antenna is the active one, the main probe is expected to measure higher power level than the second probe, due to the decrease in EM coupling with separation distance. If another antenna is actively transmitting power, supposedly located at the top of the mobile phone, the EM coupling with the second probe is higher than that with the main probe, implying higher power measured with the second probe. This goal is achieved after performing calibration [4], which involves converting the recorded raw ADC values into the correct Tx powers. This calibration process is more challenging than that of the previous version mono-probe of DEVIN since it needs to control the active Tx antenna via the Base Station Emulator.

Before the activation of sleep-mode (dynamic sampling), the overall (with both Tx power and usage detection) DEVIN5G energy consumption is measured under 3.3 V at 13 mA with 10 Hz sampling, and 64 mA with 400 Hz sampling.

2 DEVIN5G Validation

2.1 RF Performance Validation

In this section, DEVIN5G RF front-end performance and main low-level functions are characterized. Figure 3 presents the transmission response of the reconfigurable bank of band-pass filters in the frequency domain, for the seven (717, 847, 897, 1747, 1950, 2535 and 3550 MHz) central frequency bands measured between the main EM probe and the ADC. The excellent rejection of the two SAW filters shows at least 50 dB isolation between bands except for the 3500 MHz band where larger bandwidth induces only 40 dB rejection. Insertion losses are less than 8dB for sub-2GHz bands, but 3dB ripple is observed in the 2600 band which cannot be taken into account during the calibration step.

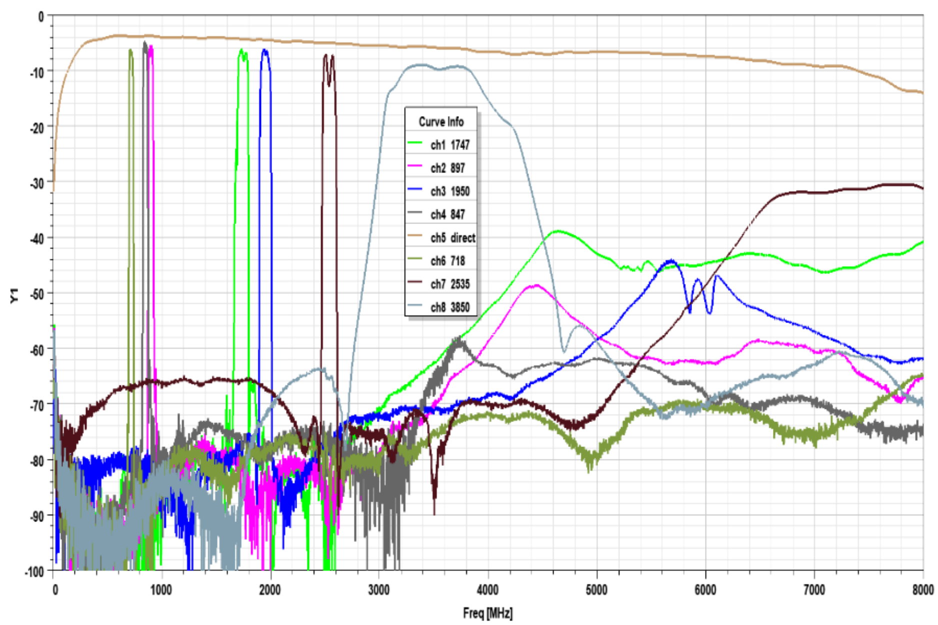

Figure 5. Measured Band-Pass filter response (dB) for the 8 cellular bands

Another important aspect is the validation of the linearity of detected RF power, and the dynamic of the RF acquisition chain. In Figure 6, the Continuous Wave input power is progressively increased while the output voltage from the rms detector is measured. The 60 dB range of RF input power is validated for all the frequency bands. The slope is constant for all the bands; only the offset is slightly different for the highest band, but this offset is compensated during the calibration step.

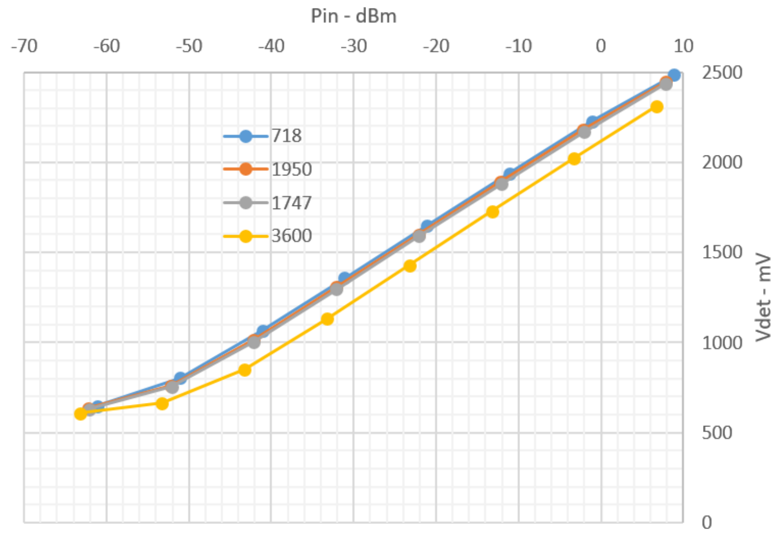

Figure 6. Linearity of the main cellular chain rms detector for four frequency bands

2.2 DEVIN5G RF Calibration Process

The RF calibration consists of evaluating two constant parameters (a,b): first driving the linear relationship between RF power and read ADC value, and second the offset in dB due to the EM coupling process. This last one depends on the mobile equipment but also from the frequency band. In the SEAWave project, the RF calibration has been carried on at the ANFR SARLAB with a Base-Station emulator that allows to order any PTx value to the mobile that carries the DEVIN5G in a specified frequency band, (*Figure 7*). *Figure 8* presents the ADC raw measurements during DEVIN5G calibration step where both PTx levels and frequency bands are swept. Simple linear regression allows to assess both parameters that are then applied to any operational measurement with the same mobile phone.

The reuse of this calibration table with another mobile phone has been tested. It has been shown that paying attention to the same DEVIN5G-mobile position fixing a 3 dB offset maximum is observed for the same size of mobile phone.

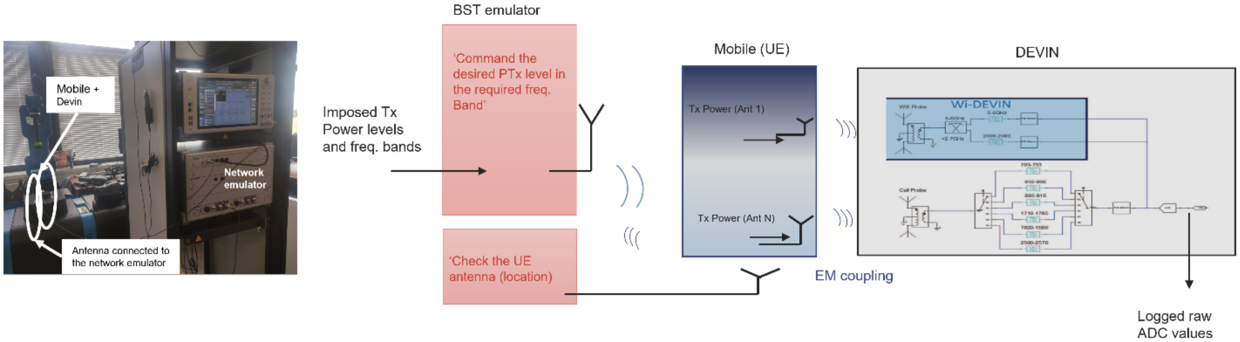

Figure 7. Picture of RF calibration with BST emulator at ANFR SARLAB (left), Calibration scheme (right)

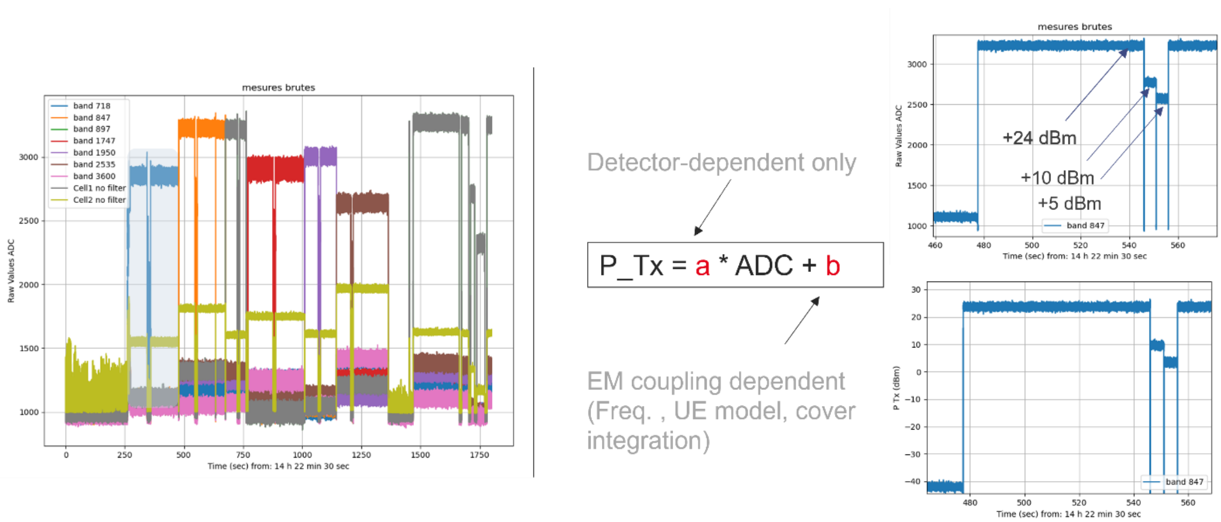

Figure 8. Example of Ptx order sequence for all the frequency band (left), Calibration equation (center), and zoom on a given band of the Ptx sequence (in raw data: top right) and in dBm once calibrated (bottom right)

2.3 System Validation

Once the DEVIN5G is assembled and all the instrument functions are validated, the real-time programming of the acquisition Tx power is checked with a fast oscilloscope for sampling frequency varying between 10 and 500 Hz. In *Figure 9*, the overall acquisition frame lasts only 475 µs whatever the sampling frequency. Notice this duration drives the energy consumption of the DEVIN5G and so its autonomy.

Sequentially (in only 475 µs) for each frequency band, the specified band pass filter is switched, the rms detector is active during a convergence time of about 50 µs, then the ADC sample the PTx and the digital value is stored in the SD card memory.

Furthermore, the battery autonomy validation shows a factor x4 improvement (compared to the previous version (before SEAWave)) to reach 64 hours with 10 Hz frequency sampling.

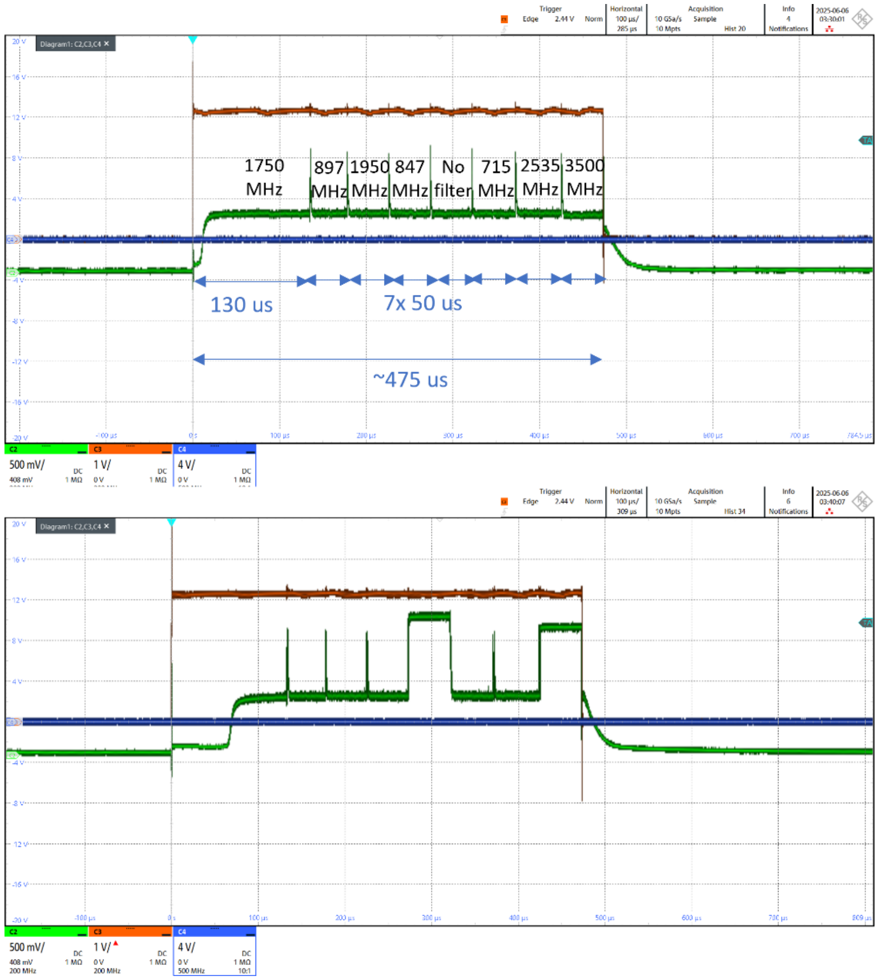

Figure 9. Chronogram of 8 bands slots for a single sample: no Tx power (top screenshoot) and with a CW signal in the 3.5 GHz band (bottom screenshoot) (notice that both the no filter and the 3.5 GHz are detected)

The last validation consists in comparing the DEVIN5G with another instrument, hereafter a Keys5G NEMO trace-mobile (a middleware modified chip that allows transmitted power information available from the Android OS) from TelecomParisTech. The DEVIN5G is fixed on such trace-mobile. The same played transmission scenario is carried on on different RAT and frequency bands (indoor and outdoor). Both instruments PTx time-series are exported and compared in *Figure 10*. We retrieved the same trends and also the same level within +/-3dB (probably due to the calibration bias). Notice how the very thin time resolution of the DEVIN5G allows to observe the very discrete nature of the packets' emission (zoom on centered and right *Figure 10*).

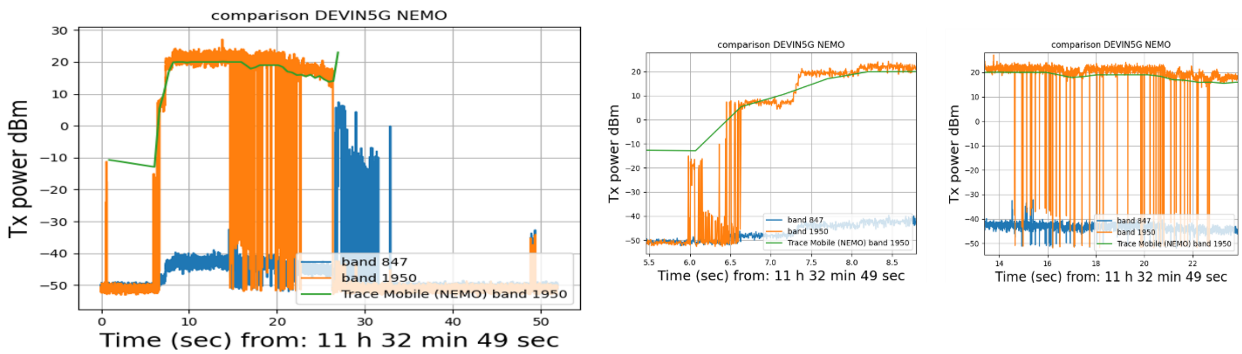

Figure 10. Inter comparison between DEVIN5G mounted on a NEMO Trace mobile: comparison of the same scenario during 50 sec. (left) and for two zooms (center and right)

2.4 Measurement examples on played scenarios

Different played scenarios are carried on in order to visualize the PTx schemes that occurs in these scenarios (frequency band unlocking, very large FTP uploading, hand or body perturbation during usage…). In *Figure 11*, PTx levels for all the frequency bands are plotted. Except for a few coupling (<-40 dB) on the rest of the bands, the Uploading signal is transmitted on the 1950 MHz band (ordered by the Network, since this mobile phone can be band-locked on the specified band). Once this lock is off, the Network requires quasi-instantaneously a frequency band switch on the band 847 MHz where the propagation is probably better and so inducing 30 dB lower transmitted power.

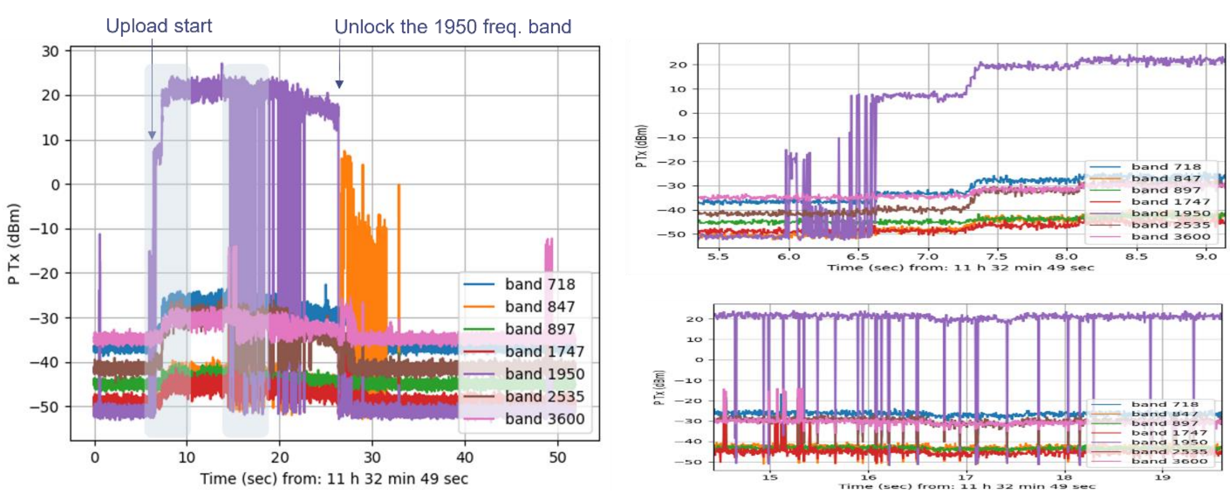

Figure 11. Time-serie of Tx power of FTP uploading scenario where the frequency band is locked at 1950 MHz then released, zoom and detail of starting uploading (center) and during the uploading (right)

3. Conclusions and Perspectives

The DEVIN5G, an UL EM exposimeter is able to log two metrics that govern the user UL exposure: the relative position of the EMF source with respect to the human body, and the Tx power emitted by the monitored source over cellular and WiFi frequency bands.

The RF power detection has been detailed showing larger than 50 dB isolation between frequency bands and 60 dB linearity of the rms power detector. Additional system validation results and played scenario Tx power time-series logged by DEVIN5G allow to observe mechanisms that drive the exposure of the mobile's user.

SEAWAve Task 1.4 has successfully demonstrated the performance and easy usage of the DEVIN5G to assess the RF transmitted power with very thin time accuracy but also for very low energy consumption. Five full operational devices have been realized and validated. Three have been shared with SEAWAve partners for tests and CEA expects some return of experiences to further improve the DEVIN5G usage (GUI interface, post-processing). A last validation will be to merge the proximeters measurements in order to validate the accuracy of mobile positioning regarding the user body.

With the two mentioned metrics logged, the next perspective is to be able to assess the 'instant' SAR by considering a database of 'Tx power-normalized' simulated SAR in the most common usages. By hybridizing these normalized EM simulations and in-situ power measurements, the daily exposure could be analyzed with an independent manner while new 5G, more and more complex Tx schemes are implemented by mobile manufacturers. An additional perspective is to exploit the large amount of raw PTx measurements to try to assess System-level behaviors thanks to the clustering and categorization of PTx patterns.

Finally, regarding the valorization of this DEVIN5G exposimeter, four conference papers (BioEM 2023, BioEM 2024, URSI GASS 2023, Eucap 2025) have been presented and one journal paper is under preparation. The DEVIN5G has been demonstrated during the Science Days (Oct. 2024) to general public that can 'visualize their own mobile transmission' and to take the opportunity to discuss and explain the 5G exposure mechanisms.

Figure 12. Views of the five full operational DEVIN5G UL-exposimeters (three have been tested by SEAWave partners)

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