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Automatic Restriction of Radiated Power in 5G Handsets based on Proximity Detection to Comply with Exposure Limits

Dr Oren Eliezer SAMSUNG
Dr. Haim Mazar ATDI

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Automatic Restriction of Radiated Power in 5G Handsets based on Proximity Detection to Comply with Exposure Limits

Oren Eliezer(Samsung Semiconductor orene@ieee.org), Gennady Feygin, Viduneth Ariyarathna, Mahmoud Abdelgelil, Pranav Dayal, Kyungwoo Yoo, Sang-Gyu Ha, Junseuk Suh, Dooseok Choi, and Haim Mazar ATDI (h.mazar@atdi-group.com) RF Spectrum Management and Engineering

Outline

1. Background:
    1) millimeter-wave beam-forming used in 5G handsets (directional transmission/reception)
    2) regulatory limits associated with human exposure to radiation
2. The problem: ensure compliance with the regulatory limits without restricting the TX too much
3. The proposed solution:
    1) use the existing transmitter to detect the proximity of the user
    2) adjust transmission power based on the proximity sensing
4. Implementation challenges
5. Summary and future work

Motivation

1. 5G handsets use **beam-forming** in millimeter-wave (up to 40 GHz)
   So are they potentially more dangerous?

2. Regulatory limits allow human exposure to radiation up to **1mW/cm^2 (10 W/m^2)** (power density on the body averaged over a 4 sec interval); next slides detail the limits of regulatory bodies: 10 W/m^2 at mm waves

3. The problem: ensure compliance with the regulatory limits while still allowing the handset to transmit at the highest power and duty cycle that is needed at that instance to support the up-link data throughput

   1) Hotspot scenario (may be used to support multiple users)

   2) 4K video streaming (high data rate due to high resolution of video)

4. Without an indication whether the user is too close or not, the EIRP would have to be limited, which could affect up-link (UL) performance

5. A body proximity sensing (BPS) solution would allow the device to limit the instances of TX power reduction to when it is really needed (close proximity)

ICNIRP (2020) Guidelines for limiting exposure to Electromagnetic Fields (100 kHz to 300 GHz)

Regulations

Table 5. Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).

Frequency range	Electric field-strength (V/m)	Equivalent plane wave power-density S_{eq} (W/m^2)
10–400 MHz	28	2
400-2000 MHz	$1.375f^{1/2}$	$f/200$
2-300 GHz	61	10

C95.1-2019- IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

Table 7—ERLs for whole-body exposure of persons in unrestricted environments (100 kHz to 300 GHz) [see Figure 3 for graphical representation]

Frequency range (MHz)	Electric field strength (E)[a,b,c] (V/m)	Magnetic field strength (H)[a,b,c] (A/m)	Power density (S)[a,b,c] (W/m^2) S_E	Power density (S)[a,b,c] (W/m^2) S_H	Averaging time (min)
0.1 to 1.34	614	$16.3 / f_M$	1000	$100\,000 / f_M^2$	30
1.34 to 30	$823.8 / f_M$	$16.3 / f_M$	$1800 / f_M^2$	$100\,000 / f_M^2$	30
30 to 100	27.5	$158.3 / f_M^{1.668}$	2	$9\,400\,000 / f_M^{3.336}$	30
100 to 400	27.5	0.0729	2		30
400 to 2000	—	—	$f_M / 200$		30
2000 to 300 000	—	—	10		30

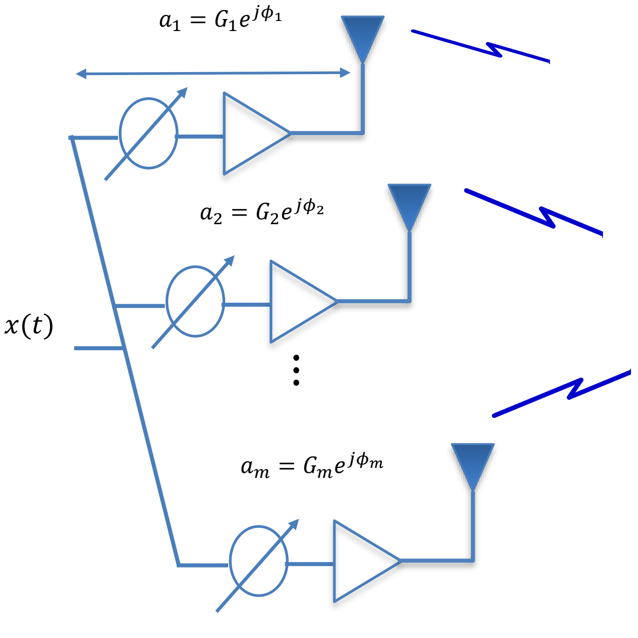
FCC Ruling

Table 1 to § 1.1310(e)(1) — Limits for Maximum Permissible Exposure (MPE)

Frequency range (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (mW/cm^2)	Averaging time (minutes)
(ii) Limits for General Population/Uncontrolled Exposure				
0.3-1.34	614	1.63	100)	<30
1.34-30	824/f	2.19/f	($180/f^2$)	<30
30-300	27.5	0.073	0.2	<30
300-1,500			f/1500	<30
1,500-100,000			1.0	<30

Background – beamforming

1. 5G mmW (FR2) communications rely on **directional beams**, unlike omni-directional transmission of previous generations
2. This is to overcome the higher propagation losses in mmW and offer better spectral utilization/reuse
3. The beamforming IC (BFIC) module in the handset typically has N = 4 to 8 active antennas/paths
4. In TX mode the same signal is sent in all N paths in parallel, with individual control of the phases of each
5. The beam is steered through the use of a phased-array with resolution on the order of 22.5° steps
6. The overall effective isotropic radiated power (EIRP) is greater than that of a single TX path by a factor of N^2 (×N the P_{out} and ×N the antenna gain)

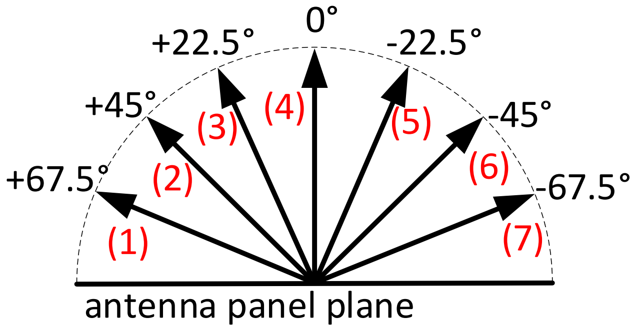


Beamforming transmitter

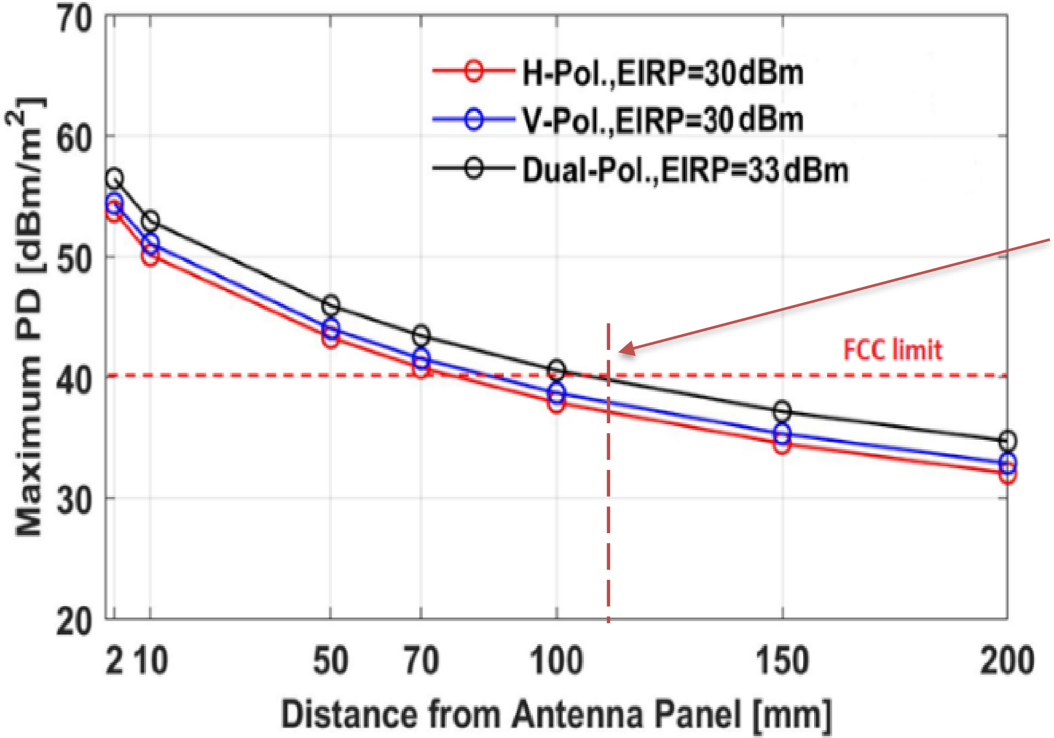
Background – The 'exposure risk'

1. Are 5G mmW handsets more dangerous with their directional beams in mmW bands?
2. The mmW energy does not penetrate deep, and therefore power-density (PD) is evaluated instead of "specific absorption rate" (SAR)
3. Regulatory limits allow human exposure to a power-density up to **1mW/cm² (10 W/m²**, see § 1.1310**)** averaged over a duration of 4sec in an area of 4cm²
4. Regulatory compliance needs to be verified over all possible beams/directions, and is based on a combination of actual measurements and simulations
5. That limit could be violated at close proximity in handsets having **EIRP ≈ 30 dBmi**

Seven possible beams in Samsung's transmitter



Regulatory Compliance Simulation



FCC limit (see § 1.1310)
exceeded at d<11cm

Simulated power density vs. distance for transmitter of EIRP = 30 dBmi

Maximum Power Reduction (MPR)

1. Since the average power density (PD) depends not only on the TX power level but also on the duty cycle (which would depend on the up-link data-rate), the reduction could be based on both TX power reduction and duty cycle reduction (both would compromise the up-link performance)
2. The table below demonstrates how a higher duty cycle of transmission (higher bit rate) may require greater MPR to comply with the 1mw/cm2 limit in the absence of proximity detection

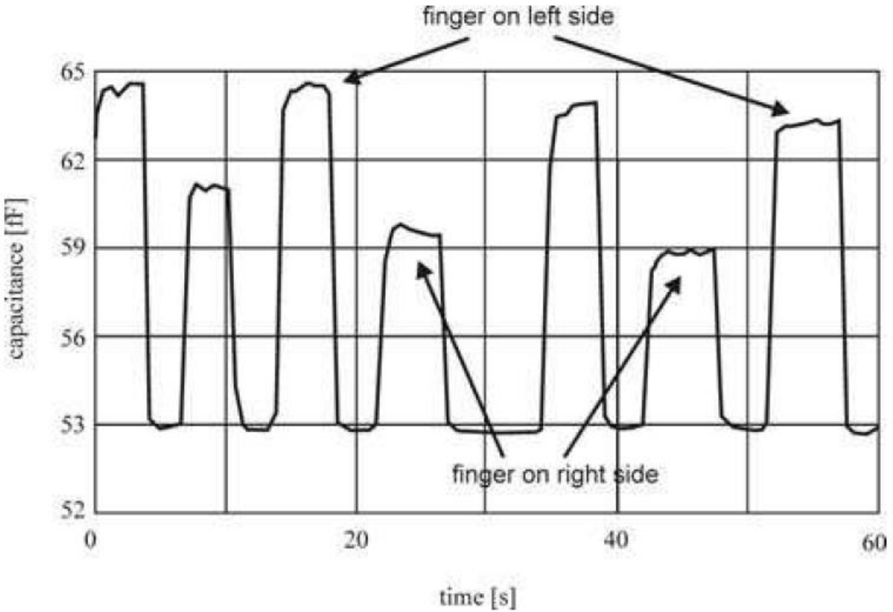
Peak EIRP [dBmi]	Required MPR [dB]	
	100% duty cycle	20% duty cycle
15	1	–
20	6	–
25	11	4
30	16	9

For a handset with **EIRP = 30 dBmi** →

Alternative proximity sensing solutions

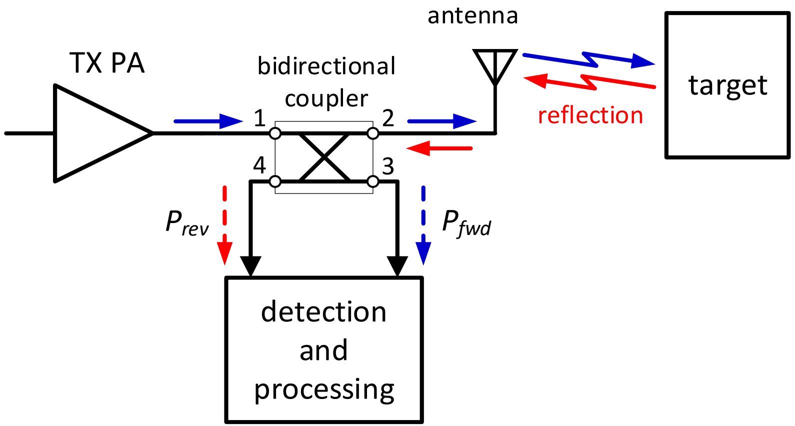
1. Thermal sensors (as demonstrated by Motorola)
2. Capacitive sensor based proximity sensing can detect only up to one centimeter, which may not be enough for body proximity sensing (BPS) considering the high EIRP scenarios.

Capacitive sensor operation



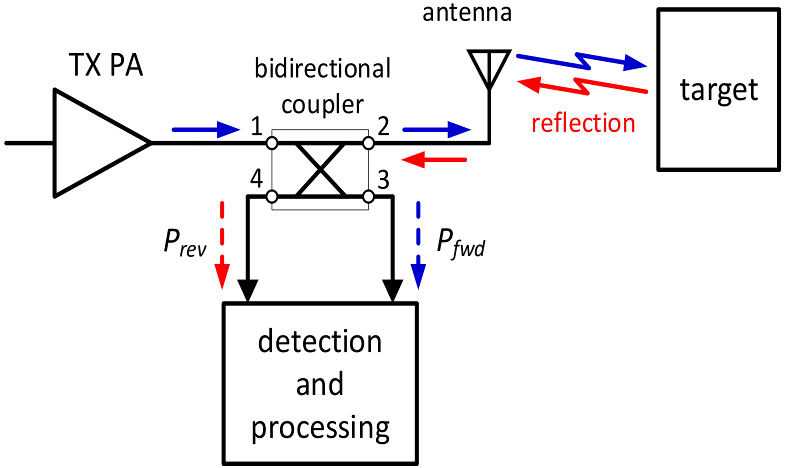
Proposed Solution – Proximity sensing based on reflections

1. Instead of a dedicated proximity sensor, can the existing transmission be used to sense a nearby human?
2. This was explored by Samsung (in collaboration with academia) in 2018 at a lower band and was shown reliable at very close proximity (a few cm)
3. Recently explored extensively in the 5G FR2 bands (mmW)
4. The principle of operation is to use the built-in measurements of transmitted and reverse/reflected power at the transmitter's outputs (based on a directional coupler)
5. The human body reflects back some of the incident emissions, which can be measured through the coupler for $\mathbf{P_{reverse}}$
6. When close enough, it could noticeably affect the antenna impedance matching, resulting in changes in both forward $\mathbf{P_{fwd}}$ and $\mathbf{P_{rev}}$



But…. the reverse power is a vector sum

1. The electromagnetic signal reflected from the target/human is summed with the electrical reflection from the antenna due to the imperfect impedance matching (i.e. conventional S11). This represents on-frequency 'interference'
2. Depending on the phase relationship between the electrical reflected power from the antenna and the electromagnetic reflection form the human, the total reverse power measured can either increase or decrease as a result of the close proximity of the human



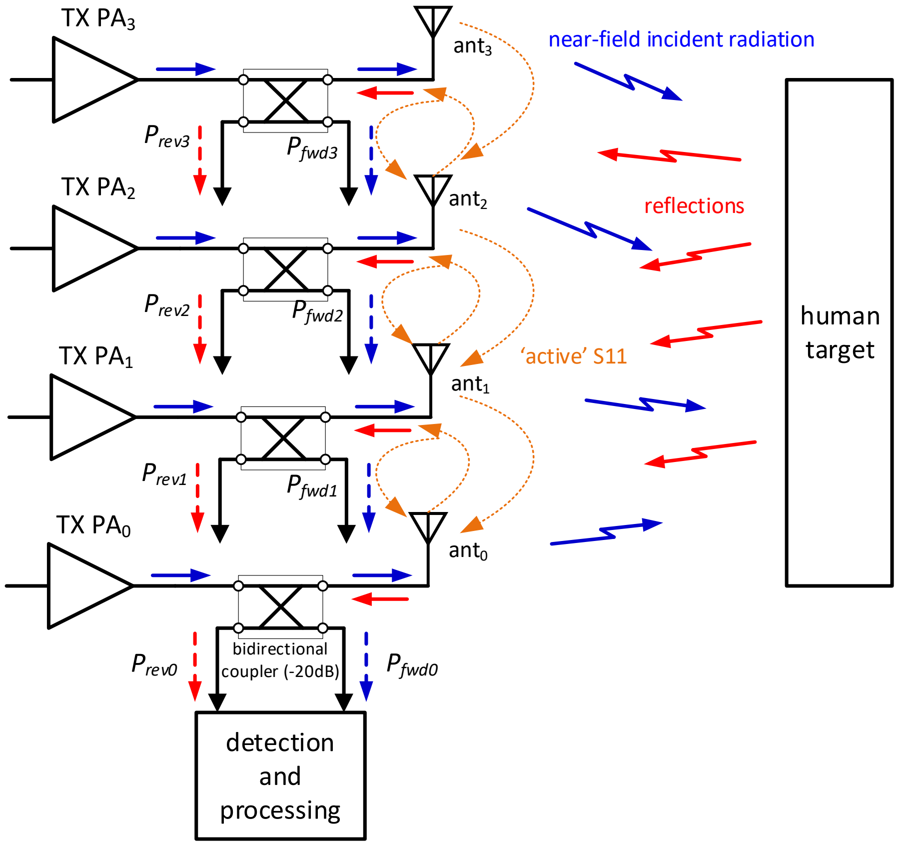
Transmitter output with directional coupler and peak detectors that measure TX forward and reverse power

The actual picture is even more complex…

1. Multiple antennas involved (N≥4)

2. Coupling (leakage) between antennas creates a matrix of 'active S11' parameters among the antenna elements

3. An algorithm is needed for determining the 'reference' conditions (i.e. in the absence of a human) and monitoring of changes to detect the close proximity of a human



Conclusion and Future Work

1. Regulatory limits are set to protect users of 5G devices
2. 5G devices may be safer than previous generations because of the directionality of their transmission
3. Devices that cannot reliably detect the proximity of humans would have to limit their average EIRP, based on the assumption that a human may always be present at zero distance
4. A detection range of 20cm would provide margin even for TX EIRP of 30dBmi (1 Watt)
5. An algorithm that reliably detects an object approaching and moving away (based on the differences in measured forward and reflected power at the antennas) can be used to determine proximity
6. The probability for false detection is not critical, but it should be sufficiently low so as not to reduce power too frequently when not necessary
7. A successful implementation of a body-proximity-sensing (BPS) system that is based on the existing transmitter would represent a zero-cost-adder solution

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Additional publications of the Author on EMF

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2) 2016 ITU R-D-T 'Intersectoral activities on human exposure to EMF'; Bangkok, 26 April 2016
3) 2017 ITU Workshop '5G, EMF & Health'; Warsaw, Poland, 5 December 2017
4) 2018 ITU workshop 'modern policies, guidelines, regulations and assessments of human exposure to RF-EMF'; Geneva, Switzerland, 10 October 2018
5) PRIDA Track 1 (T1) On-line English workshop 20thApril–1stMay2020. First_week_slides_v2; see pp. 237–296, EMF presentation 24 April 2020
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2) Human RF Exposure Limits: Reference Levels in Europe, USA, Canada, China, Japan and Korea EMC Europe 2016; Wroclaw, Poland, 9 Sept. 2016
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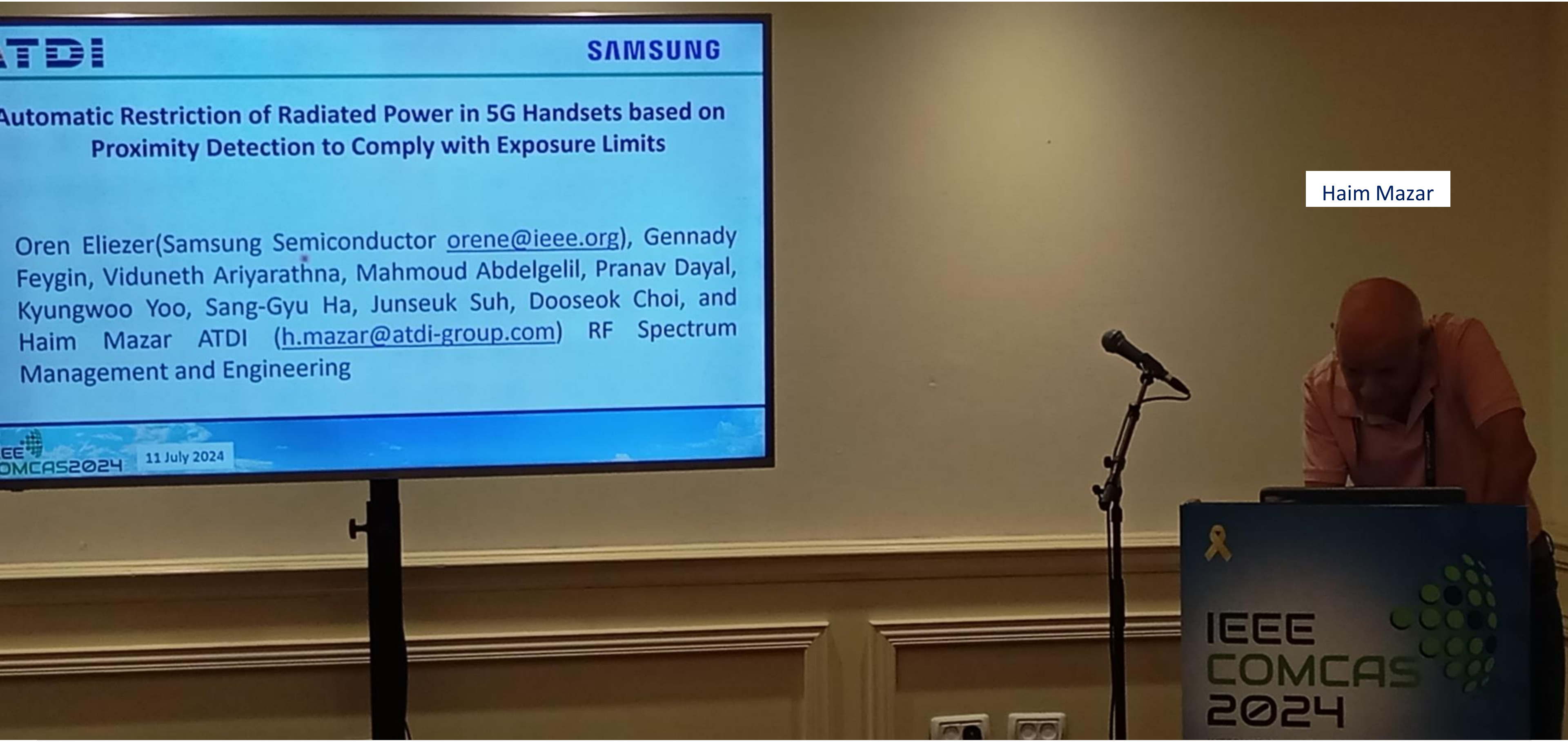
12) Convener of the ITU workshop 8 May 2024 on Workshop on recent developments relevant to EMF policy formulation. My presentation 'ITU recent activities on EMF' (https://www.itu.int/dms_pub/itu-d/oth/07/31/D073100000D0013PDFE.pdf)

Photos from the 11th July presentation (1)



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