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Response to comments by Foster et al

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In Panagopoulos et al. (2026), we showed recorded electromagnetic field (EMF) pulsations from various Wireless Communication (WC) devices, specifically “Wireless Fidelity” (Wi-Fi) router, fourth generation (4 G) Long Term Evolution (LTE), and fifth generation (5 G) New Radio (NR) mobile phone signals. The figures in our paper clearly show pulsing EMF emissions repeated at various Extremely Low Frequency (ELF: 3–3000 Hz) rates. Even if these EMF pulses contain the Radio Frequency (RF: 300 kHz–300 GHz) modulated signal, and for this reason, they are recorded by an RF spectrum analyzer (SA), they are clearly repeated at ELF rates, and they clearly represent ELF pulses with the RF signal inside them. Therefore, the description of Foster et al. of these pulsing EMF emissions simply as “RF” is neither an accurate nor complete description as our paper highlights.

The induction of non-thermal biological effects by ELF EMFs or by ELF-modulated/pulsed RF EMFs is documented by thousands of peer-reviewed published studies (see reviews by Santini et al. 2005; Ruediger 2009; Yakymenko et al. 2016; Manna and Ghosh 2016; Leach et al. 2018; Jagetia 2022; Panagopoulos et al. 2025, and many more) which obviously Foster et al. and certain health organizations such as ICNIRP (2020) refuse to see. Thus, contrary to the claims by Foster et al. the non-thermal effects of both ELF and ELF-modulated/pulsed RF EMFs are not “unsupported speculations”.

We thank Foster et al. for acknowledging that digital signals are emitted as on/off pulses repeated at ELF rates and exhibit “*intense variability*” in amplitude and shape, and that these are well-known properties of EMFs emitted by WC devices and antennas. This is what our paper demonstrates. Unfortunately, apart from a few previous papers that had sporadically shown this for

other types of WC EMFs, this important information was kept in the darkness because papers like Foster et al. (2025) or the ICNIRP (2020) do not reveal it. Actually, from those sporadic documents showing the ELF pulsations of WC EMFs before, only Pedersen (1997) was properly published in a peer-review journal showing pulsations from 2 G (GSM) mobile phone and cordless domestic (DECT) phone signals. Therefore these properties are not “well known” as Foster et al. claim, and it is of utmost importance that we recorded these ELF pulsations from today’s most common types of WC EMFs. This represents the most relevant information that should be available to the scientific community, and the scientific community will decide whether this should be revealed (which is what we did) or not revealed and be neglected (as Foster et al. did in their 2025 paper).

Foster et al. criticise us in that we “contend that the pulsations and variability are ELF components of the transmitted signal and are responsible for non-thermal biological and health effects via a mechanism for ion transport through membranes (IFO-VGIC).” Yes, we indeed contend that, and we see nothing questionable.

The Ion Forced Oscillation and Voltage-Gated Ion Channel (IFO-VGIC) mechanism (Panagopoulos et al. 2000, 2002, 2015, 2021, 2025; Panagopoulos 2022) is indeed widely accepted for the following reasons: a) It is cited more than 1,200 times by other publications; b) There is plenty of confirmation by patch-clamp recording measurements and ion channel blocker studies, that ELF EMFs and ELF-modulated/pulsed EMFs cause irregular gating to VGICs as predicted by the IFO-VGIC theory (e.g., Piacentini et al. 2008; Pall 2013; Cecchetto et al. 2020; Zheng et al. 2021); c) This mechanism has explained important documented bioeffects of man-made EMFs such as Oxidative Stress (OS), DNA

damage, infertility, cancer, etc. (Panagopoulos et al. 2021, 2025), as well as important effects of natural EMFs that were unexplained since ancient times, such as animal magnetoreception, orientation, and navigation in the geomagnetic field (Panagopoulos et al. 2024), the sensing of upcoming earthquakes by animals (Panagopoulos et al. 2020), or the sensing of upcoming thunderstorms by sensitive individuals (Panagopoulos and Balmori 2017). All these make the IFO-VGIC mechanism a most plausible and widely accepted biophysical mechanism for EMF bioeffects.

Foster et al. write, “their argument conflates modulation of an RF signal – which may indeed have low-frequency components – with transmission of signals in the ELF band: “*we do not distinguish between the standalone ELF EMFs over the ELF modulation of EMF signals ...*”. Indeed, we do not distinguish them, because in both cases we have similar non-thermal biological effects, and we have explained that similarly, the VGICs do not distinguish them, as they respond not to invariable EMFs but only to low-frequency (ELF) voltage/field changes which can be either standalone ELF EMFs or, equally, ELF amplitude-modulated RF EMFs. In other words, the VGICs, which are the most abundant and well-studied membrane ion channels in all cells of all living organisms, demodulate an ELF-modulated/pulsed RF EMF (Panagopoulos et al. 2025, 2026).

Foster et al. write: “The authors offer vaguely worded policy advice: “*the scientific community, the health authorities, and the industry ... should start measuring their inherent ELF pulsations, and ... the health authorities should revise their guidelines ...*” Without specific guidance for what characteristics of wireless signals – which vary widely across and within technologies – are relevant, the advice is meaningless. Any such advice would need to be based on direct evidence of harm”. In response to this comment, our paper explains that all digital WC EMFs contain inherent ELF pulsations and that there is no need to specialize for every specific application of this technology. A proper scan with a SA can reveal them as we demonstrated in our paper. Thus, the advice is not meaningless. And there is plenty of “direct evidence of harm” as, e.g., in the review studies cited in the 2nd paragraph above.

Foster et al. write: “One error illustrates the authors’ confusion about basic RF physics and technology. The authors state that “*there is no RF emission by any living organism, neither by the natural environment*”. This is incorrect as a matter of elementary physics. All matter above absolute zero emits thermal radiation across the full electromagnetic spectrum. The human body at 310 K emits approximately 100

nW/m² in the 1–10 GHz band, which is easily measurable by microwave radiometry.” In response to this comment we should say that, Foster et al. confuse thermal noise which is the random thermal movement of particles/molecules in all forms of matter (including living tissue) indeed, with what we all call here RF, which is entirely man-made and as such fully polarized and coherent. This illustrates Foster et al. confusion about basic RF physics and technology. They do not understand the difference between random thermal noise and a fully polarized and coherent EMF as is the technical RF. Thermal noise is almost entirely in the infrared band, and indeed slightly expanded in the neighbouring Microwave (MW) band (part of the wider RF) because the division between the bands is approximate. While the peak radiation of the human body is in the infrared (at power density $\sim 500 \times 10^9$ nW/m²), the human body also emits at lower frequencies (MW/terahertz) indeed. But the power density is extremely low in these bands compared to infrared ($\sim 5 \times 10^9$ times smaller). In other words, the power density of human body thermal radiation in the MW band as provided by Foster et al. is correct, but when compared with the corresponding emission in the infrared band, it is absolutely negligible. As for the thermal emission in the lower frequency bands (LF, VLF, ELF, ULF), it is even several orders of magnitude smaller, and thus practically non-existing (Gulyaev et al. 1995). We do have non-thermal Ultra-Low Frequency (ULF: 0–3 Hz)/ELF emissions from the body’s electrical activity (Lipkova and Cechak 2005). Most importantly, this has nothing to do with the RF EMF emissions which is the subject of our debate and is entirely man-made. RF EMFs are produced by accelerating free electrons moving in specific directions and in phase within metallic conductors, while thermal noise is random movement in any possible direction different for each particle, and with no biological significance other than heating. The fact that there is some overlap in frequency between the neighboring infrared and RF does not mean that the thermal noise in the RF band has any similarity with the technical RF that we are discussing in Panagopoulos et al. (2026). There is no biological procedure in any living organism that results in RF emission or absorption. All biological procedures in all living organisms are connected with emission/absorption in the ULF (0–3 Hz) and ELF (3–3000 Hz) bands. Thus, indeed, there is no RF emission by any living organism, or inanimate matter, apart from heat which lies almost entirely in infrared, visible, and slightly in ultraviolet. This is described by the blackbody radiation, a well-known topic in physics. RF EMF emissions as those

discussed here are entirely connected with human technology, apart perhaps from specific exceptions under specific conditions.

Foster et al. write: “Documenting that wireless signals are intermittent and appear pulsed on an amplitude-modulation receiver – which are well-known properties of digital wireless communications systems – does not establish that pulsing causes harm.” In response to this comment we must say, they do not “appear” pulsed; they are pulsed. There is nothing but pulsations, ELF pulsations, in all digital WC EMFs. If this is a well-known property as they say, why do they not report it in their Foster et al. (2025) article? We agree that the recording of the ELF pulsations alone does not establish harm. That is why in Panagopoulos et al. (2026) we refer to numerous experimental studies having compared pulsed with corresponding non-pulsed (continuous wave) RF EMFs, and finding that in almost all cases the pulsed RF EMFs with ELF pulsations were significantly more bioactive than the non-pulsed. And moreover, because ICNIRP and others have objected to the non-thermal biological effects just because “there is no mechanism to explain them”, we referred to the IFO-VGIC mechanism which explains them very well.

We believe this good-will debate helps both sides in our common quest, which is the study of the physical properties and the biological/health effects of WC EMFs, and thus we thank Foster et al. for their comments.

Author contributions

CRedit: **Dimitris J. Panagopoulos**: Writing – review & editing; **Roman Litovsky**: Writing – review & editing; **Kent Chamberlin**: Writing – review & editing.

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