Health effects of mmWave radiation

With the increasing presence of high frequency communication and sensor solutions in the market operating in the mm-wave regime (mm-wave are electromagnetic (EM) waves having a wavelength between 1–10 mm), interest into the effects of these frequencies on the human body and health is increasing.

First and most important mm-wave frequencies are categorized as a non-ionizing radiation, meaning that the energy of smallest unit of these EM-waves is too little to cause electrons to move from their orbits [1]. Being non-ionizing is quite important as this is the mechanism that is related to increasing the chances of cancer [2]. The highest photon energy of a mm-wave photon is 1.2 meV while the photon energy needed to remove an electron from its atom is around 12 eV, meaning that mm-wave photon energy is 10,000 times less than what is needed to be ionizing.

So now that mm-waves are non-ionizing, how else could they affect the human body? The energy of the waves can only cause heating to the objects they illuminate raising their temperature.

* SAR or specific absorption rate is a measure of how much power in watts falls on 1 kg of mass
PD or power density is a measure of how much power in milliwatts falls on 1 cm^2 or area

For this matter there are official standards set up by governments [3] which dictate the amount of power that can be transmitted at different frequency ranges keeping heating effects on the human body significantly below 1° [4]. Unlike lower frequency signals, like those used by cellular phones, which have relatively deep penetration in the human body, the short wavelength of the mm-waves limits their penetration of the human body to predominantly the outer layer i.e skin and eyes.

Government exposure limits
To protect humans from thermal damage by radiation, globally varying exposure limits have been introduced.

The standards used in the US and Europe, FCC and ICNRP respectively, are the most popular guidelines and were largely derived from research with animals.

Guidelines	PD restrictions for the general public in [mW/cm^2]	Frequency range [GHz]
ICNRP	1	2–300
FCC	1	1.5–100

The two main standards used as limits for radiation are power density (PD in mw/cm^2) and specific absorption rate (SAR in W/kg). Due to the limited penetration of the mm-Waves into the body making a human target appear more as a 2D surface the FCC requires using the PD method for calculating the radiation limits as PD deals with radiation on a surface area rather than a volume.

A 24 GHz system operating at the maximum allowed radiated power just 5 cm away from a human body will have a PD value of 0.3 mW/cm^2 which is below maximum limit.

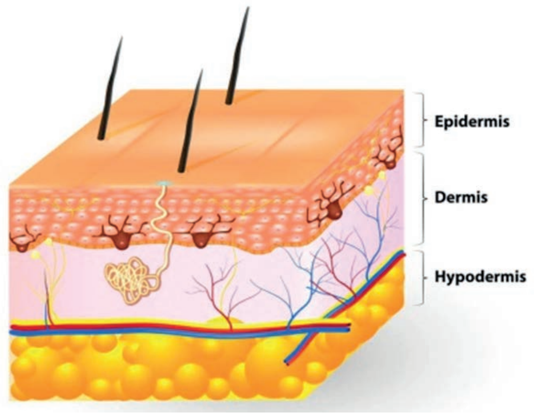
Effects on skin

Since mmWave energy dissipates easily in moist aqueous tissue the high water content in the two primary layers of skin leads to high absorption with 15–40% (epidermis) and 70–80% (dermis) water content. Even though mmWave energy permeates the epidermis, it gets absorbed to a large extent in the dermis and therefore, does not spread any further within the tissue. Several studies show that the conductivity of the skin increases with the frequency. One has to consider that conductivity varies with different levels of water content in the skin. The human palm or wrist, for example, offers low conductivity due to the fact that the skin contains only very little amounts of water.

Yet another factor that needs to be considered is the reflection of the skin. In an experiment presented in [4] it is shown that at 60 GHz 30–40% of the incident power is reflected at the skin surface. [4]

As most mmWave energy is absorbed in the skin or close to the outer layers of the skin this leads to localized heating in the affected area of the tissue. Nelson et al. [5] displayed that the skin temperature rose with energy density and was influenced by different environmental conditions, such as blood circulation, sweat rate and convection.

The layers of human skin



Nonetheless, experiments show that the steady state temperature elevation at 60 GHz with the various power density limits applied reaches about 0.8°C which is below the temperature elevation threshold of 1°C in the IEEE guideline on mmWave radiation [6].

Effects on eyes

In the skin heat can be easily diffused by blood flow. However, as the eyes lack sufficient blood flow to dissipate the heat they are more vulnerable.

Additionally, the eyes are located on the outside of the human body and thus directly exposed to mmWave radiation.

Experiments using 60 GHz mmWave radiation with 10 mW/cm^2 on nonhuman primates' eyes have shown that radiation under PD restrictions causes no ocular damage. [4] [7]

One can affirm that effects on our eyes depend largely on the intensity and duration of the exposure but as long as they are in accordance with the guidelines no adverse effects should occur.

Important Note:
The information contained in this document is derived from public sources and not based on our own scientific studies. We hereby disclaim any and all warranties and liabilities of any kind in connection with such information.

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