Design Principles and Applications of a novel Electromagnetic Spectrum Table

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Abstract- **Electromagnetic spectrum diagram is used to represent the content of electromagnetic wave. At present different kinds of electromagnetic spectrum representations make people confused. In this paper, design principles and important applications of a novel electromagnetic spectrum table are introduced. In the new table, electromagnetic wave bands are classified in more detail, especially for the first time terahertz wave band is redefined from 0.15 Thz to 6 Thz according to short millimeter wave limit and long infrared wave limit. This novel spectrum table can be used as electromagnetic spectrum representation standard in academic and will bring great convenience for researchers and learners.**

I. INTRODUCTION

The development of electromagnetic wave technology extends scientific research fields and drives many emerging disciplines. However, electromagnetic products make their users under a long time hazards of electromagnetic radiation. The electromagnetic wave application and hazard prevention make it pressing to strengthen the education and popularization of electromagnetic wave knowledge.

Traditionally the content of electromagnetic wave is described by frequency-wavelength diagrams, as shown in figure 1 and figure 2 [1]. In these diagrams, two close parallel lines signify the track of electromagnetic frequency and wavelength, respectively. Based on these two lines, electromagnetic spectrum is commonly divided into radio, microwave, infrared, visible, ultraviolet ray, X-ray and gamma ray. In some diagrams, applications of the waveband are also briefly described in the diagrams. Even though these diagrams can be helpful for people to research on electromagnetic wave, different kinds of electromagnetic wave diagrams make people confused.

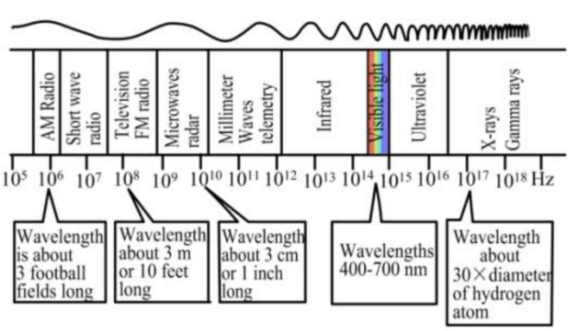

Figure 1. Electromagnetic spectrum

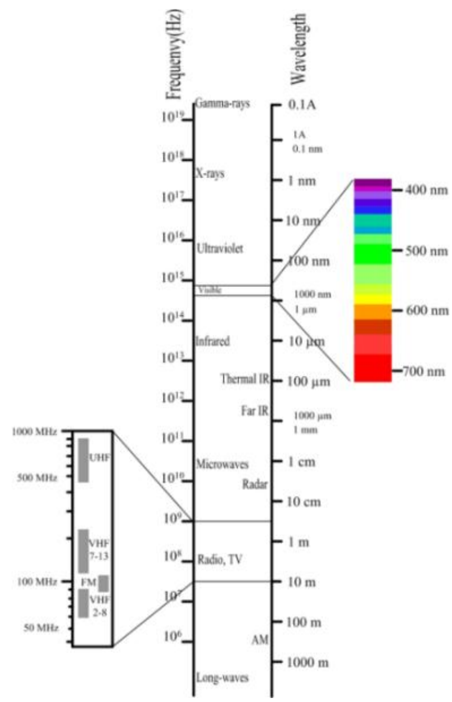

Figure 2. Electromagnetic spectrum

Furthermore, it is limited in these diagrams with one-dimensional space, because electromagnetic wave wavelength and frequency change continuously from zero to infinity. The one-dimensional representation cannot show this nature very well. In this paper, design principles and applications of a novel electromagnetic spectrum table are introduced. In the new table, electromagnetic wave is firstly divided into air wave, terahertz wave and light wave, and finer divisions are made in these three wave bands. In addition, based on short millimeter wave limit and long infrared wave limit, terahertz wave band is redefined from 0.15 Thz to 6 Thz. In terahertz wave band, the concepts and ideas of "near air wave" and "near light wave" are first proposed. "near air wave" band is from 0.15 Thz to 1 Thz and "near light wave" band is from 1 Thz to 6 Thz. These two bands help people to research on terahertz wave band referring to electronics category and photonics category.

II. DESIGN PRINCIPLES OF THE NOVEL "ELECTROMAGNETIC SPECTRUM TABLE"

Electromagnetic wave originates from the vibration of electric charge. This vibration creates a wave which has an electric component and a magnetic component. The succession of induced fields (electric to magnetic to electric to magnetic, etc.) results in the generation of electromagnetic wave [2], whose propagation velocity c is the product of wavelength λ and frequency ν,

$$c = \lambda \cdot \nu. \quad (1)$$

It is easy to obtain that it is an inverse relationship between electromagnetic wave frequency and wavelength in a specific medium. And electromagnetic wave frequency and wavelength are continuously from zero to infinity, so electromagnetic wave diagram representations in one-dimensional space are limited when comprehensively analyzing the electromagnetic wave properties. As mentioned before, the changes of frequency and wavelength in diagrams are indicated by the two close parallel lines, which cannot clearly describe the properties of electromagnetic wave bands.

In the new table 1 (see the Appendix), two improvements have been done: (1) continuous electromagnetic spectrum is described by discrete wave bands; (2) electromagnetic spectrum description is changed from one-dimensional space to two-dimensional space. In the first column of the new table, electromagnetic wave is firstly divided into air wave, terahertz wave and light wave according to obvious differences of electromagnetic wave nature and characteristics. Different kinds of air wave are listed on the basis of traditional classification (Ultra low frequency, Radio wave, etc.). In addition, light wave is divided into micron wave, nano wave and pico wave. In nano wave band, color symbols indicate the particularity and importance of visible light. Furthermore, for electromagnetic wave, some interesting properties can be learned in quantum domain [3]. The energy of each quantum is indicated at the bottom of the table, which is the product of Planck constant and electromagnetic wave frequency, i.e. E=hν=4.1357×10-15×ν, 1 Electron volt (eV) =6.6261×10-34×ν(J).

III. New division of terahertz wave band

The first occurrence of the term terahertz is attributed to Fleming in 1974, when the term was used to describe the spectral line frequency coverage of a Michelson interferometer [4]. As early as 1896 and 1897, researches of Rubens and Nichols involved this wave band. Terahertz wave band is defined from 0.1 THz to 10 THz traditionally, which lies between millimeter wave and infrared wave as marked in figure 3.

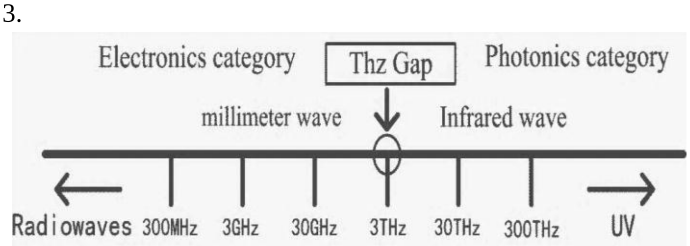

Figure 3 Terahertz wave "gap"

However, the very large THz portion of the spectrum has not been particularly useful because there were neither suitable emitters to send out controlled THz signals nor efficient sensors to collect them and record information. As a result, the THz portion of electromagnetic spectrum was called the THz gap. The long wave of terahertz wave band is overlapped with millimeter wave, and the short wave of this band is overlapped with infrared wave. On the other hand, long terahertz wave mainly belongs to electronics category, and short terahertz wave basically belongs to photonics category, thus terahertz wave band once became the research gap of the electromagnetic spectrum [5].

In the new table, terahertz wave band is redefined from 0.15 Thz to 6 Thz, because short millimeter wave limit is 2 mm (0.15 Thz) [6] and long infrared wave limit is 50 μm (6 Thz) [7]. Furthermore, terahertz wave is finely divided into "near air wave (0.15 Thz -1Thz)" and "near light wave (1Thz -6Thz)". The two names refer to the naming of near infrared wave and near ultraviolet wave. The long light wave limit is 300 μm (1Thz) [8], so it is reasonable that "near air wave" band is from 2 mm (0.15 Thz) to 300 μm (1Thz) and "near light wave" band is from 300 μm (1 Thz) to 50 μm (6 Thz).

With fine division of terahertz wave band, the study of "near air wave" and "near light wave" can refer to electronics technology and photonics technology respectively. Thus, good research ideas and methods in light wave and air wave should be used to solve terahertz wave problems. People will be easier to obtain and understand characteristics of terahertz wave knowledge.

IV. Applications of the novel "Electromagnetic Spectrum Table"

Based on the above, we can clearly find advantages of new electromagnetic spectrum table. From previous electromagnetic spectrum representations, we just roughly know the spectrum division of electromagnetic wave. It is difficult to find the features and applications of more specific electromagnetic wave bands. In addition, the division of wave bands is not very obvious in one-dimensional space, which limits people to get electromagnetic wave information in previous electromagnetic spectrum representations. In the new table, electromagnetic wave bands are arranged scientifically and detailedly, no matter the overall division or the partial division. The frequency range and principal uses of each wave band lies clearly in the new table. For a certain wave band, people can easily find the features and research on this wave band.

Most parts of electromagnetic spectrum are used in science to study and characterize matter. But the research and improvement of terahertz wave band is slower than others in a very long time because of the terahertz wave "gap". Now the applications of terahertz wave have been found in many fields, such as physics, material science, electrical engineering, chemistry and so on. The division of "near air wave" and "near light wave” is significant for terahertz wave study.

Nevertheless, exposure to strong electromagnetic field may cause damage for humans and animals, even though the exposure is of short duration. It can make the long-established physical laws of humanity seriously damaged, and lead to impaired immune function [9]. The new table let us master the electromagnetic wave knowledge better and we should use electromagnetic wave technology carefully to reduce the bad effects as many as possible.

V. Conclusion and discussion

In the new electromagnetic spectrum table, detailed wave bands and corresponding application descriptions help people research on electromagnetic wave, especially for terahertz wave. Even though the new table has important value in physics, there is still a little imperfection which needs for further study. For example, since the common view of wavelength range in visible light wave band is not clear, the range 730-400 nm in new table needs to be further discussed. However, new electromagnetic spectrum table is very useful for electromagnetic wave researchers and learners. It will play a important role in promoting for electromagnetic wave knowledge popularization and related work in education.

Acknowledgment

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Appendix

Table.1 A novel table of electromagnetic spectrum

Name of wave band					frequency section $\nu=(3\times10^8 m/s)/\lambda_0$	Wavelength section $\lambda_0=(3\times10^8 m/s)/\nu$	principal use
Air wave	Ultra low frequency (ULF)			ULW	3(Hz)-3 (kHz)	(100000-100) (Km)	Electronics, headphones......
	Radio wave	Very low frequency (VLF)		VLW	(3-30) (kHz)	(100-10) (Km)	AM radio, walkie-talkie medical, long-haul communication, induction cooker......
		low frequency (LF)		LW	(30-300) (kHz)	(10-1) (Km)	
		Middle frequency (MF)		MW	300(kHz) -3 (MHz)	(1000-100) (m)	
	Radio Frequency	High frequency (HF)		SW	(3-30) (MHz)	(100-10) (m)	TV, AM and FM radio.....
		Very high frequency (VHF)		MW	30(MHz)-1 (GHz)	(10-0.3) (m)	
	Micro wave	Ultra high frequency (UHF)	Deci meter wave	L	(1-2) (GHz)	(30-15) (cm)(ref.: 22cm)	Mobile communications, microwave oven......
				S	(2-4) (GHz)	(15-7.5) (cm) (ref: 10cm)	
		Super high frequency (SHF)	Centi meter wave	C	(4-8) (GHz)	(7.5-3.75) (cm)（ref: 5cm)	Satellite broadcasting television, medical, communication, radar, telemetry, electronic reconnaissance, detection......
				X	(8-12) (GHz)	(3.75-2.5) (cm) (ref: 3cm)	
				Ku	(12-18) (GHz)	(2.5-1.67) (cm) (ref: 2cm)	
				K	(18-27) (GHz)	(1.67-1.11) (cm) (: ref 1.25cm)	
				Ka	(27-40) (GHz)	(1.11-0.75) (cm)(ref: 0.8cm)	
		Extremely high frequency (EHF)	Milli meter wave	U	(40-60) (GHz)	(7.5-5) (mm) (ref: 6mm)	Communication, radar, Medical, astronomy, detection.....
				V	(60-80) (GHz)	(5-3.75) (mm) (ref: 4mm)	
				W	(80-150) (GHz)	(3.75-2) (mm)(ref:3mm)	
Terahertz wave		Near air wave			(0.15-1.0) (THz)	(2-0.3) (mm)	Scientific research tools, Imaging technology, plasma detection......
		Near light wave			(1/300-1/50)300 (THz)	(300-50) (μm)	
Light wave	Micron wave: infrared wave	Far infrared			(1/50-1/10.6) 300 (THz)	(50-10.6) (μm)	Heating, exploration......
		Middle infrared			(1/10.6-1/1.675)300 (THz)	(10.6-1.675) (μm)	Medical, convection oven, Laser processing......
		Near infrared	U		(1/1.675-1/1.625)300 (THz)	(1.675-1.625) (μm)	Optical transmission, wavelength complex, amplification , remote detection, sensing......
			L		(1/1.625-1/1.566)300 (THz)	(1.625-1.566) (μm)	
			C		(1/1.566-1/1.53)300 (THz)	(1.566-1.53) (μm)	
			S		(1/1.53-1/1.46)300 (THz)	(1.53-1.46) (μm)	
			E		(1/1.46-1/1.36)300 (THz)	(1.46-1.36) (μm)	
			O		(1/1.36-1/1.26)300 (THz)	(1.36-1.26) (μm)	
			Short wave		(1/1.26-1/1.06)300 (THz)	(1.26-1.06) (μm)	Laser medical, laser cosmetology, ranging, processing , guidance systems, detection ......
					(1/1.06-1/0.94)300 (THz)	(1.06-0.94) (μm)	
			Ultra short wave		(1/0.94-1/0.85)300 (THz)	(0.94-0.85) (μm)	
					(1/0.85-1/0.78)300 (THz)	(0.85-0.78) (μm)	
					(1/0.78-1/0.73)300 (THz)	(0.78-0.73) (μm)	
	Nano wave: Visible light	Red			(1/0.73-1/0.66)300 (THz)	(730-660) (nm)	Lighting, biological photosynthesis, print, copy, scanning, photovoltaic power generation, remote control...
		Orange			(1/0.66-1/0.60)300 (THz)	(660-600) (nm)	
		Yellow			(1/0.60-1/0.54)300 (THz)	(600-540) (nm)	
		Green			(1/0.54-1/0.50)300 (THz)	(540-500) (nm)	
		Cyan			(1/0.50-1/0.46)300 (THz)	(500-460) (nm)	
		Blue			(1/0.46-1/0.44)300 (THz)	(460-440) (nm)	
		Violet			(1/0.44-1/0.40)300 (THz)	(440-400) (nm)	
	Nano wave: Ultraviolet wave	Near ultraviolet			(1/0.40-1/0.20)300 (THz)	(400-200) (nm)	Disinfection, currency detector, sterilization, fault detection, Communication......
		Middle ultraviolet			(1/0.20-1/0.1)300 (THz)	(200-100) (nm)	
		Far ultraviolet			(1/0.1-1/0.01) 300 (THz)	(100-10) (nm)	
	Picometer wave	X-Ray			(100-10000) 300 (THz)	(10-0.1) (nm)	Medical check, material structure analysis ...
		Special radiation: γ-Ray			(10000-1000000)300 (THz)	(100-1) (pm)	Fault detection, and strategic weapons......
		Special radiation: High energy radiation			>300000000 (THz)	<1 (pm)	Substance processing, strategic weapons......

Note: After quantization the energy of each quantum, $E=h\nu=4.1357\times10^{-15}\times\nu$, 1 Electron volt (eV) $=6.6261\times10^{-34}\times\nu$(J)