Comparing the Attenuation in Noble Metals(Copper, Silver, Aluminum, and Gold)

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Abstract:

Electromagnetic wave propagation through noble metals are studied here. The conductivity and the attenuation of copper, silver, aluminum, and gold are calculated for various frequencies of the electromagnetic waves. The study categorized the electromagnetic waves into two parts; radio, microwave frequencies and ultra violt , x-rays frequencies. Both parts were applied to those metals. Finally, this work derives the optimum frequencies, which provides minimum attenuation and maximum conductivity in Copper, Silver, Aluminum, and Gold .

Keywords: *Copper, Silver, Aluminum, Gold, Propagation, Optimum frequency, Attenuation, Conductivity, Relaxation frequency, Drude model .*

1.Introduction

Electromagnetic attenuation is well-known problem in propagation of wave through a medium. This study is concentrated on good conductors, the four noble metals(Copper, Silver, Aluminum, and Gold) hare been chosen for the study.

The field of radio frequency (RF) and microwave engineering generally covers the behavior of alternating current signals with frequencies in the range of 100 MHz (1 MHz = 10^6 Hz) to 1000 GHz (1 GHz = 10^9 Hz). RF frequencies range from very high frequency (VHF) (30–300 MHz) to ultra high frequency (UHF) (300–3000 MHz) [6].

Conductivity and attenuation are frequency which depend on frequencies above 1GHz for good conductors. Electromagnetic waves are classified according to their frequency to calculate the conductivity and attenuation in each band for these metals. The optimum frequency obtained from the results, this frequency is recommended to increase conductivity and decrease attenuation.

2. Part A (radio and microwave frequencies)

In this section, we calculate the conductivity and attenuation for radio and microwave frequencies in the range of frequency from 1kHz to 1GHz.

2.1. Conductivity

At radio and microwave range, conductivity is independent of frequency and has almost constant value.

For frequencies such as ω<<γ, the conductivity is considered independent of frequency and equal to dc value

$$\sigma = \frac{\varepsilon 0\ \omega_{relax}{}^{2}}{\gamma} \qquad (1)$$

where ε0 is the permittivity of free space.

ω_{relax} is relaxation frequency.

The parameter γ is a measure of the rate of collisions per unit time when an electric field is applied to a conductor. It is informative to note the conductivity of several metallic conductors; typical values (in Siemens per meter) are $3.54X10^{7}$ for Aluminum, $5.8X10^{7}$ for Copper, and $6.49X10^{7}$ for silver [1].

Conductivity for Copper, Silver, Aluminum, and Gold is shown in table 1.

Table 1. Shows conductivity for Copper, Silver, Aluminum, and Gold at frequency range of (1KHz-1 GHz)

	Copper	**Silver**	**Aluminum**	**Gold**
Conductivity s/m	$5.8X10^{7}$	$6.49X10^{7}$	$3.54X10^{7}$	$4.1X10^{7}$

2.2. Attenuation

Attenuation is calculated by the equation

$$\alpha = 1.9869 \times 10^{-3} \sqrt{\sigma}\sqrt{f} \qquad (2)$$

Where σ is the conductivity of metal.

Table 2 shows the attenuation equation for Copper, Silver, Aluminum, and Gold.

Table 2. Shows the attenuation for Copper, Silver, Aluminum, and Gold at radio and microwave frequencies.

	Copper	Silver	Aluminum	Gold
α(dB/m)	$131.43\sqrt{f}$	$139\sqrt{f}$	$102.67\sqrt{f}$	$110.47\sqrt{f}$

3. Part B (ultra violt and X-rays frequencies)

We formulate analytical equations to calculate conductivity, relaxation frequency, and attenuation for the scenario of Ultra violt and X-rays frequencies in the range of frequency from 1GHz to 10^{15}Hz.

3.1. Conductivity

A good conductor is a special case of the preceding analysis, where the conductive current is much greater than the displacement current, which means that σ>>ω [6]. Conductivity depends on frequency, conductivity is calculated by Drude model.

$$\sigma(\omega) = \frac{\varepsilon 0\ \omega_{relax}{}^{2}}{\gamma + j\omega} \ \text{siemens/m} \qquad (3)$$

where ω_{relax} is relaxation frequency, $\omega_{relax} = 2\pi f_{relax}$

For Copper,

$$f_{relax} = \frac{1}{2\pi}\sqrt{\frac{Ne^2}{m\varepsilon 0}} = \sqrt{\frac{(8.4\text{x}10^{28})(1.6\text{x}10^{-19})^2}{(9.1\text{x}10^{-31})(8.854\text{x}10^{-12})}} = 2.6\text{x}10^{15}\ Hz \qquad (4)$$

Where, N is the volume density for a conductor, N_{copper}= 8.4x10^{28} electrons/m^3, e is the electronic charge and it is equal to 1.6x10^{-19} C, m is mass of electron= 9.1x10^{-31} Kg.

For copper, γ_{copper}= 4.1x10^{13} sec^{-1}.

3.1.1. Relaxation frequency of conductors

First relaxation time, The mean-time between collisions, must be determined

relaxation time $\tau = \frac{m}{ne^2\rho}$ sec. (5)

the rate of collisions $\gamma = \frac{1}{\tau}$ sec^{-1}. (6)

Where:

N is the volume density of conduction electrons, e= $1.6x10^{-19}$ C, ρ is resistivity, m= $9.1x10^{-31}$ Kg.

Table 3 shows volume density of conduction electrons and resistivity for Copper, Silver, Aluminum, and Gold.

Table 3. Shows for volume density of conduction electrons and resistivity Copper, Silver, Aluminum, and Gold .

	Copper	**Silver**	**Aluminum**	**Gold**
n (m^{-3})	$8.4X10^{28}$	$5.8X10^{28}$	$6.0X10^{28}$	$5.9X10^{28}$
ρ	$1.724X10^{-8}$	$1.54X10^{-8}$	$2.82X10^{-8}$	$2.44X10^{-8}$

Applying those parameters in equation no. (5) we get relaxation time for Copper, Silver, Aluminum, and Gold.

τ_{cp}= $2.457X10^{-14}$ s, τ_{s}= $3.98X10^{-14}$ s, τ_{al}= $2.103X10^{-14}$ s, and τ_{gl}= $2.472X10^{-14}$ s.

The rate of collisions per unit time when an electric field is applied to a conductor is the inverse of relaxation time, the value of both parameters are shown in table 4.

Table 4. Shows for values of relaxation time and rate of collisions of Copper, Silver, Aluminum, and Gold. .

	Copper	**Silver**	**Aluminum**	**Gold**
τ (s)	$2.457X10^{-14}$	$3.98X10^{-14}$	$2.103X10^{-14}$	$2.472X10^{-14}$
γ (s^{-1})	$4.069X10^{13}$	$2.51X10^{13}$	$4.75X10^{13}$	$4.045X10^{13}$

Finally relaxation frequency obtained by the equation

$$\omega_{relax} = \sqrt{\frac{Ne^2}{m\varepsilon 0}} \qquad (6)$$

Where, N is the volume density for a conductor.

N_{copper}= $8.4x10^{28}$ electrons/m^3.

$$\omega_{relax(copper)} = \sqrt{\frac{(8.4X10^{28})(1.6X10^{-19})^2}{(9.1x10^{-31})(8.854x10^{-12})}} = 1.633X10^{16}\ Hz \qquad (7)$$

By the same manner we can find the relaxation frequency for Silver, Aluminum, and Gold. Table 5 illustrated the relaxation frequency for all four conductors.

Table 5. Shows the values of relaxation frequency of Copper, Silver, Aluminum, and Gold.

	Copper	**Silver**	**Aluminum**	**Gold**
ω_{relax}	$1.633X10^{16}$	$1.356X10^{16}$	$1.38X10^{16}$	$1.368X10^{16}$

3.1.2. Attenuation

Attenuation depends on both frequency and conductivity and calculated by

$$\alpha = \sqrt{\pi f \mu \sigma(\omega)} \qquad (8)$$

Since π and μ are constants, we get the attenuation from next equation in decibel

$$\alpha = 17.258X^{-3}\sqrt{f\sigma(\omega)} \qquad (9)$$

4. Results

The conductivity as well as attenuation loss for electromagnetic waves propagating through Copper, Silver, Aluminum, and Gold are analyzed in the frequency range of 1kHz to 10^{15}Hz. This frequency range will include radio and microwave bands (from 1kHz to 1GHz) and Ultra violt and X-rays bands (from 1GHz to 10^{15}Hz).

To obtained conductivity at radio and microwave bands equation **(1)** was used where conductivity is independent of frequency range. **Table 1** shows the calculated values of conductivity of Copper, Silver, Aluminum, and Gold. The equations to obtained attenuation for the four metals where derived from equation **(1)** and set out in **Table 2**. **Figure 1** illustrates the attenuation at radio and microwave frequency through Copper, Silver, Aluminum, and Gold. The attenuation increases dramatically until reaches 0.3MHz for four metals. From 300MHz until 3 THz attenuation continues to increase less intensely.

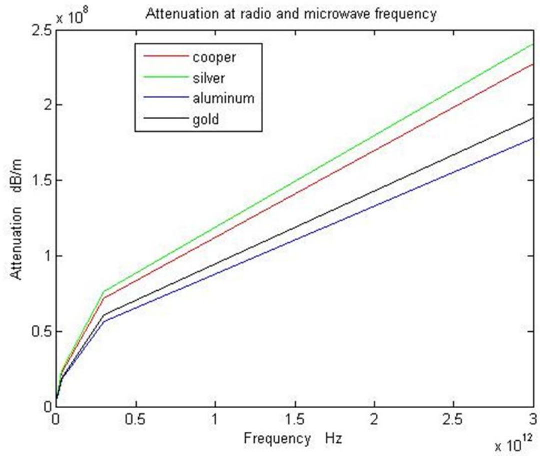

Figure 1 illustrates the attenuation at radio and microwave frequency through Copper, Silver, Aluminum, and Gold.

The volume density of conduction electrons and resistivity for metals are presented in **Table 3**. The result of collisions rate per unit time when an electric field is applied to a conductor and the relaxation time of each metal obtained from equations **(4)** and **(5)** is presented in **Table 4.**

Table 4. provides the relaxation frequency for Silver, Aluminum, and Gold. Those frequencies were calculated by equation **(6)**. **Figure 2** illustrates the attenuation at Ultra violt and X-rays frequency through Copper, Silver, Aluminum, and Gold. Attenuation increases almost linearly with frequency for all metals.

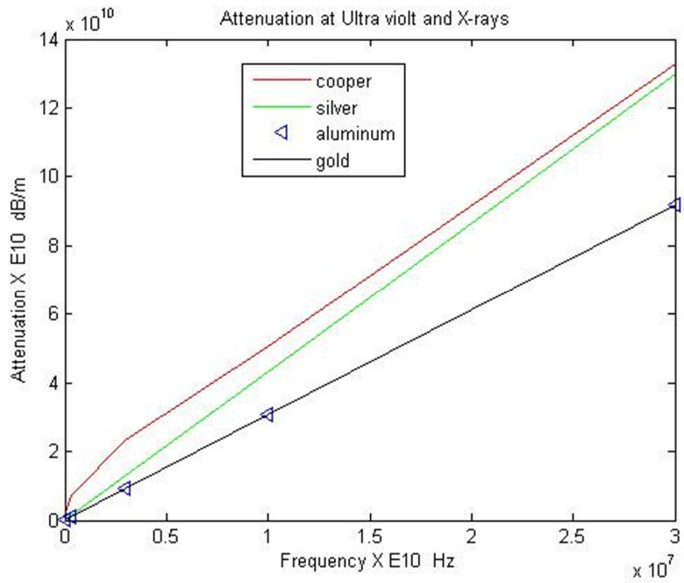

Figure 2 illustrates the attenuation at Ultra violt and X-rays frequency through Copper, Silver, Aluminum, and Gold.

Conclusion:

The main purpose of this paper was comparing the conductivity between Copper, Silver, Aluminum, Gold and obtain the optimum frequency for the four metals. The conductivity and attenuation has been calculated.

At radio and microwave frequency, the value of attenuation for Copper, Silver, Aluminum, and Gold are close to each other under 300MHz. Above this frequency, the gap between metals increases. Silver has the highest attenuation then Copper, Gold, and Aluminum respectively.

At Ultra violt and X-rays frequency, Copper, and Silver have the highest attenuation. Aluminum, and Gold have almost the same value which is less than the attenuation in Copper, and Silver.

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