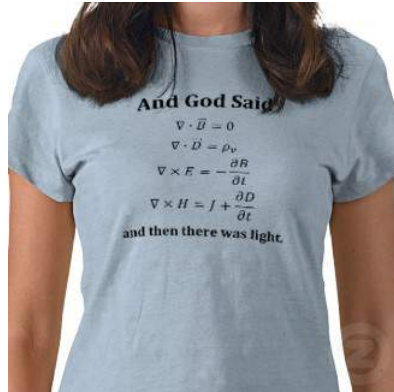


## Easy ! Maxwell's Equations

TDU



Hideyuki Nebiya  
Tokyo Denki University

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Numerical Formulas are tied up with  
Physical Formulas that we use  
in Wireless Design.

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# Every Physical Formula starts from a Circle of Radius = 1 (Unit Circle)

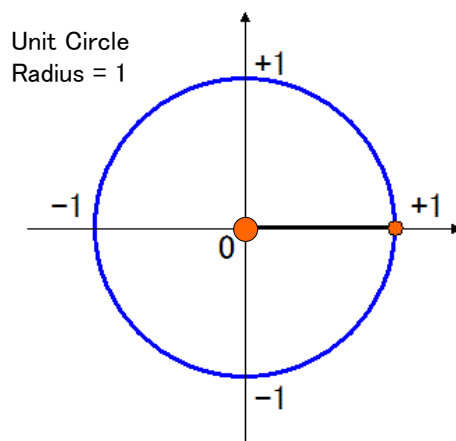
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Look at this Circle for 20 seconds !

**TDU**



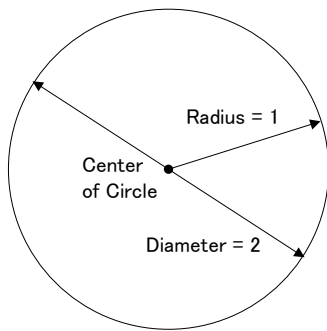
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Every Physical Formula starts from a Circle of Radius = 1 (Unit Circle)

Unit Circle (単位円)



Circle of Radius = 1 (Unit Circle / 半径 1 の単位円)

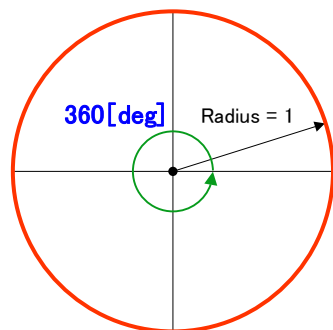
$$\begin{aligned} \Rightarrow \text{Diameter (直径)} &= \text{Radius (変形)} \times 2 \\ &= 1 \times 2 \\ &= 2 \end{aligned}$$

$$\begin{aligned} \Rightarrow \text{Length of 1 Revolution (円周の長さ)} \\ &= \text{Diameter (直径)} \times \text{Circle Ratio (円周率)} \\ &= 2 \times \pi \\ &= 2 \times 3.14 \end{aligned}$$

Length of Unit Circumference =  $2\pi$

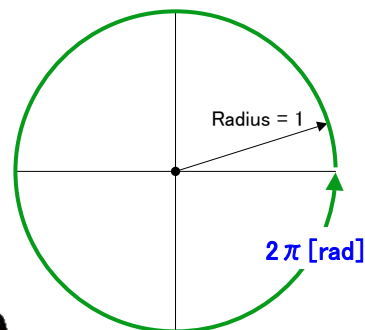
A Mathematician and a Physicist agree that 360[deg] is  $2\pi$  [rad].

Unit Circle



A Mathematician says  
"1 revolution means 360[deg]"

Unit Circle

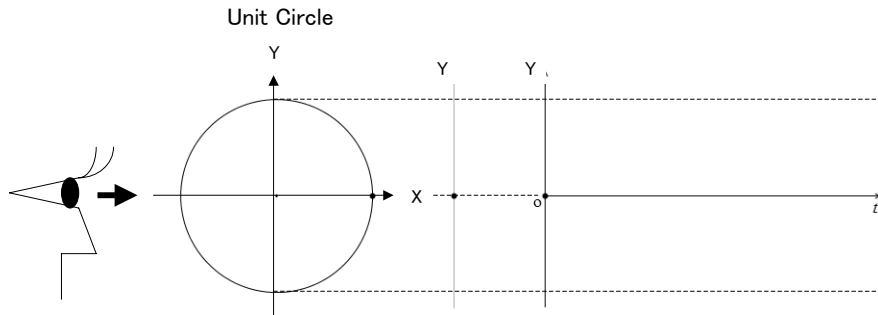


A Physicist says  
"1 revolution means  $2\pi$  [rad]"

$$360[\text{deg}] = 2\pi [\text{rad}]$$

## Trigonometrical Function understood from a unit circle

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A man observes the height of a Pendulum rotating by same velocity from the negative side of an X axis.

Time Domain →

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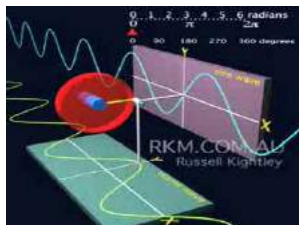
## “Sine” and “Cosine”

TDU

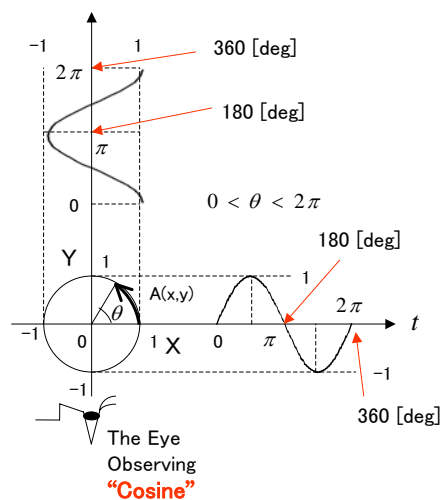
“Sine” and “Cosine” are the same function.

Just **Difference** is :

“Sine” is observed the height of a Pendulum rotating by same velocity from the negative side of an X axis, and “Cosine” is observed from the negative side of an Y axis.



The Eye observing “Sine”



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## Time, Distance, Velocity Equations ?

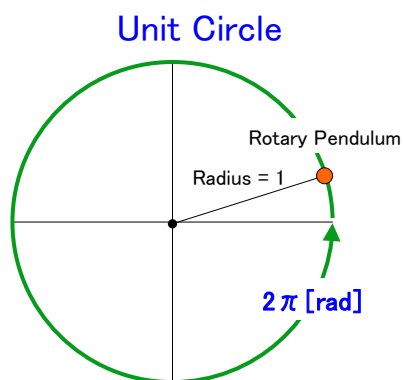
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## Frequency $f$ [Hz] and Angular Velocity $\omega$ [deg]

TDU



The Circumference of 1 revolution  
=  $2\pi$  [rad]

### Rotary Pendulum

When the Rotary Pendulum turns  $f$  revolutions for 1 second,

The Circumference  $\omega$  from which the Rotary Pendulum turns  $f$  revolutions,

$$\begin{aligned}\omega &= 2\pi (\text{Circumference}) \times f (\text{revolutions}) \\ &= 2\pi f\end{aligned}$$

$f$  is called "Frequency (周波数)", and

$\omega$  is called "Angular Velocity (角速度)".

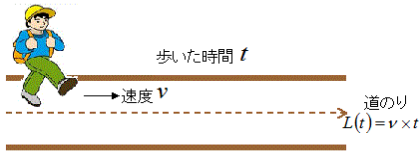
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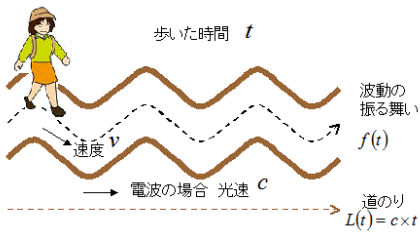
# Distance = Velocity × Time

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Distance  $L(t) = v \times t$

Velocity ↑  
Time ↑



Behavior of a Wave Motion

$f(t) = \sin(v \times t)$

Just Meaning of Winding Shape ↑ Velocity ↑ Time ↑

$= \sin(2\pi f \times t)$

Distance for one Second = Length of Circumference × Frequency ↑

$= \sin(\omega \times t)$

Angular Velocity ↑ Time ↑

Distance  $L(t) = c \times t$

Velocity of Light ↑ Time ↑

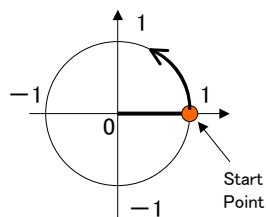
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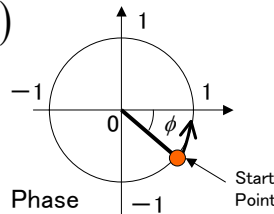
# Wave Function Equation

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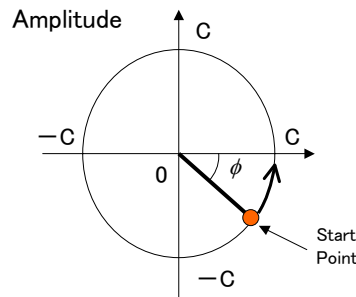


$f(t) = \sin(2\pi f t)$

Basic Equation



$f(t) = \sin(2\pi f t - \phi)$



$f(t) = C \sin(2\pi f t - \phi)$

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# Maxwell's Equations

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## Maxwell's Equations

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$$\left\{ \begin{array}{l} \text{rot} \vec{H} = \vec{J} + \frac{\partial}{\partial t} \vec{D} \quad \dots (1) \\ \text{rot} \vec{E} = -\frac{\partial}{\partial t} \vec{B} \quad \dots (2) \\ \text{div} \vec{B} = 0 \quad \dots (3) \\ \text{div} \vec{D} = \frac{\rho}{\epsilon_0} \quad \dots (4) \end{array} \right.$$

Where

$\vec{H}$  is the Magnetic Field Intensity

$\vec{J}$  is the Free Current Density

$\vec{D}$  is the Electric Displacement Field

$\vec{E}$  is the Electric Field

$\vec{B}$  is the Magnetic Field Density

$\rho$  is the Electric Charge Density

$\epsilon_0$  is the permittivity of Free Space

( $8.854 \times 10^{-12}$  [F/m])

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# The 1st Equation of Maxwell's Equations

## Ampère's Law

$$\text{rot}\vec{H} = \vec{J}$$

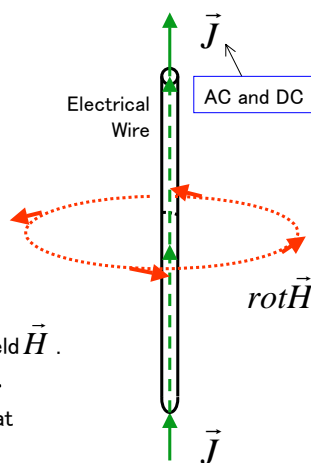
Where  
 $\vec{H}$  is the Magnetic Field Intensity  
 $\vec{J}$  is the Free Current Density

$$\text{rot}\vec{H} = \vec{J}$$



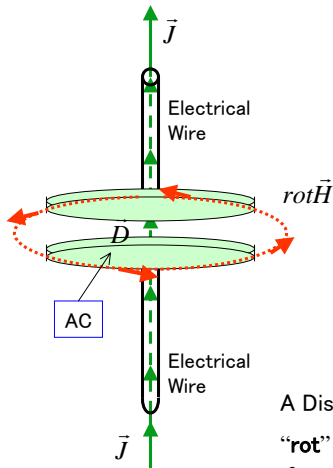
An Electric Current  $\vec{J}$  produces a Magnetic Field  $\vec{H}$ .

“rot” (rotation) means **Cross Product in Vector Algebra**, but it is easy for you to understand that “rot” means **Right-Handed Screw Rule**.





# Maxwell's Displacement Current



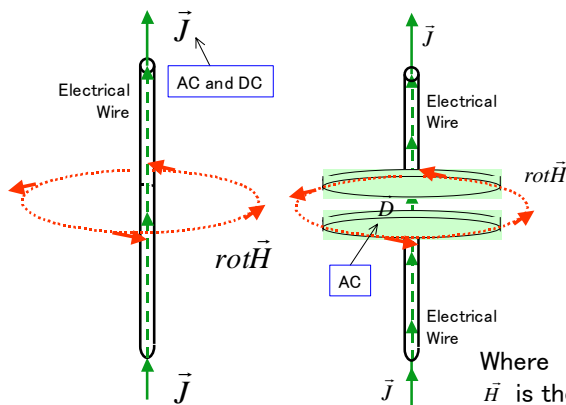
$$\text{rot} \vec{H} = \frac{\partial \vec{D}}{\partial t}$$

Where  
 $\vec{H}$  is the Magnetic Field Intensity  
 $\vec{D}$  is the Electric Displacement Field

$$\text{rot} \vec{H} = \frac{\partial \vec{D}}{\partial t}$$

A Displacement Current  $\vec{D}$  produces a Magnetic Field  $\vec{H}$ .  
 "rot" (rotation) means **Right-Handed Screw Rule**.  
 $\frac{\partial}{\partial t}$  means "it occurs in case of AC (Alternating Current)".

# Ampère's Law and Maxwell's Displacement Current



$$\text{rot} \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

Ampère's Law  
 Maxwell's Displacement Current

Where  
 $\vec{H}$  is the Magnetic Field Intensity  
 $\vec{J}$  is the Free Current Density  
 $\vec{D}$  is the Electric Displacement Field

## The 2nd Equation of Maxwell's Equations

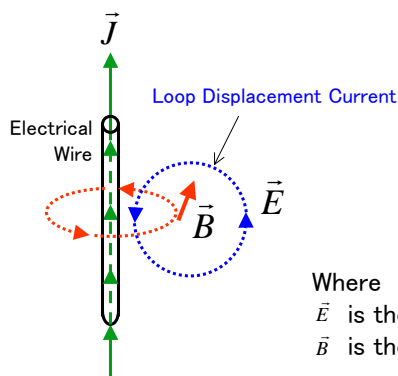
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## Faraday's Law

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Negative "Right-Handed Screw Rule"  
 $\Rightarrow$  "Left-Handed Screw Rule"

$$\text{rot} \vec{E} = - \frac{\partial}{\partial t} \vec{B}$$

Where  
 $\vec{E}$  is the Electric Field  
 $\vec{B}$  is the Magnetic Field Density

A Magnetic Field Density  $\vec{B}$  produces a Electric Field  $\vec{E}$ .

Negative (-) "rot" (rotation) means **Left-Handed Screw Rule**.

$\frac{\partial}{\partial t}$  means "it occurs in case of AC (Alternating Current)".

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## The 3rd Equation of Maxwell's Equations

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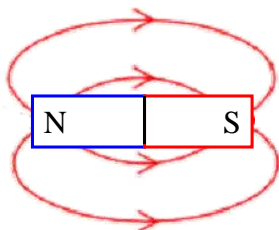
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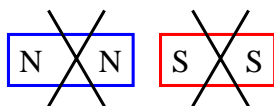
## The Magnetic Monopole is a hypothetical concept.

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Magnetic Field Density



Magnetic Field Density



$$\text{div} \vec{B} = 0$$

Where

$\vec{B}$  is the Magnetic Field Density

A **Magnetic Monopole** (N-Pole only or S-Pole only) is a **hypothetical concept** now. A Magnet has both N-Pole and S-Pole.

As a **Magnetic Field Density** flows to the S-Pole from the N-Pole, it is **NOT divergent**.

“div” (divergence) means **Inner Product in Vector Algebra**, but it is easy for you to understand that “div” means “**Gush out**” or “**Suck in**”.

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초간단 ! Very Easy ! 超簡単 !



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## The 4th Equation of Maxwell's Equations

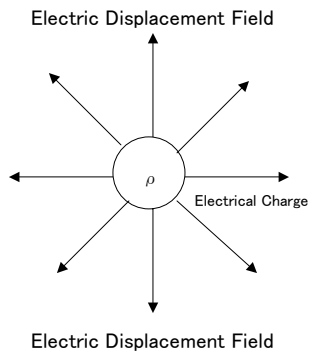
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## Coulomb's Law

Describes Force interacting between static electrically charged particles.



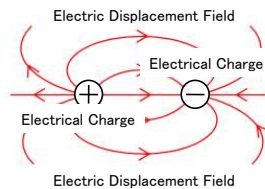
$$\text{div}\vec{D} = \frac{\rho}{\epsilon_0}$$

Where

$\vec{D}$  is the Electric Displacement Field

$\rho$  is the Electric Charge Density

$\epsilon_0$  is the Permittivity of Free Space  
( $8.854 \times 10^{-12}$  [F/m])



## Algebra in Maxwell's Equations

- $\left\{ \begin{array}{l} \text{rot} : \text{Rotation} \\ \rightarrow \text{ means Cross Product in Vector Algebra (difficult to understand)} \\ \Rightarrow \text{ means Right-Handed Screw Rule (easy to understand)} \end{array} \right.$
- $\left\{ \begin{array}{l} \frac{\partial}{\partial t} : \text{Partial Differentiation} \\ \rightarrow \text{ Value changes as well as time } t \text{ (difficult to understand)} \\ \Rightarrow \text{ means "it occurs in case of AC (RF)". (easy to understand)} \end{array} \right.$
- $\left\{ \begin{array}{l} \text{div} : \text{Divergence} \\ \rightarrow \text{ means Inner Product in Vector Algebra (difficult to understand)} \\ \Rightarrow \text{ means "Gush out" or "Suck in". (easy to understand)} \end{array} \right.$

## Maxwell's Equations

### ... Physicists' Compilation + Displacement Current

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$$\left\{ \begin{array}{l} \text{rot} \vec{H} = \vec{J} + \frac{\partial}{\partial t} \vec{D} \quad \dots (1) \\ \text{rot} \vec{E} = -\frac{\partial}{\partial t} \vec{B} \quad \dots (2) \end{array} \right. \quad \left\{ \begin{array}{l} \text{div} \vec{B} = 0 \quad \dots (3) \\ \text{div} \vec{D} = \frac{\rho}{\epsilon_0} \quad \dots (4) \end{array} \right.$$

Ampère's Law

Maxwell's Displacement Current

The Magnetic Monopole is a hypothetical concept.

Faraday's Law

Coulomb's Law

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## Mechanism of Electromagnetic Noise Radiation

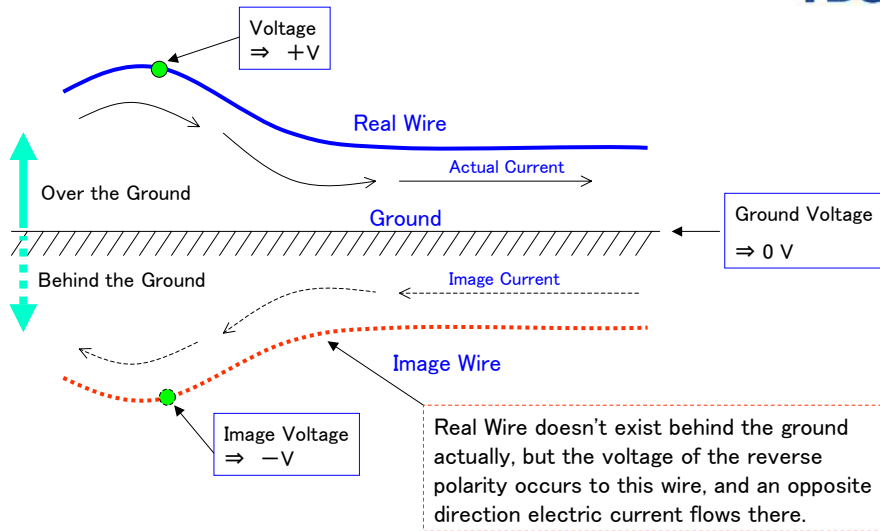
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## Real Wire and Image Wire

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## Ampère's Law

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$$\text{rot}\vec{H} = \vec{J}$$

Where

$\vec{H}$  is the Magnetic Field Intensity

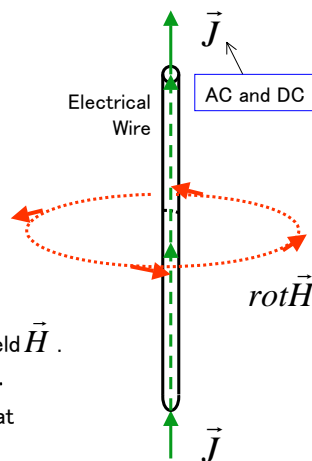
$\vec{J}$  is the Free Current Density

$$\text{rot}\vec{H} = \vec{J}$$



An Electric Current  $\vec{J}$  produces a Magnetic Field  $\vec{H}$ .

“rot” (rotation) means **Cross Product in Vector Algebra**, but it is easy for you to understand that “rot” means **Right-Handed Screw Rule**.

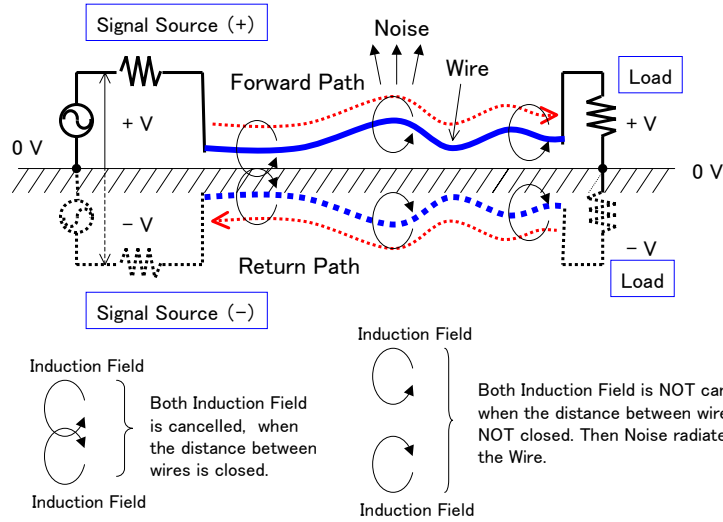


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# The Place where Noise radiates.

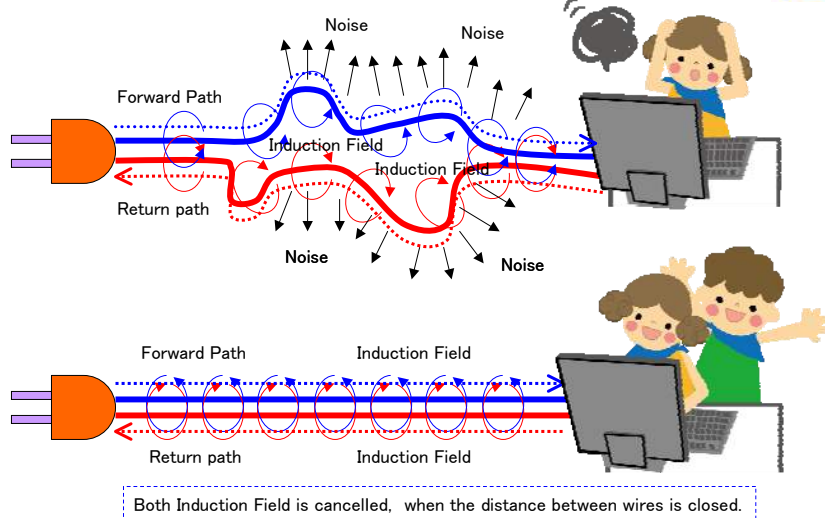


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# AC 100V Power Cable



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## Two Parallel Wires

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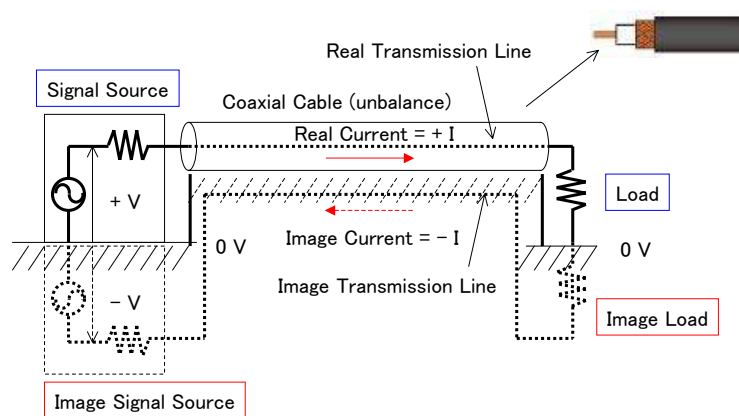
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## Coaxial Cable (unbalance)

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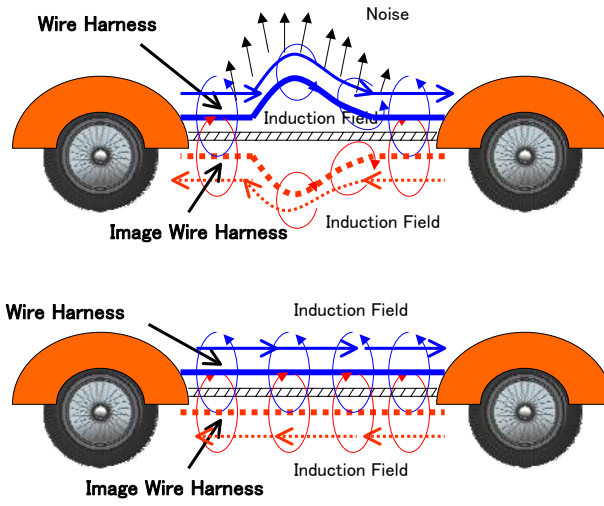


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# Wire Harness on the Motor Vehicle



Both Induction Field is cancelled, when the distance between wires is closed.

# Thank you for your attention.


**TDU**  
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