

# Lecture 1: Introduction. Overview of Pertinent Electromagnetics.

In this microwave engineering course, we will focus primarily on electrical circuits operating at frequencies of **1 GHz and higher**. In terms of band designations, we will be working with circuits **above UHF**:

	<b>Band</b>	<b>Frequency</b>
RF Region	HF	3 MHz-30 MHz
	VHF	30 MHz-300 MHz
	UHF	300 MHz-1 GHz
Microwave Region ( $\lambda = 30$ cm to 8 mm)	L	1-2 GHz
	S	2-4 GHz
	C	4-8 GHz
	X	8-12 GHz
	Ku	12-18 GHz
	K	18-27 GHz
	Ka	27-40 GHz
Millimeter Wave Region	V	40-75 GHz
	W	75-110 GHz
	mm	110-300 GHz

RF, microwave, and millimeter wave circuit design and construction is **far more complicated** than low frequency work. So why do it?

## Advantages of microwave circuits:

1. The **gain of certain antennas** increases (with reference to an isotropic radiator) with its electrical size. Therefore, one can construct high gain antennas at microwave frequencies that are physically small. (DBS, for example.)
2. **More bandwidth.** A 1% bandwidth, for example, provides more absolute frequency range at microwave frequencies than at HF.
3. Microwave signals **travel** predominately by **line of sight**. Plus, they don't reflect off the ionosphere like HF signals do. Consequently, communication links between (and among) satellites and terrestrial stations are possible.
4. At microwave frequencies, the electromagnetic **properties** of many materials are **changing with frequency**. This is due to molecular, atomic, and nuclear resonances. This behavior is useful for remote sensing and other applications.
5. There is **much less background noise** at microwave frequencies than at RF.

Examples of commercial products involving microwave circuits include wireless data networks [Bluetooth, WiFi (IEEE Standard 802.11), WiMax (IEEE Standard 802.16), ZigBee], GPS, cellular telephones, etc. Can you think of some others?

## Difficulties

As was mentioned, microwave circuits are much more difficult to analyze than low frequency ones. Why?

1. **Voltage is not well defined** if the distance between the two points is not electrically small. At microwave frequencies, “electrically large” distances may be just a few millimeters! Moving the probe leads around will also likely affect voltage measurements.
  2. One must **carefully choose lumped elements** (L, C, R, diodes, transistors, etc.) for use in the microwave region. Typical low frequency components do not behave as expected.
  3. To “transport” electrical signals from one position to another, one must use special “wires.” It is more common to speak of **“guiding” signals** at these frequencies.
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## Electromagnetism

Electricity is an electromagnetic (EM) phenomenon involving forces produced by stationary and moving charge.

Low frequency circuits are generally very, very small wrt the smallest EM wavelength present in the circuit. Because of this,

**simple lumped element circuit models** can be used to describe the EM effects of resistors, inductors, capacitors, voltage and current sources, etc.

Conversely, at microwave frequencies the circuits **may not be electrically small**. This requires a shift in our approach to the EM analysis. Nevertheless, the electrical signals remain the outcome of EM phenomenon.

Perhaps the two most important of the **Maxwell equations** are

	Differential form:	Integral form:
<b>Faraday's Law</b>	$\nabla \times \bar{\mathcal{E}} = -\frac{\partial \bar{\mathcal{B}}}{\partial t}$	$\oint_{c(s)} \bar{\mathcal{E}} \cdot d\bar{l} = -\frac{d}{dt} \int_{s(c)} \bar{\mathcal{B}} \cdot d\bar{s}$
<b>Ampere's Law</b>	$\nabla \times \bar{\mathcal{H}} = \bar{\mathcal{J}} + \frac{\partial \bar{\mathcal{D}}}{\partial t}$	$\oint_{c(s)} \bar{\mathcal{H}} \cdot d\bar{l} = \int_{s(c)} \bar{\mathcal{J}} \cdot d\bar{s} + \frac{d}{dt} \int_{s(c)} \bar{\mathcal{D}} \cdot d\bar{s}$

Much of our work in this course will be in the **sinusoidal steady state**. With an assumed (and suppressed)  $e^{j\omega t}$  time convention, these curl equations become:

	Differential form:	Integral form:
<b>Faraday's Law</b>	$\nabla \times \bar{\mathcal{E}} = -j\omega \bar{\mathcal{B}}$	$\oint_{c(s)} \bar{\mathcal{E}} \cdot d\bar{l} = -j\omega \int_{s(c)} \bar{\mathcal{B}} \cdot d\bar{s}$
<b>Ampere's Law</b>	$\nabla \times \bar{\mathcal{H}} = \bar{\mathcal{J}} + j\omega \bar{\mathcal{D}}$	$\oint_{c(s)} \bar{\mathcal{H}} \cdot d\bar{l} = \int_{s(c)} \bar{\mathcal{J}} \cdot d\bar{s} + j\omega \int_{s(c)} \bar{\mathcal{D}} \cdot d\bar{s}$

where  $\bar{E}$ ,  $\bar{B}$ ,  $\bar{D}$ ,  $\bar{H}$ , and  $\bar{J}$  are all **vector phasors**.

Of course, both the differential and integral forms are equally valid. Which of these to use depends on the problem:

- To derive equations to solve for  $\bar{E}$  and  $\bar{H}$ , the differential forms are often better.
- For circuit approximations of devices (or other physical interpretations), the integral forms are often more useful.

Rather than using the full-blown Maxwell's equations in microwave circuit design, approximations are often made to simplify the solutions. Transmission line theory, to be discussed next, is one of these.

We will **not explicitly** be seeing much of Maxwell's equations in this course.