Unit-2.1 Data and Signals

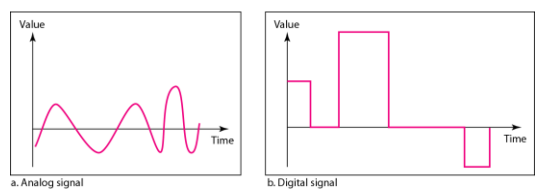
Prepared By:
Prof. Vishal A. Polara
Assistant Professor
Information Technology Department
Birla Vishvakarma Mahavidyalaya Engineering College

Outline

1. ANALOG AND DIGITAL

- To be transmitted, Data must be transform to electromagnetic signals.
- Data can be analog or digital. The term analog data refers to information that is continuous; digital data refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.
- Ex. Sound is analog, Computer data are digital
- Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

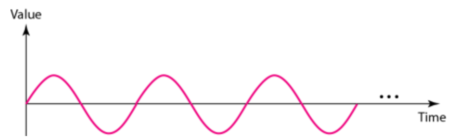
Figure: Comparison of analog and digital signals



2. Periodic analog signals

- A signal is periodic when it completes a pattern within a measurable time frame called a period and repeats that pattern over subsequent identical periods.
- A signal is nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.
- Periodic analog signals can be classified as simple or composite. A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves.
- A sine wave can be represented by three parameters: The peak amplitude, the frequency and the phase.
- In data communications, we commonly use periodic analog signals and non periodic digital signals.

Figure: A sine wave



- Peak Amplitude: It is the absolute value of its highest intensity ,propositional to the energy it carries. It is normally measured in volts.
- Period: it is refers to the amount of time in seconds a signal needs to complete 1 cycle.
- Frequency: It is refers to the number of period in 1s.
- Frequency and period are the inverse of each other.
- Phase:
  - It describes the position of the waveform relative to time 0
  - Phase is measured in degrees or radians.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Figure: Two signals with the same phase and frequency, but different amplitudes

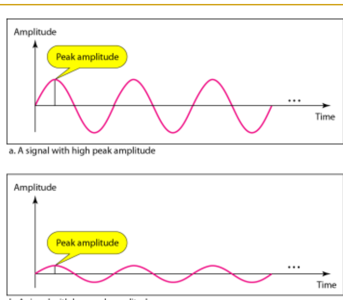


Figure: Two signals with the same amplitude and phase, but different frequencies

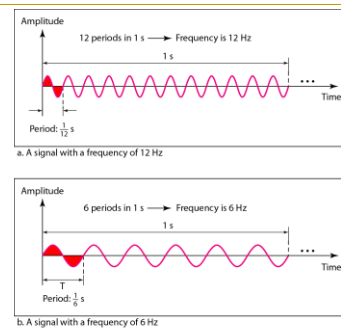


Table Units of period and frequency

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Example

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166\ \text{s} = 0.0166 \times 10^{3}\ \text{ms} = 16.6\ \text{ms}$$

Example

Express a period of 100 ms in microseconds.

Solution

find the equivalents of 1 ms (1 ms is 10^{-3} s) and 1 s (1 s is 10^6 μs). We make the following substitutions:.

$$\boxed{100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 100 \times 10^{-3} \times 10^{6}\ \mu\text{s} = 10^{2} \times 10^{-3} \times 10^{6}\ \mu\text{s} = 10^{5}\ \mu\text{s}}$$

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Example

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

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Frequency is the rate of change with respect to time.

Change in a short span of time means high frequency.

Change over a long span of time means low frequency.

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If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

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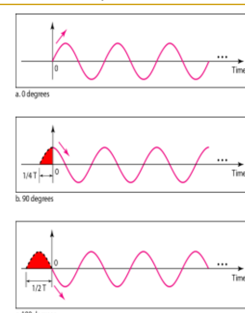
Figure Three sine waves with the same amplitude and frequency, but different phases



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Example

A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

Solution

We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

$$\boxed{\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}}$$

Radian = degree x π / 180

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- **Wavelength:**
- It is another characteristic of a signal traveling through a transmission medium.
- It binds the period or the frequency of a simple wave to the propagation speed of the medium.

$$Wavelength = propagation\ speed \times period = \frac{propagation\ speed}{frequency}$$

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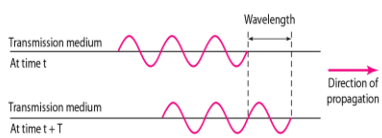
Figure Wavelength and period



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A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

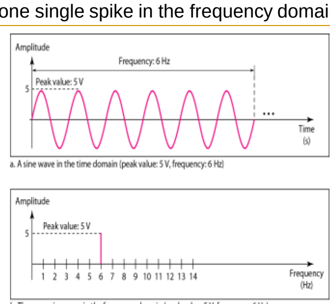

Figure The time-domain and frequency-domain plots of a sine wave

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The frequency domain is more compact and useful when we are dealing with more than one sine wave.
For example, Figure shows three sine waves, each with different amplitude and frequency.
All can be represented by three spikes in the frequency domain.

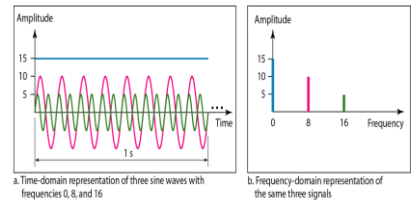

Figure The time domain and frequency domain of three sine waves

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Composite Periodic Signal

- A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.
- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies
- If the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

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Figure A composite periodic signal

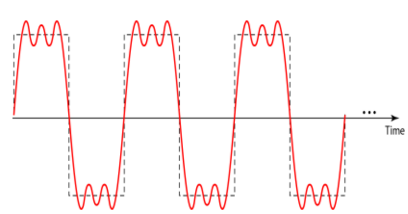

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Figure ***Decomposition of a composite periodic signal in the time and frequency domains***

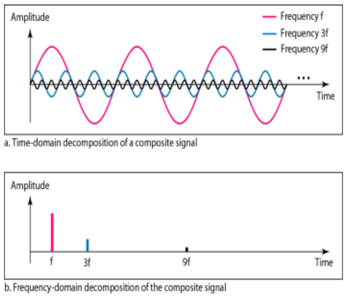
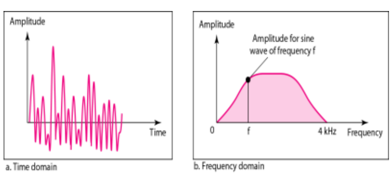


Figure ***The time and frequency domains of a nonperiodic signal***



The **bandwidth** of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

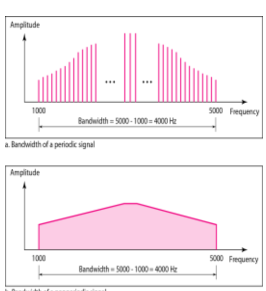


Figure ***The bandwidth of periodic and nonperiodic composite signals***

Example

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

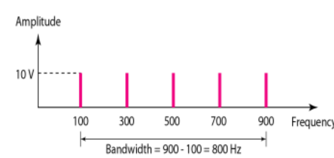
Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure 3.13).

Figure ***The bandwidth***



Example

A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

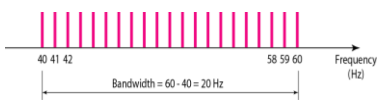
Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$\boxed{B = f_h - f_l \;\Rightarrow\; 20 = 60 - f_l \;\Rightarrow\; f_l = 60 - 20 = 40 \text{ Hz}}$$

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 3.14).

Figure *The bandwidth*



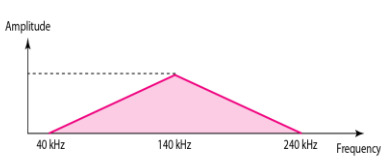
Example

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.

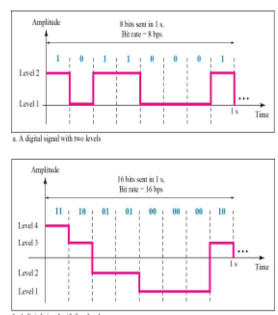
Figure *The bandwidth*



3. Digital Signals

- A digital signal can have more than two levels.
- In this case, we can send more than 1 bit for each level.
- For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage.
- Bit rate is used here to describe the digital signal. It is the number of bits in 1s.
- Bit length is the distance one bit occupies on the transmission medium(like wavalength).
- Bit length = Propagation speed * bit duration

Figure Two digital signals: one with two signal levels and the other with four signal levels



Example

1) A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Each signal level is represented by 3 bits.

2) A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

Example

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$

Example

A digitized voice channel, as we will see in Chapter 4, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

$$2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

Example

What is the bit rate for high-definition TV (HDTV)?

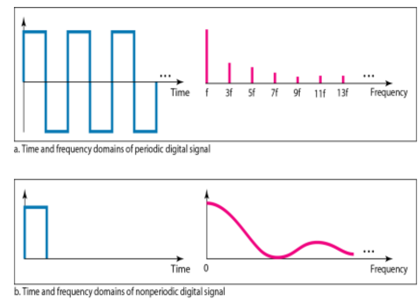
Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$1920 \times 1080 \times 30 \times 24 = 1{,}492{,}992{,}000 \text{ or } 1.5 \text{ Gbps}$$

The TV stations reduce this rate to 20 to 40 Mbps through compression.

Figure *The time and frequency domains of periodic and nonperiodic digital signals*



a. Time and frequency domains of periodic digital signal

b. Time and frequency domains of nonperiodic digital signal

Baseband Transmission

- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.
- A digital signal is a composite analog signal with an infinite bandwidth.
- It requires that we have low-pass channel, a channel with a bandwidth that starts from zero.
- Example two computer directly connected or bus communication only two computers active at a time.

Figure *Baseband transmission*

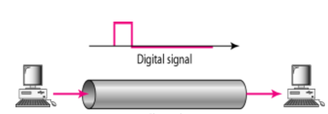


Figure ***Bandwidths of two low-pass channels***

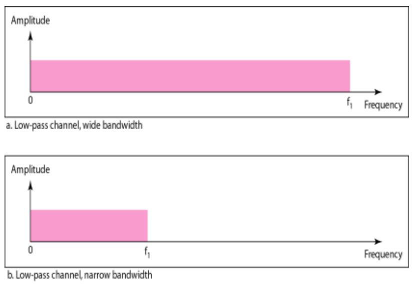
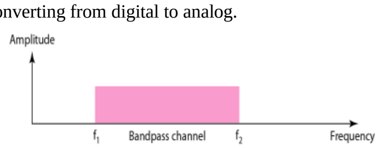


Figure Broadband transmission and Bandwidth of a bandpass channel

-A bandwidth that doesnot start from zero.
- low-pass channel can be considered a bandpass channel with the lower frequency starting at zero.
-Modulation allows us to use a bandpass channel.
-When channel is bandpass signal can not transmitted without converting from digital to analog.



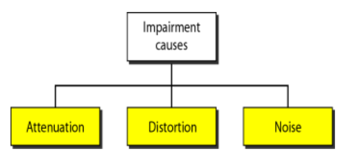
Example

An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel. We convert the digital signal from the computer to an analog signal, and send the analog signal. We can install two converters to change the digital signal to analog and vice versa at the receiving end. The converter, in this case, is called a modem.

4. TRANSMISSION IMPAIRMENT

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.

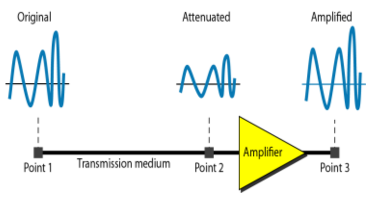
Figure ***Causes of impairment***



Attenuation

- It means a loss of energy.
-When signal travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
-Amplifier is used to amplify the signal.

Figure ***Attenuation***



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Distortion

-It means that the signal changes its form or shape.
-It can occur in a composite signal made of different frequencies.

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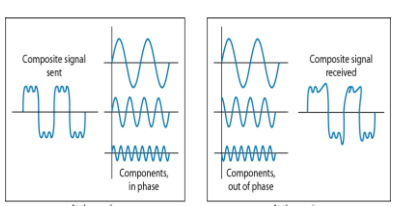
Figure ***Distortion***



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Noise

-Noise is another cause of impairment.
-It is due to thermal noise, induced noise, crosstalk and impulse noise.
-Thermal noise is the random motion of electrons in a wire which creates and extra signal.
-Induced noise comes from such as motors and appliances.
-Crosstalk is the effect of the one wire on the other.,
-Impulse noise is a spike(signal with high energy in a very short time) that comes from power lines, lightning.

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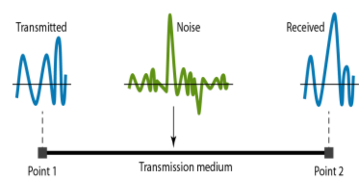
Figure ***Noise***



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Signal to noise ratio(SNR)

-SNR is actually the ratio of what is wanted to what is not wanted
-A high SNR means the signal is less corrupted by noise and a low SNR means the signal is more corrupted by noise.

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5. Data rate limits

- It means how fast we can send data in bit per second over a channel. It depends on following factors
- The bandwidth available
- The level of the signals we use
- The quality of the channel.
- Two way we can calculate the data rate by using Nyquist for a noiseless channel and using Shannon capacity for noisy channel.
- Nyquist Bit rate = 2 * bandwidth * log2 L
- Increasing the levels of a signal may reduce the reliability of the system.

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- It is impossible to have noiseless channel. So shannon capacity is used to determine the highest data rate for a noisy channel.
- Capacity = bandwidth * $\log_2(1+\text{SNR})$
- Here in this formula there is no indication of signal level which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel.

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Example

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?

Solution

The values of SNR and SNR_{dB} can be calculated as follows:

$$\text{SNR} = \frac{10{,}000\ \mu\text{W}}{1\ \text{mW}} = 10{,}000$$
$$\text{SNR}_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

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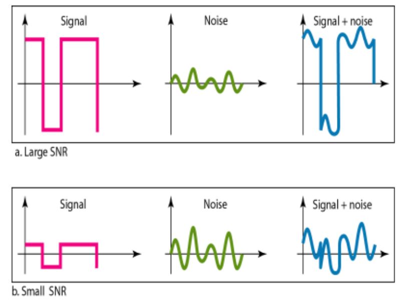
Figure ***Two cases of SNR: a high SNR and a low SNR***



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Example

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2\ \text{Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.

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Example

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 108 m/s in cable.

Solution

We can calculate the propagation time as

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50\ \text{ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

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Example

What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission time as shown on the next slide:

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Example (continued)

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time. The transmission time can be ignored.

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Example

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 10^8 m/s.

Solution

We can calculate the propagation and transmission times as shown on the next slide.

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Example(continued)

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the transmission time, not the propagation time. The propagation time can be ignored.

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Thank You

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