1

Introduction

1.1 Travel time around the Earth.

Assuming a perfect sphere, the Earth's circumference is πD, where D is the diameter. Hence we have

$$t = \frac{l}{v} = \frac{\pi D}{c} \simeq \frac{\pi \times (1.274 \times 10^4 \text{ km})}{3 \times 10^5 \text{ km-s}^{-1}} \simeq 0.1334 \text{ s}$$

1.2 Travel time between the Earth and the Moon.

The time t it takes an electromagnetic wave to travel a distance $d = 384,400$ km is

$$t = \frac{d}{c} \simeq \frac{384,400 \text{ km}}{3 \times 10^5 \text{ km-s}^{-1}} \simeq 1.281 \text{ s}$$

1.3 Earth-Moon communication.

Using the average Earth-Moon distance $d = 384,400$ km, and a noting that the one-way time delay is given by $t_d = (2.7/2)$ s, we have

$$c = \frac{d}{t_d} = \frac{384,400 \text{ km}}{(2.7/2) \text{ s}} \simeq 2.847 \times 10^5 \text{ km-s}^{-1}$$

1.4 Time delay of a radar signal.

We note that since the round trip time of the radio pulse is 40 μs, the one-way travel time t is 20 μs. Hence the distance d from the radar system to the target is

$$d = ct \simeq \left(3 \times 10^5 \text{ km-s}^{-1}\right)\left(20 \times 10^{-6} \text{ s}\right) = 6 \text{ km}$$

1.5 Echo from a cliff.

Since the one-way travel time is given by $t_d = 3/2$ s, the cliff's distance d from the man is given by

$$d = vt_d = (340 \text{ m-s}^{-1}) \left(\frac{3}{2} \text{ s}\right) = 510 \text{ m}$$

1.6 Sonar.

We note that the round trip time of the sonar signal is 6 s, which means that the one-way travel time is 3 s. Thus the depth d is given by

$$d = vt = \left(1.5 \times 10^3 \text{ m-s}^{-1}\right)(3 \text{ s}) = 4,500 \text{ m} = 4.5 \text{ km}$$

1.7 Sonar.

Using the one-way travel time $t = 3.7/2$ s, the depth d is given by

$$d = vt = (1.5 \text{ km-s}^{-1}) \left(\frac{3.7}{2} \text{ s}\right) = 2.775 \text{ km}$$

1.8 Auto-focus camera.

We note that the round trip time of the ultrasonic sound wave is 0.1 s, which means that the one-way travel time t is 0.05 s. Hence the distance from the camera to the object is

$$d = vt = \left(340\text{m-s}^{-1}\right)(0.05 \text{ s}) = 17 \text{ m}$$

1.9 Lightning and thunder.

The approximate distance is given by

$$d = vt = (340 \text{ m-s}^{-1})(5 \text{ s}) = 1700 \text{ m} = 1.7 \text{ km}$$

1.10 A light-year.

The equivalent distance d is given by the speed of light c multiplied by the unit of time t:

$$d = ct$$

Assuming each year to have 365.25 days, we have

$$\begin{aligned} 1 \text{ ly} &\simeq \left(3 \times 10^5 \text{ km-s}^{-1}\right)(1 \text{ year})\left(365.25 \text{ day-year}^{-1}\right)\left(24 \text{ hr-day}^{-1}\right)\left(3600 \text{ s-hr}^{-1}\right) \\ &\simeq 9.467 \times 10^{12} \text{ km} \end{aligned}$$

1.11 A light-nanosecond.

The light-nanosecond length l in meters is

$$l = ct \simeq \left(3 \times 10^5 \text{ km-s}^{-1}\right)\left(10^{-9} \text{ s}\right) = 3 \times 10^{-4} \text{ km} = 0.3 \text{ m}$$

1.12 1 Astronomical Unit.

Since

$$1 \text{ light-second} \simeq \left(3 \times 10^5 \text{ km-s}^{-1}\right)(1 \text{ s}) = 3 \times 10^5 \text{ km}$$

we have

$$1 \text{ AU} \simeq \frac{1.5 \times 10^8 \text{ km}}{3 \times 10^5 \text{ km-(light-second)}^{-1}} = 500 \text{ light-seconds}$$

or about 8.3 light-minutes.

1.13 Distance between Proxima Centauri and Earth.

Assuming 365.25 days in a year, one light year is equivalent to

$$\begin{aligned} 1 \text{ light year} &\simeq \left(3 \times 10^5 \text{ km-s}^{-1}\right)\left(365.25 \frac{\text{day}}{\text{year}}\right)\left(24 \frac{\text{hour}}{\text{day}}\right)\left(3600 \frac{\text{s}}{\text{hour}}\right) \\ &\simeq 9.467 \times 10^{12} \text{ km} \end{aligned}$$

Hence the distance d between Proxima Centauri and Earth, given in light-years (ly), is

$$d = 4 \times 10^{13} \text{ km} \simeq \frac{4 \times 10^{13} \text{ km}}{9.467 \times 10^{12} \text{ km-(ly)}^{-1}} \simeq 4.225 \text{ ly}$$

1.14 Seismic waves.

The time delay from the epicenter of the earthquake to the seismograph station t is

$$t = \frac{d}{v} = \frac{900 \text{ km}}{5 \text{ km-s}^{-1}} = 180 \text{ s} = 3 \text{ minutes}$$

1.15 Tsunami waves.

The average speed of the tsunami wave is

$$v_{\text{average}} = \frac{d}{t} = \frac{8020 \text{ km}}{10 \text{ hr}} = 802 \text{ km-hr}^{-1} \simeq 223 \text{ m-s}^{-1}$$

1.16 The Indian Ocean tsunami.

The delay t of the tsunami between the epicenter of the tsunami and a location a distance d away from it is given by

$$t = \frac{d}{v}$$

where $v = 800 \text{ km-hr}^{-1}$. Hence the delay between the epicenter to Sumatra is

$$t_{\text{Sumatra}} = \frac{160 \text{ km}}{800 \text{ km-hr}^{-1}} = 0.2 \text{ hr} = 12 \text{ minutes}$$

and the delay between the epicenter to Africa is

$$t_{\text{Africa}} = \frac{4500 \text{ km}}{800 \text{ km-hr}^{-1}} \simeq 5.63 \text{ hr}$$

1.17 Micro-bats.

The round-trip distance d between the micro-bat and the insect is 2×10 m, so the total time delay t between the emitted and detected pulses is

$$t = \frac{d}{v} = \frac{2 \times 10 \text{ m}}{340 \text{ m-s}^{-1}} \simeq 0.0588 \text{ s} = 58.8 \text{ ms}$$

1.18 Overhead power lines.

The propagation delay t_d is related to the propagation distance l by $t_d = l/v$, where v is the propagation speed. Noting that the signal period $T = f^{-1}$, we may write the range of lengths where a lumped analysis is appropriate to use as (equation (1.4))

$$l_{\text{lumped}} < 0.01\frac{v}{f}$$

Once again assuming propagation at the speed of light, a 50 Hz signal corresponds to a maximum line length of

$$l_{\max} = 0.01 \cdot \frac{3 \times 10^5 \text{ km-s}^{-1}}{50 \text{ s}^{-1}} = 60 \text{ km}$$

1.19 Maximum path length.

From (1.1), lumped-circuit analysis is appropriate when $t_r/t_d > 6$, or

$$t_d < \frac{t_r}{6}$$

Using $t_r = 250$ ps, the limit on t_d becomes

$$t_d < \frac{250 \text{ ps}}{6}$$

Using $t_d = l/v$, where $v = c/3$, we have

$$l_{\max} = vt_d = \left(\frac{c}{3}\right)\left(\frac{250 \text{ ps}}{6}\right) \simeq 4.17 \times 10^{-3} \text{ m} = 0.417 \text{ cm}$$

1.20 Maximum coax length.

Using (1.3), the one-way time delay of the maximum cable length for a lumped-circuit analysis is given by

$$t_d = 0.01T$$

Hence the maximum cable length $l_{\max}$ for a lumped-circuit analysis satisfies

$$\frac{l_{\max}}{v} = \frac{0.01}{f}$$

Solving for $l_{\max}$, we have

$$l_{\max} = 0.01\frac{v}{f} = (0.01)\frac{2 \times 10^8 \text{ m-s}^{-1}}{900 \times 10^6 \text{ s}^{-1}} \simeq 2.22 \times 10^{-3} \text{ m} = 2.22 \text{ mm}$$

1.21 Travel time of a microstrip transmission line.

The one-way travel time t_d is given by

$$t_d = \frac{l}{v} = \frac{9 \text{ cm}}{1.7 \times 10^{10} \text{ cm-s}^{-1}} \simeq 5.29 \times 10^{-10} \text{ s} = 0.529 \text{ ns}$$

1.22 Maximum cable length.

Using (1.3), the one-way time delay of the maximum cable length for a lumped-circuit analysis is given by

$$t_d = 0.01T$$

Hence the maximum cable length $l_{\max}$ for a lumped-circuit analysis satisfies

$$\frac{l_{\max}}{v} = \frac{0.01}{f}$$

Solving for $l_{\max}$, we have

$$l_{\max} = 0.01\frac{v}{f} = (0.01)\frac{2 \times 10^8 \text{ m-s}^{-1}}{30 \times 10^6 \text{ s}^{-1}} \simeq 6.66 \times 10^{-2} \text{ m} = 6.66 \text{ cm}$$

1.23 Microstrip transmission line.

The delay time t_d of the transmission line is

$$t_d = \frac{l}{v} = \frac{6 \text{ cm}}{2 \times 10^{10} \text{ cm-s}^{-1}} = 3 \times 10^{-10} \text{ s} = 0.3 \text{ ns}$$

The ratio between the rise time and the delay time is thus

$$\frac{t_r}{t_d} = \frac{1 \text{ ns}}{0.3 \text{ ns}} \simeq 3.3$$

Using (1.1), since t_r/t_d is not greater than 6, it is not appropriate to neglect transmission line effects and use lumped circuit analysis.

1.24 Stripline transmission line.

The time delay t_d of the stripline is

$$t_d = \frac{l}{v} \simeq \frac{12 \text{ cm}}{(3 \times 10^{10}\text{cm-s}^{-1})/2} = 8 \times 10^{-10} \text{ s} = 0.8 \text{ ns}$$

Using (1.1),

$$\frac{t_r}{t_d} = \frac{0.5 \text{ ns}}{0.8 \text{ ns}} = 0.625 < 2.5$$

Thus, it is appropriate to consider transmission line effects.

1.25 On-chip GaAs interconnect.

Using (1.1), for a lumped-circuit analysis to be valid, we need

$$\frac{t_r}{t_d} > 6 \quad \rightarrow \quad \frac{t_d}{t_r} < \frac{1}{6} \quad \rightarrow \quad t_d < \frac{t_r}{6}$$

Hence the time delay must satisfy

$$t_d = \frac{l}{v} < \frac{50 \text{ ps}}{6}$$

Hence the largest length $l_{\max}$ is given by

$$l_{\max} = \left(\frac{50}{6} \times 10^{-12} \text{ s}\right)\left(8 \times 10^{7} \text{ m-s}^{-1}\right) \simeq 6.7 \times 10^{-4} \text{ m} = 0.67 \text{ mm}$$

1.26 A coaxial cable-lumped or distributed analysis?

Using (1.3), the shortest period T of the sinusoidal steady-state signal for the coaxial cable to be considered as a lumped system satisfies

$$t_d = 0.01T$$

Thus the highest frequency for which lumped-circuit analysis is still applicable can be found as

$$\frac{l}{v} = \frac{0.01}{f}$$

Solving for f, we have

$$f = \frac{0.01v}{l} \simeq \frac{0.01\,(0.75)\left(3 \times 10^{8} \text{ m-s}^{-1}\right)}{10 \text{ m}} = 225,000 \text{ Hz} = 225 \text{ kHz}$$

If the frequency f exceeds 225 kHz, then the coaxial cable must be treated as a distributed element.