RF Field Engineer Course: A Practical Introduction

Jordan Hanson

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Course Introduction

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4. Zoom Credentials: (ID) 796 092 0745 (Passcode) 667725
5. **Reading: Stimson's Introduction to Airborne Radar, 3rd Edition**. (Hughes Radar Handbook)
6. **Box Folder**: `https://app.box.com/s/qalsptcztyeq8hjvu3pmf4mlodmopop7`

Summary

Reading: *Stimson3 ch. 1-6*

- Week 1: Units and estimation. **Key skills**: mental math, wave concepts
  - Electromagnetic units, estimation, and decibels
  - Waves and the wave equation
  - Reflections, refraction, and diffraction
  - Phase, amplitude, frequency, polarization
- Week 2: Basic Training in Mathematics. **Key skills**: estimate pulse bandwidth, pulse trains and uncertainty principle
  - **Complex numbers**: applications to phasors and radio waves, complex imdedance of filters and antennas
  - **Fourier series and transforms**, filters and attenuation, properties of waveforms, power spectra, and spectrograms, cross-correlation and convolution
  - **Statistics and probability**: applications to noise, signal-to-noise ratio

Reading: *Stimson3 ch. 7-11*

- Week 3: RF Antenna Properties. **Key skills**: characterize an antenna, diagnose a problem with an antenna system
  - Radiation pattern, directivity, and gain
  - Complex impedance and reflection coefficient, S11, S21
  - Bandwidth, narrow and wide
  - Antenna temperature
  - Angular resolution
  - Attenuation: applications to remote sensing
- Week 4: **Electronically Scanned Antenna Systems**
  - **Basics**: spacing, wavelength, and scan angle
  - **Design classes**: AESA and PESA
  - **Wideband considerations**: Scan losses, time-delays
  - Bonus: FDTD demonstrations of ESAs
- Week 5: Review of Weeks 1-4, pulsed radar concepts

Reading: *Stimson3 ch. 12-13, part IV (18-22), 23*

- Week 6: Range Equations. **Key skills**: diagnose issues with distance target detection, estimate radar cross section (RCS)
    - Radar cross-section
    - Noise and noise figure, signal-to-noise ratio (SNR)
    - Thermal noise floor and detection probability
    - **Ranging techniques**: pulse compression, frequency modulation
- Week 7: Overview of Pulse Doppler Radar **(Cumulative Example)**
    - Connections with Telemetry
    - See Stimson3 part IV
    - Connections to digital signal processing: sampling and digitization
- Week 8: Clutter and Attenuation
    - Clutter: sources and spectra
    - Attenuation: absorption and scattering, components

Course Summary

- Week 9: Link Budgets (Cumulative Example)
    - Assembling the pieces
    - Example calculations
- Week 10: Course Review
    - Review Weeks 1-9
    - Skill Review
        1. Estimation and approximations
        2. Conceptual challenge questions
        3. Worked examples

Estimation, Approximation, Units

Estimation, Approximation, Units

RF radiation travels at a constant speed.

$$\frac{c}{n} = \nu\lambda \tag{1}$$

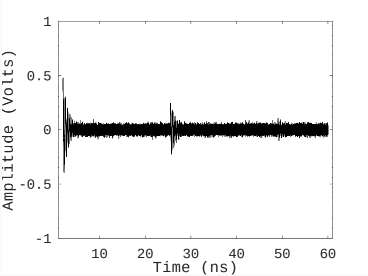
$$\Delta x = \left(\frac{c}{n}\right)\Delta t \tag{2}$$

$$T = \frac{1}{\nu} \tag{3}$$

- c: speed of light in vaccuum, 0.299792458 m/ns, ≈ 0.3 m GHz
- ν: frequency of the radiation, Hz.
- λ: wavelength of the radiation, meters.
- Δx: displacement
- Δt: time duration

Estimation, Approximation, Units

A signal enters a cable that is 3 meters long and reflects at the end back towards the source. How many nanoseconds after the signal enters the cable will the signal return to the end?



- How does it work conceptually? Distance equals speed multiplied by time duration.
- How do you correct for the speed in the cable?
- How could we apply this to radar? Remember, this is a *reflection*.

Estimation, Approximation, Units

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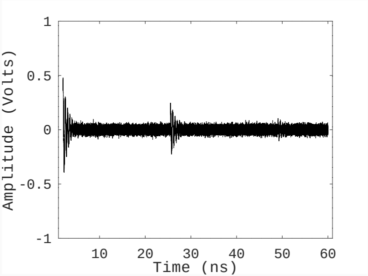

- 20 ns x 0.3 (m/ns) $\approx$ 6 m. Why 6 meters?
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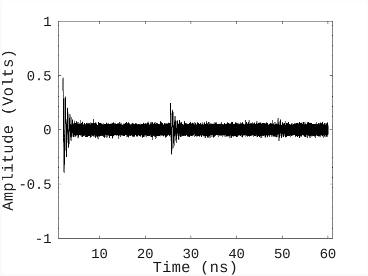

- 20 ns x 0.3 (m/ns) $\approx$ 6 m. Why 6 meters?
- Typical speed in RF cable: 85% speed of light. What is Δt for 6 meters at reduced speed?
- How could we apply this to radar? Remember, this is a *reflection*.

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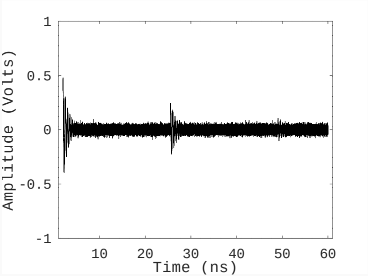
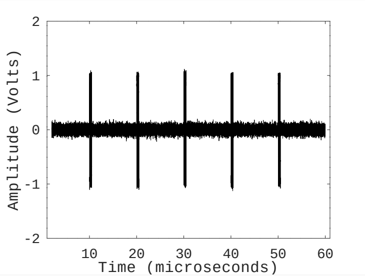


- 20 ns x 0.3 (m/ns) $\approx$ 6 m. Why 6 meters?
- Typical speed in RF cable: 85% speed of light. What is Δt for 6 meters at reduced speed?
- If a radar echo returns 30 microseconds later, how far away is the reflector?

Estimation, Approximation, Units

What does this mean? *A radar system creates a 20 MHz sine wave modulated by a 5 percent duty-cycle. The pulse repetition frequency is 0.1 MHz.*



- What's the period of a 20 MHz sine wave? Which part of the waveform at left represents this oscillation?
- If a signal is repeated regularly, it has a PRF, or pulse repetition frequency. Work out the PRF of the waveform at left.
- What does duty cycle mean?

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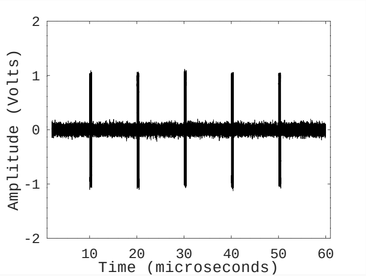

- $1/20.0\,\text{MHz}^{-1} = 0.05\,\mu\text{s} = 50\,\text{ns}$. These oscillations are within the pulses.
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Estimation, Approximation, Units

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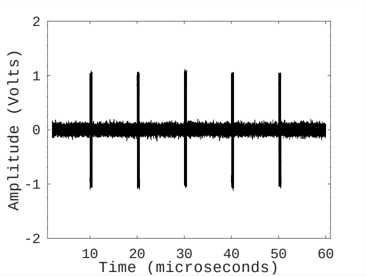

- $1/20.0\,\text{MHz}^{-1} = 0.05\,\mu\text{s} = 50\,\text{ns}$. These oscillations are within the pulses.
- It appears the pulses are separated by $\approx 10\,\mu\text{s}$. Invert to find $1/10\,\text{MHz}$.
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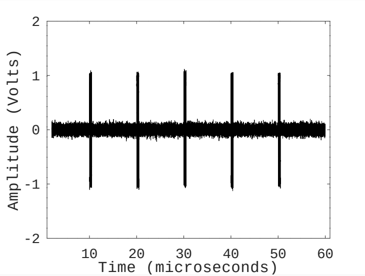

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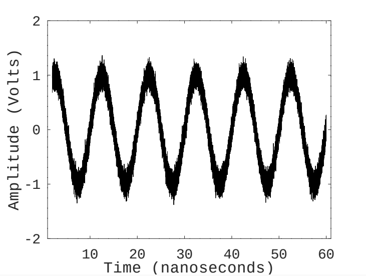
- It appears the pulses are separated by $\approx 10\,\mu\mathrm{s}$. Invert to find $1/10\,\mathrm{MHz}$.
- 100 percent corresponds a constant 20 MHz sine tone. Fifty percent is half-on, half-off … $D = PW/T \times 100$.

Estimation, Approximation, Units

What is the wavelength of the received radio wave in the figure? Recall $c \approx 0.3\ m/ns$.



- What is the period? Pay attention to the units on the axes.
- What is the frequency? (How do you convert period to frequency?)
- What is the wavelength?
- What size antenna woud receive this signal?

Estimation, Approximation, Units

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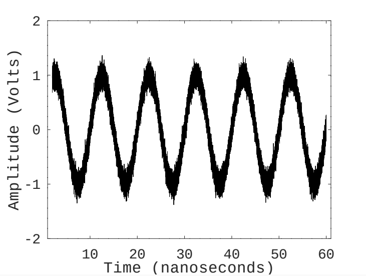

- The period appears to be about 10.0 ns.
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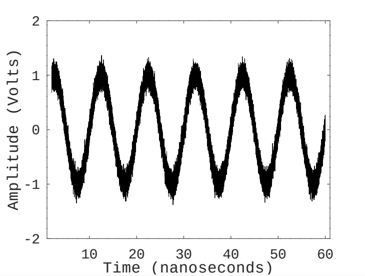

- The period appears to be about 10.0 ns.
- Invert the period: $1/10\ \text{ns}^{-1} = 100\ \text{MHz}$.
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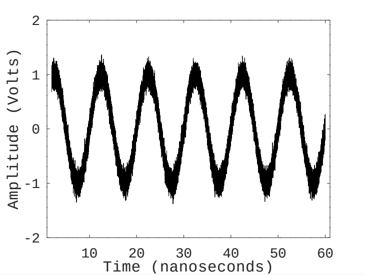


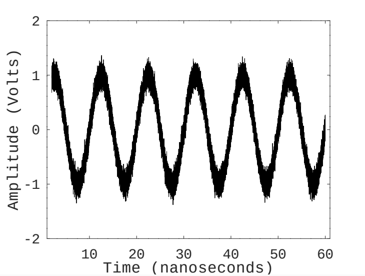
- The period appears to be about 10.0 ns.
- Invert the period: $1/10\,\text{ns}^{-1} = 100\,\text{MHz}$.
- What is the wavelength of a 100 MHz signal?

$$0.3\,\text{m}\,\text{GHz} = 100\,\text{MHz}(\lambda) \tag{4}$$
$$\frac{0.3\,\text{m}\,\text{GHz}}{100\,\text{MHz}} = \lambda \tag{5}$$
$$\lambda = 3\,\text{m} \tag{6}$$

- What size antenna?

Estimation, Approximation, Units

What is the wavelength of the received radio wave in the figure? Recall $c \approx 0.3\ m/ns$.



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$$0.3\ \mathrm{m\ GHz} = 100\ \mathrm{MHz}(\lambda) \tag{7}$$

$$\frac{0.3\ \mathrm{m\ GHz}}{100\ \mathrm{MHz}} = \lambda \tag{8}$$

$$\lambda = 3\ \mathrm{m} \tag{9}$$

- About 1.5 meter dipole.

Decibels

Decibels

RF parameters have a large dynamic range, and it becomes necessary to use logarithmic definitions.

$$P_{\mathrm{dB}} = 10 \log_{10} \left(\frac{P_2}{P_1} \right) \tag{10}$$

$$\frac{P_2}{P_1} = 10^{P_{\mathrm{dB}}/10} \tag{11}$$

- P_{dB}: power ratio in decibels.
- P_1: input power, transmitted power.
- P_2: output power, received power.

Historical motivations for the decibel:

- $V(x) = V_i \exp(-x/\lambda)$, λ is attenuation factor, such that if $x = \lambda$ for telephone cable, $P_{\mathrm{dB}} \approx -1$.

Decibels

RF parameters have a large dynamic range, and it becomes necessary to use logarithmic definitions.

$$P_{\mathrm{dB}} = 10 \log_{10}\left(\frac{P_2}{P_1}\right) \tag{12}$$

$$\frac{P_2}{P_1} = 10^{P_{\mathrm{dB}}/10} \tag{13}$$

- P_{dB}: power ratio in decibels.
- P_1: input power, transmitted power.
- P_2: output power, received power.

Historical motivations for the decibel:

- Let P_1 and P_2 be the initial and final acoustic power. $P_{\mathrm{dB}} \approx -1$ represents smallest change we can hear.

If our transmit power is 1 W, and our return (echo) is only 2.5 mW, what is that in decibels?

$$P_{\mathrm{dB}} = 10 \log_{10}\left(\frac{P_2}{P_1}\right) \tag{14}$$

$$\frac{P_2}{P_1} = 10^{P_{\mathrm{dB}}/10} \tag{15}$$

1. Which is P_2 and which is P_1? What's the ratio?
2. Perform logarithm on power of 10 and decimal separately.
3. Memorize the basics.

Estimation, Approximation, Units

If our transmit power is 1 W, and our return (echo) is only 2.5 mW, what is that in decibels?

$$P_{\mathrm{dB}} = 10 \log_{10}\left(\frac{P_2}{P_1}\right) \tag{16}$$

$$\frac{P_2}{P_1} = 10^{P_{\mathrm{dB}}/10} \tag{17}$$

1. Transmit power (P_1) is 1 W, and receive power (P_2) is 2.5 mW, so $P_2/P_1 = 2.5\,\mathrm{mW}\,\mathrm{W}^{-1} = 2.5 \times 10^{-3}$
2. Perform logarithm on power of 10 and decimal separately.
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Estimation, Approximation, Units

If our transmit power is 1 W, and our return (echo) is only 2.5 mW, what is that in decibels?

$$P_{\mathrm{dB}} = 10 \log_{10}\left(\frac{P_2}{P_1}\right) \tag{18}$$

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2. Take the $\log_{10}$ of the number and multiply by 10: $10\log_{10}(2.5) + 10\log_{10}(10^{-3}) = -30 + 10\log_{10}(2.5)$.
3. Memorize the basics.

Estimation, Approximation, Units

If our transmit power is 1 W, and our return (echo) is only 2.5 mW, what is that in decibels?

P_{dB}	P_2/P_1
0	1
1	1.26
2	1.6
3	2
4	2.5
5	3.2
6	4
7	5
8	6.3
9	8

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2. Take the $\log_{10}$ of the number and multiply by 10: $10\log_{10}(2.5) + 10\log_{10}(10^{-3}) = -30 + 10\log_{10}(2.5)$.
3. So we know it's about -30 dB. What is $10\log_{10}(2.5)$? About $+4$, so $-30 + 4 = -26$ dB.

Graphical Analysis and Radar Echoes

Graphical Analysis

As an example, let's consider a radar echo, on a graph of signal frequency versus time.

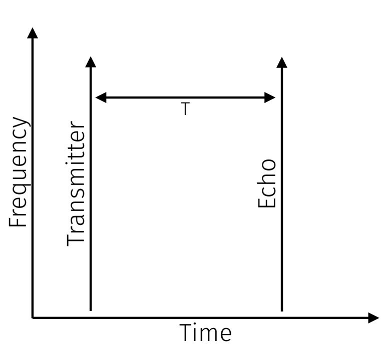

Figure 1

1. What does it mean to have a signal *at all frequencies* at a single time, for the transmitter?
2. What determines the echo time, *T*?
3. How will the graph change if the radar target moves closer to the transmitter?

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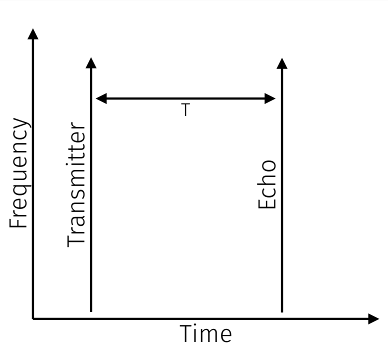

Figure 2

1. A *pulse* is a short time-duration signal. Pulses can be conceptualized as many signals of different frequencies added together with the right phases.
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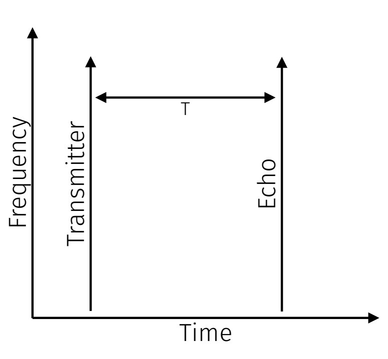

Figure 3

1. A *pulse* is a short time-duration signal. Pulses can be conceptualized as many signals of different frequencies added together with the right phases.
2. $T = R/c$, the range divided by the speed of light.
3. How will the graph change if the radar target moves closer to the transmitter?

Graphical Analysis

As an example, let's consider a radar echo, on a graph of signal frequency versus time.

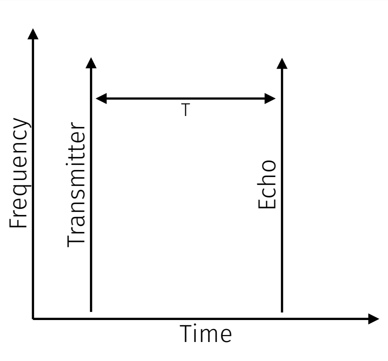

Figure 4

1. A *pulse* is a short time-duration signal. Pulses can be conceptualized as many signals of different frequencies added together with the right phases.
2. $T = R/c$, the range divided by the speed of light.
3. $T = R/c$, so if R decreases, T will decrease and thus the echo line will move left.

Graphical Analysis

Now a little more complex, we consider FM ranging. Imagine the transmitter chirps, and the echo returns.

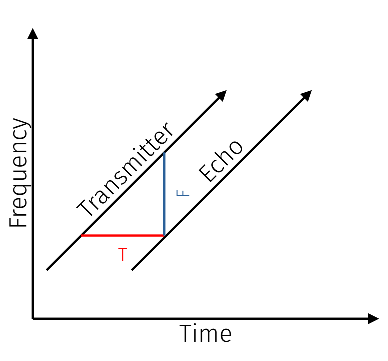

Figure 5

1. What does it mean to chirp? What is the chirp rate, and what are the units of chirp rate?
2. How are T and F, the time difference and frequency difference of the transmitter and echo, connected to range?
3. How can we derive the range without explicitly measuring T?

Graphical Analysis

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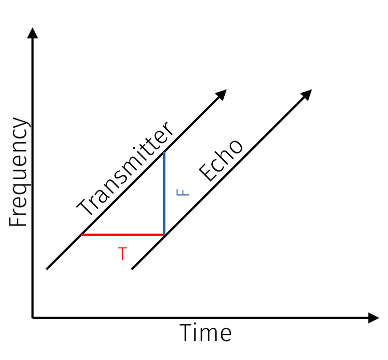

Figure 6

1. A chirp is a signal for which the frequency changes with time. The linear chirp rate is the slope of the transmitter signal, with units of $1\,\mathrm{Hz\,s^{-1}}$.
2. How are T and F, the time difference and frequency difference of the transmitter and echo, connected to range?
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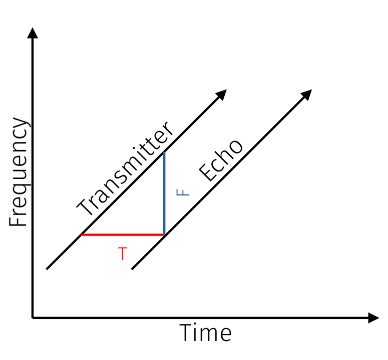

Figure 7

1. A chirp is a signal for which the frequency changes with time. The linear chirp rate is the slope of the transmitter signal, with units of $1\,\mathrm{Hz\,s^{-1}}$.
2. $R = (c/2)T$. Show that $F = kT$.
3. How can we derive the range without explicitly measuring T?

Now a little more complex, we consider FM ranging. Imagine the transmitter chirps, and the echo returns.

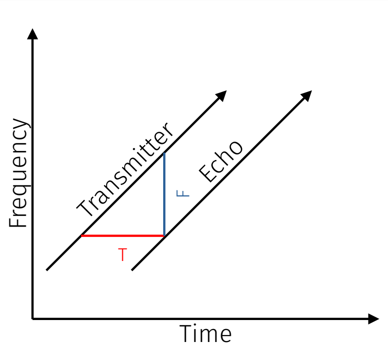

Figure 8

1. A chirp is a signal for which the frequency changes with time. The linear chirp rate is the slope of the transmitter signal, with units of $1\,\mathrm{Hz\,s^{-1}}$.
2. $R = (c/2)T$. Show that $F = kT$.
3. This means: $R = (c/2)(F/k)$, so the range can be found *without* measuring T. Build a chirping system that measures F.

Graphical Analysis

Finally, the doppler shift of RF waves is a small effect introduced by relative target-source motion that changes the frequency.

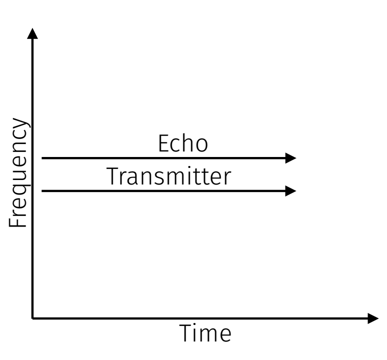

Figure 9

1. What is significance the ratio of frequencies?
2. What is the relationship between transmitter and echo frequencies?
3. What is a practical limitation of this technique?

Graphical Analysis

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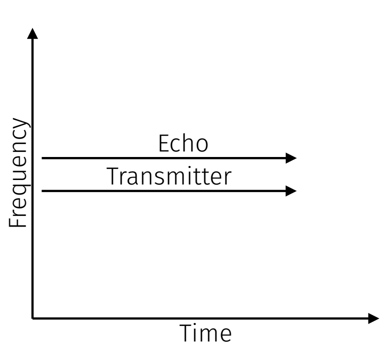

Figure 10

1. If $f_e > f_t$, the target is approaching the transmitter. If $f_e < f_t$, the target is moving away from the transmitter.
2. What is the relationship between transmitter and echo frequencies?
3. What is a practical limitation of this technique?

Graphical Analysis

Finally, the doppler shift of RF waves is a small effect introduced by relative target-source motion that changes the frequency.

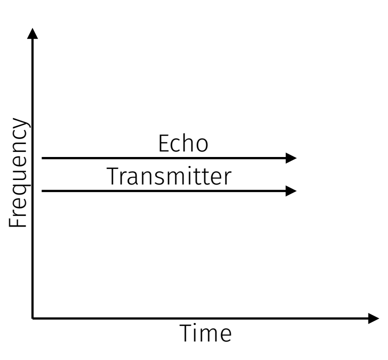

Figure 11

1. If $f_e > f_t$, the target is approaching the transmitter. If $f_e < f_t$, the target is moving away from the transmitter.
2. $\Delta f \approx 2(\Delta v/c)f_t$, with Δv equal to the relative velocity.
3. What is a practical limitation of this technique?

Finally, the doppler shift of RF waves is a small effect introduced by relative target-source motion that changes the frequency.

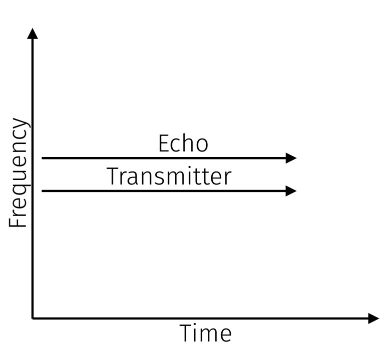

Figure 12

1. If $f_e > f_t$, the target is approaching the transmitter. If $f_e < f_t$, the target is moving away from the transmitter.
2. $\Delta f \approx 2(\Delta v/c) f_t$, with Δv equal to the relative velocity, and $\Delta f = f_e - f_t$.
3. For Earth-bound, anthropogenic targets, $\Delta v/c \ll 1$, so frequency shifts are very small.

Finally, the doppler shift of RF waves is a small effect introduced by relative target-source motion that changes the frequency.

$$\Delta f = 2(\Delta v/c) f_t \qquad (20)$$

1. If the relative velocity, or range rate, of the target is $400\,\mathrm{km\,h^{-1}}$, and $f_t = 400\,\mathrm{MHz}$, what is f_e?
2. How would we observe this shift? (Think about a *beat frequency*).

Conclusion

Summary

Introductory concepts:

- Units, estimation, approximation
- Decibels
- Graphical analysis, range, and doppler shift

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4. Zoom Credentials: (ID) 796 092 0745 (Passcode) 667725
5. **Reading: Stimson's Introduction to Airborne Radar, 3rd Edition**. (Hughes Radar Handbook)
6. **Box Folder**: `https://app.box.com/s/qalsptcztyeq8hjvu3pmf4mlodmopop7`