National Science Foundation

Research Experience for Undergraduates Program

Radio Propagation and Diversity

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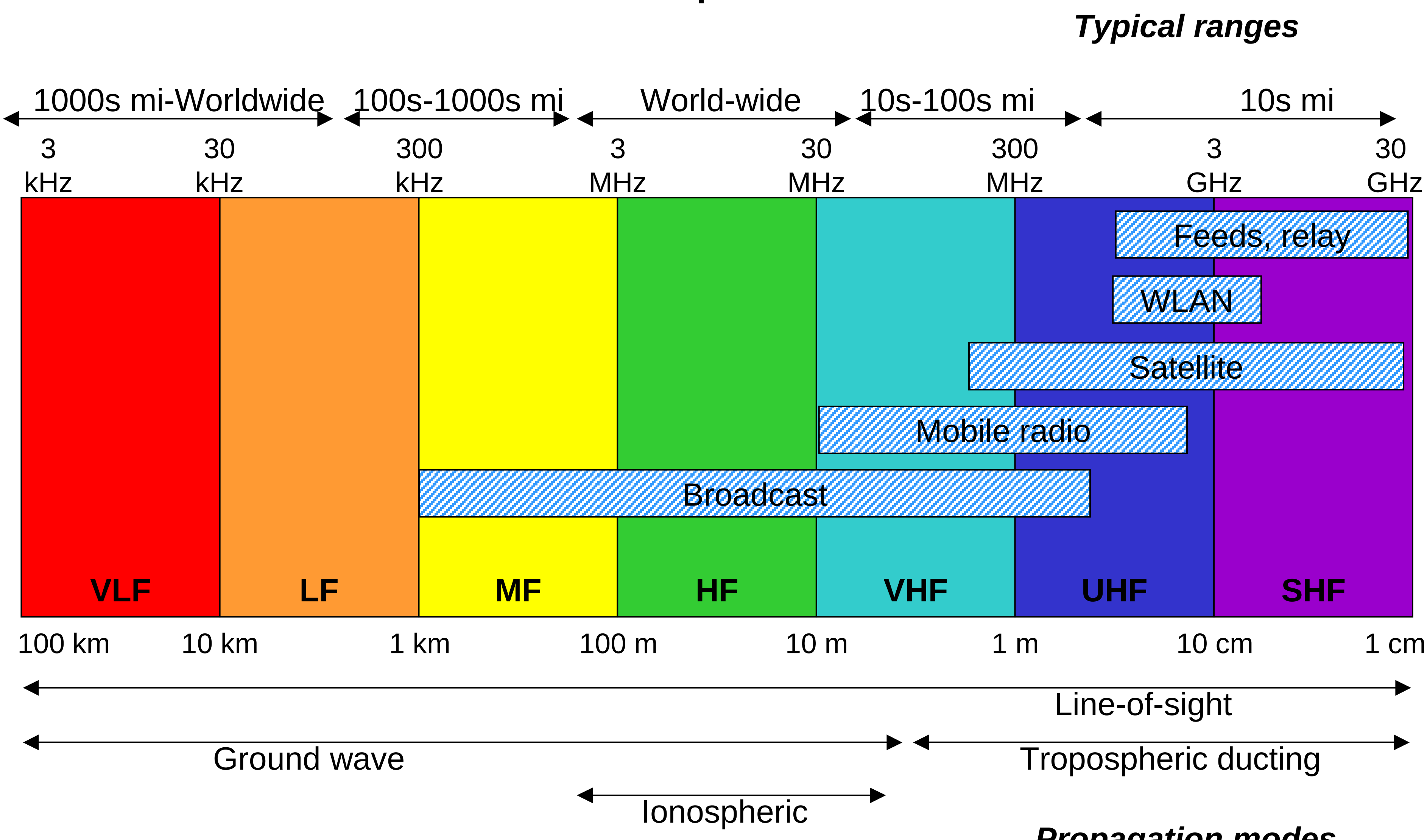
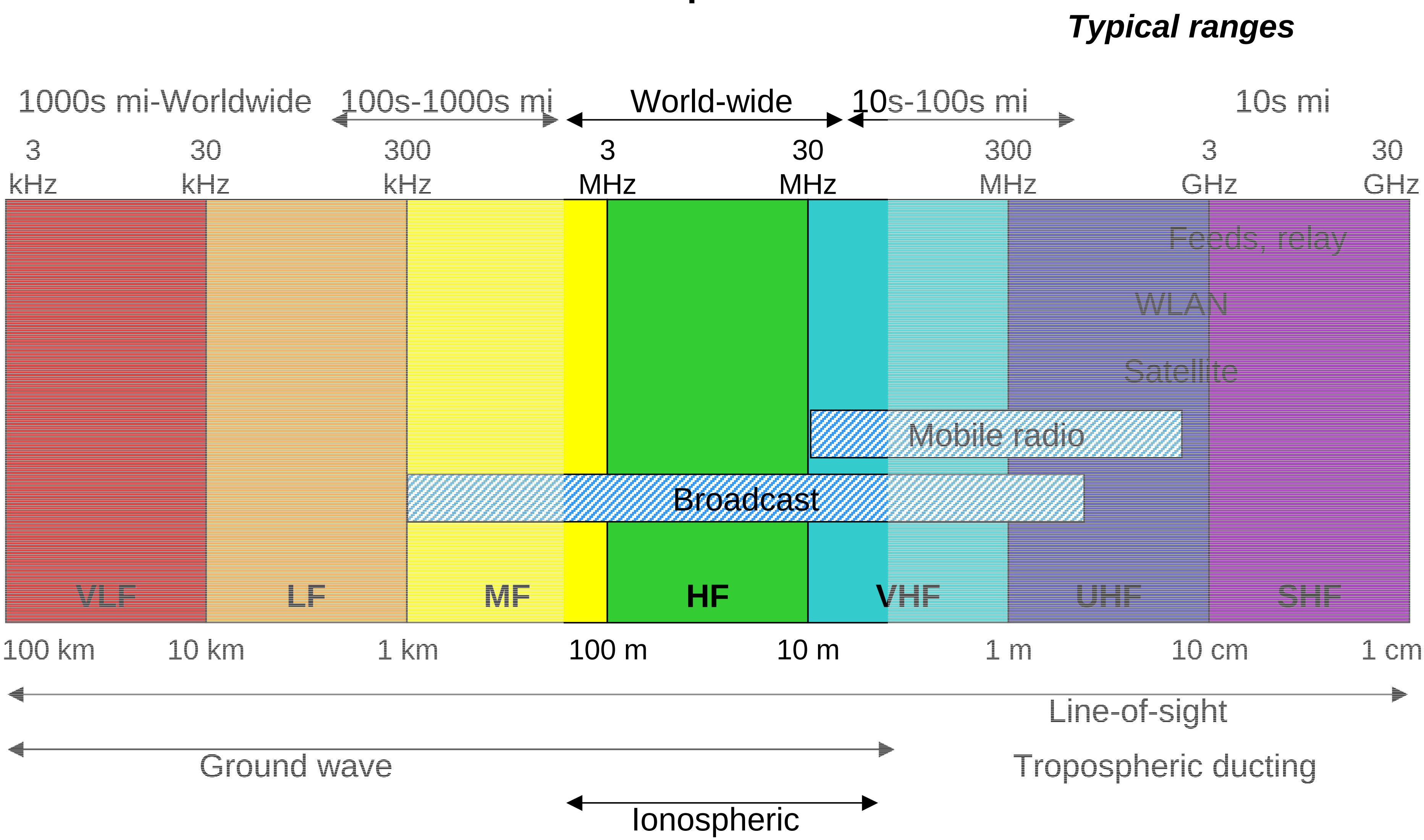
RF Spectrum



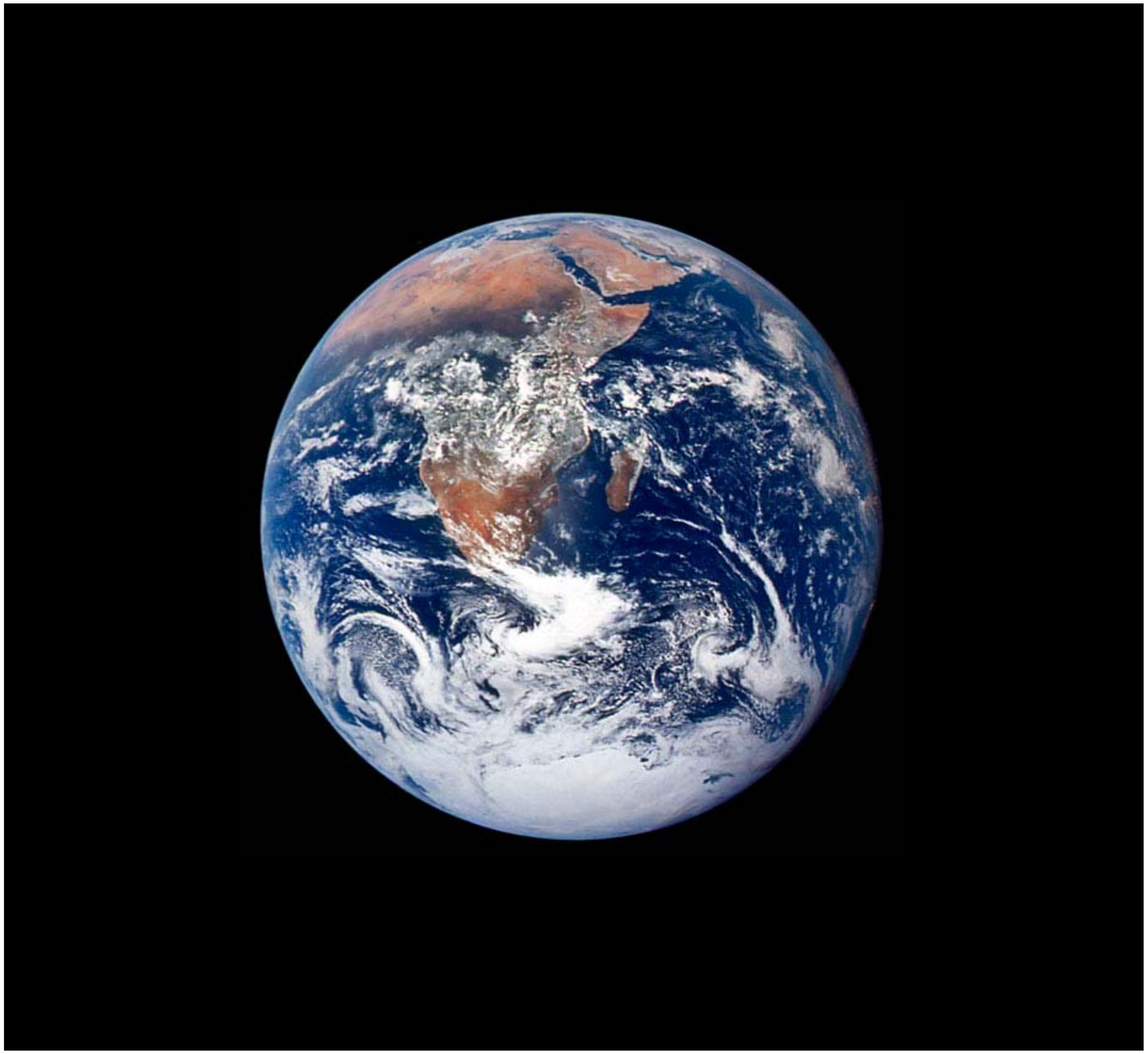
See http://www.ntia.doc.gov/osmhome/allochrt.pdf for full details (1996)
Or http://www.jsc.mil/images/speccht.jpg for the military view

RF Spectrum



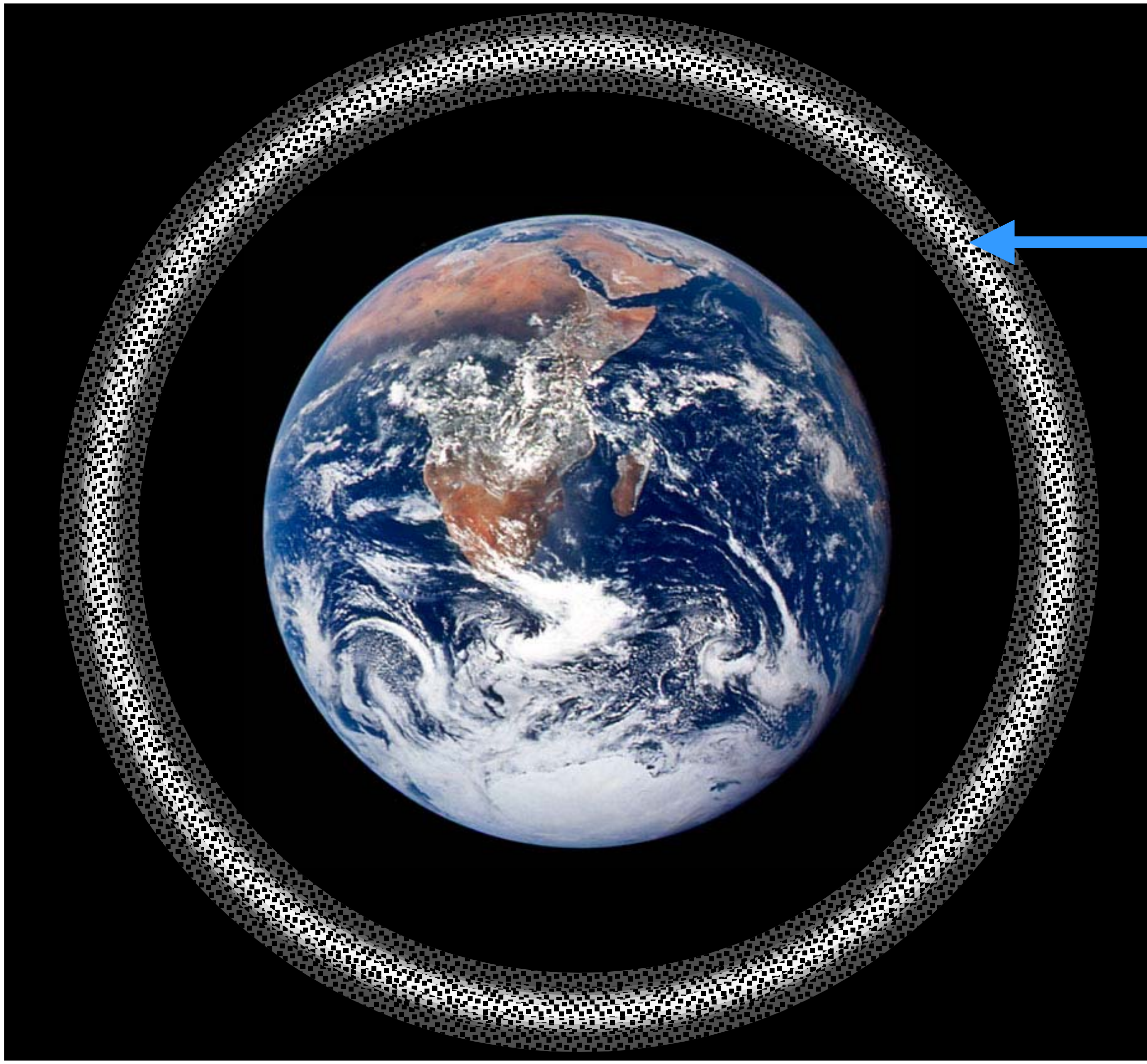
Typical ranges
1000s mi-Worldwide
100s-1000s mi
World-wide
10s-100s mi
10s mi
3 kHz
30 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
Feeds, relay
WLAN
Satellite
Mobile radio
Broadcast
VLF
LF
MF
HF
VHF
UHF
SHF
100 km
10 km
1 km
100 m
10 m
1 m
10 cm
1 cm
Line-of-sight
Ground wave
Tropospheric ducting
Ionospheric

HF Ionospheric Radio Propagation



"Blue Marble" image courtesy of: Image Science and Analysis Laboratory, NASA-Johnson Space Center. 8 May, 2003.   "Earth from Space - Search by Category." <http://earth.jsc.nasa.gov/sseop/efs/categories.htm>   (31 May 2005).

HF Ionospheric Radio Propagation

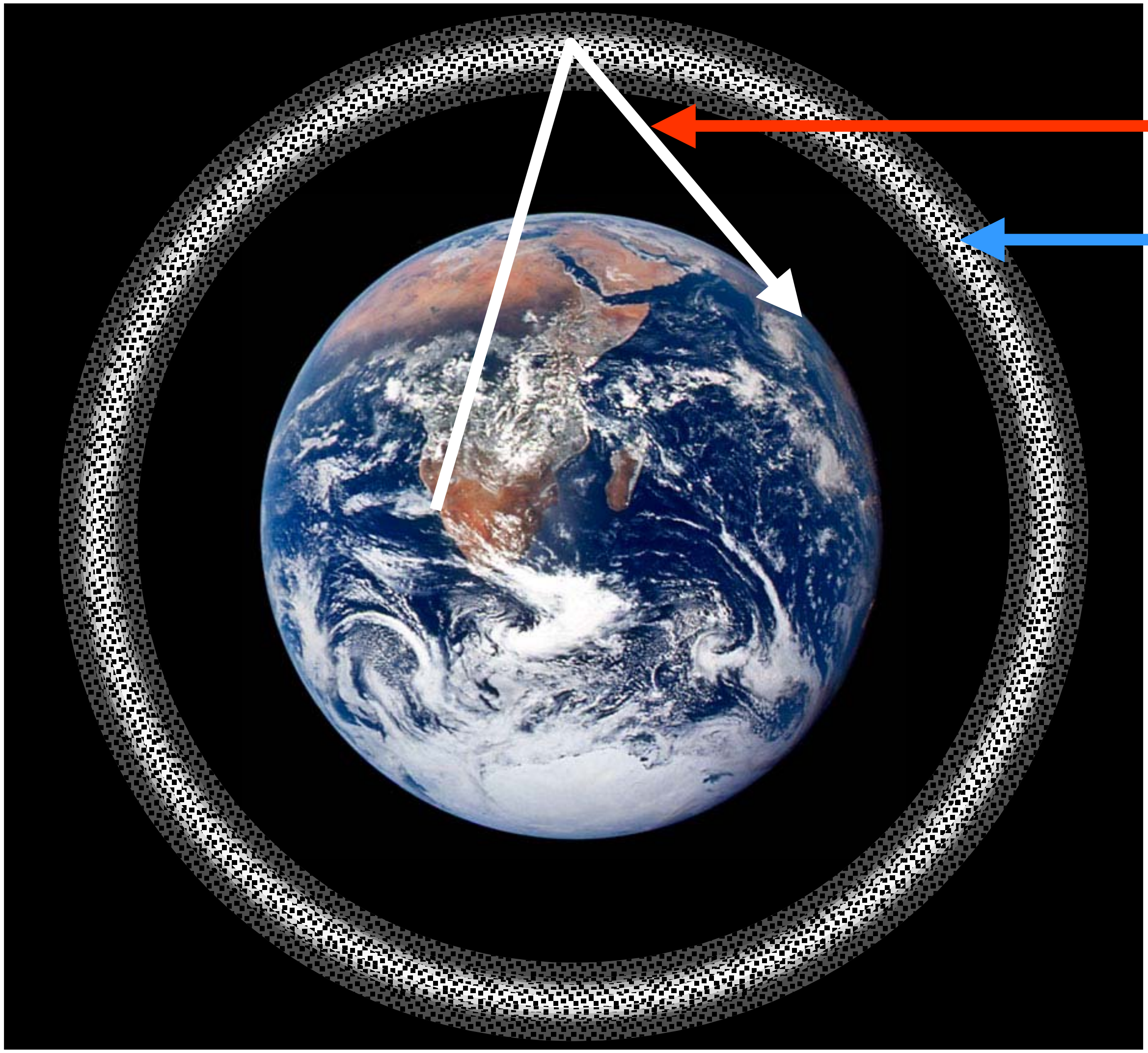


Ionosphere

• The Sun ionizes Earth’s upper atmosphere, creating the “Ionosphere”

"Blue Marble" image courtesy of: Image Science and Analysis Laboratory, NASA-Johnson Space Center. 8 May, 2003. "Earth from Space - Search by Category." <http://earth.jsc.nasa.gov/sseop/efs/categories.htm > (31 May 2005).

HF Ionospheric Radio Propagation



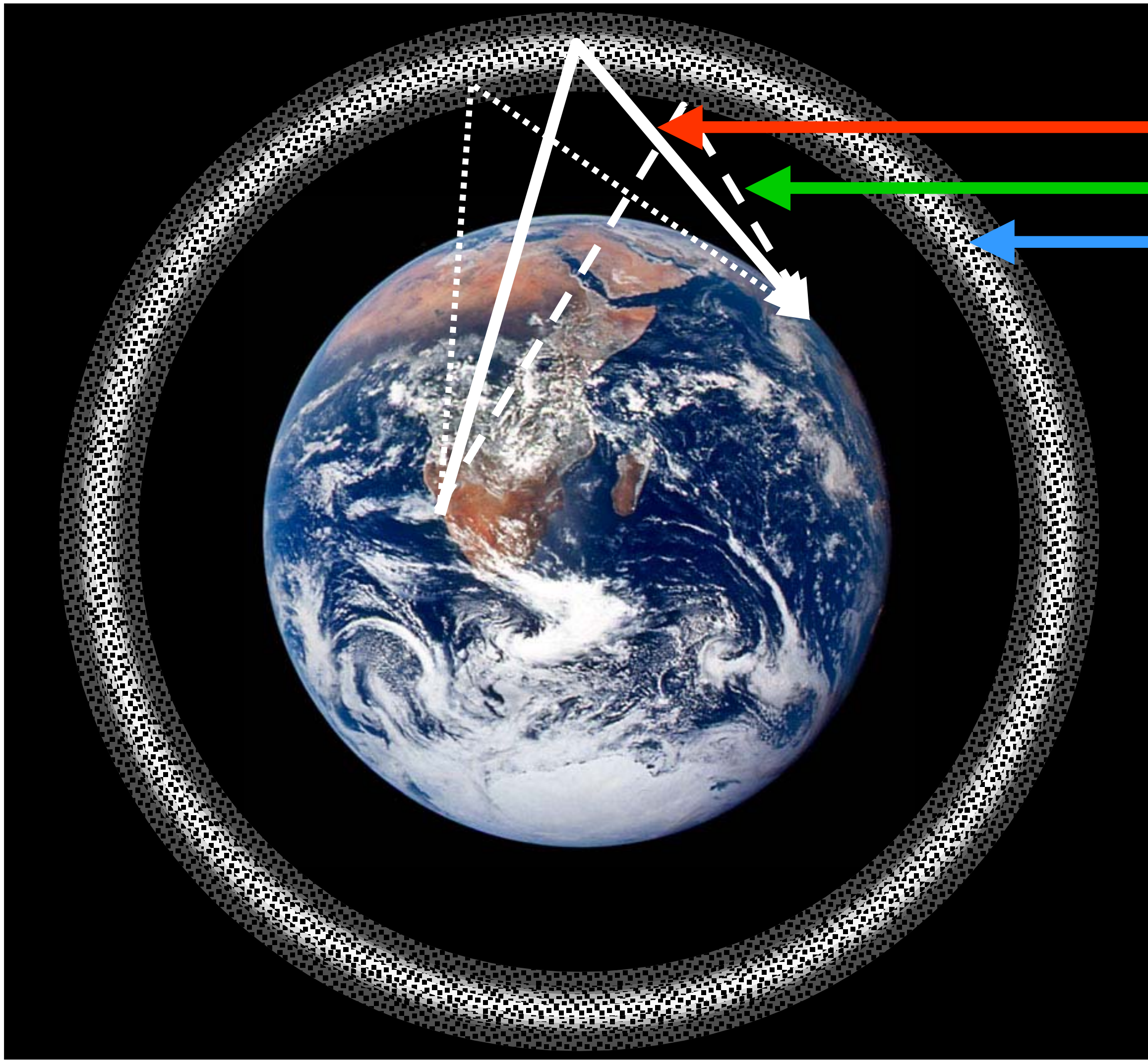
Reflected signal

Ionosphere

• The Sun ionizes Earth's upper atmosphere, creating the "Ionosphere"
• The Ionosphere reflects MF, HF, and some VHF radio signals, allowing long distance communications

"Blue Marble" image courtesy of: Image Science and Analysis Laboratory, NASA-Johnson Space Center. 8 May, 2003. "Earth from Space - Search by Category." <http://earth.jsc.nasa.gov/sseop/efs/categories.htm> (31 May 2005).

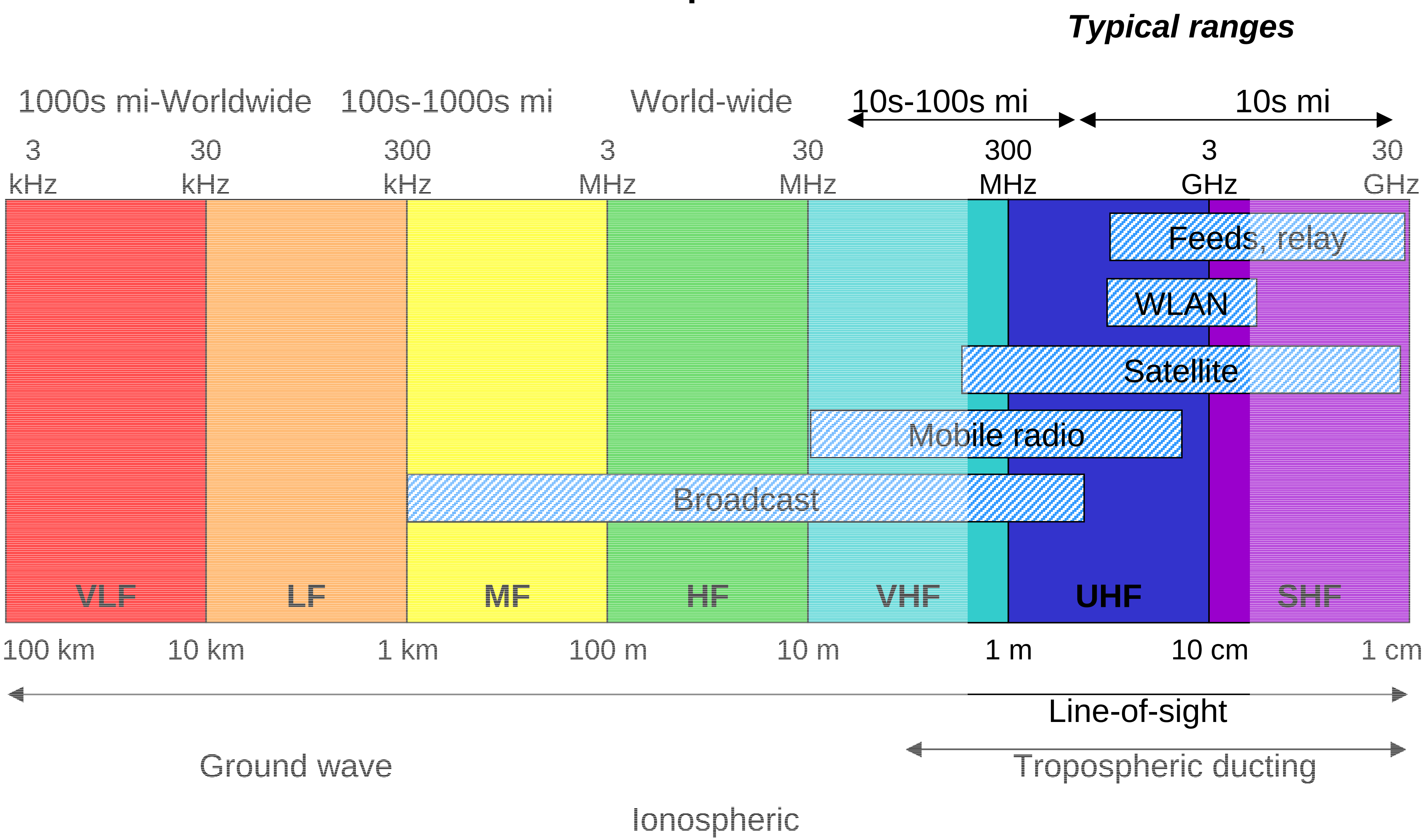
HF Ionospheric Radio Propagation



- The Sun ionizes Earth's upper atmosphere, creating the "Ionosphere"
- The Ionosphere reflects MF, HF, and some VHF radio signals, allowing long distance communications
- Radio signals leave the antenna at different angles, creating multiple reflected signals

"Blue Marble" image courtesy of: Image Science and Analysis Laboratory, NASA-Johnson Space Center. 8 May, 2003. "Earth from Space - Search by Category." <http://earth.jsc.nasa.gov/sseop/efs/categories.htm> (31 May 2005).

RF Spectrum



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3 MHz
30 MHz
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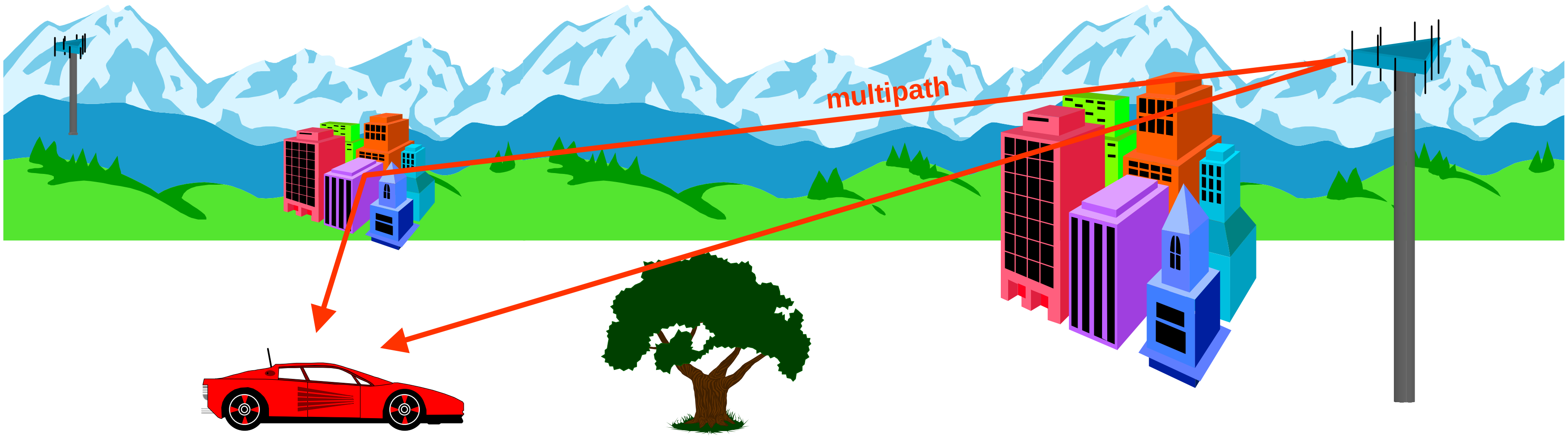
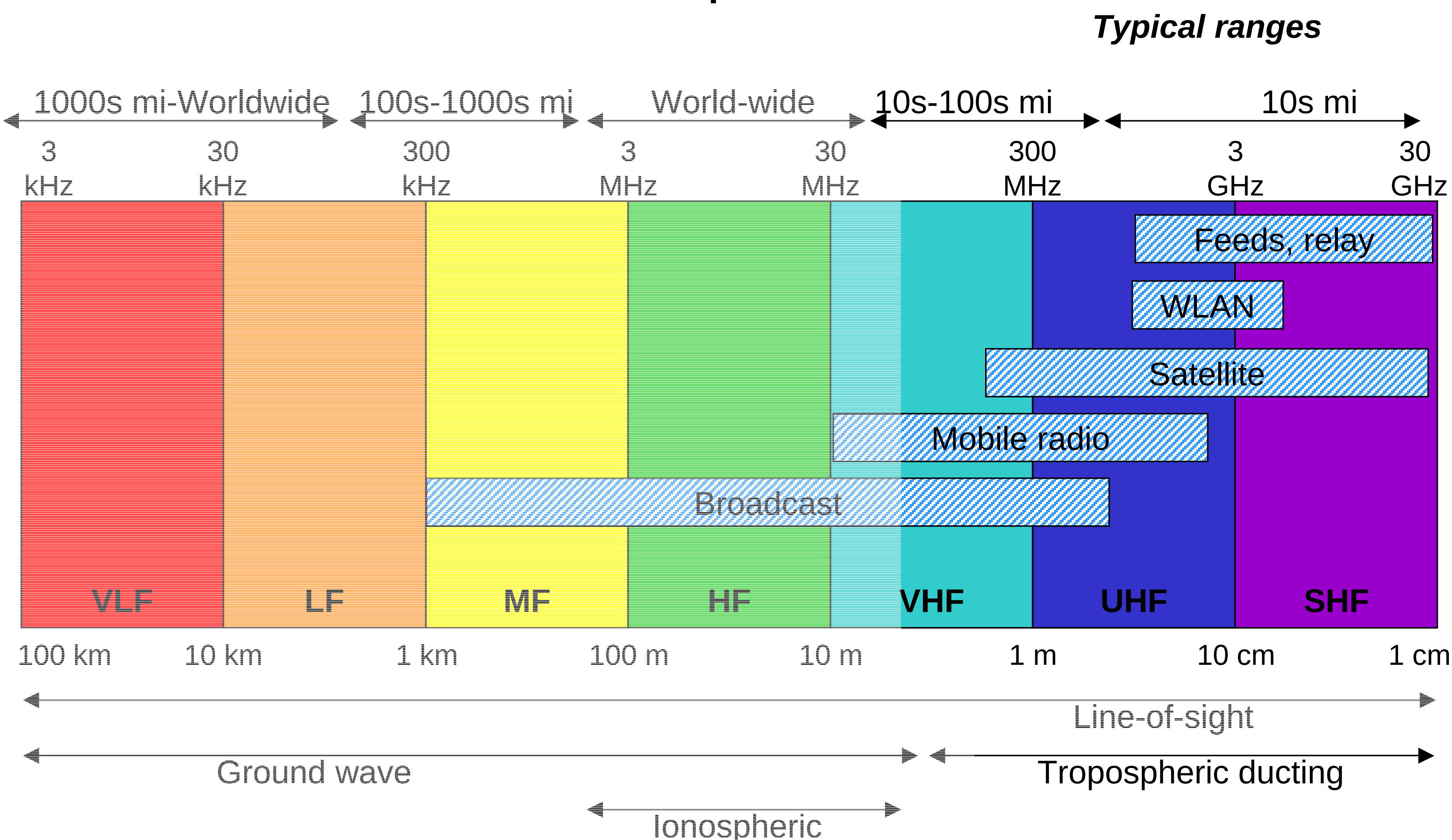
WLAN
Satellite
Mobile radio
Broadcast
VLF
LF
MF
HF
VHF
UHF
SHF
100 km
10 km
1 km
100 m
10 m
1 m
10 cm
1 cm
Line-of-sight
Ground wave
Tropospheric ducting
Ionospheric

UHF Propagation



- Propagation is mostly line-of-sight
- Reflections off conductive objects (buildings, vehicles, fences, etc.) are prevalent
- Refraction around obstacles is possible

RF Spectrum



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VLF
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MF
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VHF
UHF
SHF
100 km
10 km
1 km
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1 m
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Ground wave
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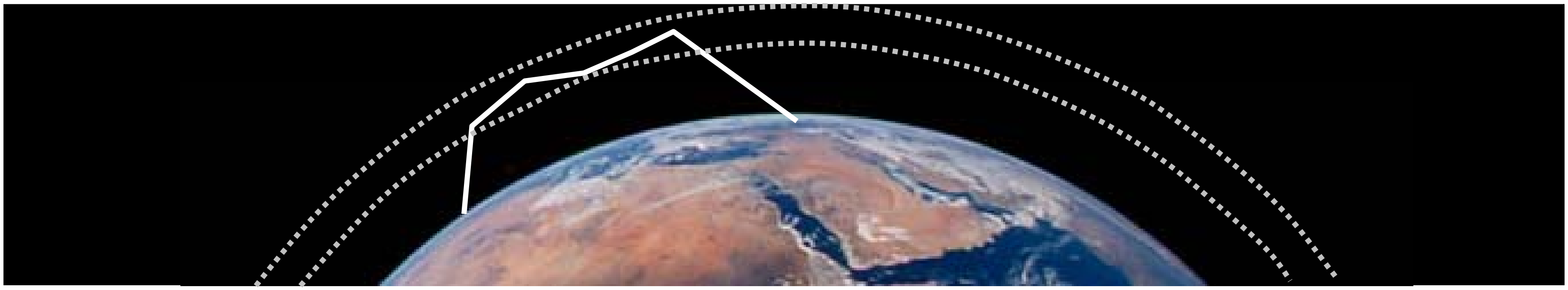
Ionospheric

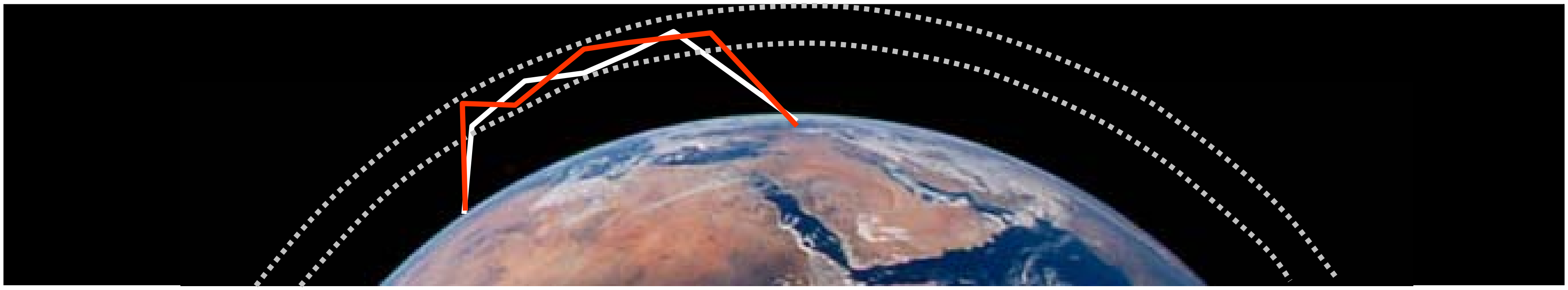
Tropospheric Ducting

- Generally caused by regional weather conditions, e.g., Temperature Inversion
- Radio signal can propagate 100s of miles with little or no loss
- Specific routes are unpredictable

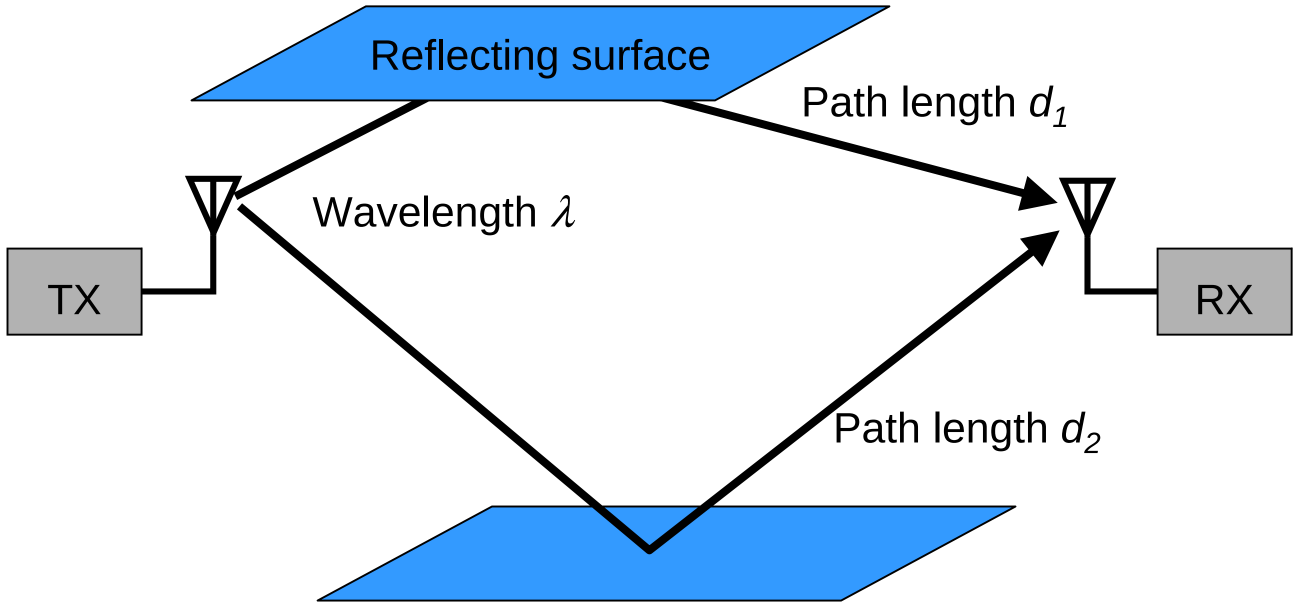


Tropospheric Ducting

- Generally caused by regional weather conditions, e.g., Temperature Inversion
- Radio signal can propagate 100s of miles with little or no loss
- Specific routes are unpredictable
- Multipath is prevalent



Effects of Multipath

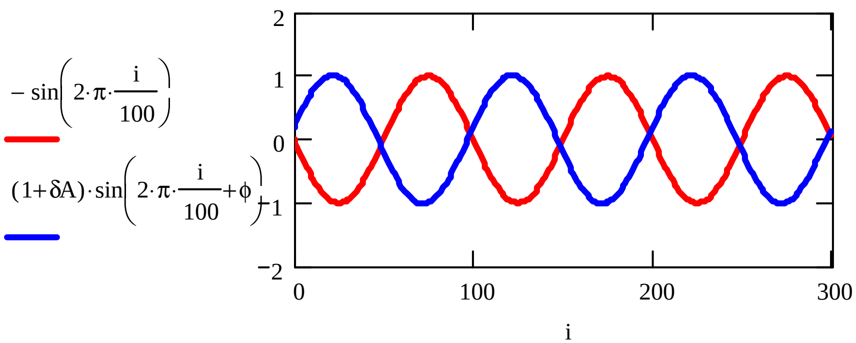


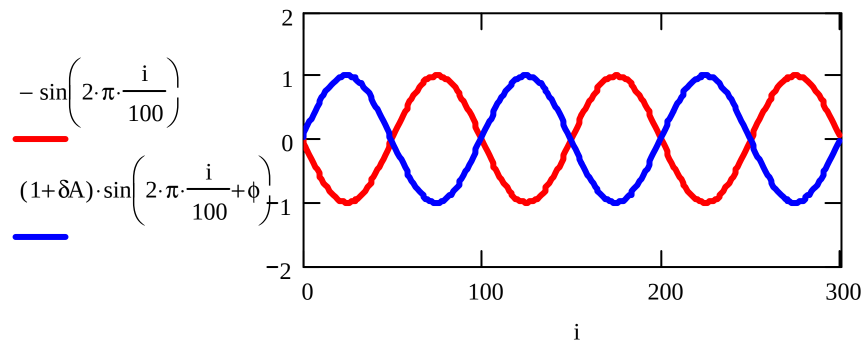
- Conditions for complete, destructive interference between path_1 and path_2 :

$A_1 = A_2$ • Equal signal strengths

$d_1 - d_2 = (k + .5)\lambda$ • Odd multiple of one half wavelength path difference

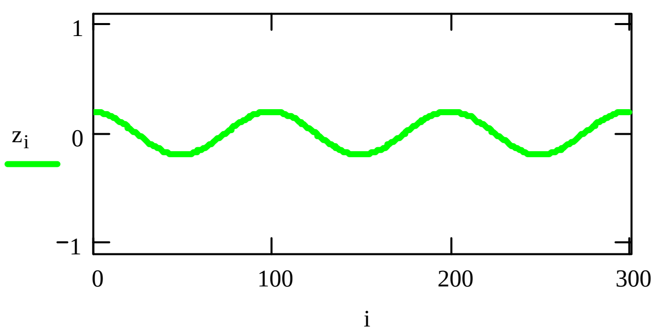
Requirements for Destructive Interference

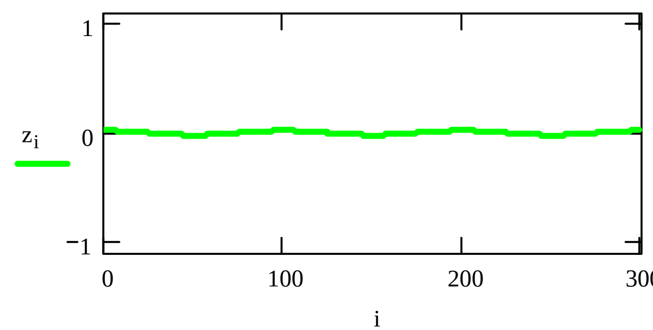




$z := x + y$ $\quad \phi = 0.2$ $\quad \delta A = 0.01$

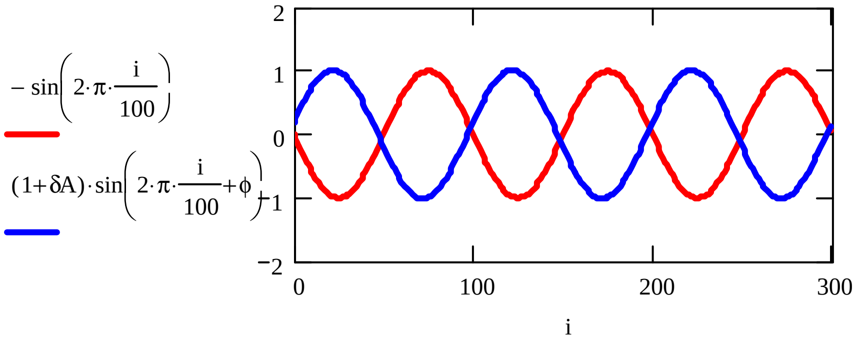
$z := x + y$ $\quad \phi = 0.02$ $\quad \delta A = 1 \times 10^{-3}$

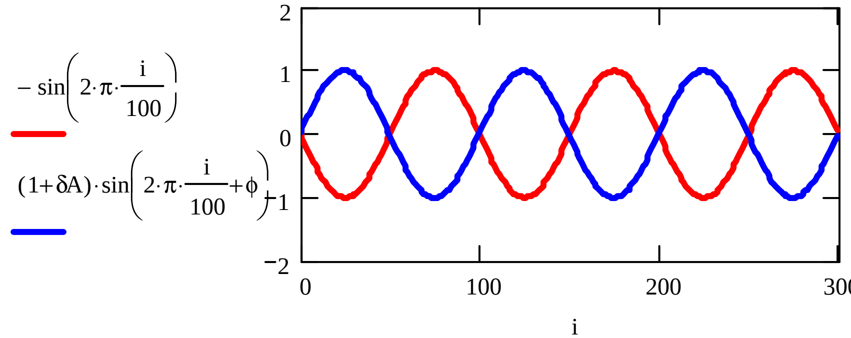




- Two multipath signals must be nearly the same amplitude and almost exactly 180º out of phase with each other to cancel.

Requirements for Destructive Interference





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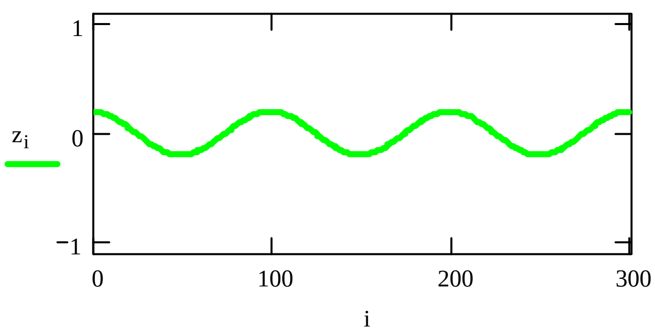
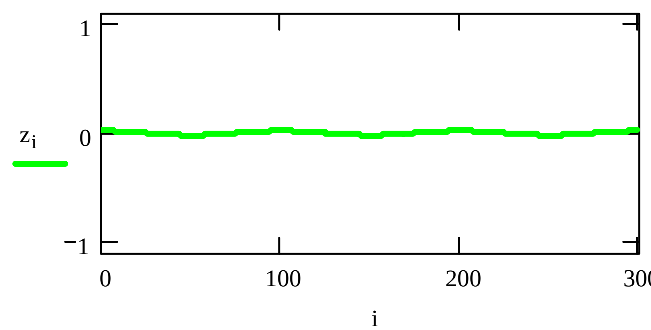
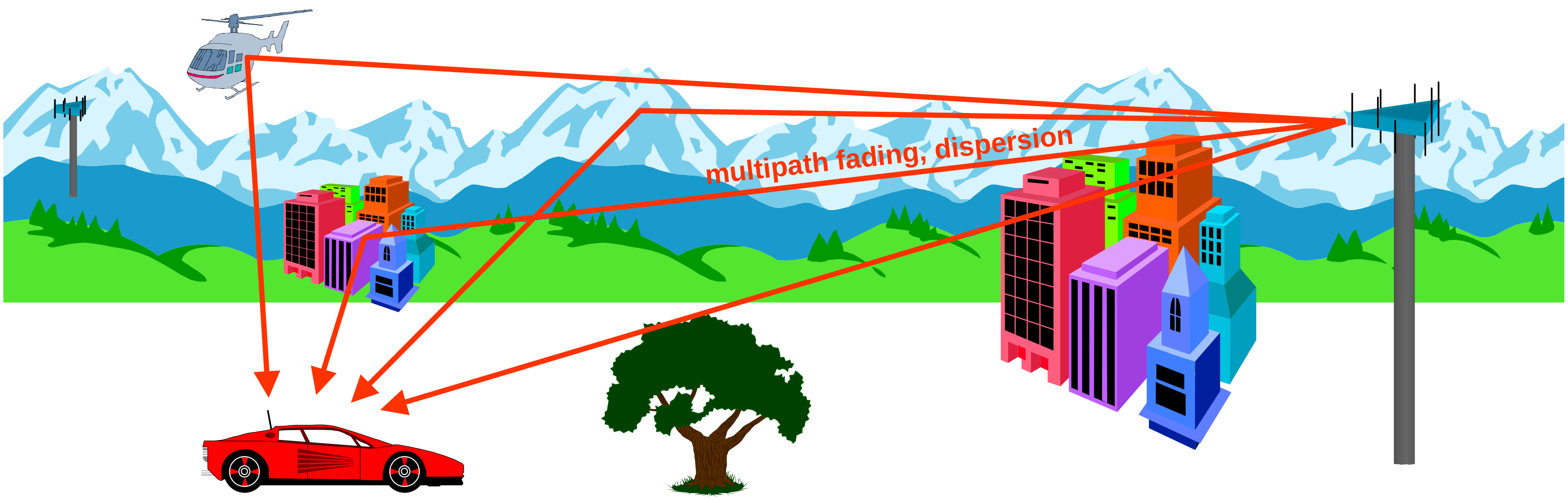




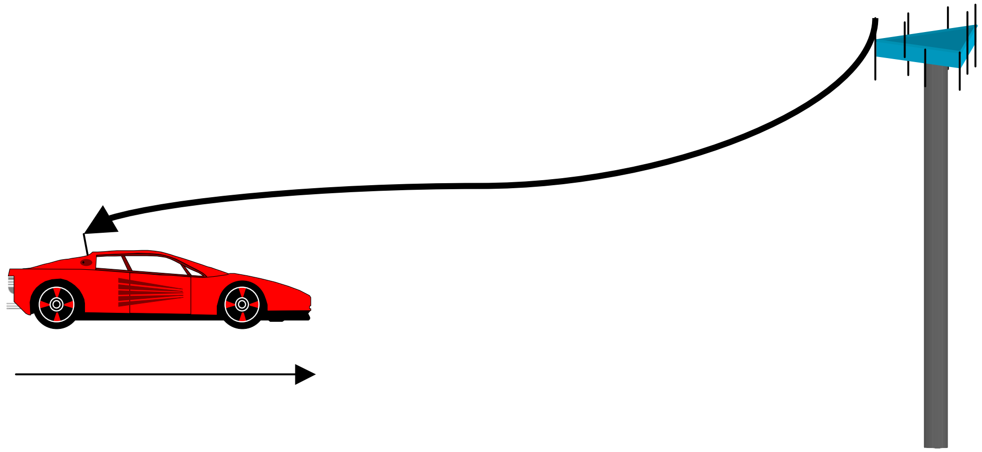
- Two multipath signals must be nearly the same amplitude and almost exactly 180º out of phase with each other to cancel.
- ***Changing the paths slightly will prevent cancellation***

Channel dispersion



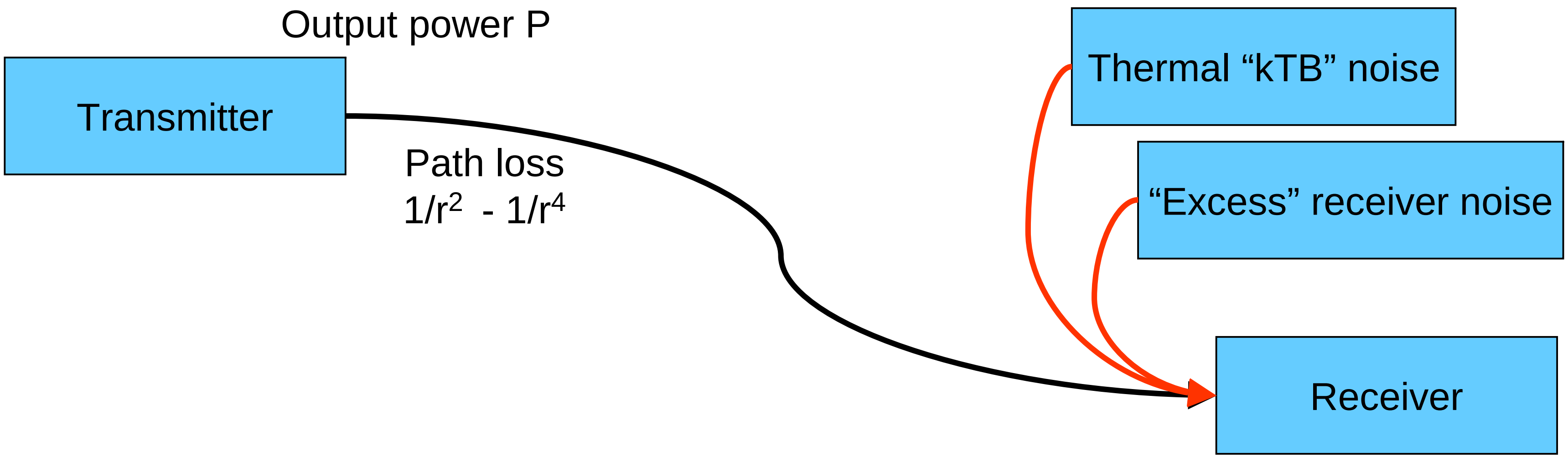
- Multipath reflections create time dispersion of the received signal
- Movement of the receiver, transmitter or objects in the environment create changes in the multipath environment

Doppler Shift



- Relative motion of transmitter/receiver creates an apparent frequency offset due to Doppler shift
- Offset is proportional to speed and frequency
- At a 2 GHz carrier frequency, 60 mph creates a 200 Hz Doppler shift

Noise, Signal-to-Noise Ratio

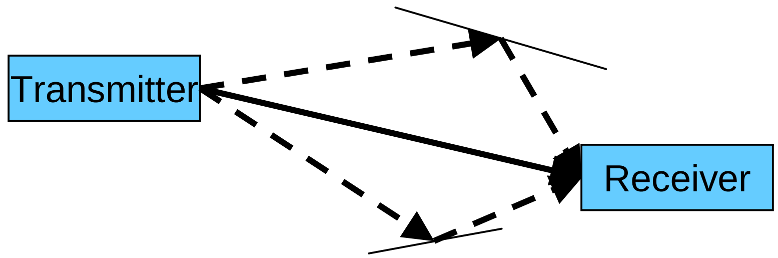


- Thermal noise is proportional to receiver bandwidth
- -174 dBm/Hz
- Increased by noise figure of receiver

- Transmitter signal attenuated by distance, obstacles
- Square law attenuation in free space, ~3.5 power in terrestrial environment

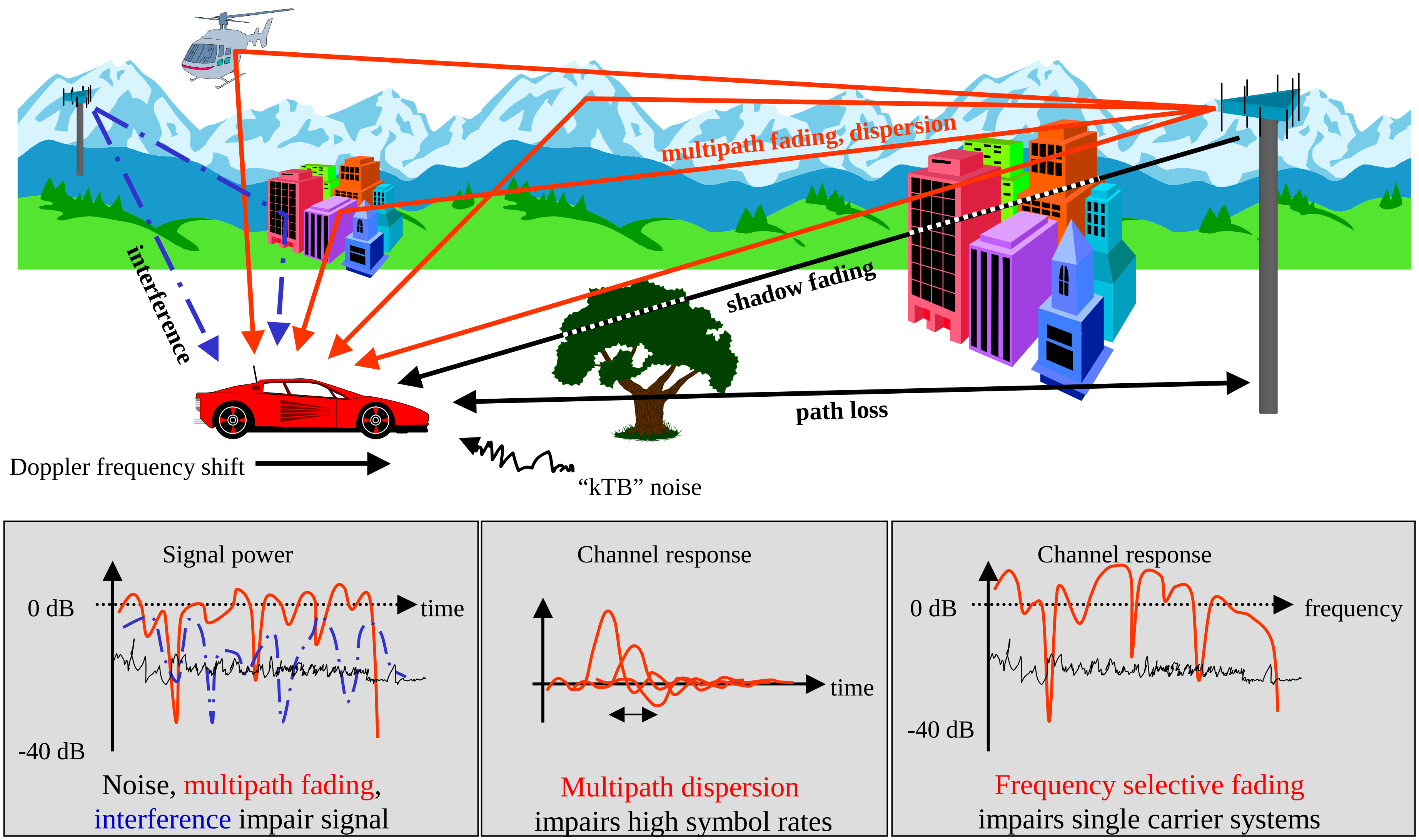
- Link budget limits receiver performance

Multipath Dispersion/
Frequency Selective Fading

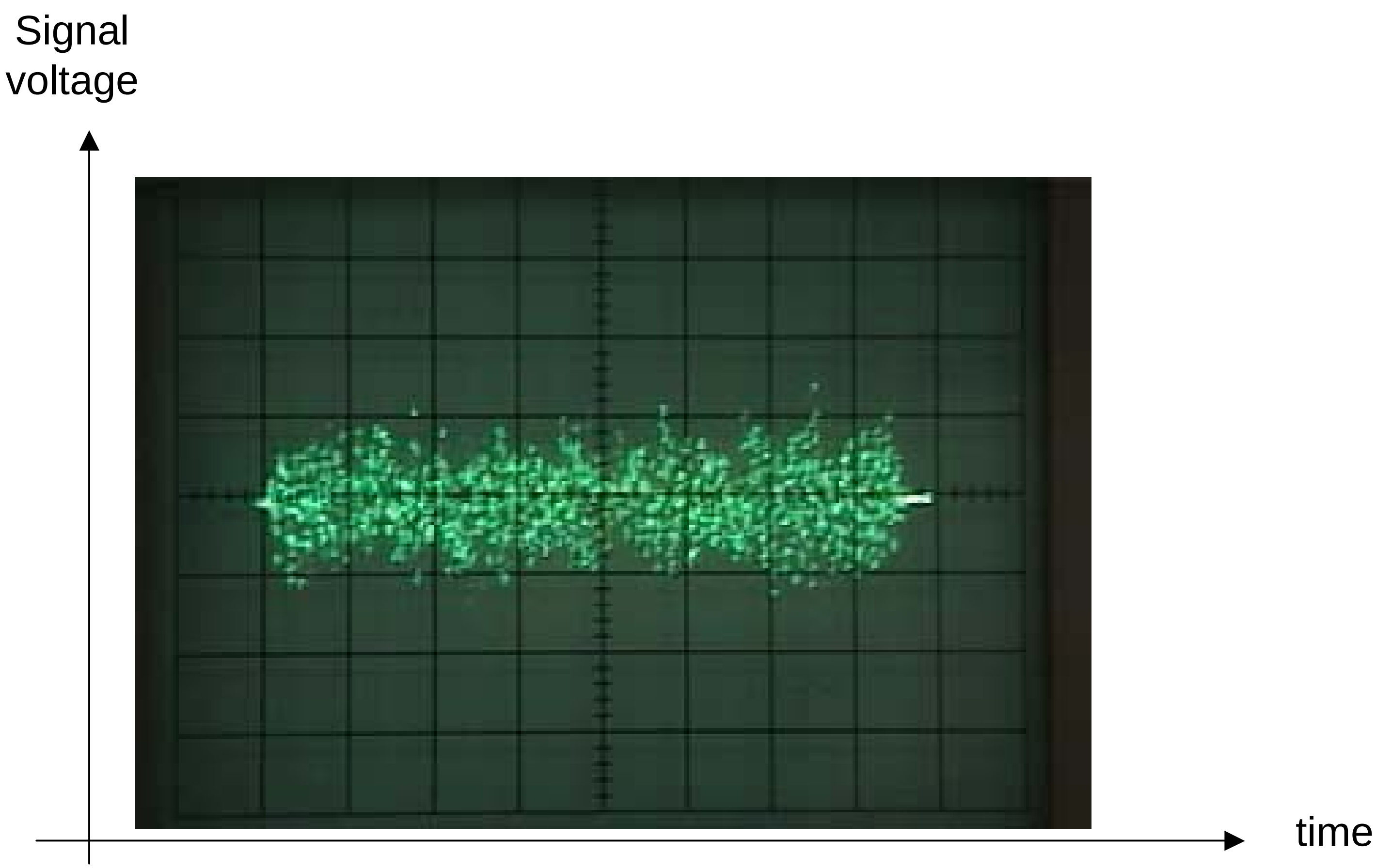


- Delayed versions of signal interfere with each other
  - Equivalent to intersymbol interference on a baseband wireline system
- Multipath is modeled as a delay profile - signal delay and average amplitude with randomly varying instantaneous signal level
- For comparison purposes, typical indoor and outdoor delay profiles have been standardized:
  - Typical Urban, Hilly Terrain, Mountainous Terrain profiles
  - Exponential delay profile
- Through the Fourier Transform, delay profile can be studied in frequency domain

Wireless Communications Challenges

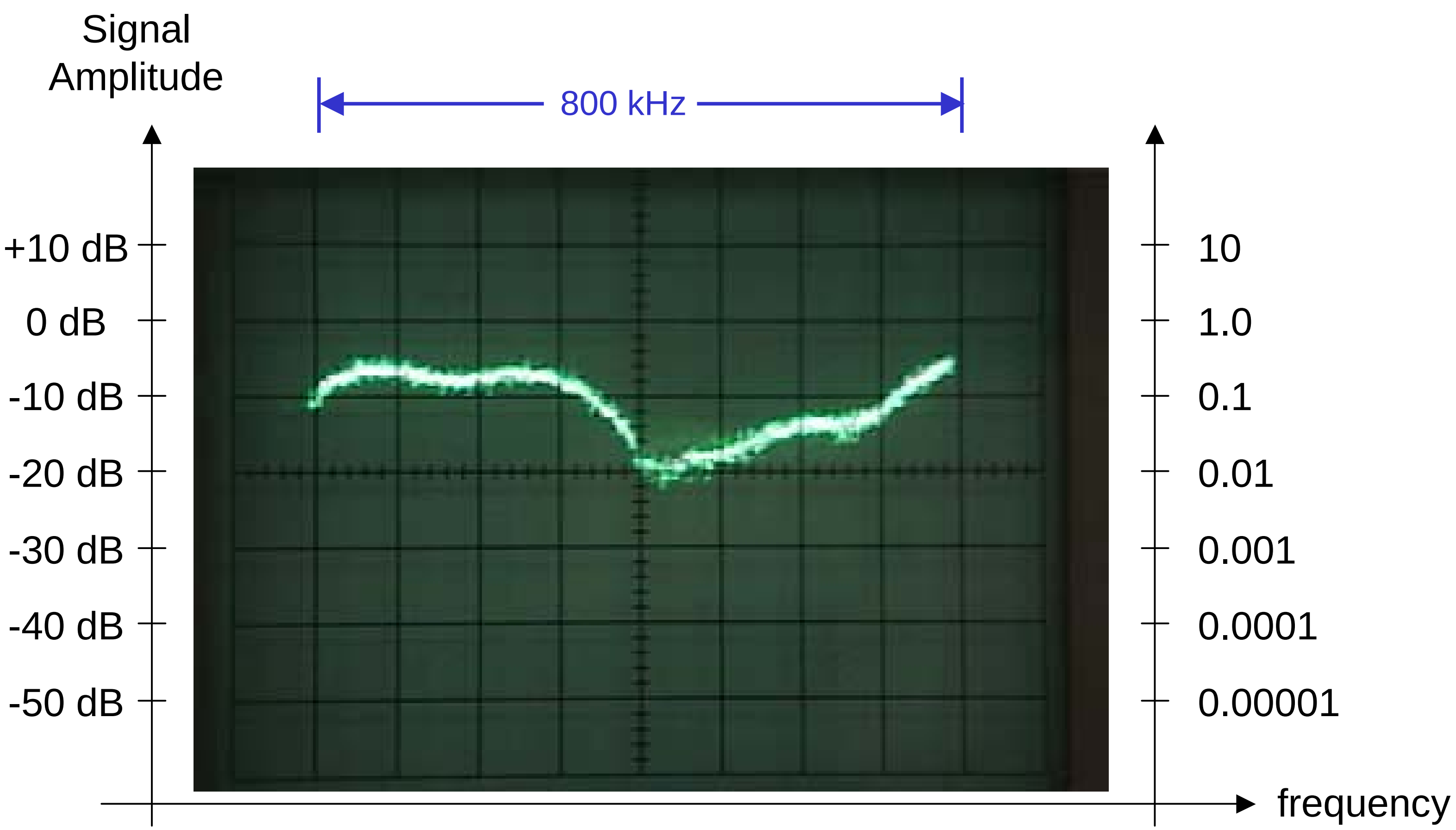


Signal in Time Domain



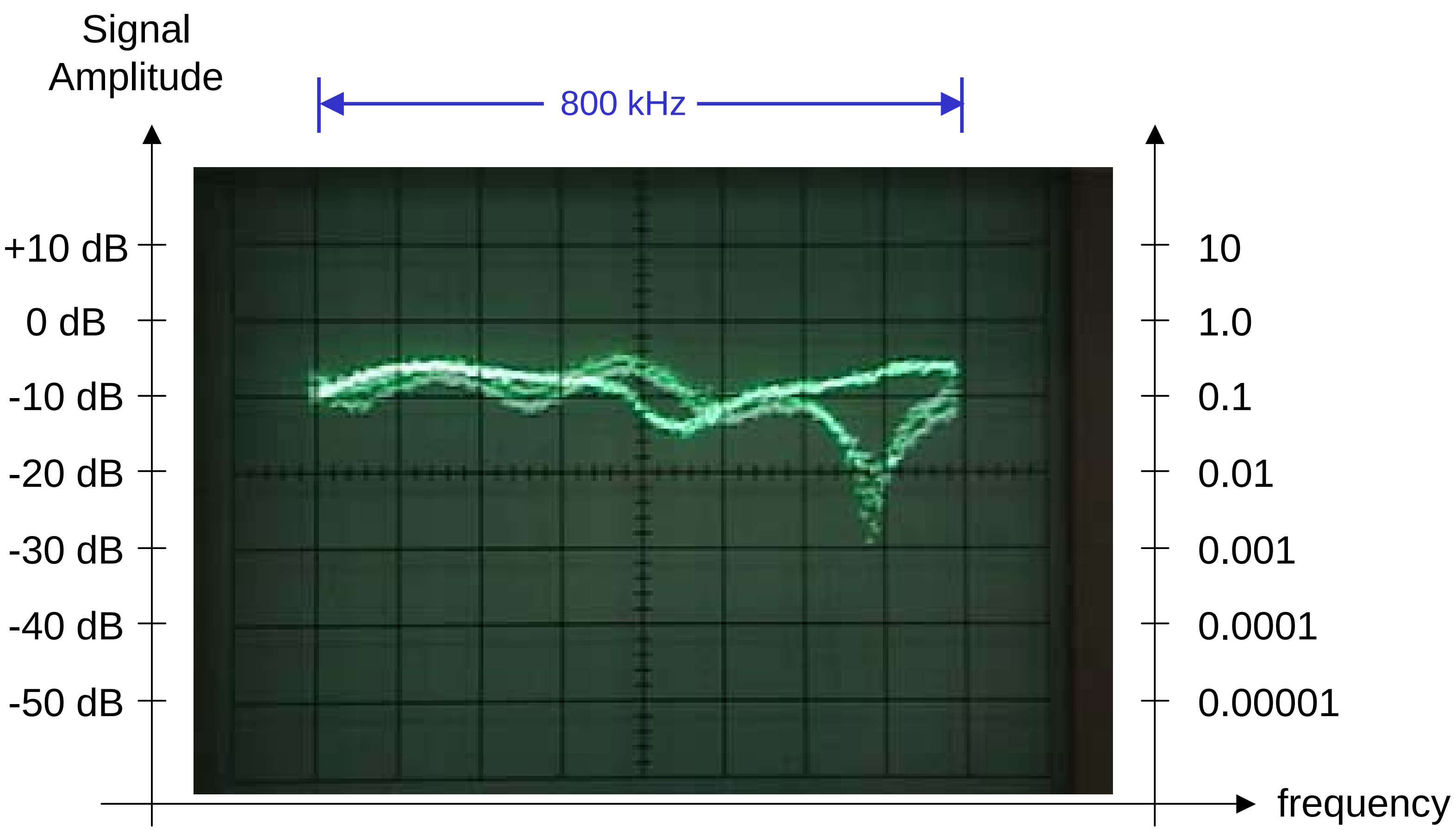
GSM "Typical Urban" channel

Signal in Frequency Domain



GSM “Typical Urban” channel

Multiple Signals in Frequency Domain



GSM "Typical Urban" channel

~10 years of Wireless Evolution

~1994 600 mW
Analog AMPS
12.7 oz – 360 gm

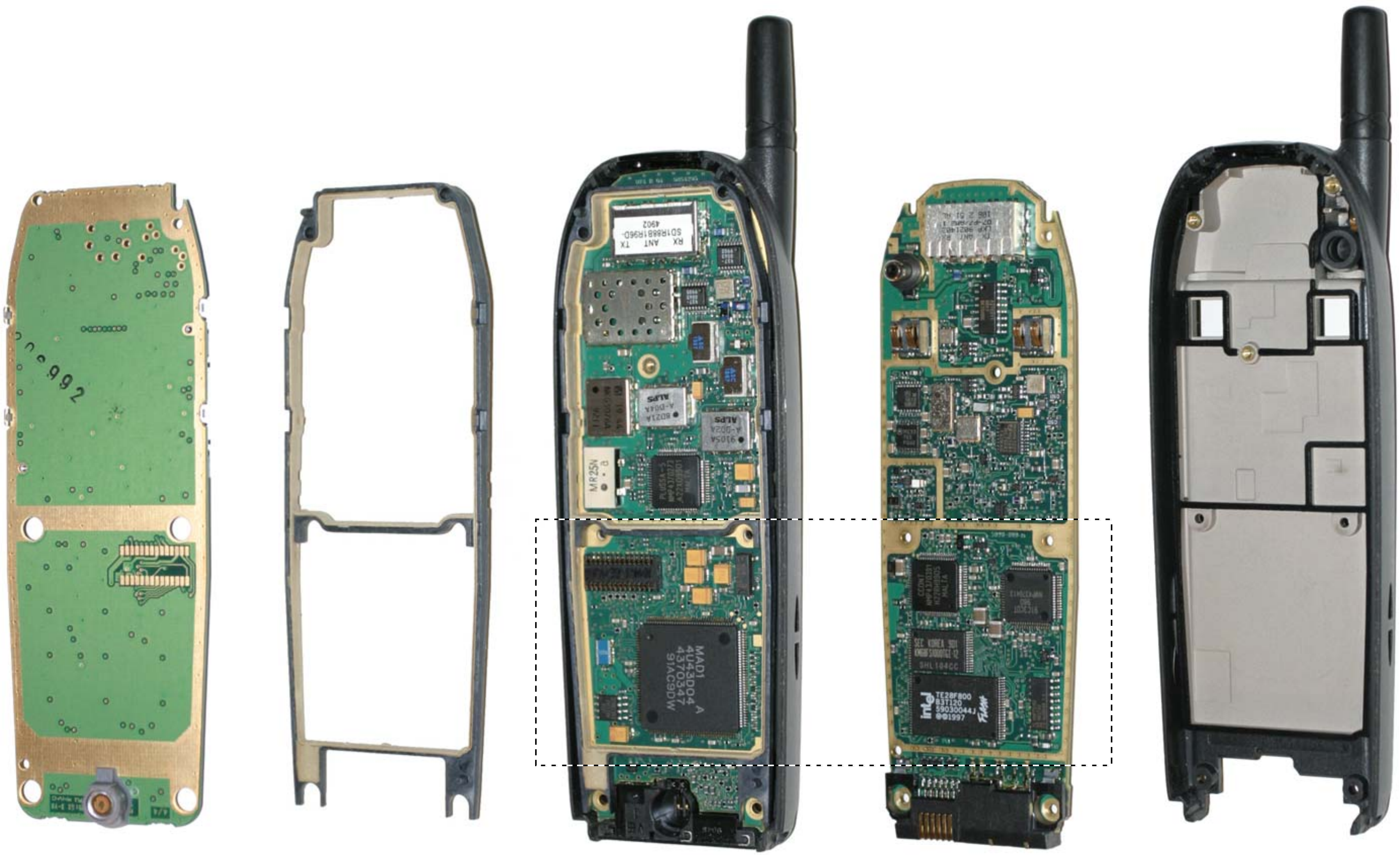
~1996 600 mW
AMPS/TDMA
6 oz – 170 gm

~2001 600 mW
AMPS/TDMA
3.4 oz – 96 gm

~1990 3W
Analog AMPS
67.4 oz – 1900 gm

Transceiver Anatomy 101

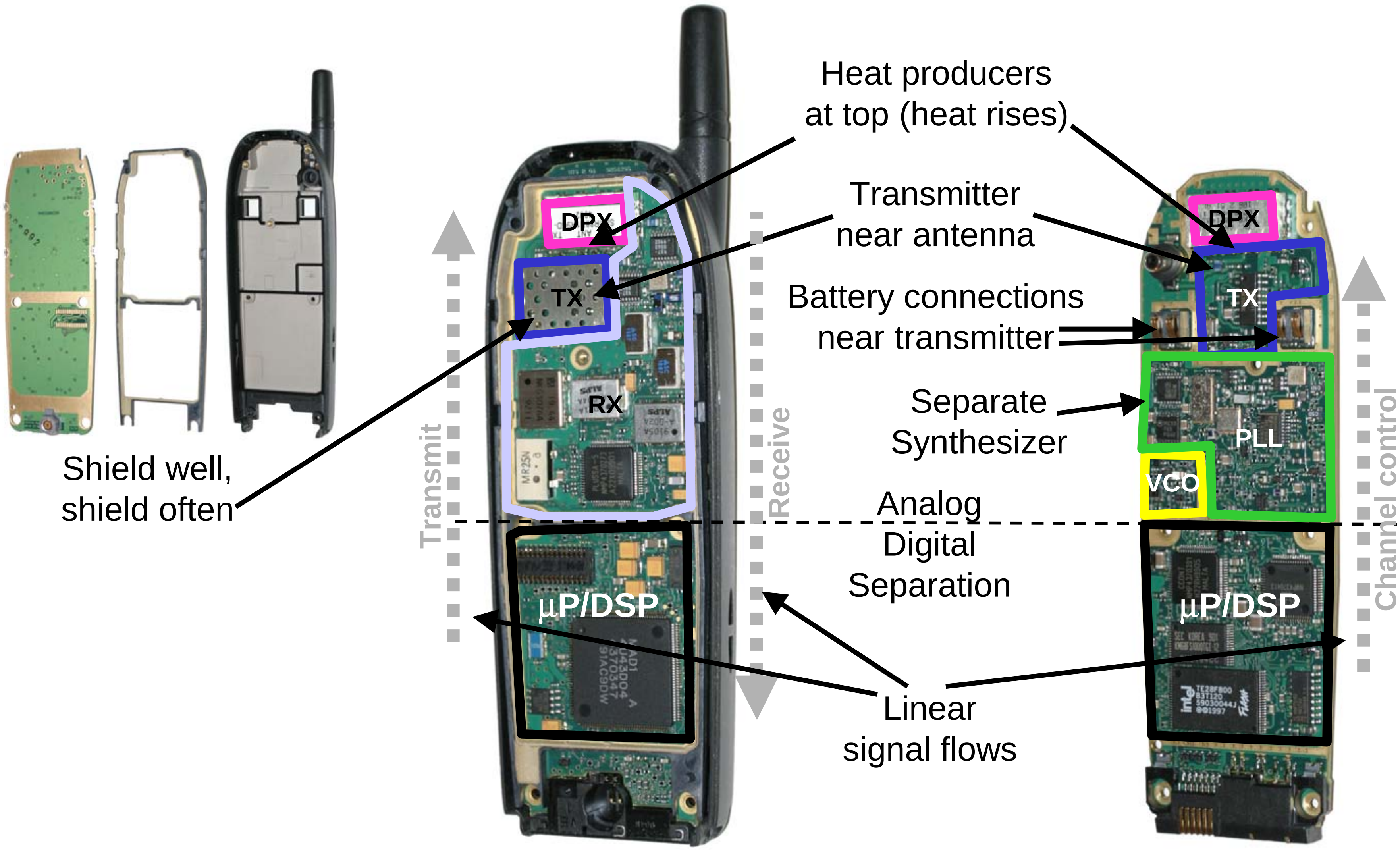
Transceiver Anatomy 102A



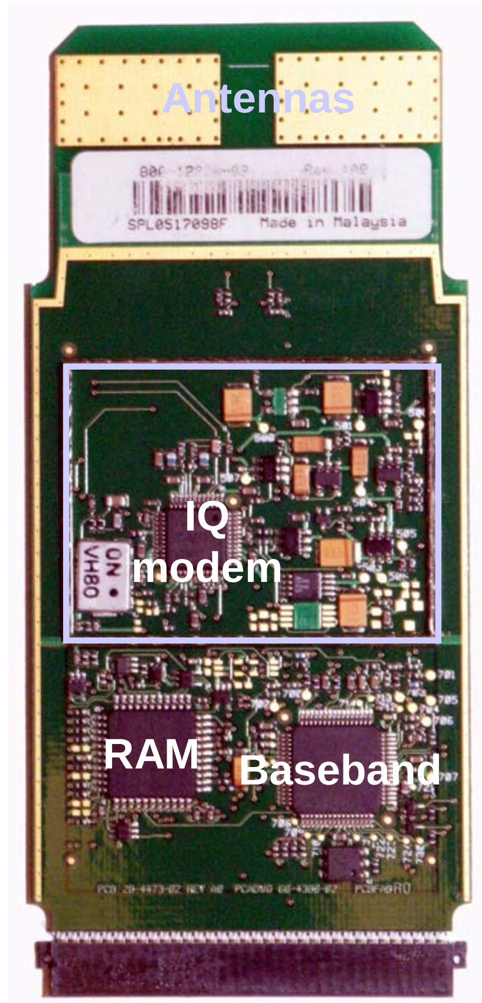
NSF-REU
6/1/05

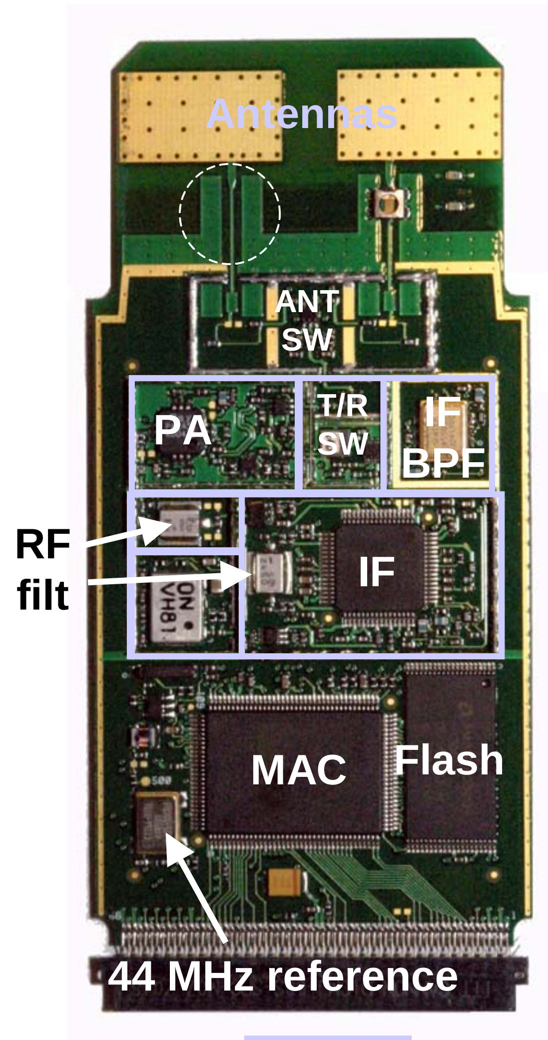
Transceiver Anatomy 102B

Lessons from Anatomy



Alternative Wireless Technologies – Cisco 802.11b WLAN Adapter





Shield

Alternative Wireless Technologies – Orinoco 802.11b WLAN Adapter