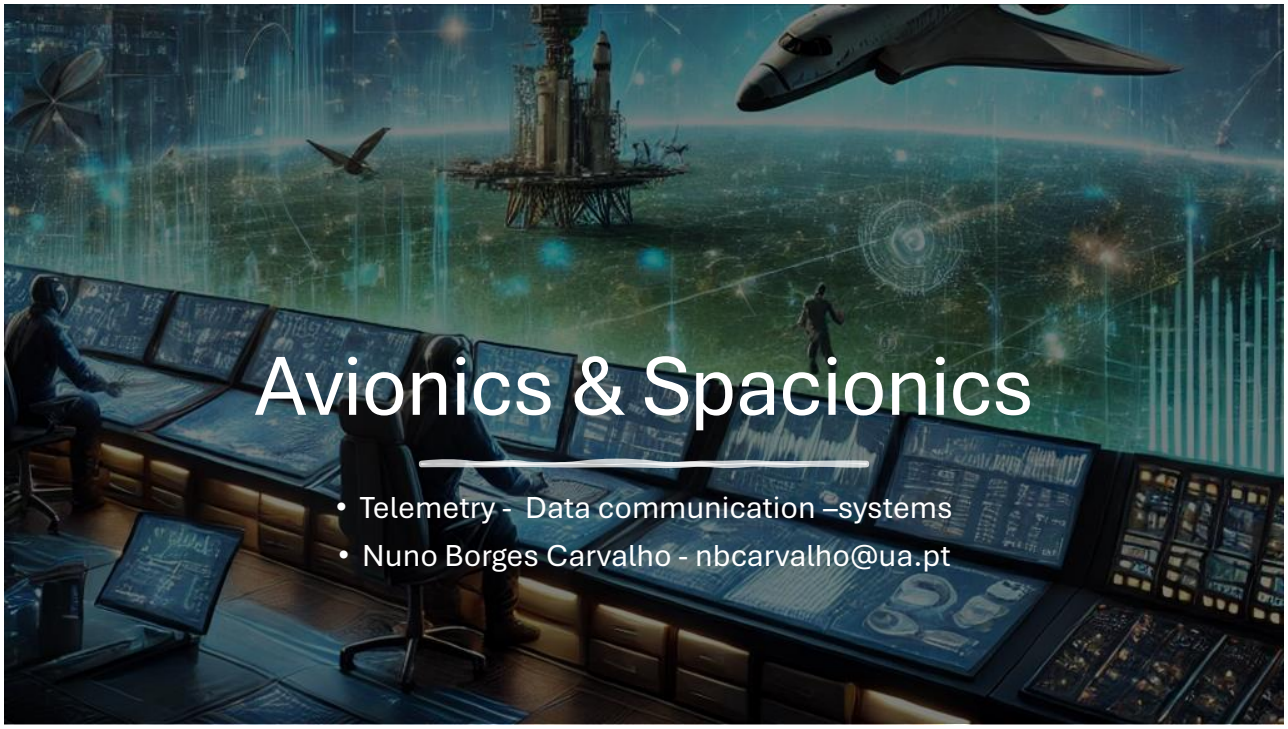
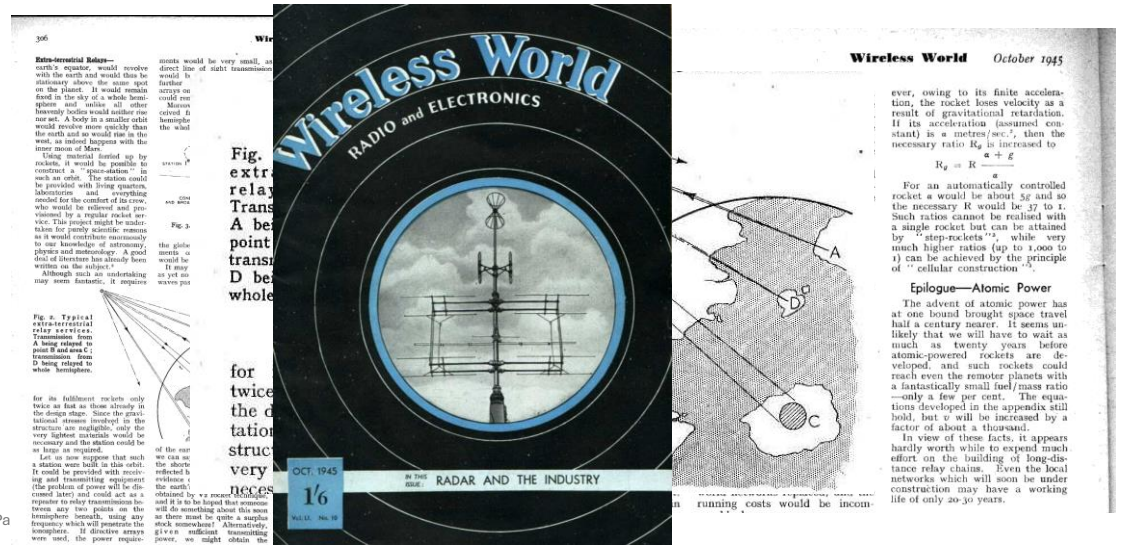


Avionics & Spacionics

- Telemetry - Data communication –systems
- Nuno Borges Carvalho - nbcarvalho@ua.pt

1

Satellite communication system

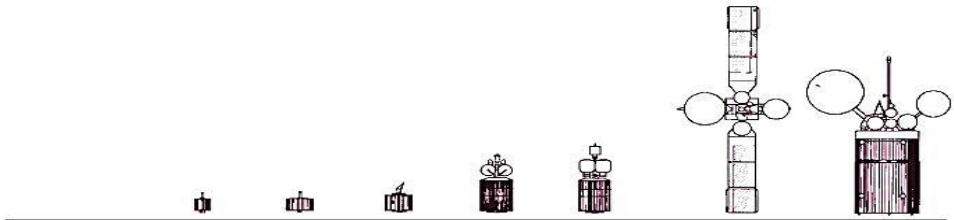


2

Satellite communication system

3

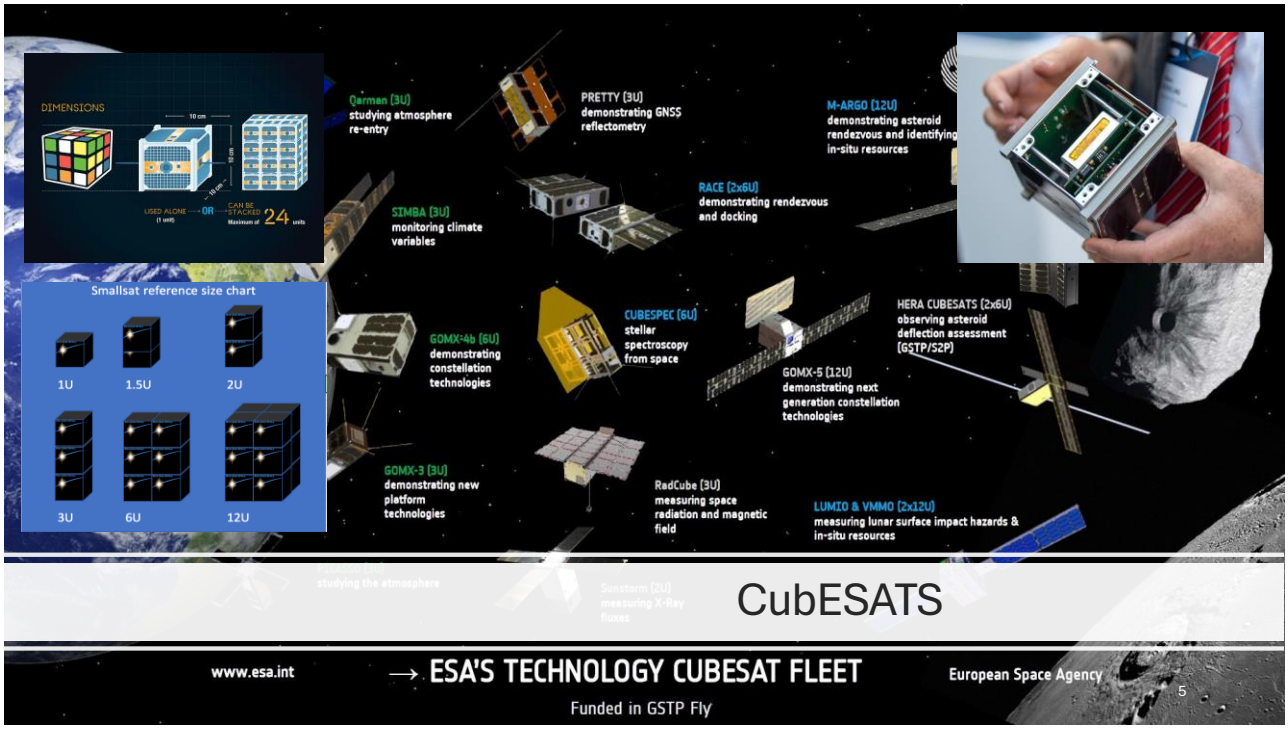
Introduction : History of Satellites



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

Evolution of INTELSAT satellites. (*From Colino 1985; courtesy of ITU Telecommunications Journal.*)

4



5

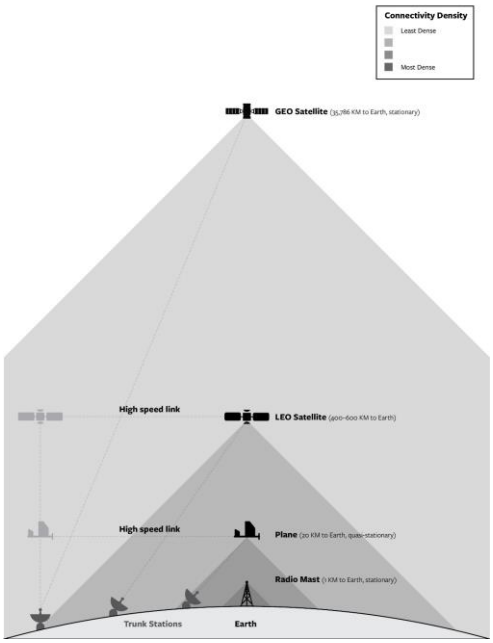
Introduction : History of Satellites

6

Context

- - Companies like Google and Facebook working to use drones and balloons to provide internet access
- - SpaceX and OneWeb propose to do the same with satellites
- - These approaches have raised technical, regulatory and policy questions

SPACEX facebook Google OneWeb



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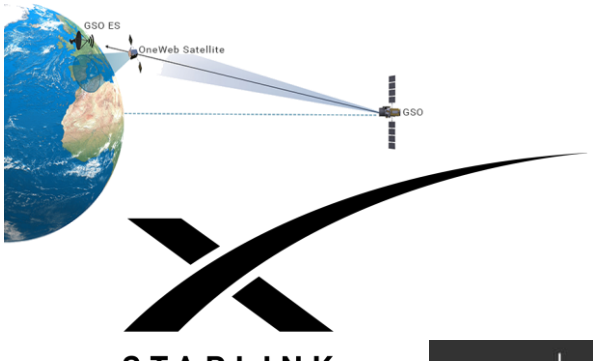
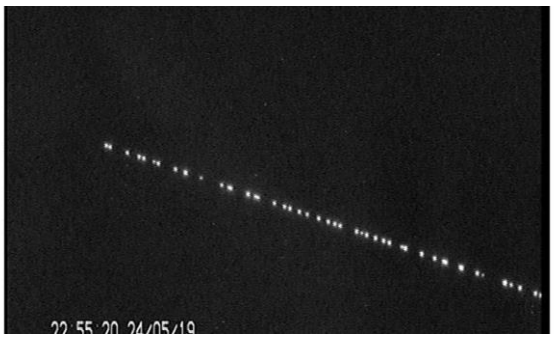
Introduction : History of Satellites



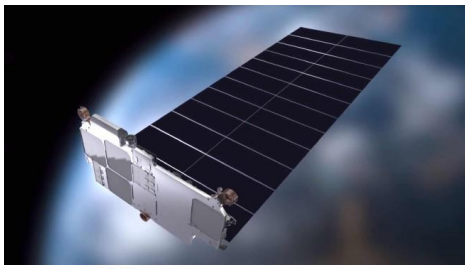


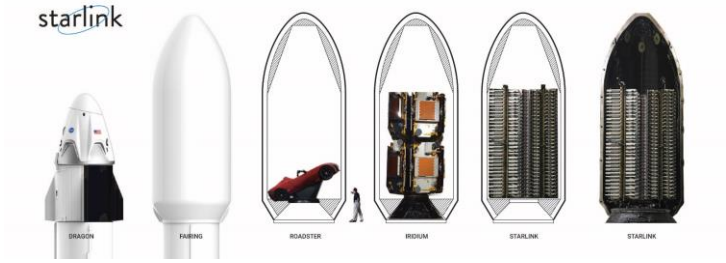
STARLINK amazon | project kuiper OneWeb

https://www.youtube.com/watch?v=Aw3R-4UC4wI

8

Introduction : History of Satellites





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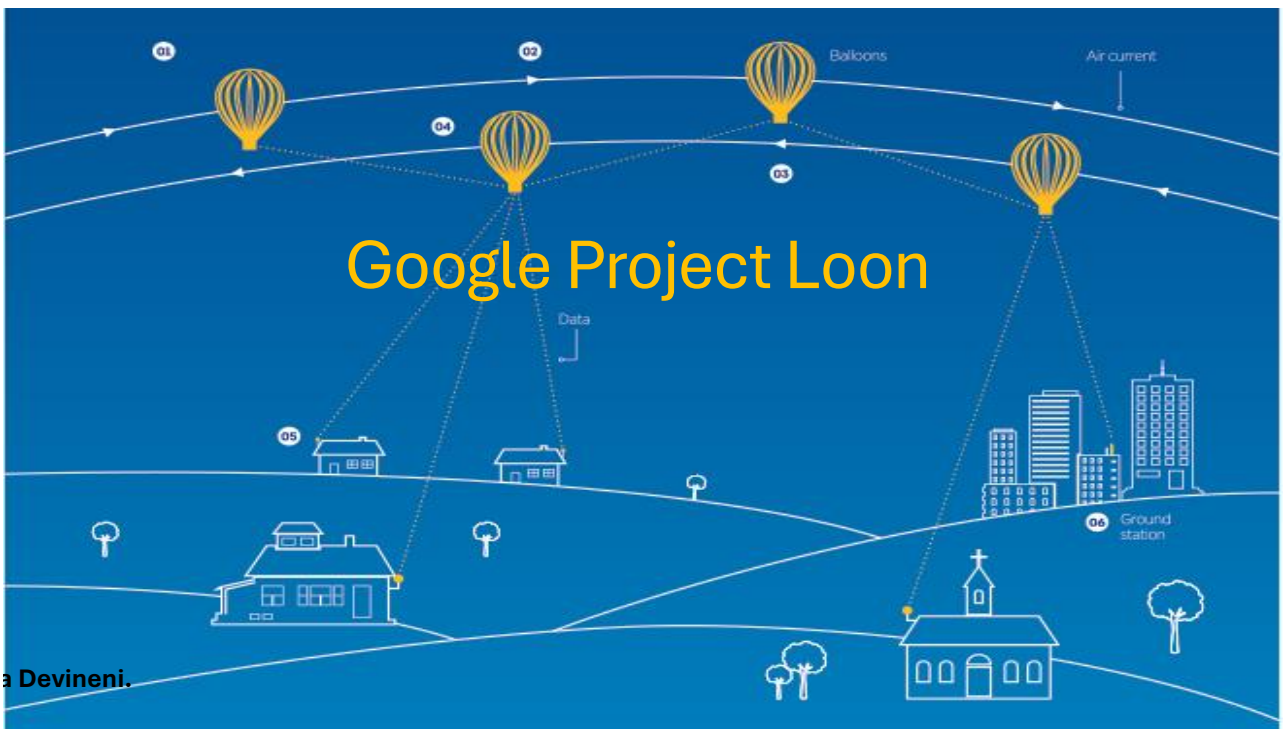

a Devineni.

10

Stratosphere

- Stratosphere is situated on the edge of space, between 10 km and 60 km in altitude having steady winds below 20 mph.
- In the stratosphere, there are many layers of wind, and each layer of wind varies in direction and speed.
- Loon balloons are directed by rising or descending into a layer of wind blowing in the desired direction of travel by using wind data from NOAA.

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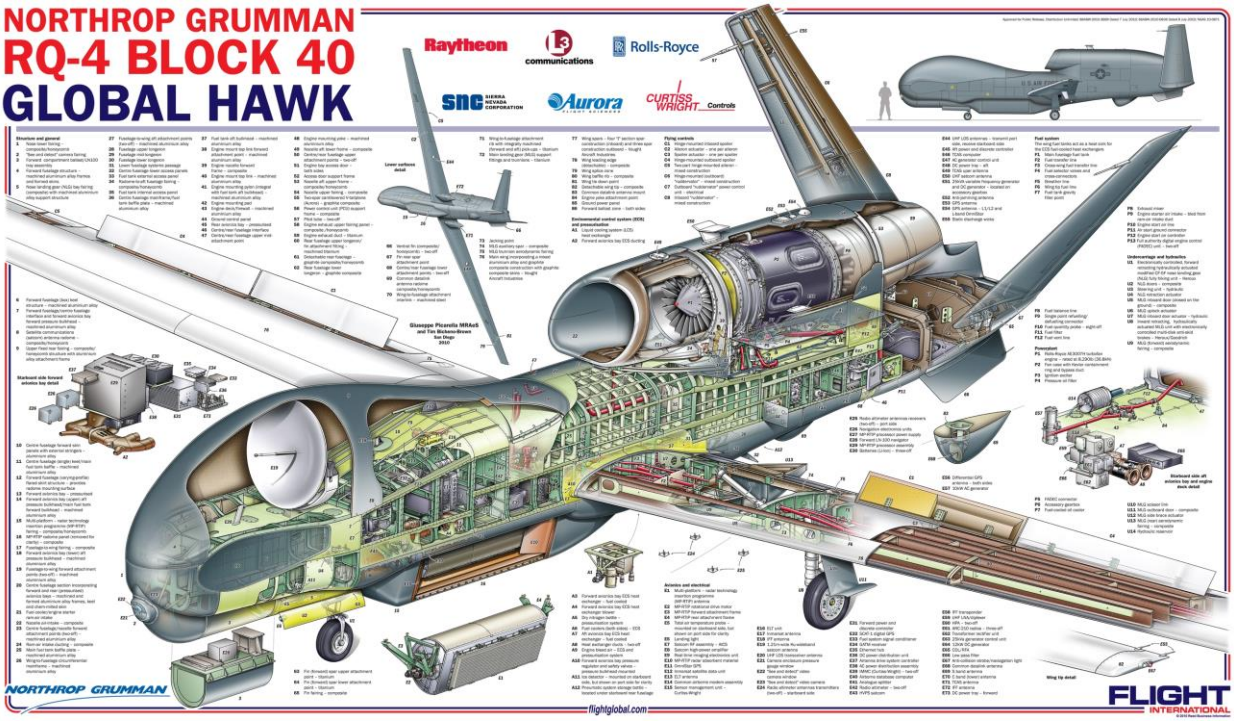
Drones – Facebook Aquila

- Rapid response
- Emergency services usage

- More expensive than balloons
- Many nodes → complicates networking

https://www.facebook.com/facebook/videos/10154835146021729/

12


NORTHROP GRUMMAN
RQ-4 BLOCK 40
GLOBAL HAWK
Raytheon
L3 communications
Rolls-Royce
SNC SIERRA NEVADA CORPORATION
Aurora
CURTISS WRIGHT Controls
NORTHROP GRUMMAN
flightglobal.com
FLIGHT INTERNATIONAL

13

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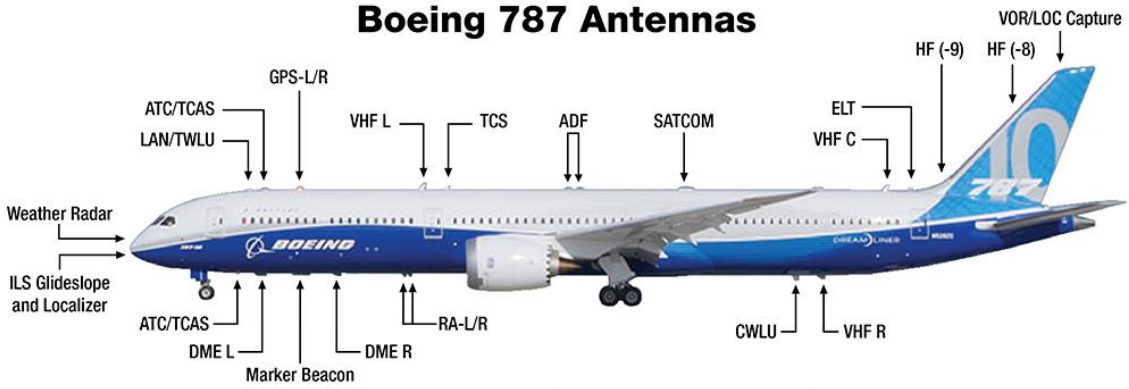
Boeing 787 Antennas



- **LAN/TWLU** Terminal wireless local area network (LAN) unit
- **ATC/TCAS** Air traffic control/traffic collision and avoidance system
- **DME** Distance measuring equipment
- **RA** Radio altimeter
- **GPS** Global positioning system
- **TCS** Terminal cellular system
- **ADF** Automatic direction finder
- **CWLU** Crew wireless LAN unit
- **ELT** Emergency locator transmitter
- **HF** High-frequency radio
- **VOR** VHF omni-directional ranging

Source: Boeing

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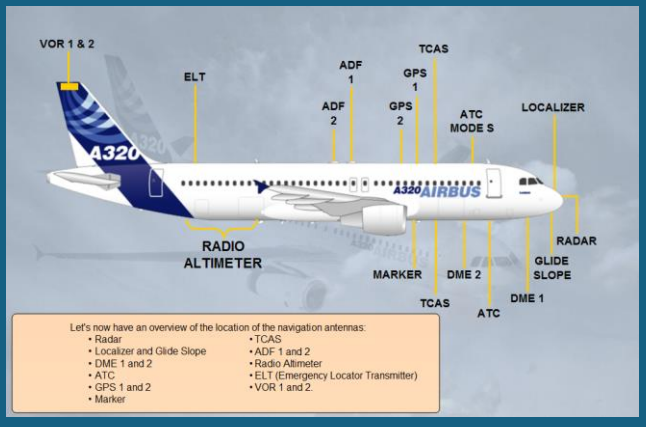

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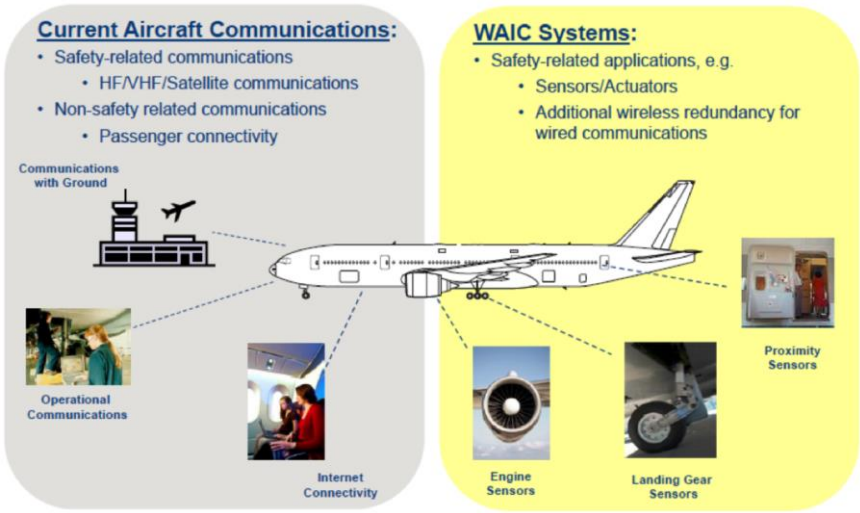
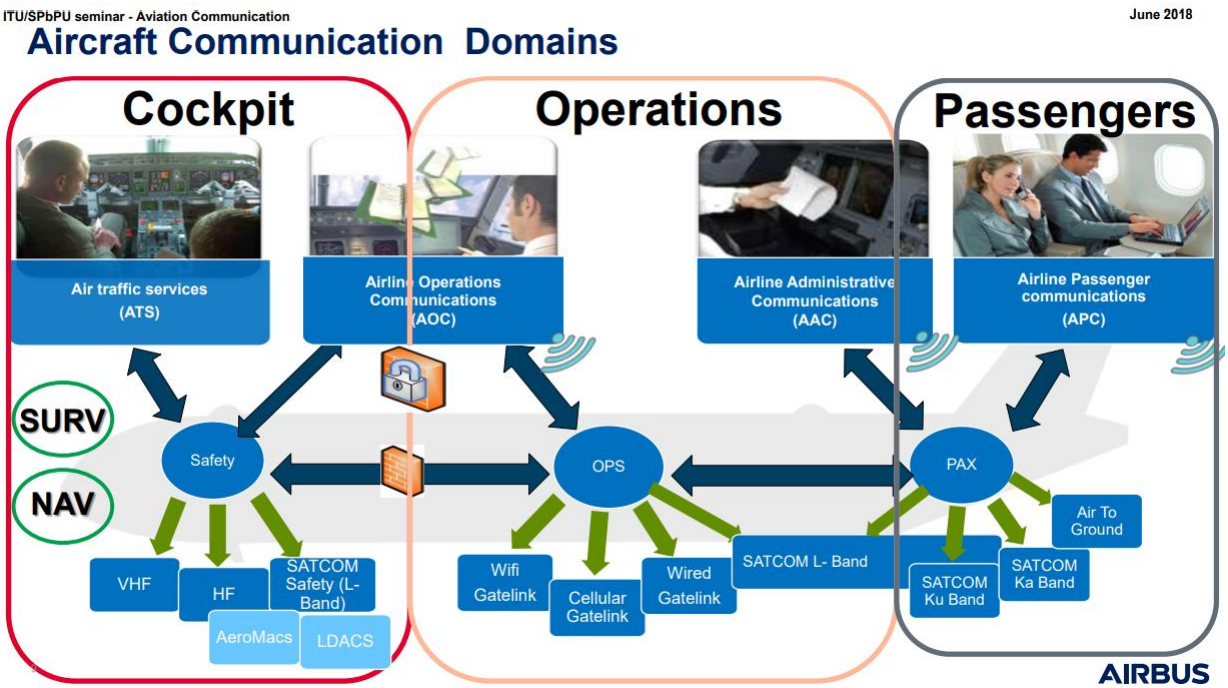


https://interactive.aviationtoday.com/avionicsmagazine/june-july-2017/development-of-wireless-avionics-intra-communications/

17



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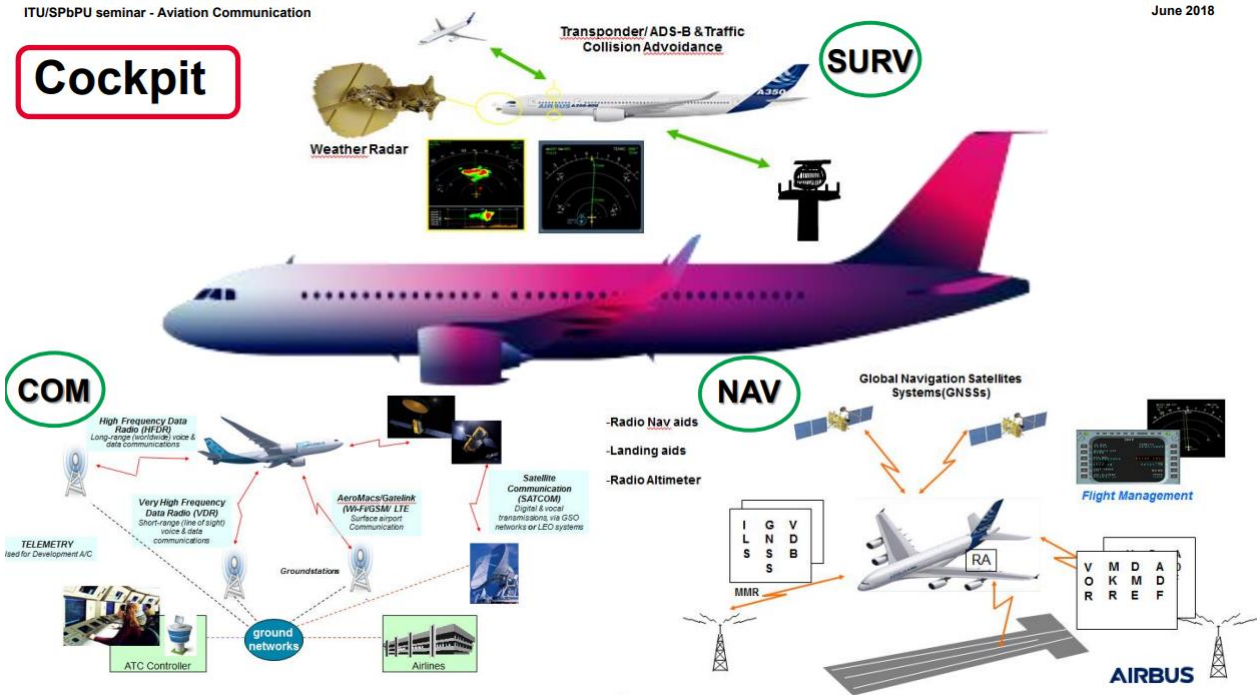

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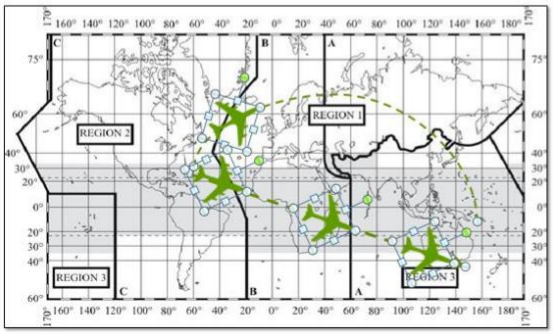
Recent evolutions within Aeronautical sector:

Cockpit

- WAIC - Wireless Avionics Intra Communications
- Space based ADS-B
- GADSS - Global Aeronautical Distress Safety System

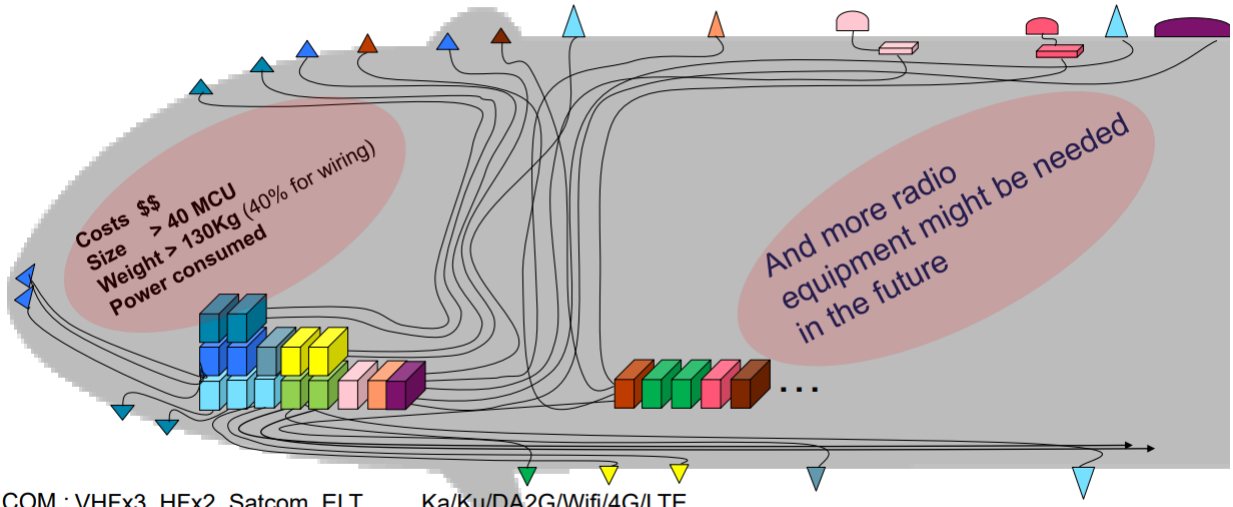
>>>> Efficient use of current aeronautical spectrum



20

Installation and Rationalization

Aircraft carry many radio equipment and antennas



COM : VHFx3, HFx2, Satcom, ELT Ka/Ku/DA2G/Wifi/4G/LTE
NAV : ILS(LOC & Glide)x2, VOR/Marker, DMEx2, GNSSx2, ADFx2
SURV: TCASx2, XPDR/MODE S/ADS-Bx2, WXR

Aeromacs, IRIS, LDACS
5G, IoT, new Wifi…

AIRBUS

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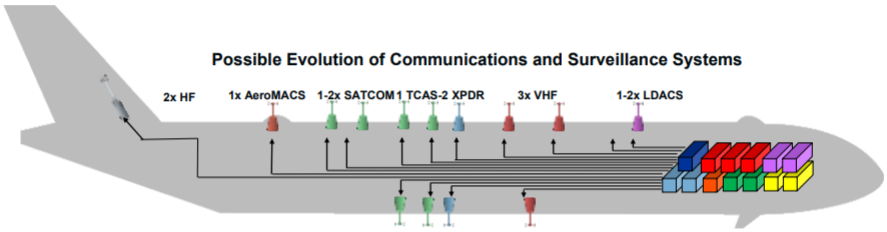
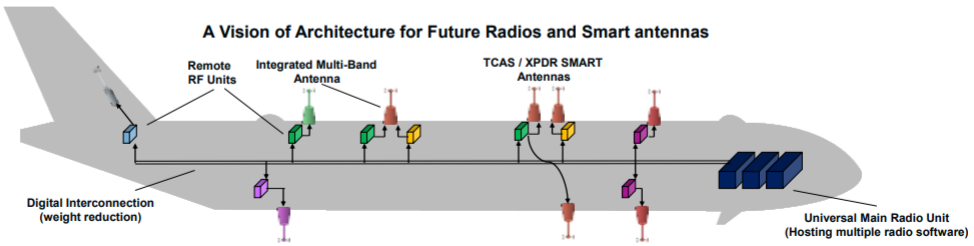
Installation and Rationalization

Vision of a future globally distributed radio architecture for CNS





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AIRBUS

22

How “Aviation Communications” will evolve

- **Aviation demands**
  - –Traffic growth
  - –New functions for Cockpit , Operations and Passengers
  - –Additional airspace users (Drones, HAPS, Space planes, Orbital planes ...)

- **New technologies on the horizon**
  - –Next Generation Radio Architecture (SDR, Antenna Beam forming..)
  - –5G with dual, satellite and terrestrial components
  - –Internet of Things
  - –Massive LEO satellite constellations
  - –Q/V Bands for Satellite use

AIRBUS

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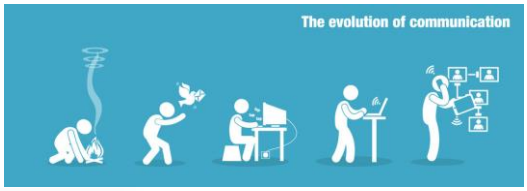
Transmission



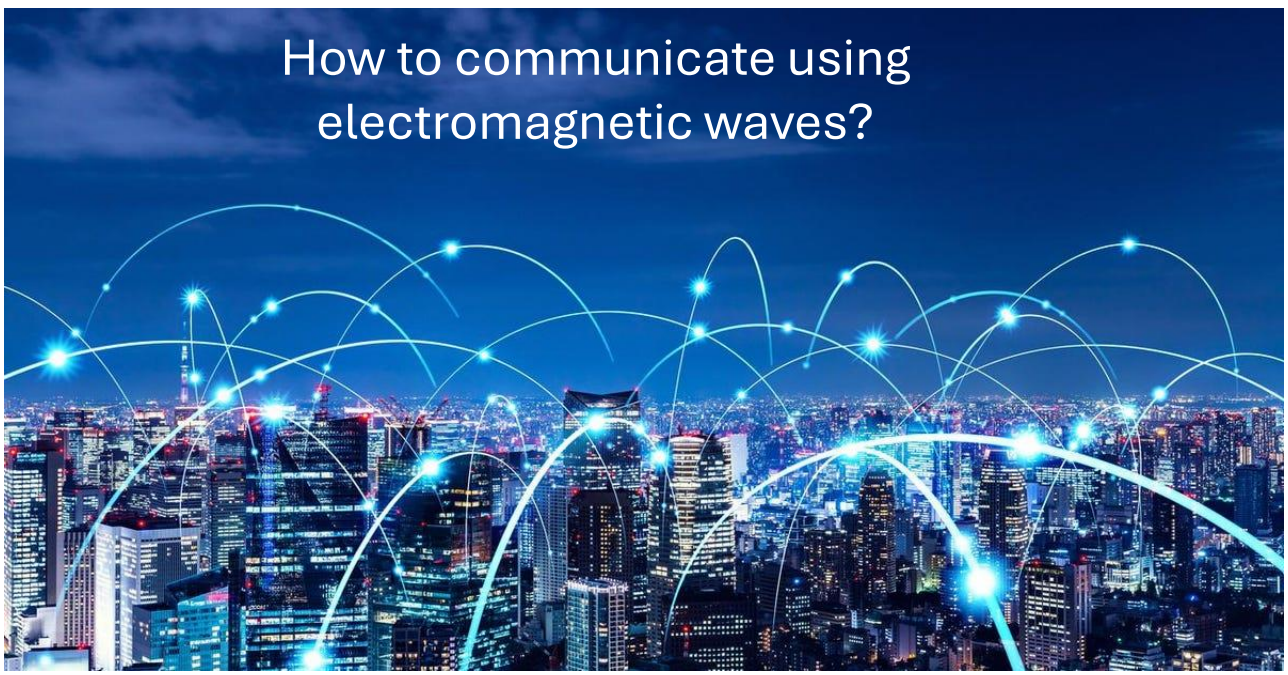
Pre historical smoke signals burning wood

Carrier pigeons corn

15th century Discovery era wind and food

25

25



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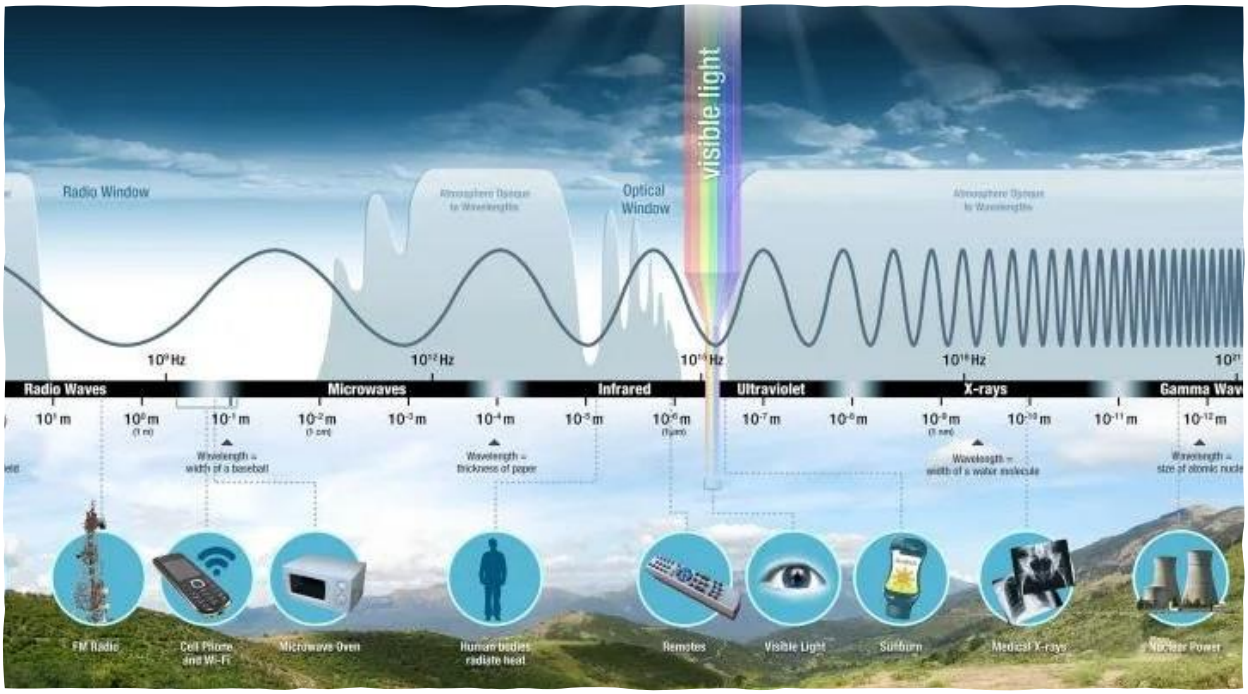

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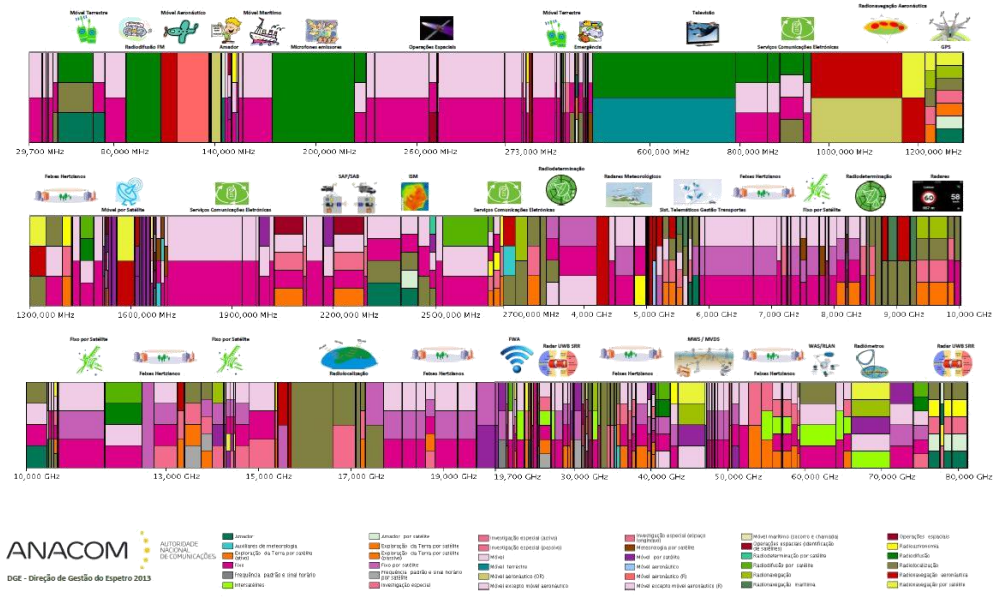

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DGE - Direção de Gestão do Espetro 2013

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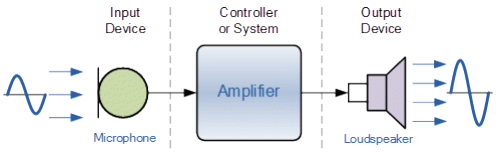
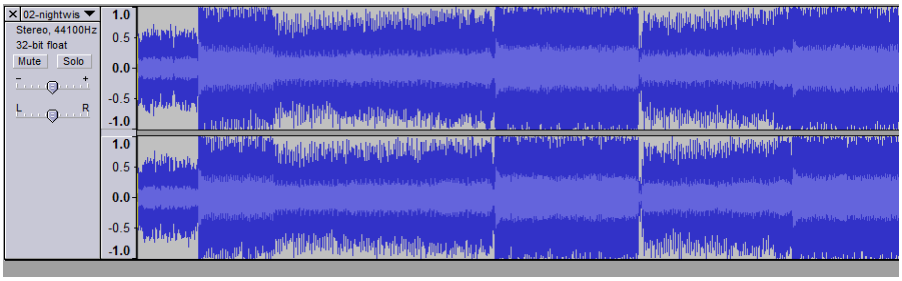
Signals

Signals represent some form of information, for instance analog signals can represent sound .



https://wavesurfer-js.org/



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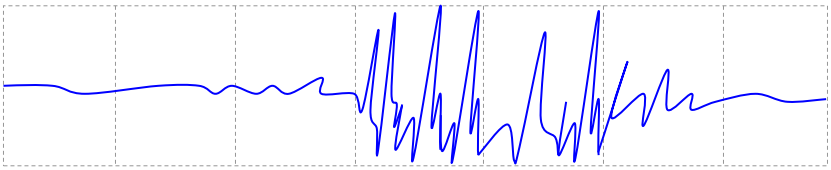
Signal

- The Speech Signal



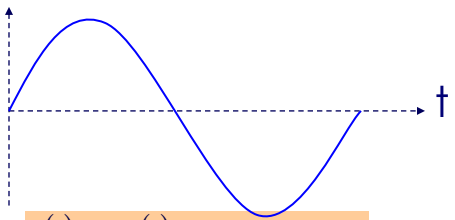
- The ECG Signal

30

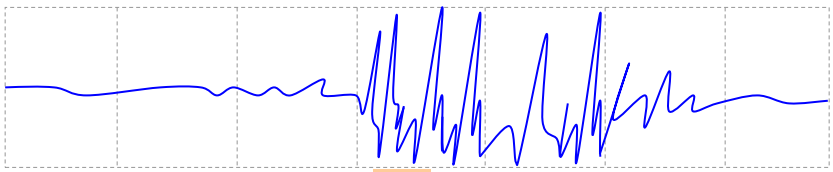
30

Mathematical Representation

- We can represent a signal as a function of one or more independent variables
- Examples



$$v(t) = \sin(t) \qquad 0 \le t \le 2\pi$$



$$s(t)$$

31

How to transmit?

- **Jean Baptiste Joseph Fourier (1768-1830)**
- French mathematician and physicist

- Idea:
- ***"any" periodic function can be decomposed into an (infinite) sum of sines and cosines***
-
- Fourier applied it to problems of heat flow.

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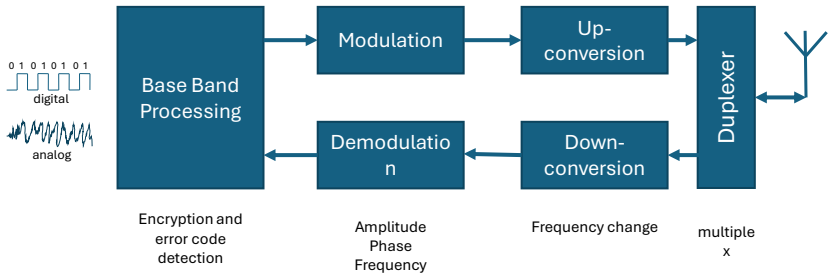
Fundamental Concepts

The correct design of the radio system entails a previous study of the power levels involved in the entire Transmit/Receive chain.



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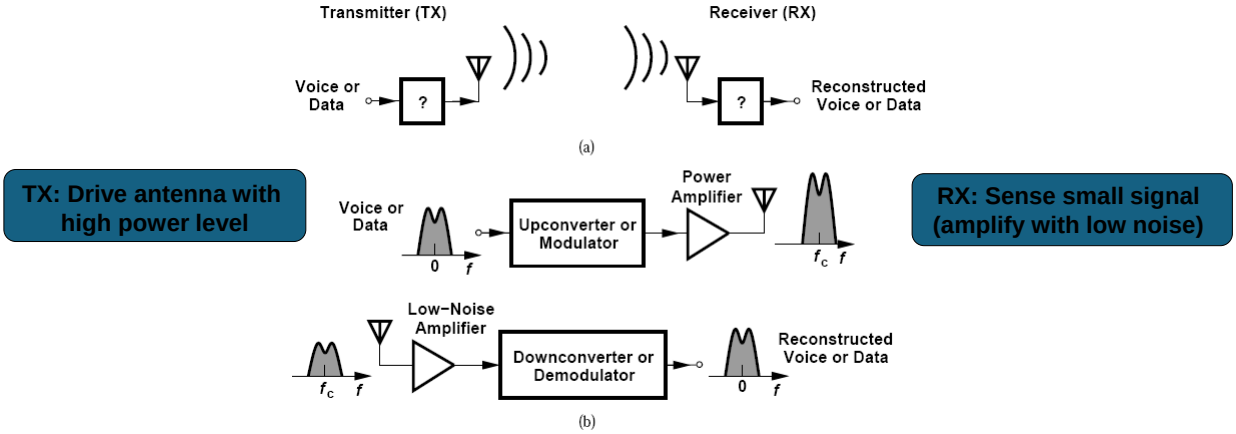
RF Communication – Concept I



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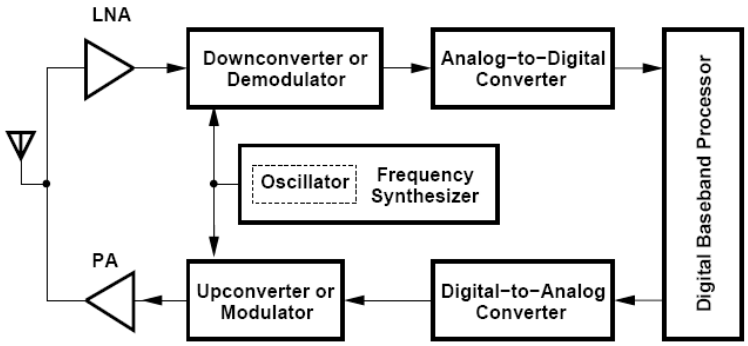
RF Communication – Concept II



- **Signals are upconverted/downconverted at TX/RX, by an oscillator controlled by a Frequency Synthesizer**
- **Up/down conversion may be direct or have one / several stages**

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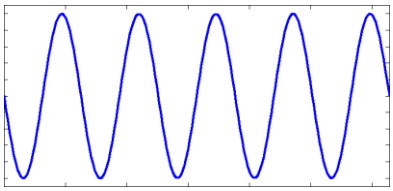
RF Concept III

- RF Communications use carriers to transport the information signal

White sheet of paper: carrier for written information



sinewave: carrier to transport Information converted to electrical signals

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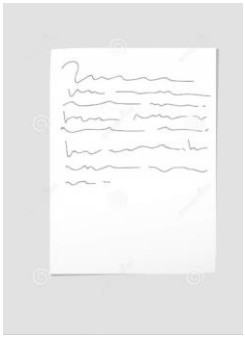
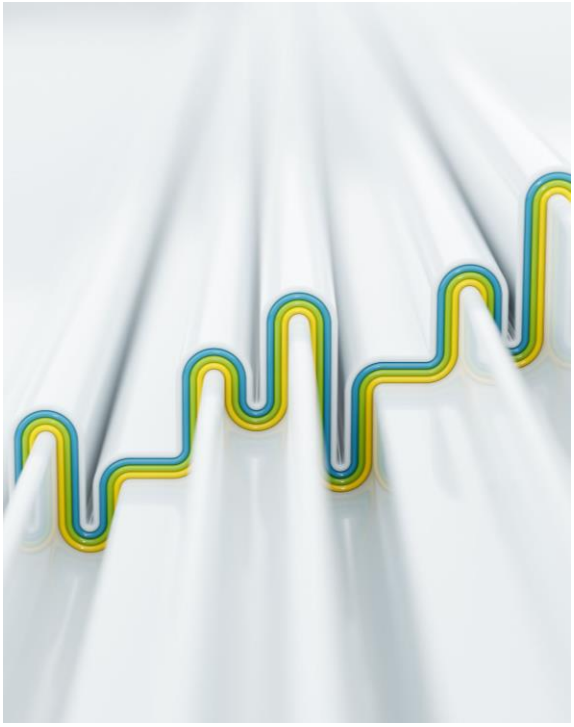
RF Concept III



Modification of the sheet color in some points ➔ allows you to transmit information

Modification of one characteristic of the sinewave (amplitude in this case) ➔ allows you to transmit information

37



RF concept IV

- The key aspect of RF is that it uses a sinusoidal carrier
  - Signals are translated to the carrier frequency ➔ bandpass signals
    - While in baseband the Information carrying signal is sent directly to the channel (cable, fiber, …)

Need to consolidate some aspects of bandpass signals

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Preliminaries- Baseband Transmission I

Baseband transmission

- **transmitted signal is** (linear modulation)

$$s_{LP}(t) = \sqrt{E_s}.\sum_k a_k.p(t-kT_s)$$

Linear combination of Information symbols ➔ linear modulation

- **transmitted signals have to be real**,

a_k and $p(t)$ are reals

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Modulation

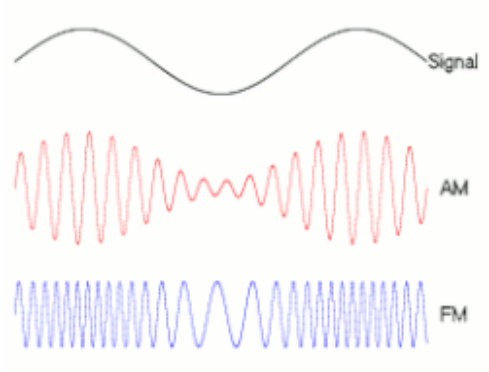

Table 4
Comparison of modulation formats 100G and beyond:
OSNR penalties related to same bitrates (PM-BPSK serves as reference).

Modulation format	PM-BPSK	PM-QPSK	PM-8QAM	PM-16QAM	PM-32QAM	PM-64QAM
bits/Symbol	2x1	2x2	2x3	2x4	2x5	2x6
Constellation						
OSNR penalty (dB)	0	0	2	4	6	8.5

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Frequency Domain Representation

Nevertheless if we want to use a computer to treat the information, for instance a 8 bit computer, then the signal must be converted into bits.....

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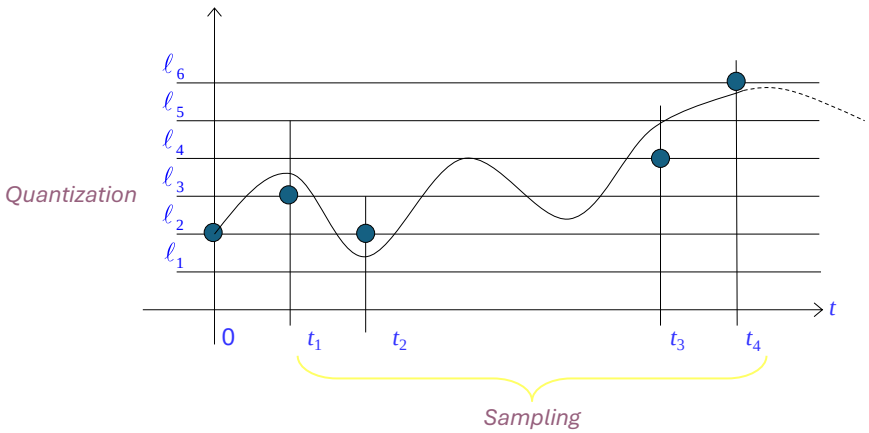
Frequency Domain Representation

This can be achieved by using sampling and quantization .....



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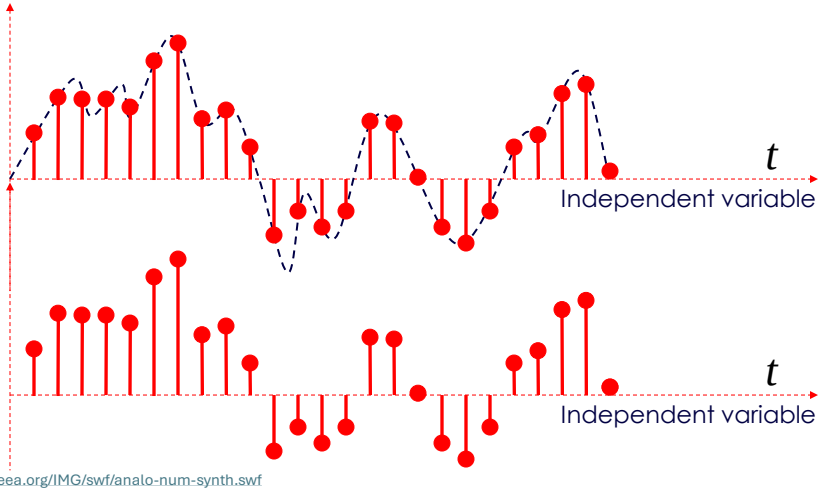
Sampling

The value of signal exists only at equally spaced discrete points in time



http://www.geea.org/IMG/swf/analo-num-synth.swf

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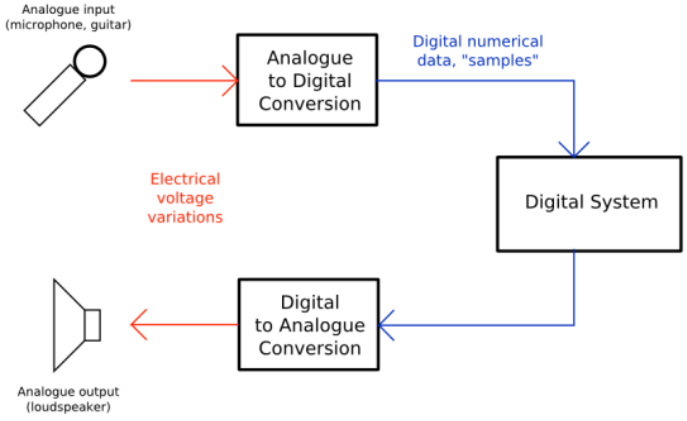
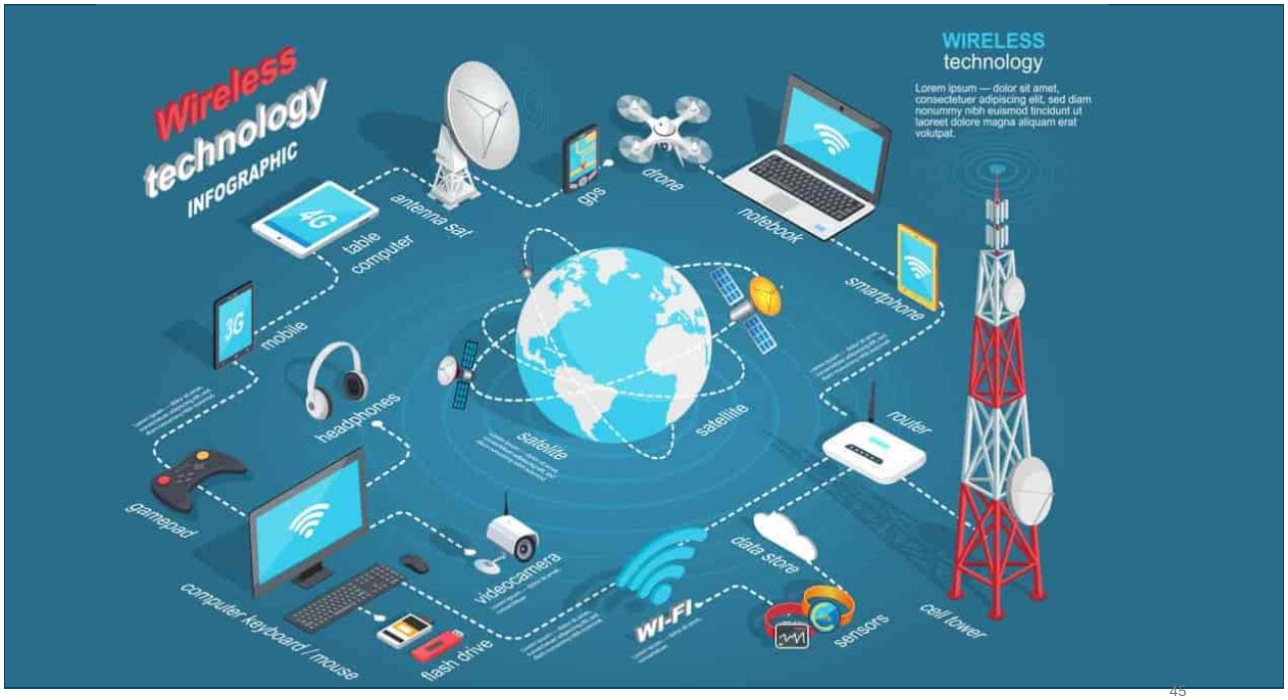
Analog to Digital Converter

ADC's





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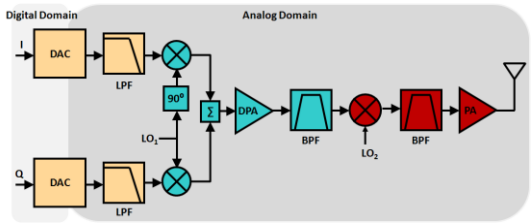
Transmitter

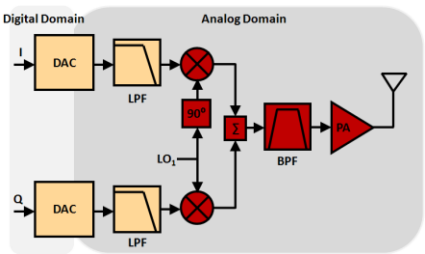


Super-Heterodyne Transmitter

- Digital baseband signals are converted and directly modulated to RF
- Reduced amount of circuitry that allows high level integration
- Carrier leakage, phase gain mismatch, and requires highly linear PA
- With careful design can be employed in SDR TX's

- Signal created in digital domain, modulated at IF, and up-converted
- I/Q modulator working at IF; Output spectrum is far away from LO
- Suffers from similar problems of the receiver case
- Multi-mode implementation is difficult

Direct-Conversion Transmitter



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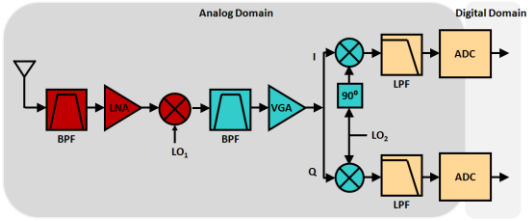
Receiver

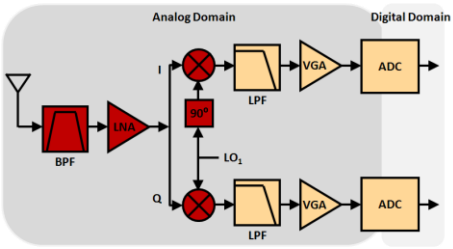


- Conversion to the digital domain at baseband where it can be processed
- Currently adopted in most radio receivers due to low cost components
- Full on-chip integration is concerned and its design to a specific channel
  → prevents the expansion of receiving band

Super-heterodyne

- Signal is selected at RF by BPF, amplified and directly translated to DC
- Evident reduction in number of components → high level integration
- Components much more difficult to design
  DC offset, 2nd order IMD products generated around DC

Zero-IF



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UHF Electromagnetic Propagation

- Electromagnetic wave propagation is used for data transmission (and powering transponders in the case of passive tags)
- The reader transmits an electromagnetic (EM) wave which propagates outward
- The amount of energy available is decreasing (1/d^2) as the distance from the reader increases

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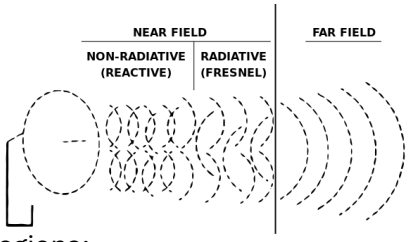
Antenna Basics - Field Regions



The space around an antenna is usually divided into three regions:

- Reactive Near Field

  The reactive near-field region is defined as “that region of the field immediately surrounding the antenna wherein the reactive field predominates.” For most antennas, the outer boundary of this region is commonly taken to exist at a distance $R < 0{,}62\sqrt{D^3/\lambda}$ from the antenna, where λ is the wavelength and D is the largest dimension of the antenna.
- Radiating Near Field (Fresnel)

  The radiating near-field (Fresnel) region is defined as “that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna.” The radial distance R over which this region exists is $0{,}62\sqrt{D^3/\lambda} < R < 2D^2/\lambda$ (provided D is large compared to the wavelength).
- Far-field (Fraunhofer)

  The far-field (Fraunhofer) region is defined as "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna." In this region, the real part of the power density is dominant. The radial distance R over which this region exists is $R \geq 2D^2/\lambda$ (provided D is large compared to the wavelength).

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From balanis

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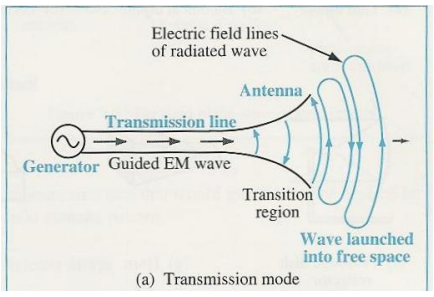
UHF Electromagnetic Propagation

The same analogy can be used in electronic devices :



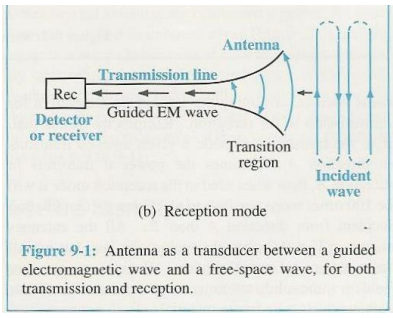


Figure 9-1: Antenna as a transducer between a guided electromagnetic wave and a free-space wave, for both transmission and reception.

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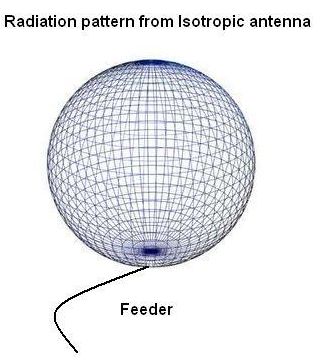
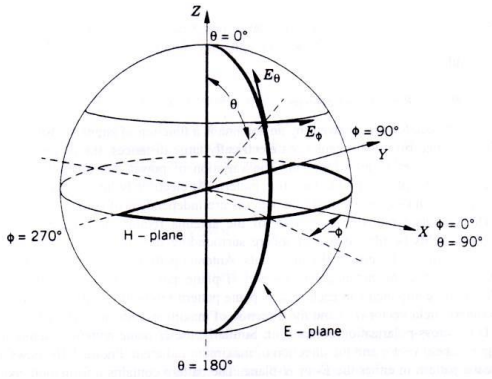
UHF Electromagnetic Propagation

Transmitted power is related to the distance from the source …





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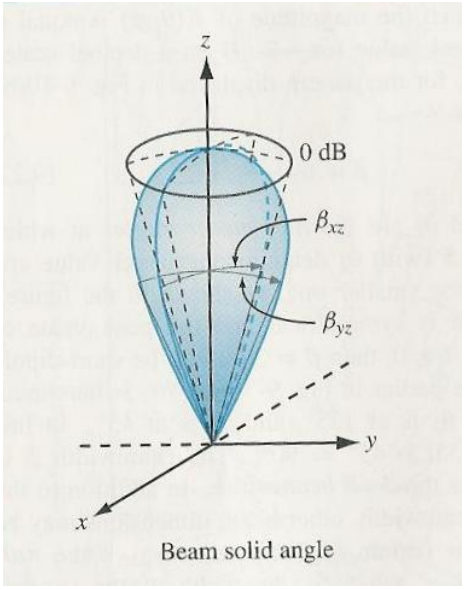
UHF Electromagnetic Propagation

Antennas can have a certain direction of propagation …



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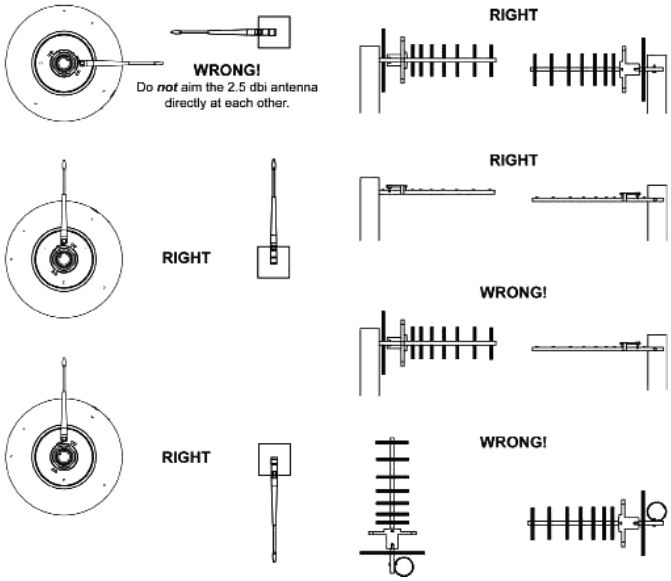
UHF Electromagnetic Propagation

Antennas can also use different polarization for each wave, and thus maximize the transmission of information …



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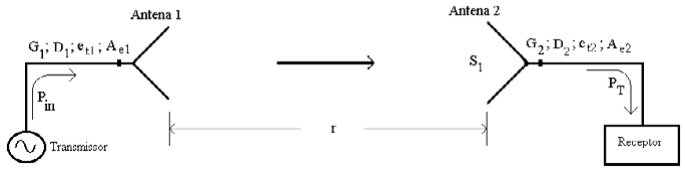
UHF Electromagnetic Propagation

http://www.cdt21.com/resources/siryo3_01.asp

The received power can be related to the transmitted power by using the Friis formula that states:



$$P_R = A_{e2}\frac{P_{in}}{4\pi r^2}G_1 = \frac{\lambda^2}{4\pi}G_2\frac{P_{in}}{4\pi r^2}G_1 \Leftrightarrow P_R = P_{in}\left(\frac{\lambda}{4\pi r}\right)^2 G_t G_r$$

where $\left(\frac{\lambda}{4\pi r}\right)^2$ is the free space attenuation, and l the wavelength

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