TSEK02: Radio Electronics Lecture 6: Propagation and Noise

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LINKÖPING UNIVERSITY

Propagation and Noise
- Channel and antenna: not in the Razavi book
- Noise: 2.3

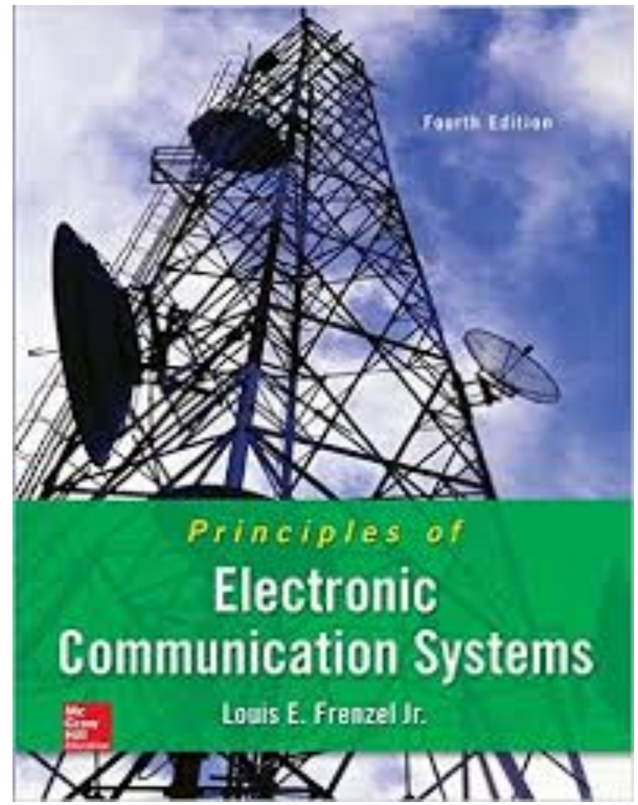
- The wireless channel
- The antenna
- Signal quality
- Noise

Propagation and Noise

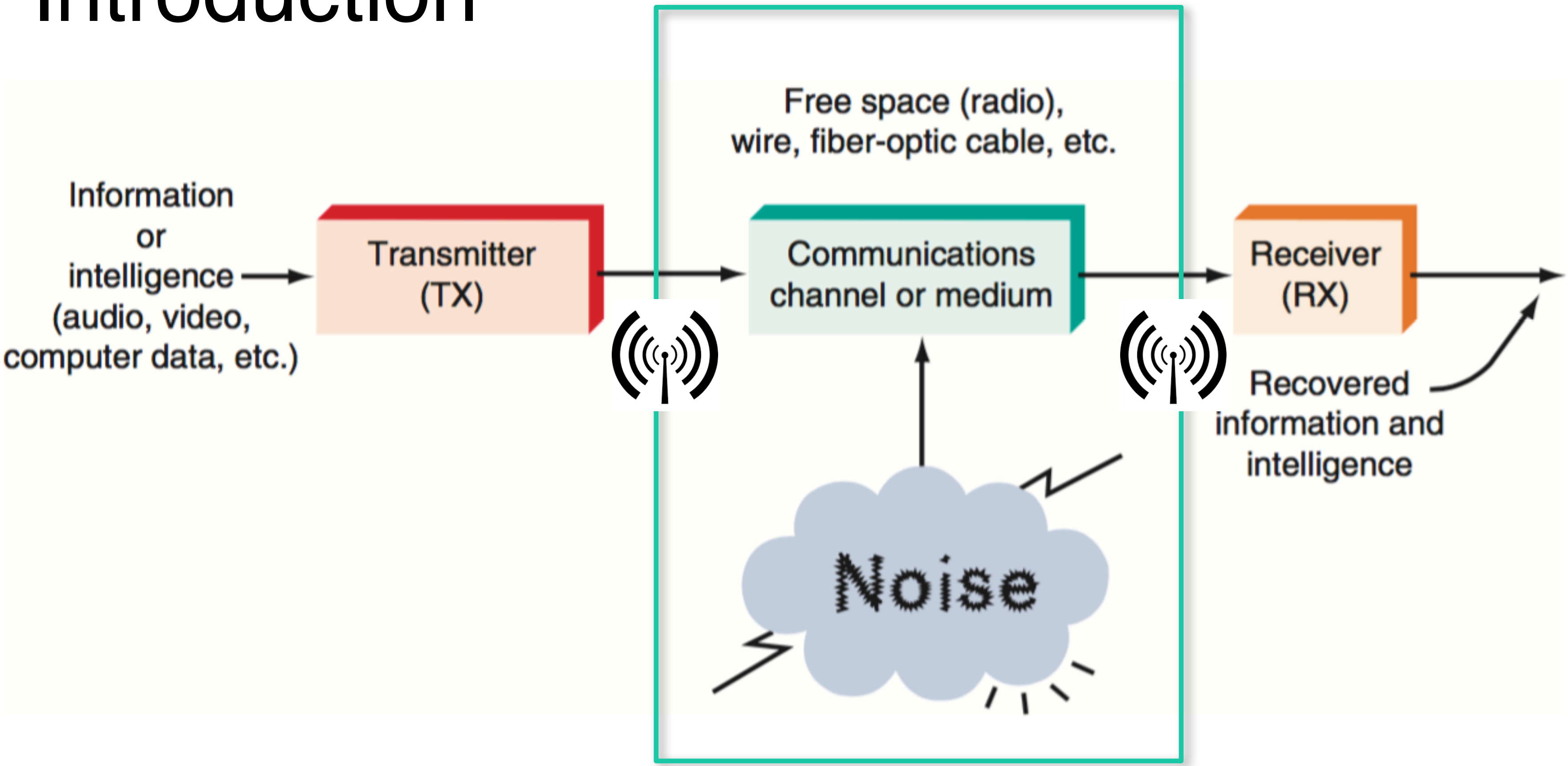
- **The wireless channel**
- The antenna
- Signal quality
- Noise

- Propagation, channel and antenna:

  One of many sources: Frenzel, Principles of Electronic Communication Systems, chapter 14.



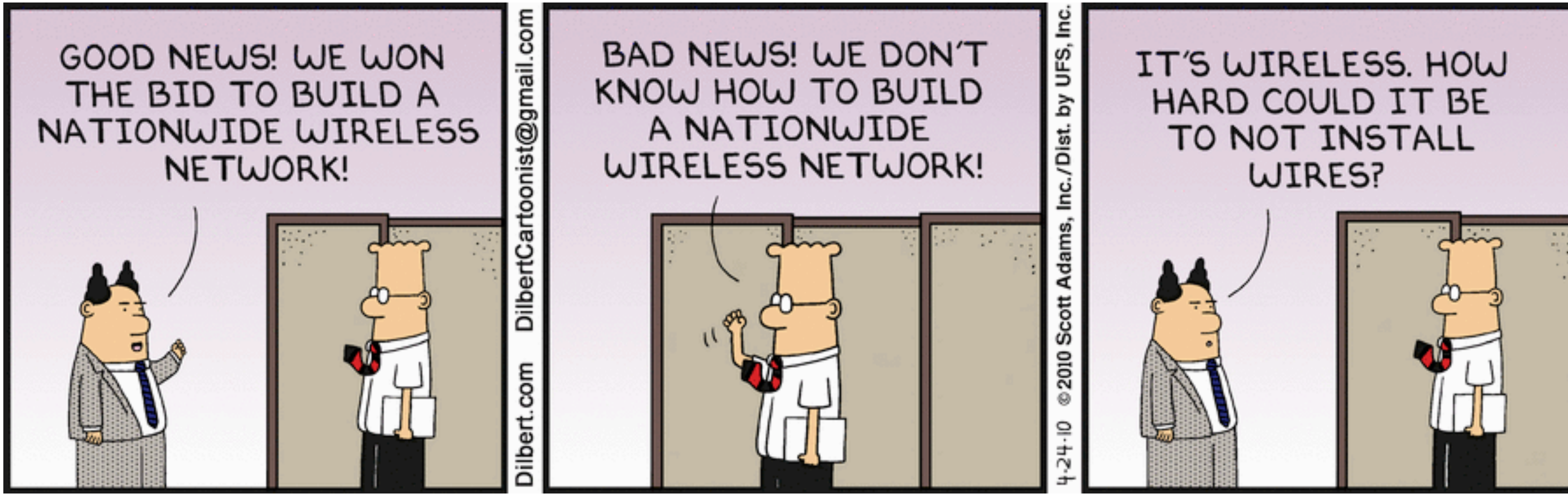
Introduction



The channel

The Channel

- In a communication system, the channel may be
  - A transmission line connecting two physical points
    - A trace on a printed circuit (e.g. CPU to HDD communication)
    - Pair of twisted wires (e.g. telephone lines, indoor Ethernet)
    - A coaxial cable (e.g. DSL lines combining TV, telephone, and data)
    - A fiber optical cable (e.g. backhaul network)
    - A waveguide (e.g. interconnection of a mm-Wave system)
  - A wireless media
    - Air (free space): radio, light (electromagnetic waves), sound
  - A time span
    - The time difference between write and read instances in HDD



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Heinrich Hertz

From Wikipedia, the free encyclopedia

Heinrich Rudolf Hertz (German: [hɛʁts]; 22 February 1857 – 1 January 1894) was a German physicist who first conclusively proved the existence of electromagnetic waves theorized by James Clerk Maxwell's electromagnetic theory of light. Hertz proved the theory by engineering instruments to transmit and receive radio pulses using experimental procedures that ruled out all other known wireless phenomena. The unit of frequency – cycle per second – was named the "hertz" in his honor.[1]

Contents [hide]

Biography [edit]

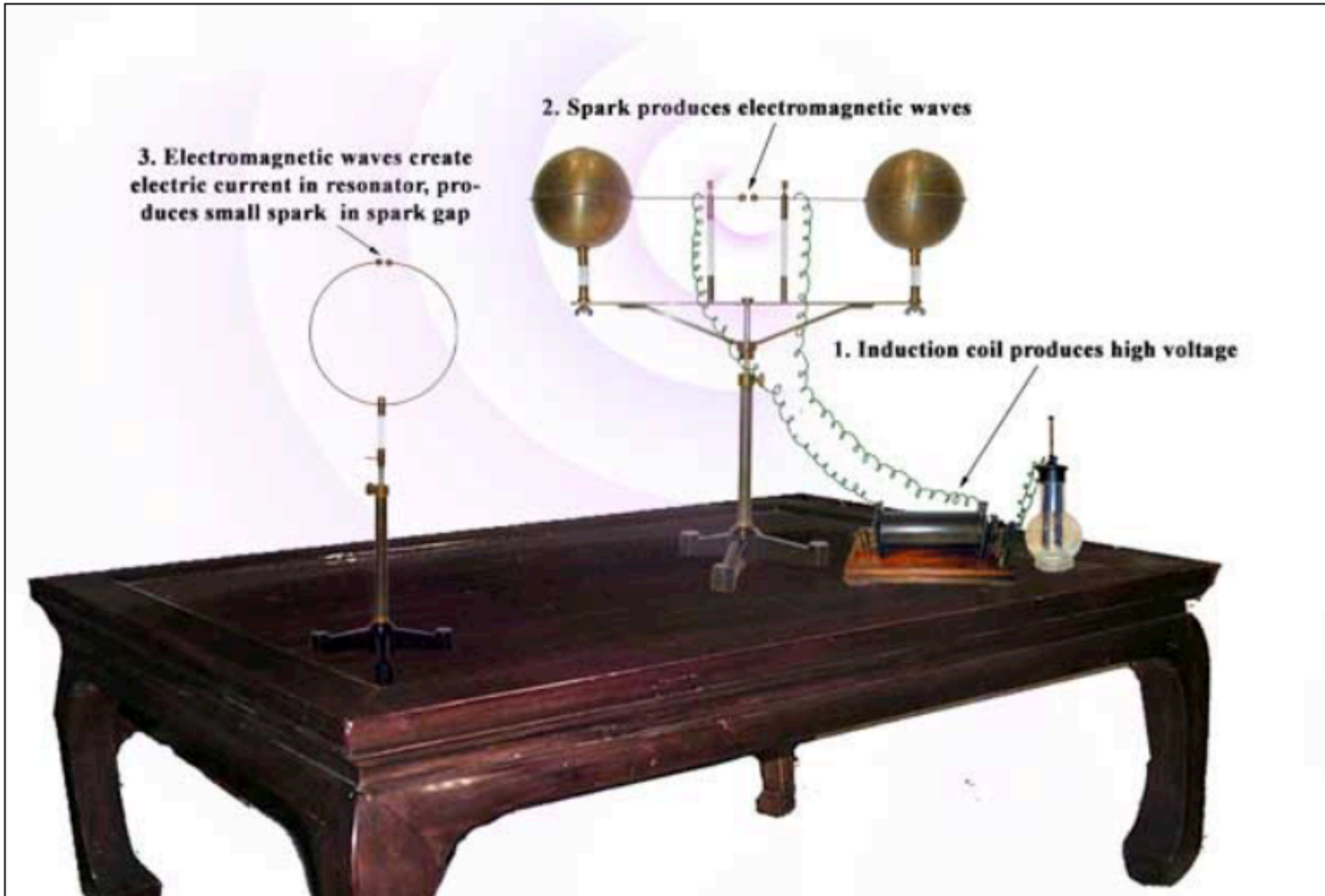
Heinrich Rudolf Hertz was born in 1857 in Hamburg, then a sovereign state of the German Confederation, into a prosperous and cultured Hanseatic family. His father Gustav Ferdinand Hertz (originally named David Gustav Hertz) (1827–1914) was a barrister and later a senator.[2] His mother was Anna Elisabeth Pfefferkorn.

Heinrich Hertz

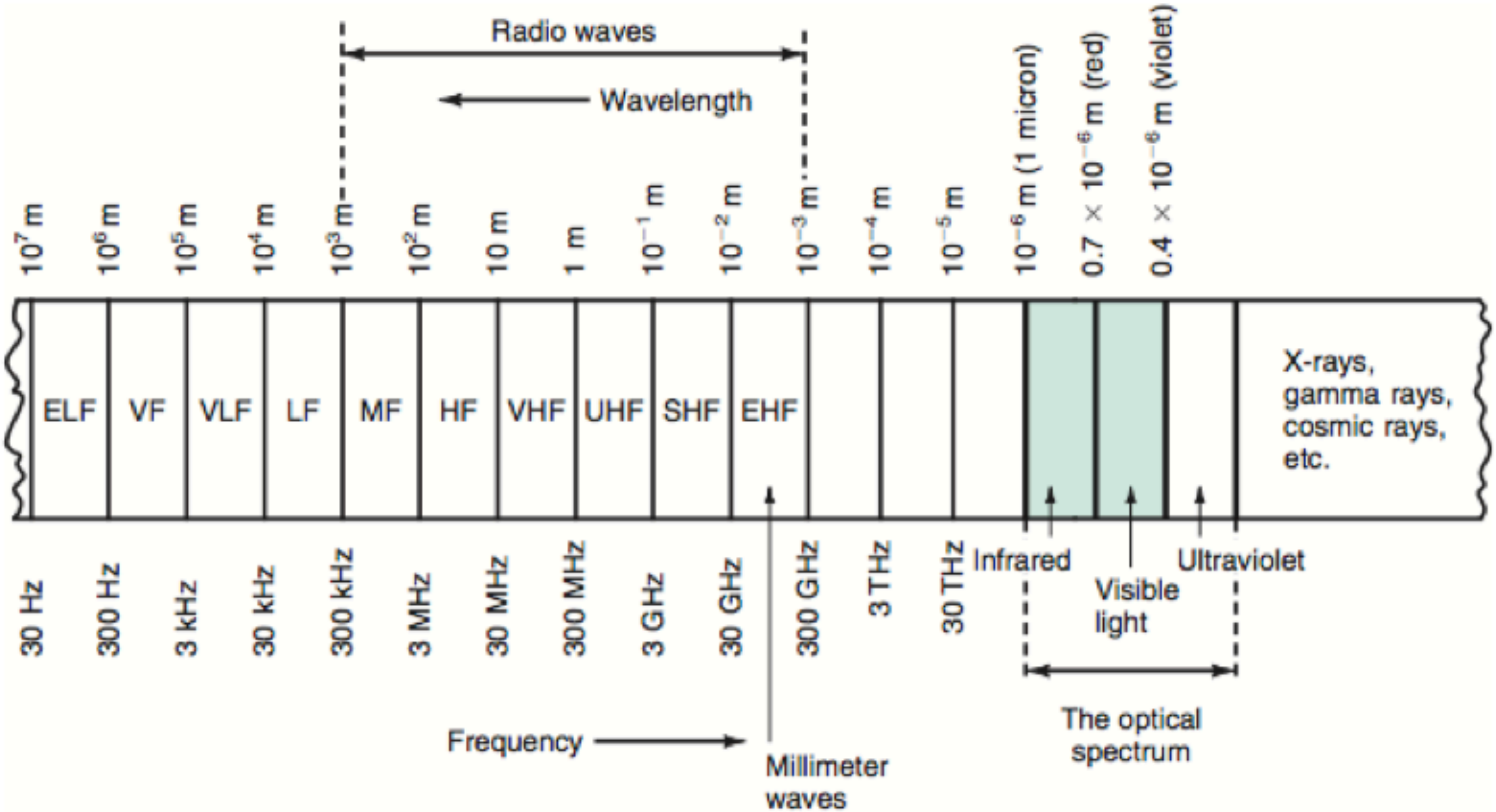
Born	Heinrich Rudolf Hertz 22 February 1857 Hamburg, German Confederation
Died	1 January 1894 (aged 36) Bonn, German Empire
Residence	Germany
Nationality	German
Fields	Physics Electronic Engineering
Institutions	University of Kiel University of Karlsruhe University of Bonn

- In 1887 German physicist Heinrich Hertz was the first to demonstrate the effect of electromagnetic radiation through space. The distance of transmission was only a few feet, but this transmission proved that radio waves could travel from one place to another without the need for any connecting wires. Hertz also proved that radio waves, although invisible, travel at the same velocity as light waves.

Hertz's Experiment:



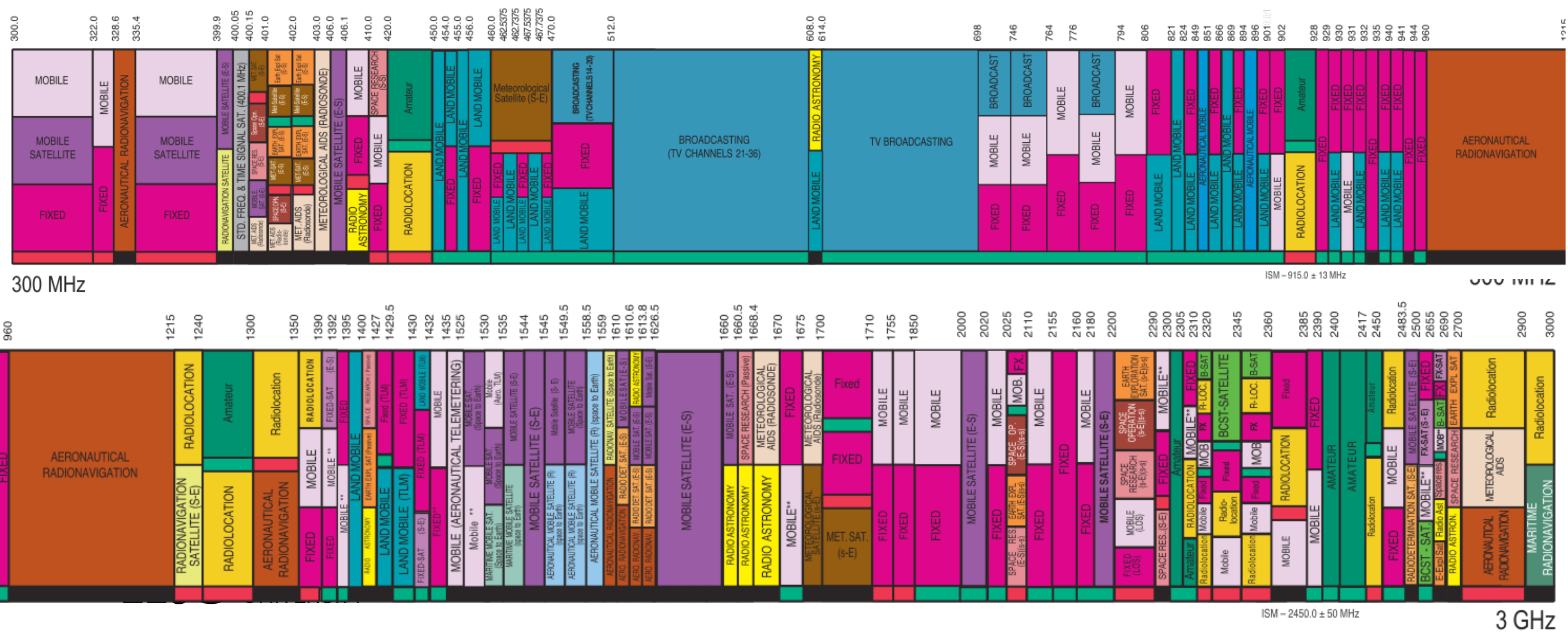
The electromagnetic spectrum



The electromagnetic spectrum used in electronic communication

Name	Frequency	Wavelength
Extremely low frequencies (ELFs)	30–300 Hz	10^7-10^6 m
Voice frequencies (VFs)	300–3000 Hz	10^6-10^5 m
Very low frequencies (VLFs)	3–30 kHz	10^5-10^4 m
Low frequencies (LFs)	30–300 kHz	10^4-10^3 m
Medium frequencies (MFs)	300 kHz–3 MHz	10^3-10^2 m
High frequencies (HFs)	3–30 MHz	10^2-10^1 m
Very high frequencies (VHFs)	30–300 MHz	10^1-1 m
Ultra high frequencies (UHFs)	300 MHz–3 GHz	$1-10^{-1}$ m
Super high frequencies (SHFs)	3–30 GHz	$10^{-1}-10^{-2}$ m
Extremely high frequencies (EHFs)	30–300 GHz	$10^{-2}-10^{-3}$ m
Infrared	—	0.7–10 μm
The visible spectrum (light)	—	0.4–0.8 μm

US frequency allocation, 0.3 - 3 GHz

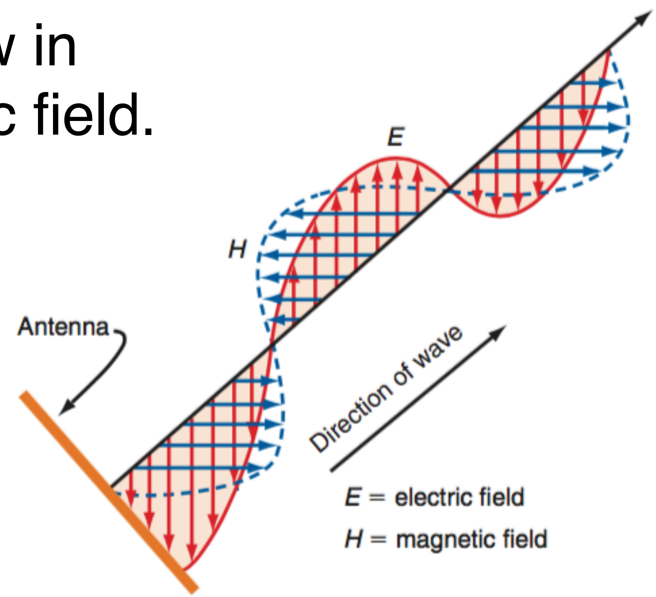


Propagation and Noise

- The wireless channel
- **The antenna**
- Signal quality
- Noise

Antenna fundamentals

- A radio signal is called an electromagnetic wave because it is made up of both electric and magnetic fields.
  - Apply voltage to an antenna: an electric field is set up.
  - This voltage causes current to flow in the antenna, producing a magnetic field.
- The fields are emitted from the antenna and propagate through space over very long distances at the speed of light.

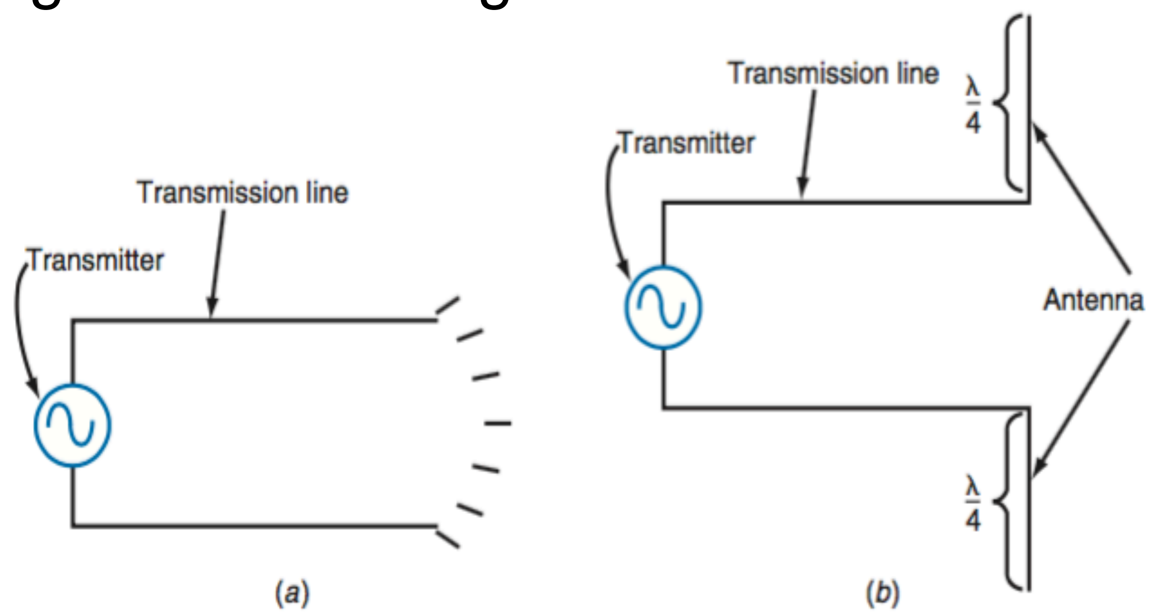


Antenna fundamentals

(a) An open transmission line radiates a little.

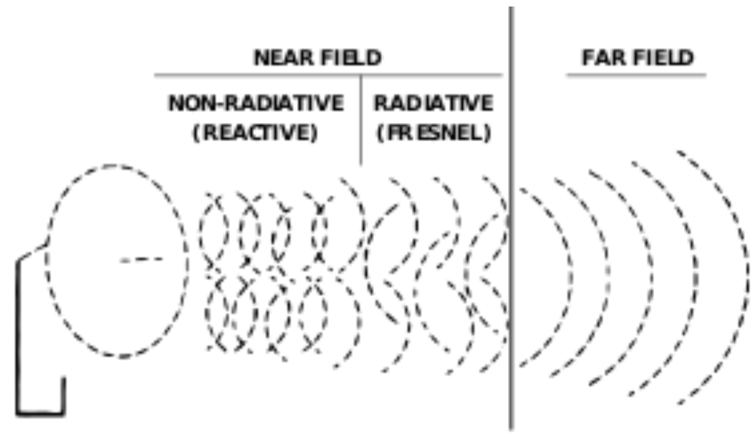
(b) Bending the open transmission line at right angles creates an efficient radiation pattern.

(c) Standing wave to have good transmission.



Near field/far field

- The *near field* and *far field* are regions of the electromagnetic field around an object, such as a transmitting antenna, or the result of radiation scattering off an object.
- The near field describes the region directly around the antenna where the electric and magnetic fields are distinct.
- These fields are not the radio waves, but they do contain any information transmitted, but weaken fast, approximately by the quadruple power of the distance.



[Wikipedia]

Near field/far field

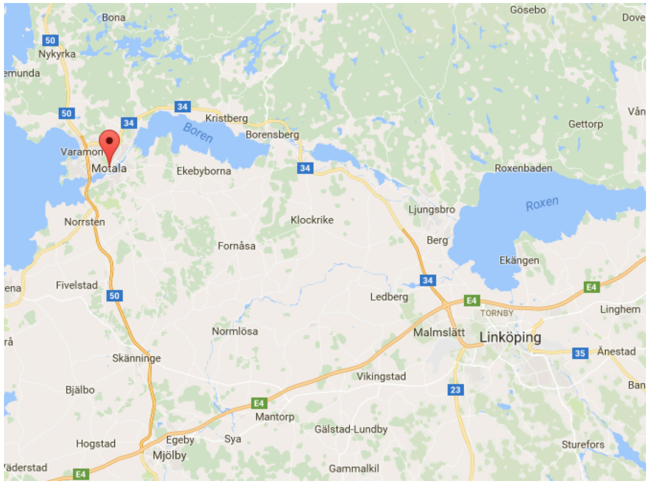
- The far field, approximately **>10 wavelengths** from the antenna, is the radio waves with the composite electric and magnetic fields (2.4 GHz -> ~ 1.2 m). Weakens as square of the distance.

- NFC (Near-field communication) on the 13.56 MHz frequency band facilitates communication through magnetic coupling between devices, ranging from near contact to about a few centimeters.
- Used e.g. for contact-less payments with credit cards, electronic tickets and mobile phones.

"blippa"

Antenna basics

- Antennas radiate most effectively when their length is directly related to the wavelength of the transmitted signal, to create a standing wave.
- $\lambda/2$ and $\lambda/4$ wavelengths are most common.
- Frequencies between 1 MHz and 100 GHz have wavelengths within the range of practical conductors and wires, e.g., a 900-MHz signal has a wavelength of ~30 cm.
- Antennas are reciprocal, i.e. work for transmit and receive in the same way.

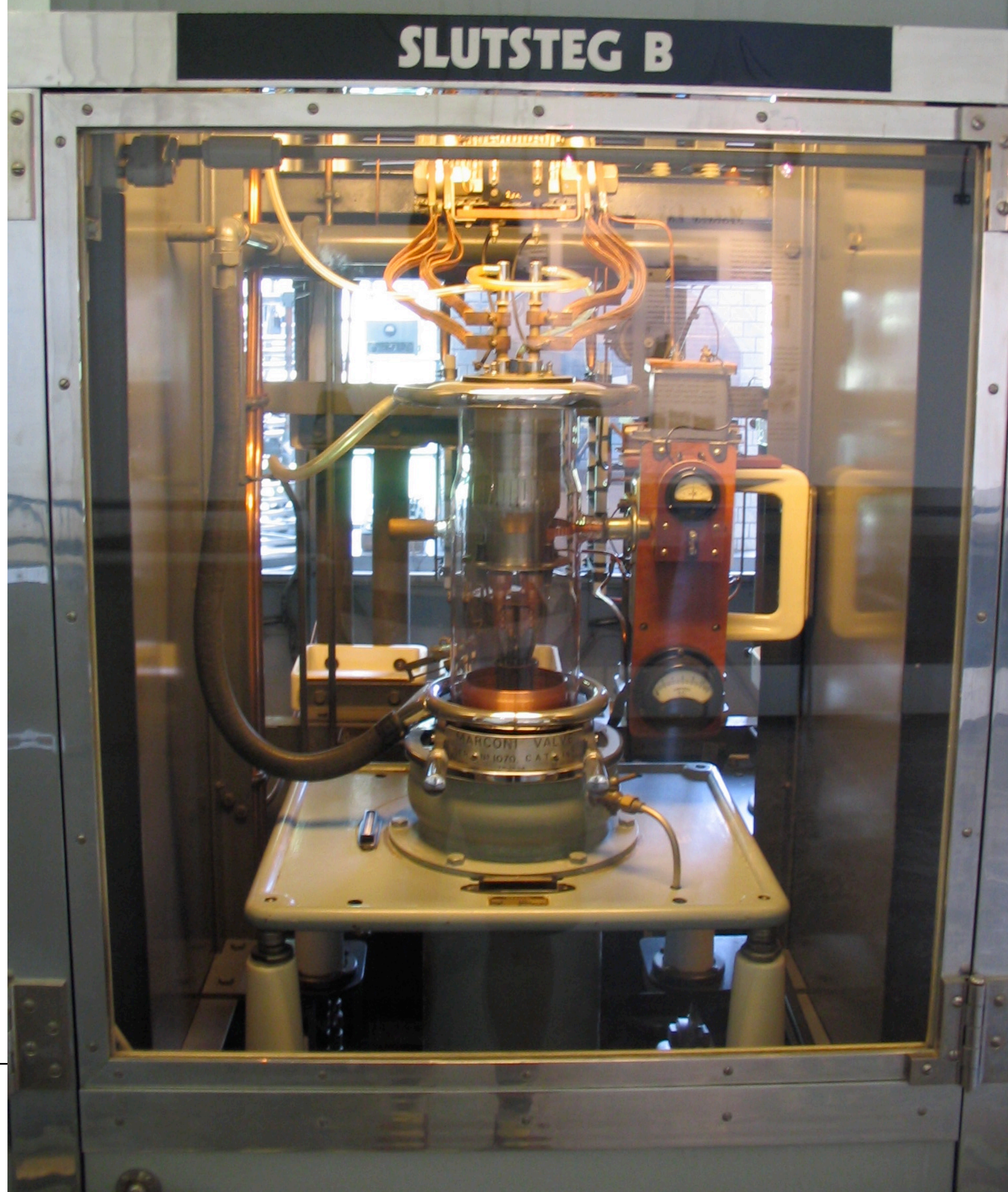


A well-known radio transmitter is the Motala Long-Wave station that was used for broadcasting at 227 kHz during 1927-1962, and is a museum since 1977.

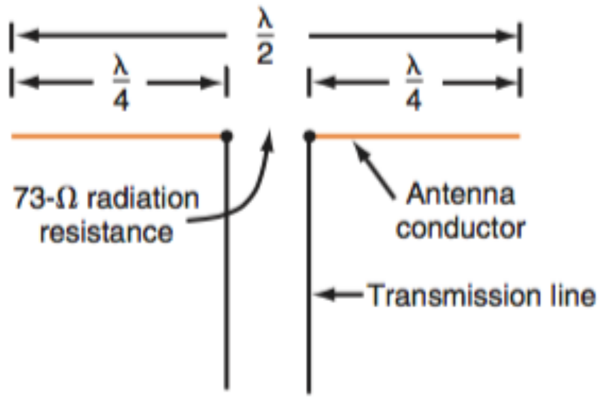
The antenna is 140 m between the two towers, and it transmitted a 150 kW signal.


SLUTSTEG
ANOD: 20 000 Volt 5 Ampère/rör
GLÖD: 30 Volt 400 Ampère/rör
VATTENKYLNING

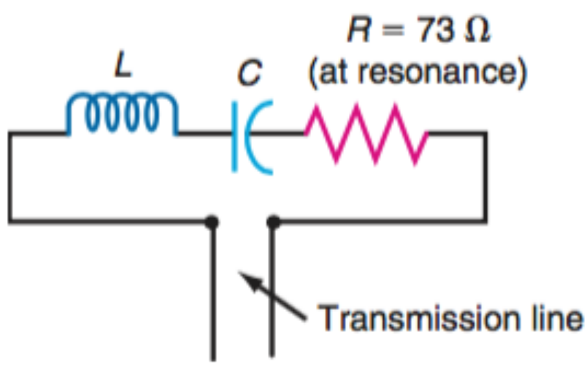

MODULATOR
Blandning av ljud och bärvåg
(216 kilohertz = 216 000 svängningar/sekund)
TILL SLUTSTEG
LJUD från LJUDSTATIVET
BÄRVÅG från STYRSÄNDAREN
MODULATOR HÖGFREKVENS
MANÖVERBORD FÖR KYLSYSTEMET
WATER FLOW


SLUTSTEG B

The dipole antenna (Hertz antenna)

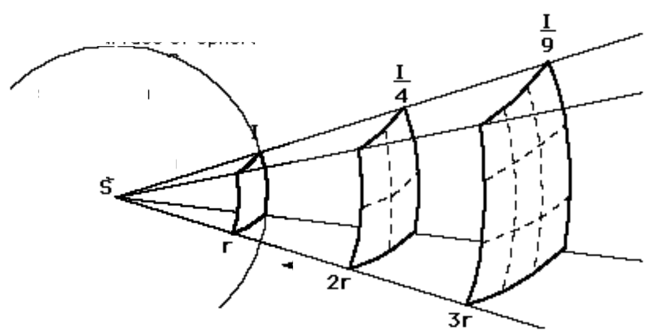


- Equivalent circuit of a dipole



Isotropic Radiation (nondirectional antenna)

- If energy is emitted from a signal point, it will distribute equally in all directions over a hypothetical sphere.
- Power density is defined as the power that the point source emits divided by the area of this sphere:

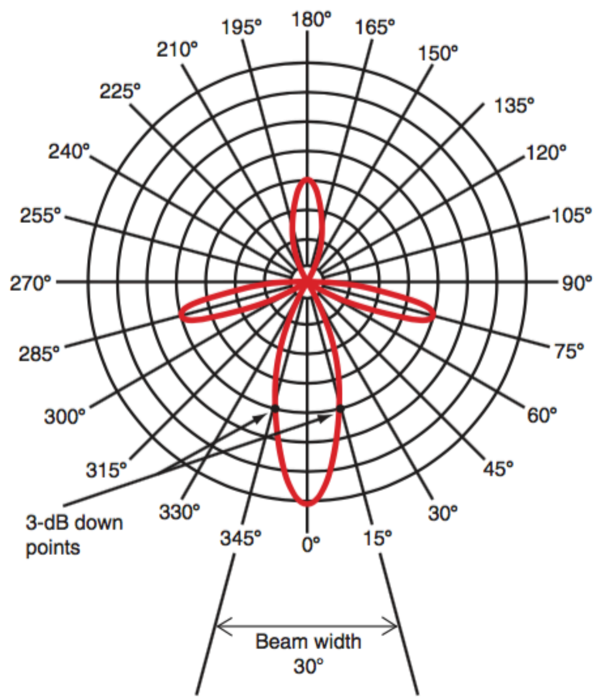


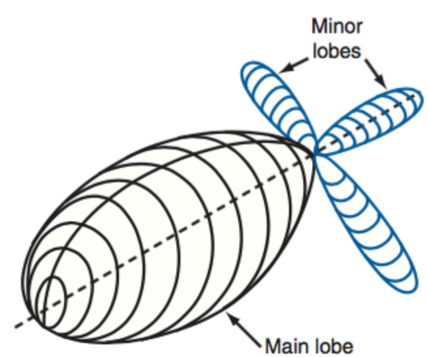
Since area of the sphere with radius r is given by $4\pi r^2$, the power density reduces by r^2.

- Transmitted power density = $$\frac{P_t}{4\pi r^2}$$

Directional antennas

- Most antennas are directional, i.e. radiate or receive energy in a specific direction. Typically the radiation is concentrated in a pattern that has a recognisable geometric shape.





Antenna Gain

- The power gain of an antenna can be expressed as the ratio of the power transmitted P_{trans} to the input power of the antenna P_{in}.

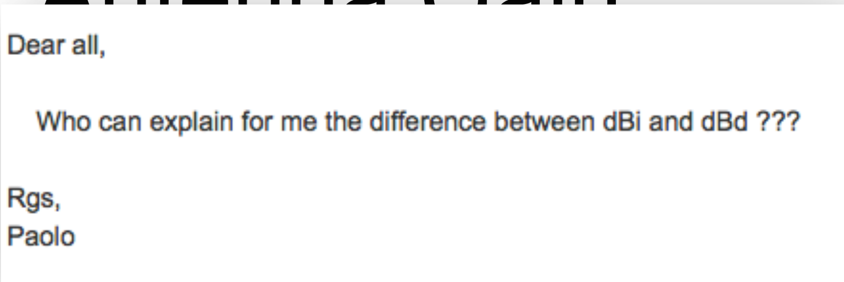
$$\text{dB} = 10 \log \frac{P_{\text{trans}}}{P_{\text{in}}}$$

- Power gains of 10 or more are easily achieved for directional antennas.
- This means that a 100-W transmitter can be made to perform as a 1000-W transmitter when applied to an antenna with gain.

Antenna Gain

- It the transmitter is only aiming to send its signal towards a particular receiver, isotropic radiation may be regarded as loss of power.
- Directivity is a measure of how focused an antenna can transmit and receive power.
- Antenna gain is related to the directivity as the <u>effective radiated power</u> relative the input power:
  - antenna gain [dB] = 10 log (Pout/Pin) for the antenna
- A dipole is often used as a reference: gain=1.64 = 2.15 dB.
- Other gains [dBd] are given relative to this level (dBi=dBd+2.15).

Antenna Gain

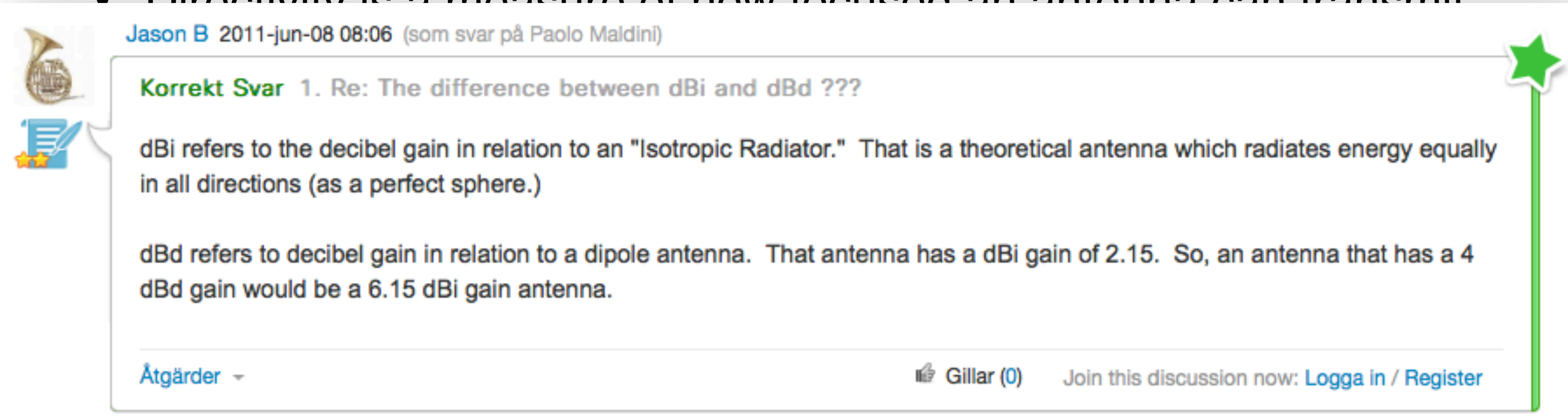

Dear all,

Who can explain for me the difference between dBi and dBd ???

Rgs,
Paolo

to send its signal towards a
liation may be regarded as loss
of power.

- Directivity is a measure of how focused an antenna can transmit


Jason B 2011-jun-08 08:06 (som svar på Paolo Maldini)

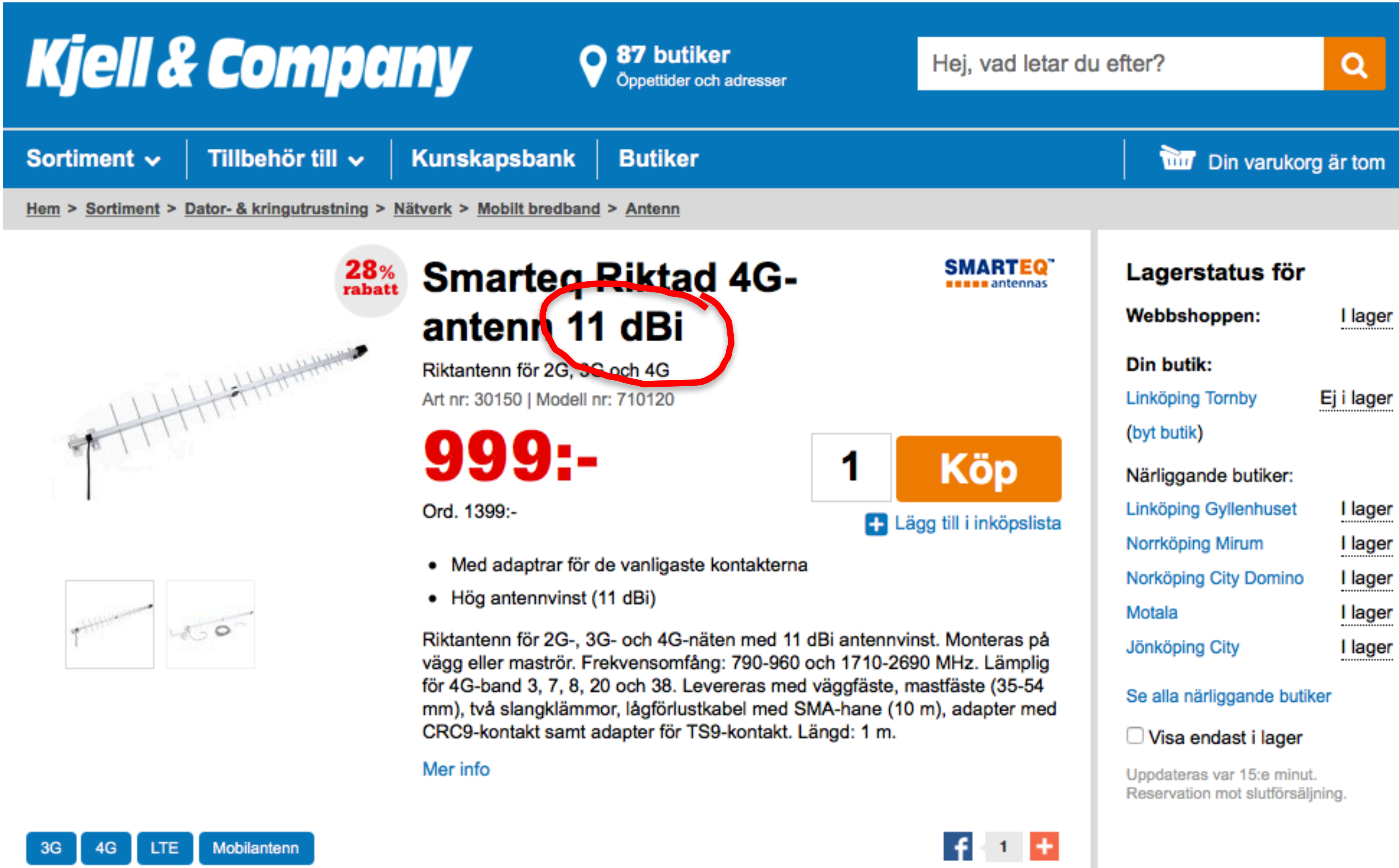
Korrekt Svar 1. Re: The difference between dBi and dBd ???

dBi refers to the decibel gain in relation to an "Isotropic Radiator." That is a theoretical antenna which radiates energy equally in all directions (as a perfect sphere.)

dBd refers to decibel gain in relation to a dipole antenna. That antenna has a dBi gain of 2.15. So, an antenna that has a 4 dBd gain would be a 6.15 dBi gain antenna.

Åtgärder Gillar (0) Join this discussion now: Logga in / Register

Other gains [dBd] are given relative to this level
(dBi=dBd+2.15).


Kjell & Company
87 butiker
Öppettider och adresser
Hej, vad letar du efter?
Sortiment
Tillbehör till
Kunskapsbank
Butiker
Din varukorg är tom
Hem > Sortiment > Dator- & kringutrustning > Nätverk > Mobilt bredband > Antenn
28% rabatt
Smarteq Riktad 4G-antenn 11 dBi
SMARTEQ antennas
Riktantenn för 2G, 3G och 4G
Art nr: 30150 | Modell nr: 710120
999:-
1
Köp
Ord. 1399:-
Lägg till i inköpslista
Med adaptrar för de vanligaste kontakterna
Hög antennvinst (11 dBi)
Riktantenn för 2G-, 3G- och 4G-näten med 11 dBi antennvinst. Monteras på vägg eller maströr. Frekvensomfång: 790-960 och 1710-2690 MHz. Lämplig för 4G-band 3, 7, 8, 20 och 38. Levereras med väggfäste, mastfäste (35-54 mm), två slangklämmor, lågförlustkabel med SMA-hane (10 m), adapter med CRC9-kontakt samt adapter för TS9-kontakt. Längd: 1 m.
Mer info
3G
4G
LTE
Mobilantenn
1
Lagerstatus för
Webbshoppen: I lager
Din butik:
Linköping Tornby Ej i lager
(byt butik)
Närliggande butiker:
Linköping Gyllenhuset I lager
Norrköping Mirum I lager
Norköping City Domino I lager
Motala I lager
Jönköping City I lager
Se alla närliggande butiker
Visa endast i lager
Uppdateras var 15:e minut.
Reservation mot slutförsäljning.

Receiver Effective Area

- A receiver uses the antenna to collect parts of the transmitted power which reaches it after transmission.
- The amount of received power depends on the receiver antenna effective area:

$$P_r = \frac{P_t}{4\pi r^2} A_{RX}$$

Received power = (transmitted power density at r) * A_{RX}

Antenna Gain

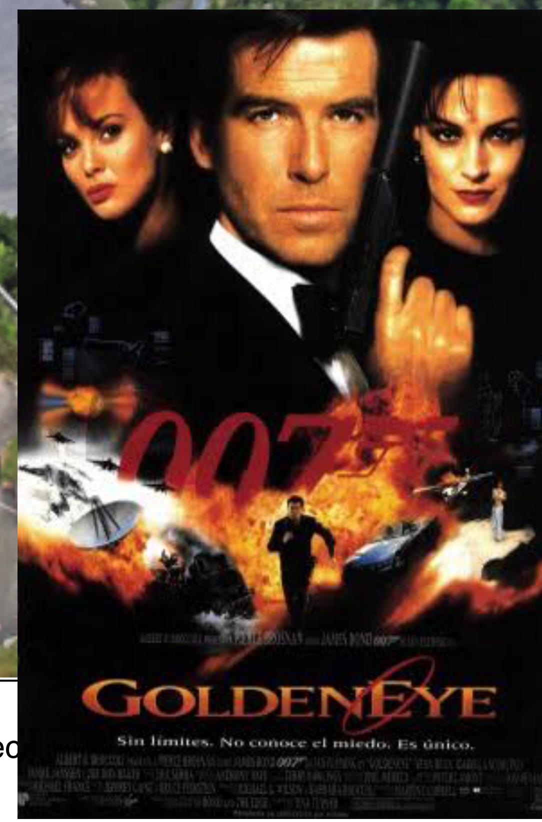
- If the antenna has a larger effective area (e.g. more directional), it collects more power. We can interpret this as antenna gain.

$$A_{RX} = 4\pi \frac{A_{eff}}{\lambda^2}$$

- Antenna gain is therefore dependent on the antenna size.
- Size of the antenna should always be stated in comparison to the wavelength.
- What is the largest antenna you have seen?

The Arecibo Observatory in Puerto Rico has the world's second largest single-aperture telescope (diameter 305 m).

The Arecibo Observatory in Puerto Rico has the world's second largest single-aperture telescope (diameter 305 m).
If you have not seen it before, go watch the Bond movie “Goldeneye”!



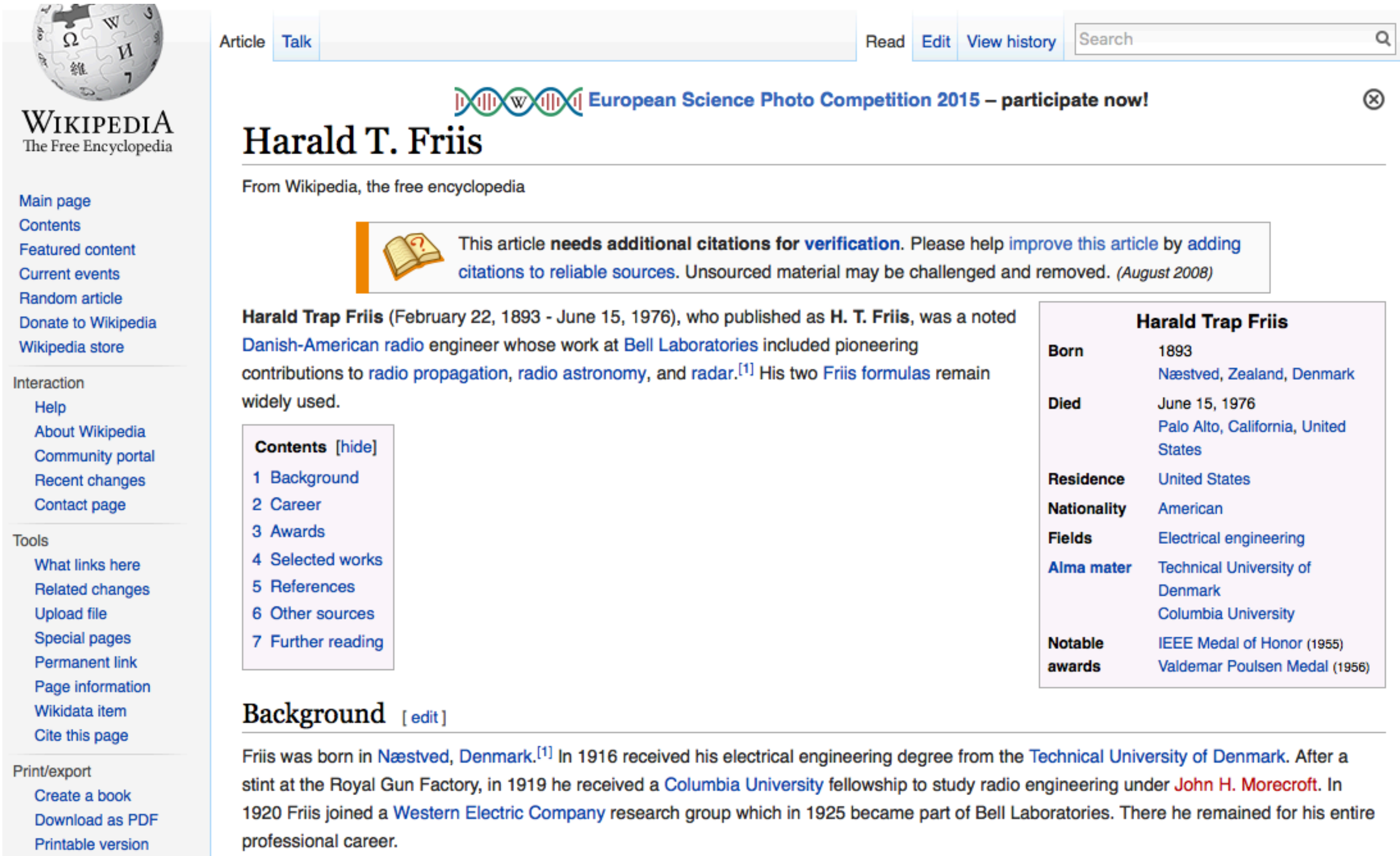
The world's largest radio telescope is the 500 meter Aperture Spherical Telescope (FAST) in southwest China.
Began operating in 2016.
Used to help search for extraterrestrial life.

Friis' Transmission Equation

- If we include transmitter and receiver antenna gains, the ratio of the received power to transmit power will be given by

$$P_{receive} = P_{transmit} G_t G_r \left(\frac{\lambda}{4\pi r} \right)^2$$

- Received power
  - decreases with distance,
  - increases by using directive antennas (large),
  - decreases with frequency (smaller), but at the same time, antenna sizes are now larger compared to λ,
  - increases as transmitted power increases.



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Harald T. Friis

From Wikipedia, the free encyclopedia

This article **needs additional citations for verification**. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed. *(August 2008)*

Harald Trap Friis (February 22, 1893 - June 15, 1976), who published as **H. T. Friis**, was a noted Danish-American radio engineer whose work at Bell Laboratories included pioneering contributions to radio propagation, radio astronomy, and radar.[1] His two Friis formulas remain widely used.

Harald Trap Friis	
Born	1893 Næstved, Zealand, Denmark
Died	June 15, 1976 Palo Alto, California, United States
Residence	United States
Nationality	American
Fields	Electrical engineering
Alma mater	Technical University of Denmark Columbia University
Notable awards	IEEE Medal of Honor (1955) Valdemar Poulsen Medal (1956)

Contents [hide]

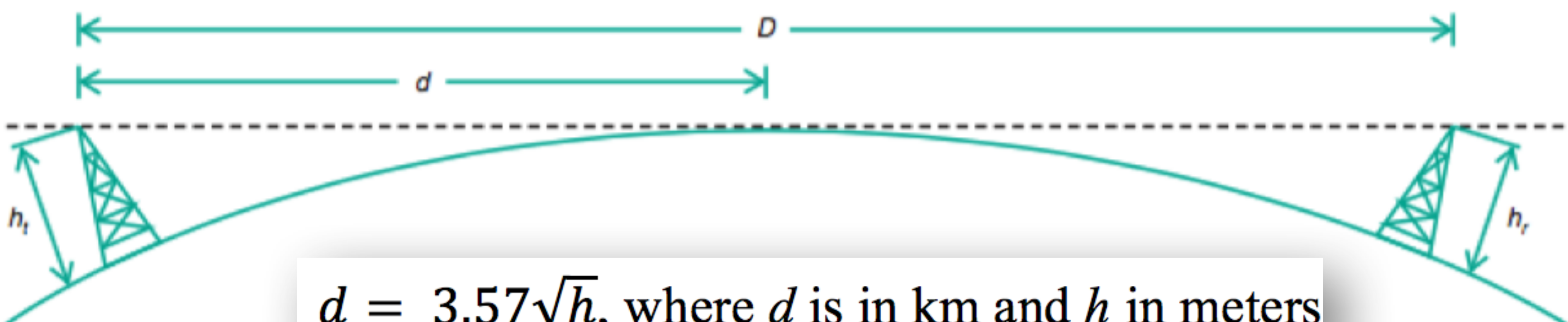
Background [edit]

Friis was born in Næstved, Denmark.[1] In 1916 received his electrical engineering degree from the Technical University of Denmark. After a stint at the Royal Gun Factory, in 1919 he received a Columbia University fellowship to study radio engineering under John H. Morecroft. In 1920 Friis joined a Western Electric Company research group which in 1925 became part of Bell Laboratories. There he remained for his entire professional career.

Friis' transmission equation was derived in 1945. Friis is also known for the Friis' formula for noise (cascaded noise figure).

Propagation of radio waves

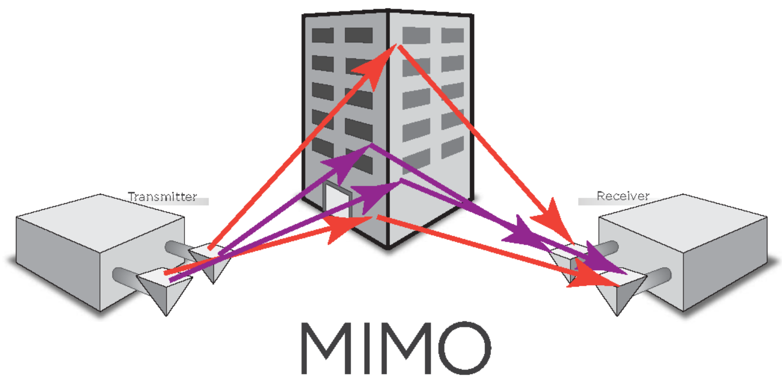
- Radio waves can propagate in many different ways:
- < 3 MHz: ground/surface waves, following the curvatures of the earth.
- 3-30 MHz: sky waves (reflections) in the ionosphere.
- > 30 MHz: direct/space waves, ”line-of-sight"..



$d = 3.57\sqrt{h}$, where d is in km and h in meters

MIMO: multiple-input and multiple-output

- MIMO: ”a method for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation” [Wikipedia]

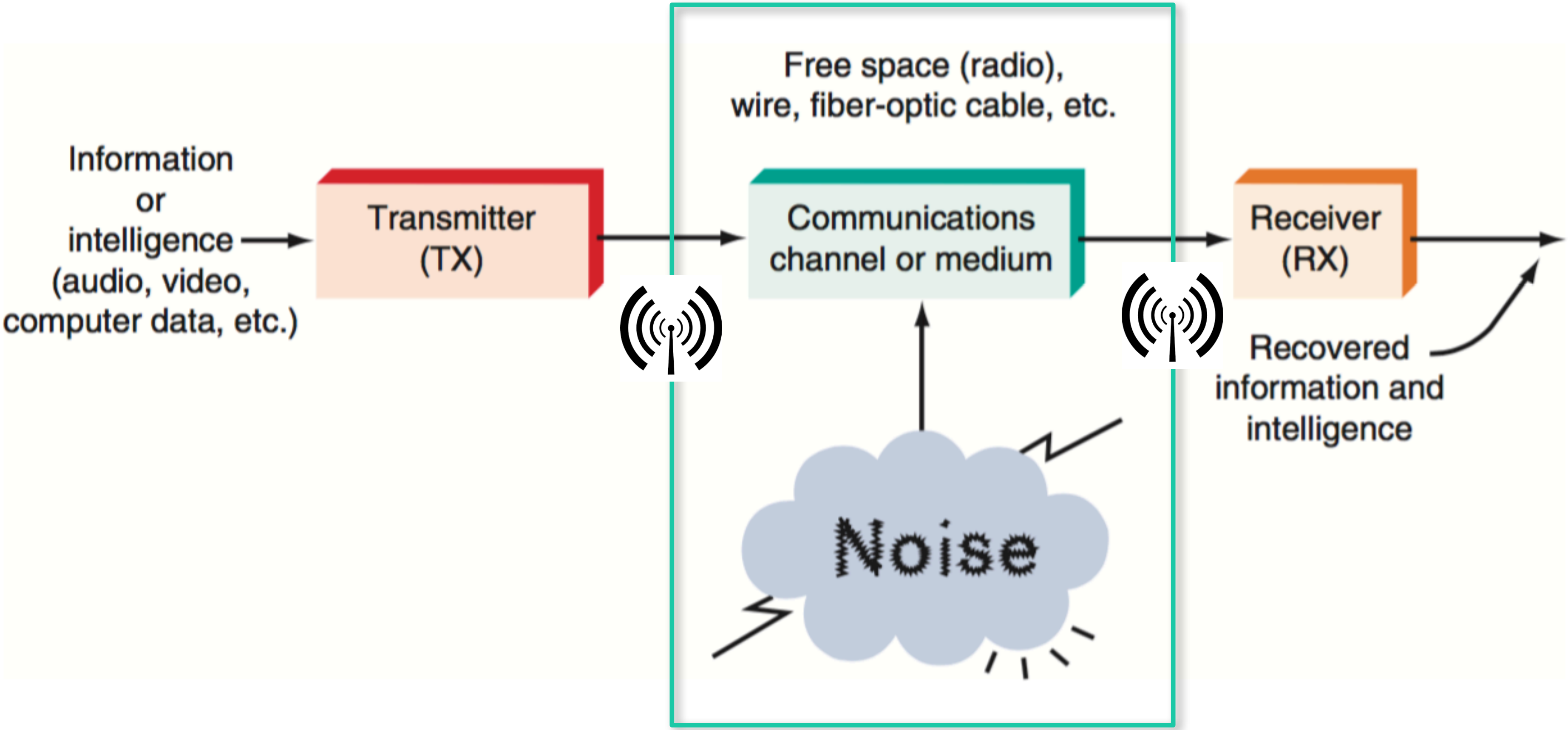


WLAN MIMO router

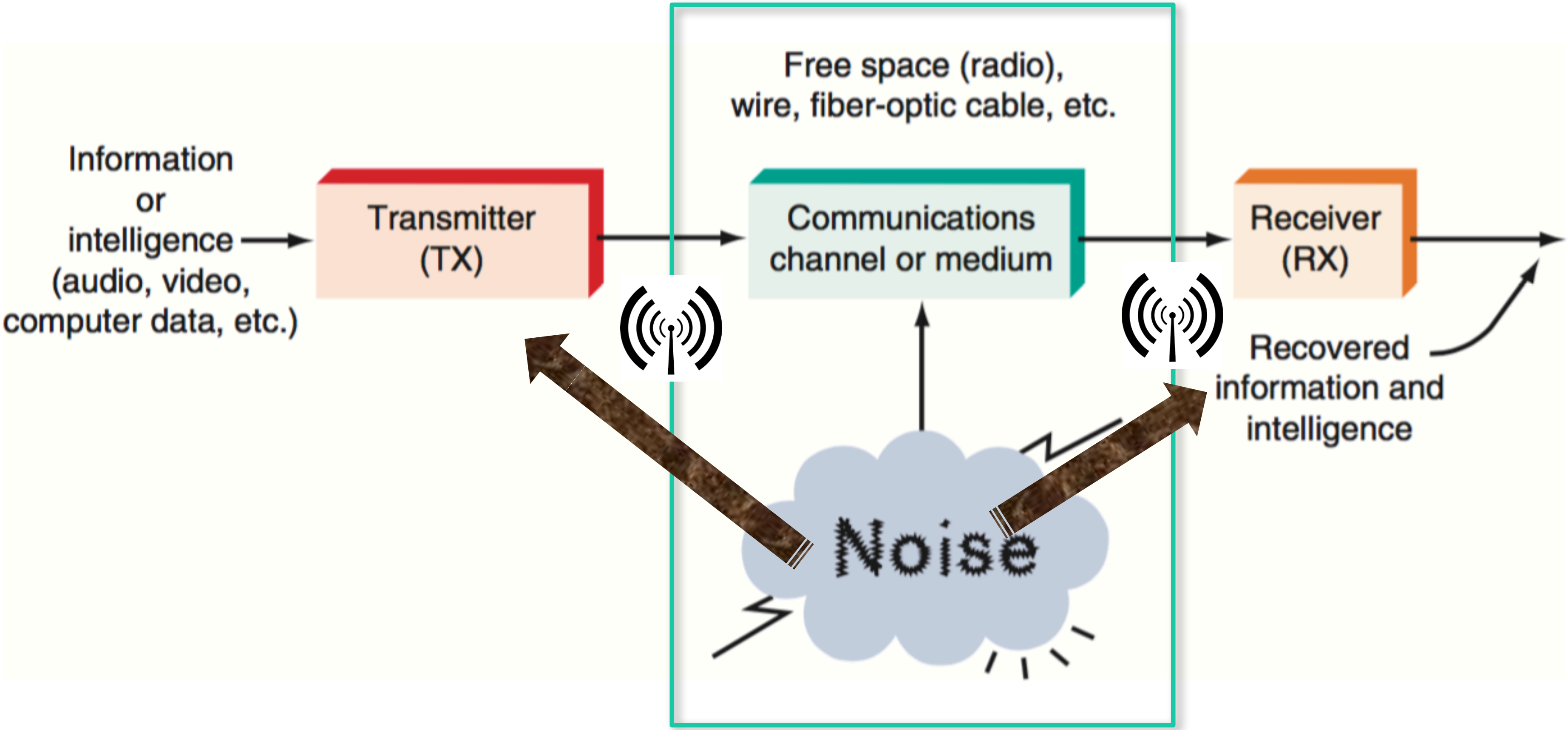
Propagation and Noise

- The wireless channel
- The antenna
- **Signal quality**
- Noise

Signal quality



Signal quality



Signal Quality

- Signal *impairment* could be due to
  - Random noise
  - Distortion (nonlinearity)
- These impairments can be reduced but cannot be removed completely.

- Note that amplitude loss is not an impairment!
  - Weak signals can always be amplified
- It is also possible to correct “linear” distortion
  - Equalization, predistortion

Signal Quality

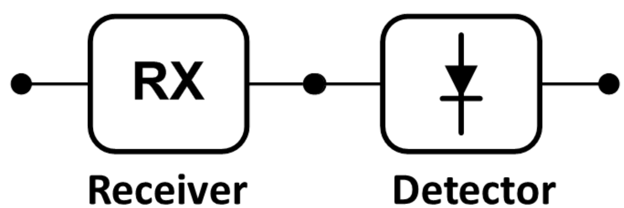
- Signal-to-Noise Ratio:

$$\boxed{\textbf{SNR} = \frac{\textbf{Signal Power}}{\textbf{Noise Power}}}$$

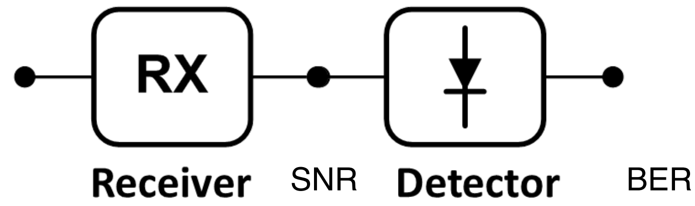
- all random noise and distortion regarded as noise
- sometime also S/N or CNR (Carrier-to-Noise Ratio)
- often in dB
- there are numbers of other related similar ratios

Detector (digital signals)

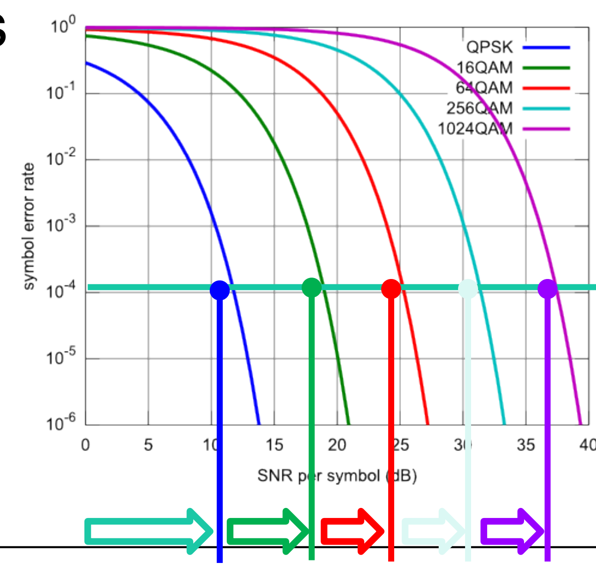
- There is always some error in the detection.
- Probability of Error (P_e) indicates the rate at which an error may occur.
- P_e is often stated as **Bit Error Rate (BER)** or **Symbol Error Rate (SER)**.
- Ex: BER=10^{-8} => in every 100,000,000 detected bits, 1 bit may be estimated incorrectly



BER vs SNR



- BER depends on SNR of the received signal, i.e. the signal after the receiver block.
- More complicated modulation schemes require higher SNR for the same error (trade off between BW and BER)
- It may be possible to correct errors with advanced Forward Error Correction (FEC) Coding (reduce BER for the same SNR)



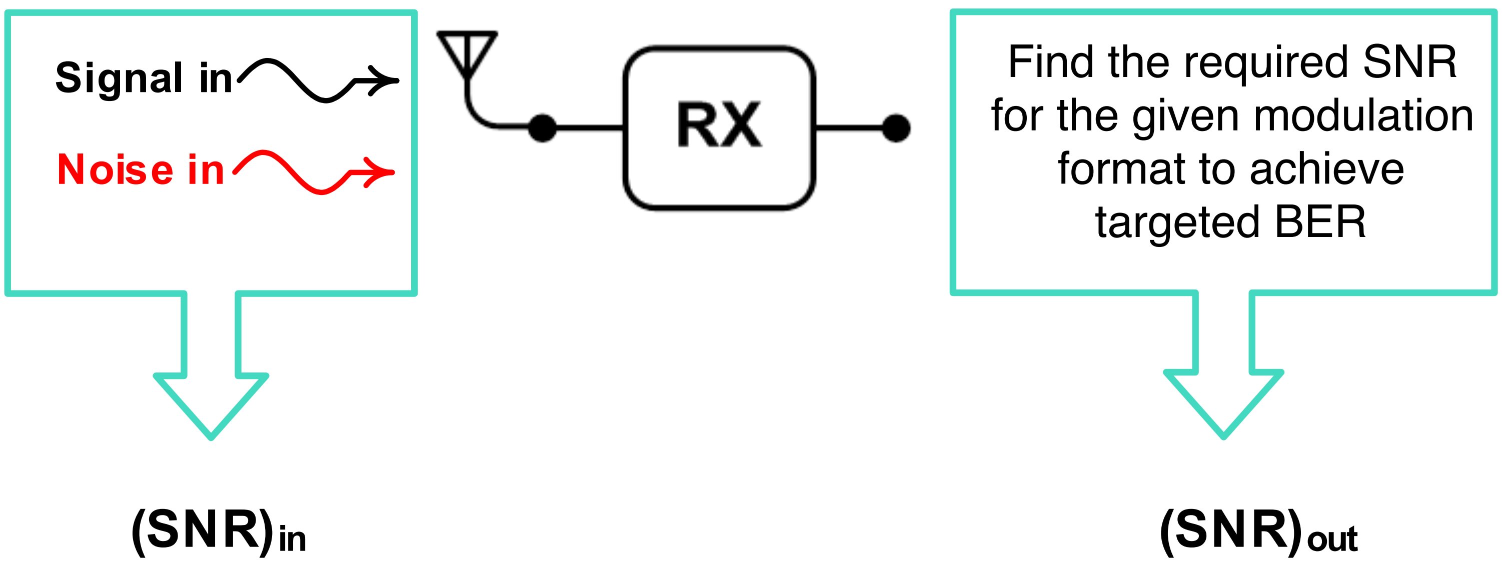
Propagation and Noise

- The wireless channel
- The antenna
- Signal quality
- **Noise (Razavi Ch 2.3)**

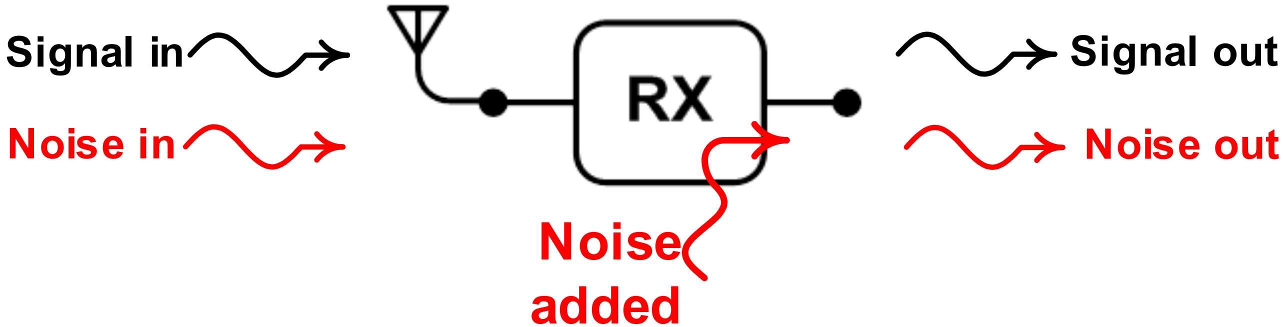
Receiver Design

- How good does a receiver have to be to achieve a certain BER?

Detector Requirements



Noise Figure



- Noise figure: $NF = \frac{(SNR)_{in}}{(SNR)_{out}}$
- >=1
- A receiver degrades the SNR
- Often called "noise factor" as above, "noise figure" in dB

Questions

- Q1: If the receiver degrades the SNR and therefore increases BER, then why do we use a receiver at all?

- Q2: Is it at all possible to improve the SNR with the receiver and therefore improve BER?

Questions

- Q1: If the receiver degrades the SNR and therefore increases BER, then why do we use a receiver at all?
- A1: Incoming signals are often very weak (e.g. -100 dBm) and must be amplified before they can be detected.

- Q2: Is it at all possible to improve the SNR with the receiver and therefore improve BER?
- A2: Yes, by limiting the incoming noise from reaching the detector. This can be done by filtering.

Questions

- Q1: If the receiver degrades the SNR and therefore increases BER, then why do we use a receiver at all?
- A1: Incoming signals are often very weak (e.g. -100 dBm) and must be amplified before they can be detected.

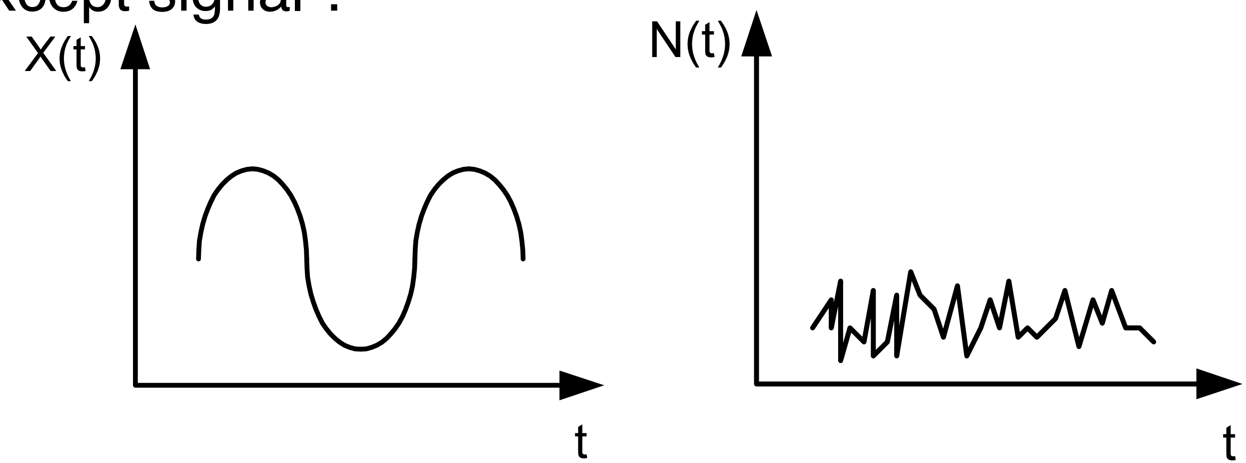
AMPLIFICATION

- Q2: Is it at all possible to improve the SNR with the receiver and therefore improve BER?
- A2: Yes, by limiting the incoming noise from reaching the detector. This can be done by filtering.

FILTERING

2.3 Noise

- What is noise? Typically, it is known as “everything except signal”:



- It affects the sensitivity of communication systems
- There are different types of noise (e.g. thermal noise, shot noise, flicker noise, etc.)

Types of Noise

- Noise may have different physical origins (outside the scope of this course)
- It is good however to know some types of noise:
  - Thermal Noise (also known as Johnson or Nyquist noise)
  - Flicker Noise (also known as 1/f or low frequency noise)
  - Phase Noise (also known as jitter)
  - Shot noise
  - ...
- Strictly, noise is random and can not be predicted (except average values).

This is strictly not noise!

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A Methodology to Predict the Impact of Substrate Noise in Analog/RF Systems

Stephane Bronckers, Karen Scheir, *Student Member, IEEE*, Geert Van der Plas, Gerd Vandersteen, *Member, IEEE*, and Yves Rolain, *Fellow, IEEE*

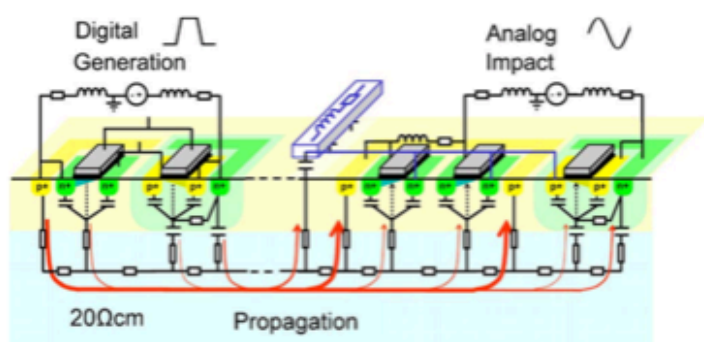
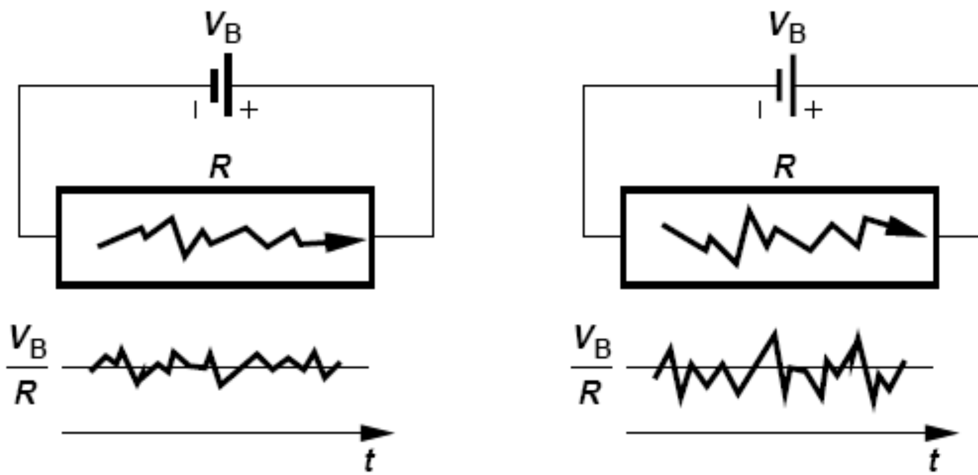


Fig. 1. Switching activity of the digital circuits degrades the performance of the analog circuits through the common substrate.

2.3.1 Noise

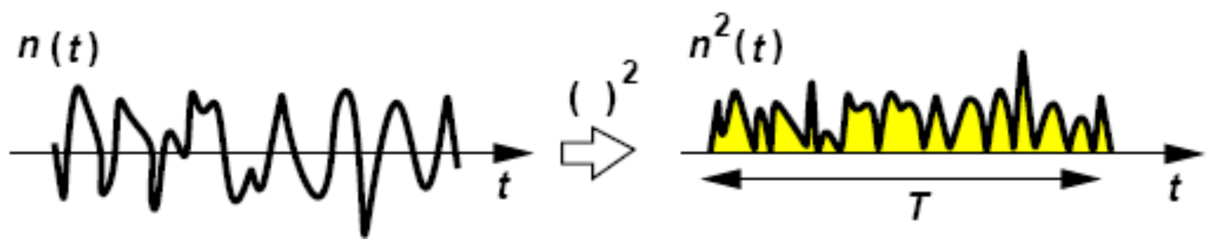
- The average current remains equal to V_B/R but the instantaneous current displays random values.



Lower temperature **Higher temperature**

Noise Power

Noise, n(t), is a random process, so its average power can be calculated by measuring the area under $n^2(t)$ over a long time.



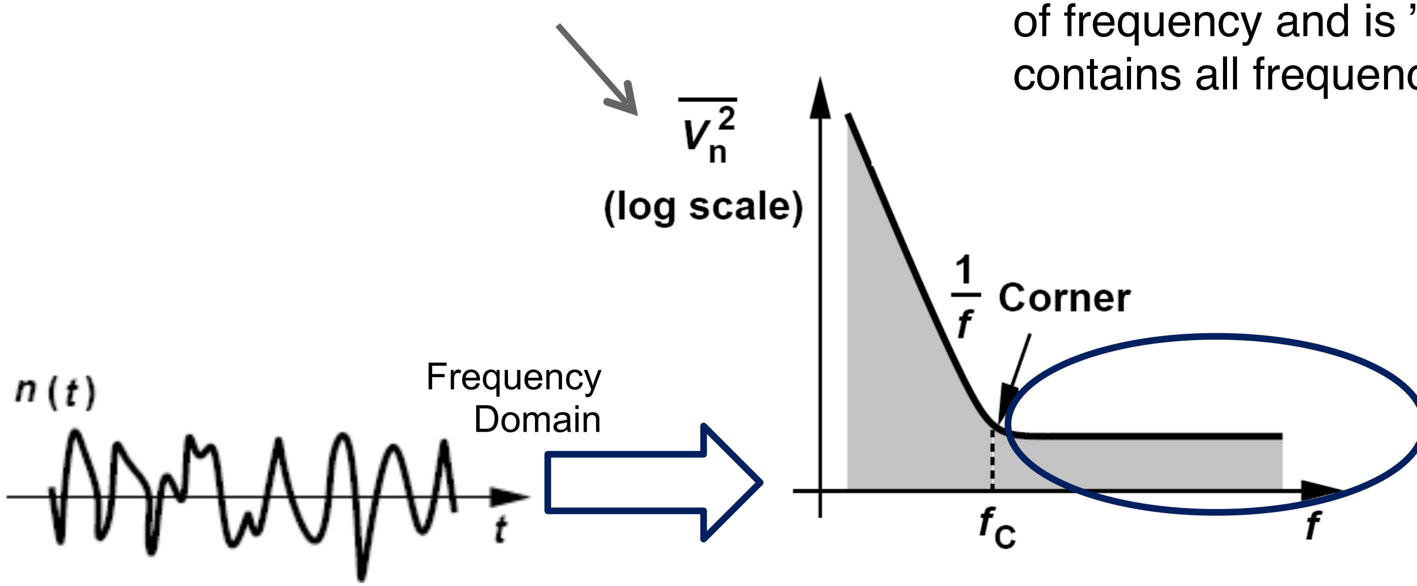
$$P_n = \lim_{T \to \infty} \frac{1}{T} \int_0^T n^2(t)dt$$

Noise Power Spectral Density

Since it is impractical to analyze noise in the time-domain, we turn into its frequency domain representation

Note that this is the noise ”Power Spectral Density” (PSD), unit [W/Hz] or [V2/Hz]

At radio frequencies, noise power density is independent of frequency and is ”white” (it contains all frequencies)

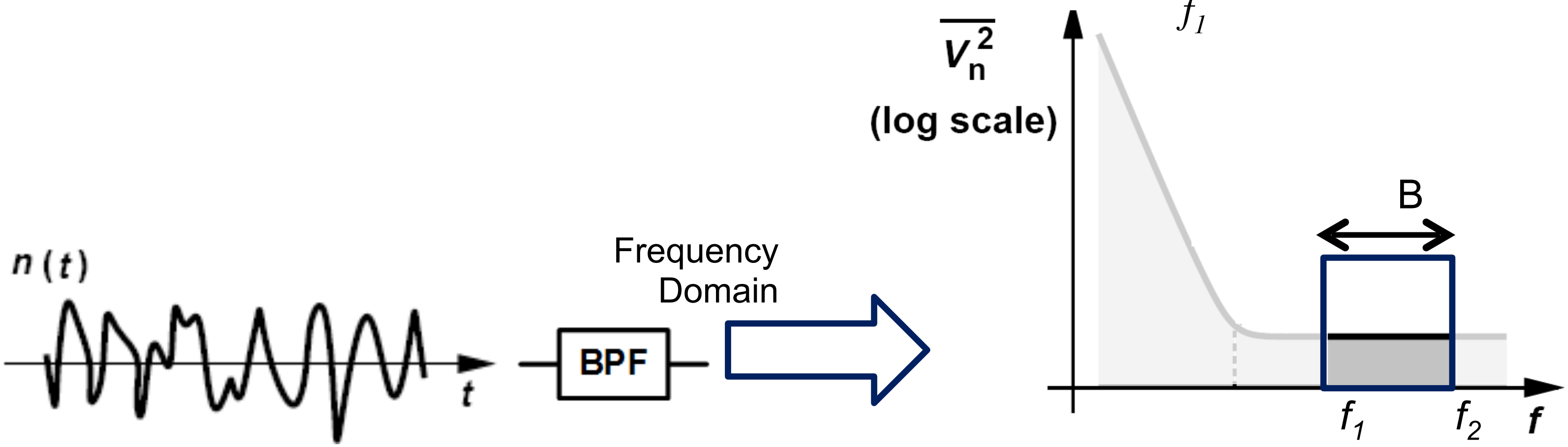


Noise Power Spectral Density

Since it is impractical to analyze noise in the time-domain, we turn into its frequency domain representation

For a given bandwidth, the area under $S_n(f)$ equals the noise power

$$P_n = \int_{f_1}^{f_2} S_x(f)\,df = \text{constant x B}$$



Thermal Noise

- Charge carriers, which are thermally affected generate a random varying current. It produces a random voltage which is called “thermal noise”.
- Thermal noise power is proportional to *T [K].* The PSD of a resistor is given by:

$$S_v(f) = 4kTR \quad (k = 1.38\text{E-}23 \text{ J/K}) \quad [\text{V}^2/\text{Hz}]$$

- It is independent of frequency, because it is considered as “white” noise (noise power is the same over any given absolute bandwidth).

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