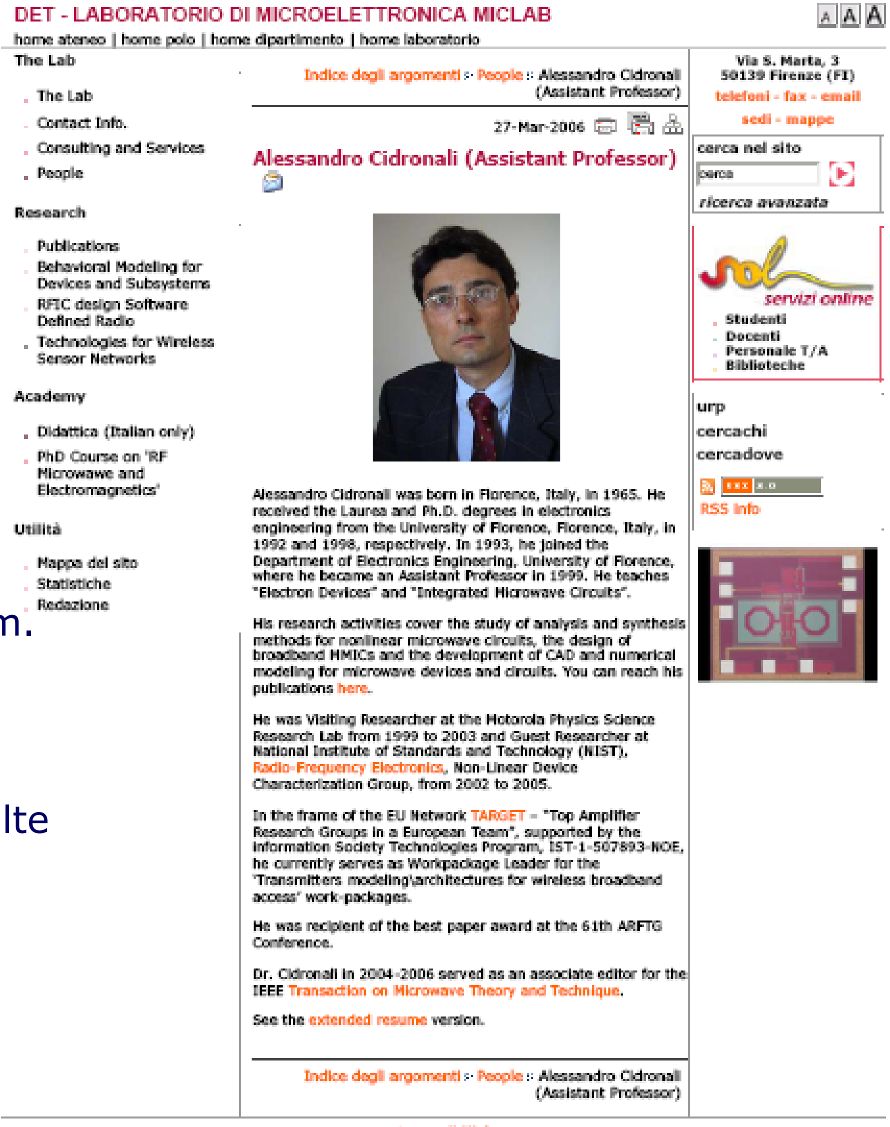
Intro – concetti base

- **Ing. Alessandro Cidronali**
- Dipartimento di Elettronica e Telecomunicazioni – Facoltà di Ingegneria
- Didattica:
  - *Elettronica dei Sistemi a Radiofrequenza*

    Laurea in Ing. Elettronica
  - *Dispositivi Elettronici*

    Laurea Specialistica Ing. Elettronica e Telecomm.
- Area di Ricerca
  - Caratterizzazione dispositivi elettronici per alte frequenze
  - Circuiti integrati a microonde
  - Sistemi wireless



DET - LABORATORIO DI MICROELETTRONICA MICLAB

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The Lab

- The Lab
- Contact Info.
- Consulting and Services
- People

Research

- Publications
- Behavioral Modeling for Devices and Subsystems
- RFIC design Software Defined Radio
- Technologies for Wireless Sensor Networks

Academy

- Didattica (Italian only)
- PhD Course on 'RF Microwawe and Electromagnetics'

Utilità

- Mappa del sito
- Statistiche
- Redazione

Indice degli argomenti :· People :: Alessandro Cidronali (Assistant Professor)

27-Mar-2006

Alessandro Cidronali (Assistant Professor)

Alessandro Cidronali was born in Florence, Italy, in 1965. He received the Laurea and Ph.D. degrees in electronics engineering from the University of Florence, Florence, Italy, in 1992 and 1998, respectively. In 1993, he joined the Department of Electronics Engineering, University of Florence, where he became an Assistant Professor in 1999. He teaches "Electron Devices" and "Integrated Microwave Circuits".

His research activities cover the study of analysis and synthesis methods for nonlinear microwave circuits, the design of broadband HMICs and the development of CAD and numerical modeling for microwave devices and circuits. You can reach his publications here.

He was Visiting Researcher at the Motorola Physics Science Research Lab from 1999 to 2003 and Guest Researcher at National Institute of Standards and Technology (NIST), Radio-Frequency Electronics, Non-Linear Device Characterization Group, from 2002 to 2005.

In the frame of the EU Network TARGET - "Top Amplifier Research Groups in a European Team", supported by the Information Society Technologies Program, IST-1-507893-NOE, he currently serves as Workpackage Leader for the 'Transmitters modeling\architectures for wireless broadband access' work-packages.

He was recipient of the best paper award at the 61th ARFTG Conference.

Dr. Cidronali in 2004-2006 served as an associate editor for the IEEE Transaction on Microwave Theory and Technique.

See the extended resume version.

Indice degli argomenti :· People :: Alessandro Cidronali (Assistant Professor)

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RSS Info

www.unifi.it/miclab

Programma del Corso di Laboratorio di Elettronica

(Elettronica dei Sistemi a Radiofrequenza)

- Concetti base
- Circuiti selettivi ed adattamenti
- Dispositivi attivi ed amplificatori
- Modulatori e demodulatori
- Oscillatori ed anelli ad aggancio di fase
- Amplificatori di potenza
- Filtri
- Tecniche digitali nelle radio
- Esercitazioni in Laboratorio

Modalità Svolgimento Corso ed Esami

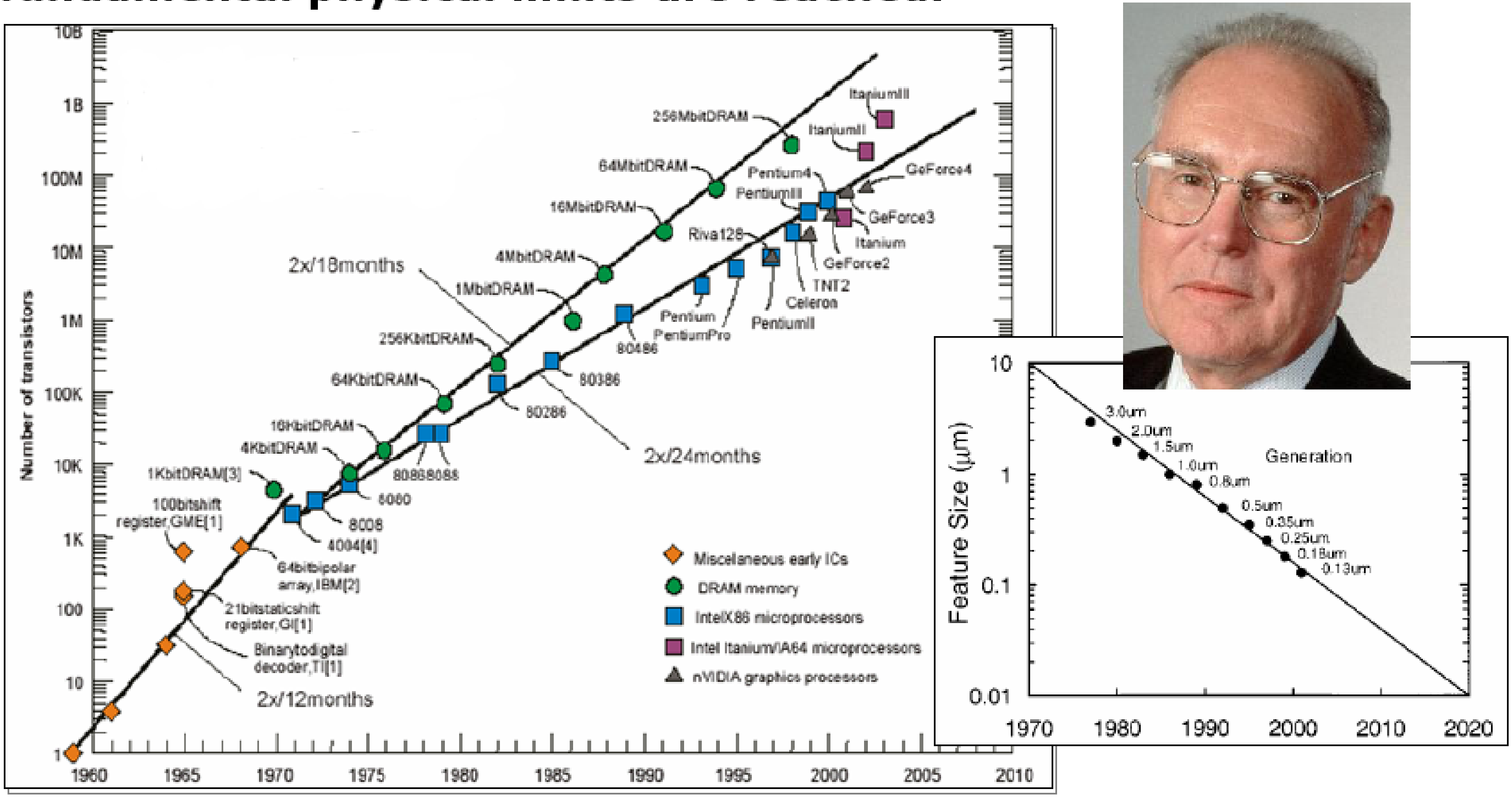
- 3 ore di didattica frontale
- 4 ore di laboratorio progettazione CAD didattico
- 1 prova intermedia Mercoledì 18 Febbraio 2008 ore 14:30
- Esami:
  - Venerdi 3 aprile ore 15:00
  - -

Finalità del corso

- Introduzione di importanti concetti e tecniche dell’elettronica dei sistemi a radiofrequenza.
- Si assume che siano acquisiti gli elementi di base dell’elettronica e dell’elettromagnetismo
- Non verrà data una completa descrizione delle problematiche relative alle problematiche delle radiocomunicazioni, piuttosto un sufficiente grado di conoscenze tale da permettere di affrontare argomenti avanzati in questa area.
- La prima parte è destinata a fornire una panoramica generale di tale concetti per poi descrivere ciascuna di queste in dettaglio

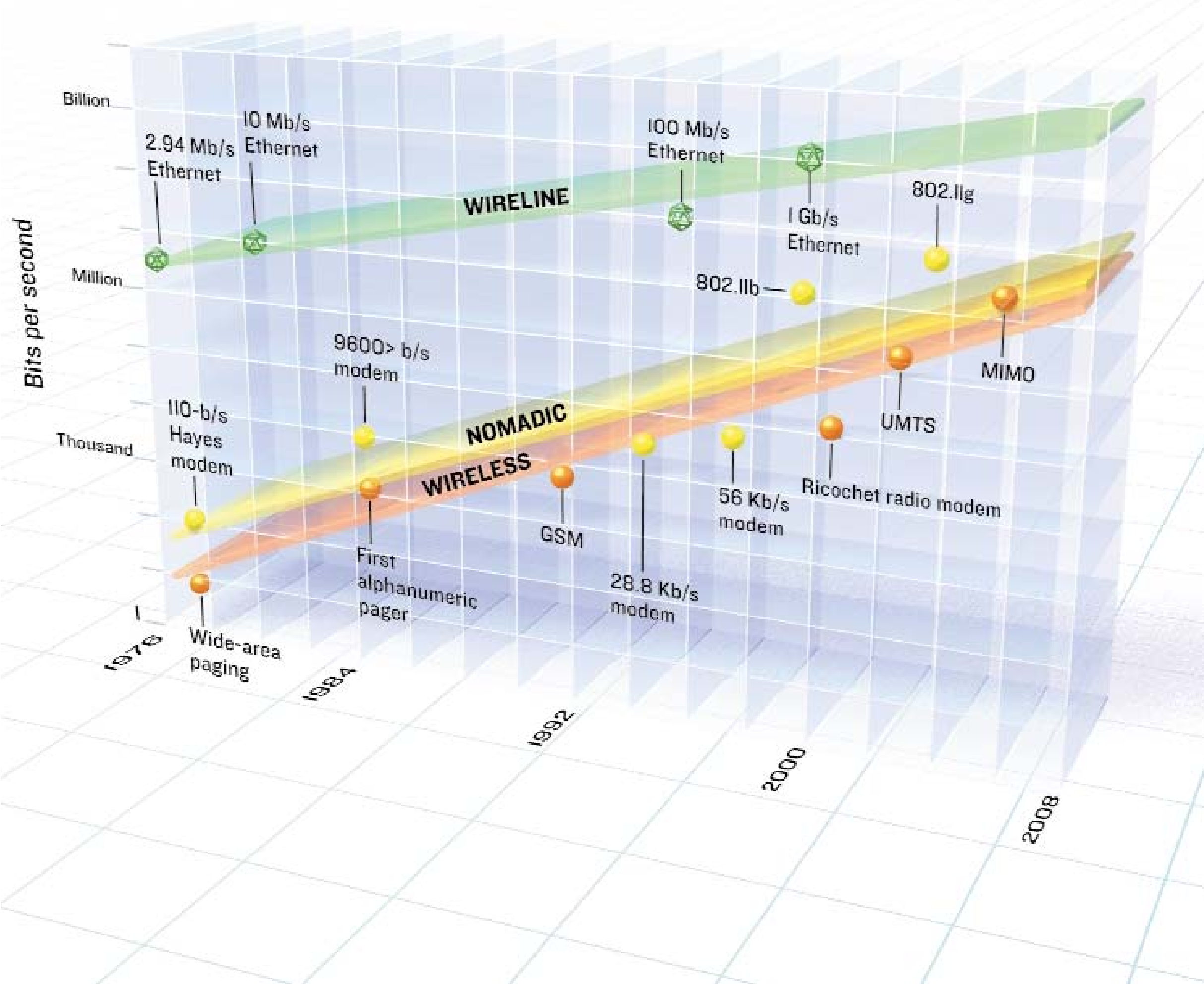
Moore's law

1973. Gordon Moore first made the prediction the number of transistors on a chip would double every 18 months until fundamental physical limits are reached.



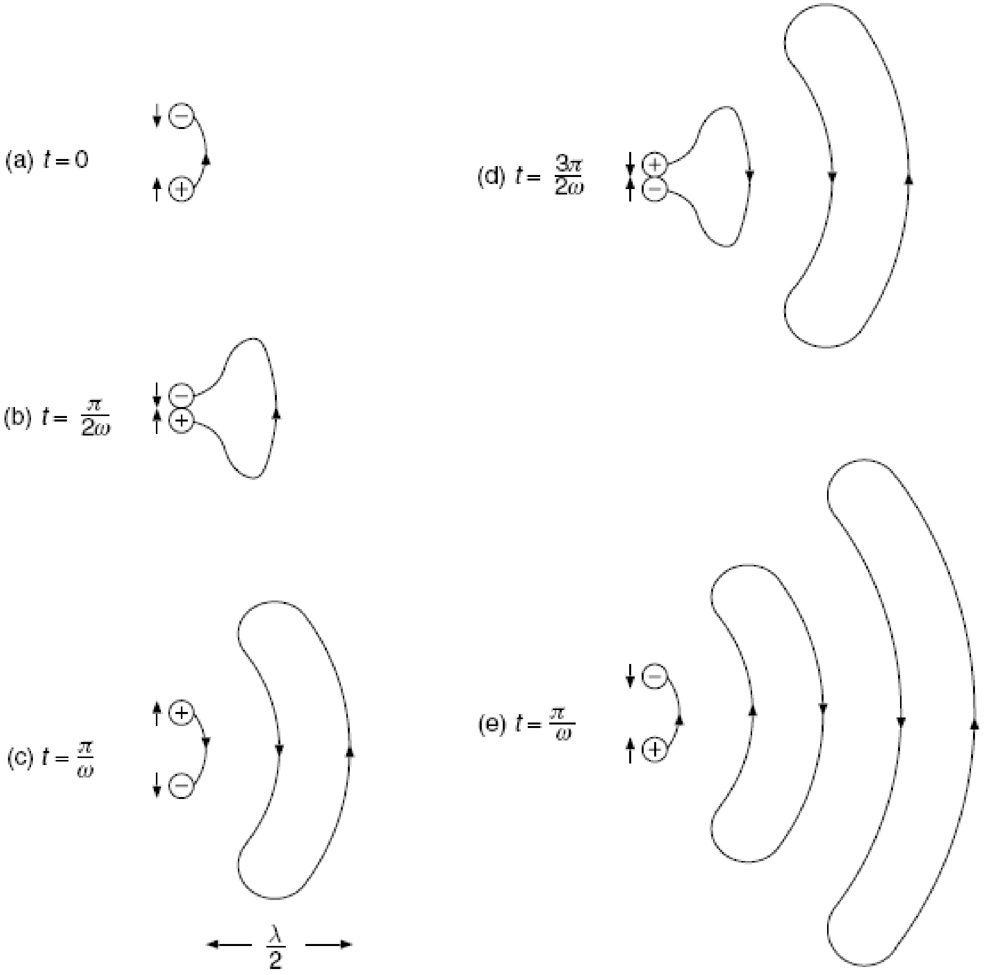
EDHOLM’S LAW OF BANDWIDTH Telecom. data rates are as predictable as Moore’s Law

- Wireline, nomadic, and wireless technologies improve in a manner reminiscent of Moore’s Law.
- Soon, even slower communications channels like cellphones and radio modems will eclipse the capacity of early Ethernet, thanks to upcoming standards known as UMTS and MIMO



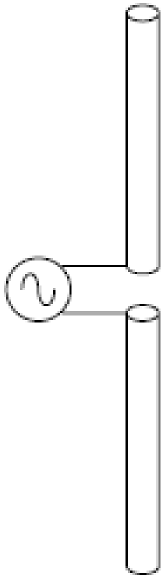
Generation of e. m. waves

- Can be illustrated through the evolution of the electric field of a simple oscillating dipole.
- The electric field lines will evolve as shown in Figure
- When the charges pass, the field lines will join together and break away to make room for new field lines to develop (note that field lines cannot cross).
- After one period of oscillation, the field lines joining the charges will look identical to those at the start.
- The actual field lines, however, will have moved a *wavelength* λ out from the charges ($\lambda = c/f$ where f is the frequency of oscillation in hertz).
- As the oscillations continue, the field lines will continue to move out by a distance λ for each period of oscillation.



Transmitter system

- In a realistic communications system, the *radiation* fields will be produced by an electronic source that drives current into a metallic structure known as an antenna.
- At the atomic level, the antenna will consist of a complex combination of simple oscillating dipoles whose fields will combine to form a pattern of radiation that is dictated by the geometry of the antenna.

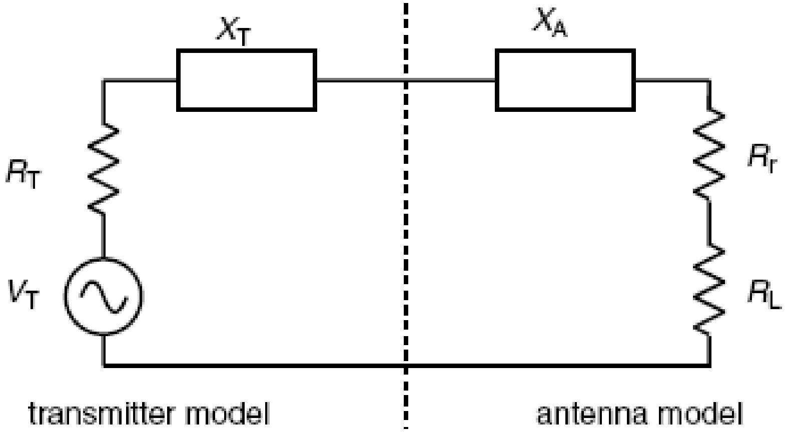


$$\text{directivity} = \frac{\text{power radiated in a particular direction}}{\text{average of power radiated in all directions}}.$$

$$\text{gain} = 4\pi \frac{\text{power radiated into a unit solid angle}}{\text{total power supplied}}$$

Transmitting system

- From a circuit viewpoint, a transmit antenna can be represented by the circuit shown in Figure



- Note the $R_T + jX_T$ is the impedance of the RF source (the transmitter or Tx) and $R_r + R_L + jX_L$ is the impedance of the antenna.
- The antenna has two resistance contributions
  - R_L which represents the ohmic (heating) losses in the antenna
  - and R_r which represents the losses due to power radiated away from the antenna

Transmitting system

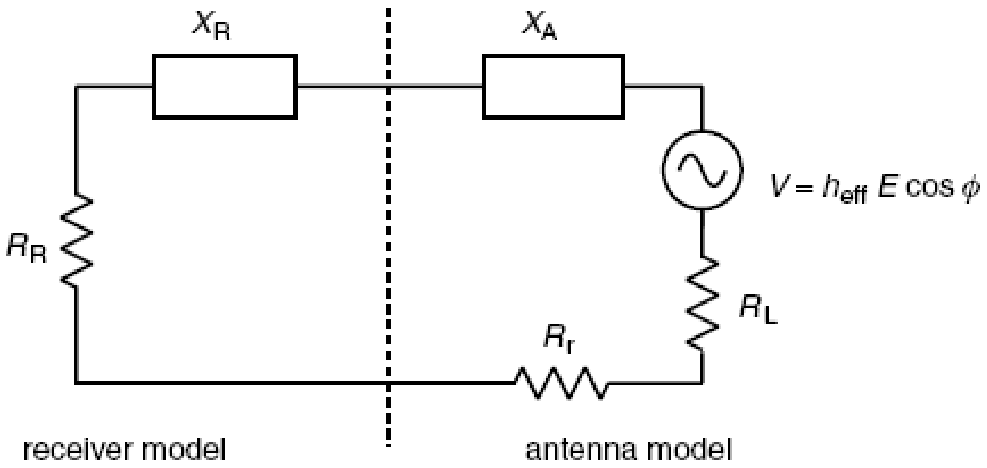
- From the circuit model, the power *P*r radiated by the antenna will be given by:

$$P_r = \frac{V_T^2 R_r}{2(R_T + R_r + R_L)^2 + 2(X_T + X_A)^2}.$$

- This power will take its maximum value, that is $(V_T)^2/8R_r$, when $X_T = -X_A$ and $R_r = R_T + R_L$

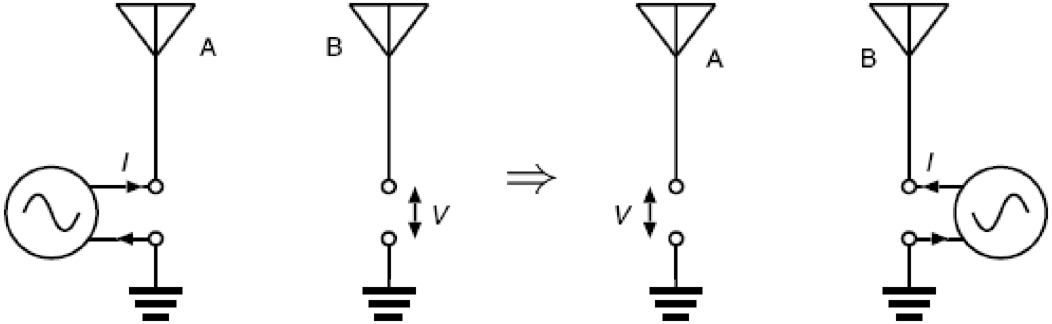
Receiving system

- A circuit model for a receiving antenna is shown in figure;
- the antenna exhibits the same impedance $R_r + R_L + jX_A$ in receive and transmit modes
  - maximum power will be received when $X_R = -X_A$ and $R_R = R_r + R_L$.



Radio Link

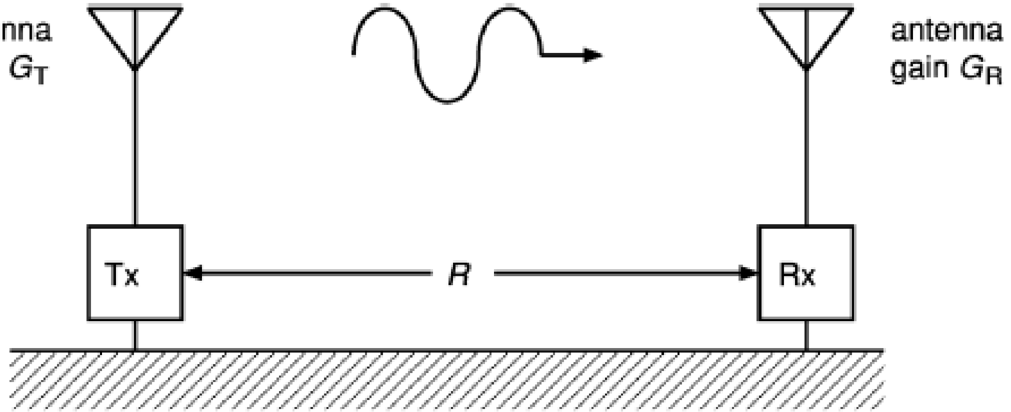
- A further result concerning the interchangeability of transmit and receive properties is known as *reciprocity*.
- Consider two antennas (A and B) with antenna A driven by current I and causing an open circuit voltage V in antenna B.
- If we now drive antenna B with the same current I and measure the open circuit voltage in A, we will find it to be the same voltage V.
- This is the case, even if A and B are completely different antennas.
- An important consequence of this result is the ability to infer two-way communication properties from one-way properties. To investigate the coverage of a mobile communications base station, for example, it is only necessary to investigate coverage of signals transmitted from the base station.



Radio Link

- the level of transmit power that is required in order to achieve a given level of power at the receiver, can be calculated using the *Friis* equation.

$$P_R = P_T \left(\frac{\lambda}{4\pi R} \right)^2 G_R G_T ,$$



Noise

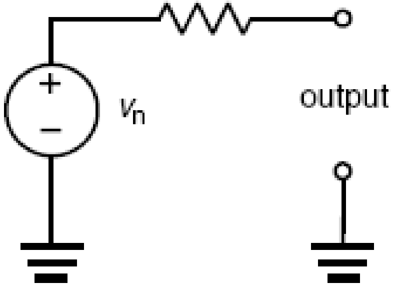
- It might seem that we could transmit at any level of signal power and simply introduce a suitable amount of amplification at the receiver end.
- Unfortunately, this is not the case due to the fact that the signal will be *competing* with an ever present environment of random signals or *noise*.
- For example, a simple resistor will create a noise voltage v_n due to the random thermal motion of its electrons and this can be shown to have an rms voltage that satisfies

$$\overline{v_n^2} = 4kT\,B\,R$$

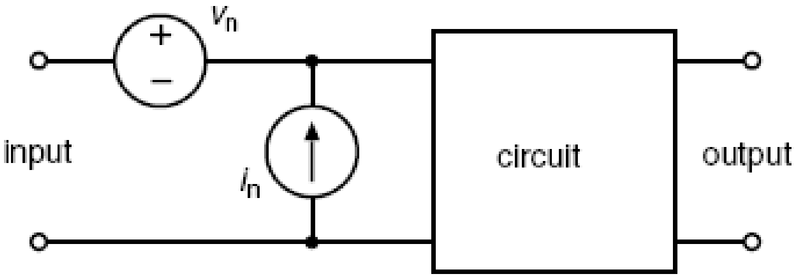
- T (in kelvin) is the absolute temperature, B (in hertz) is the bandwidth of the measurement, R (in ohms) is the resistance and k is the Boltzmann constant (1.38×10^{-23} joules per kelvin).
- The above equation still applies to a general impedance Z providing R is interpreted as the resistive part of the impedance, i.e., $R = \{Z\}$.

Noise

- In general, the noise in an electronic circuit can be modelled by removing the noise sources within the circuit and replacing them by equivalent current and voltage sources at the input.



Simple noisy resistor



equivalent sources from a two-port linear circuit

- These equivalent sources can be quite complex since a general circuit can contain other forms of noise besides that due to the resistance (the shot and flicker noises of semiconductor devices, for example).
- In a radio receiver, the input signal will already be in competition with *external noise* from man-made sources (ignition interference, for example) and natural sources

Noise

- In general, a noise source that is *non-thermal* can be treated as a thermal source with a suitably chosen *noise temperature*.
- External noise is not under the control of the designer. For best performance, a radio receiver should be designed such that it is *externally noise limited* (i.e., the internal noise is below the expected level of external noise).
- If an RF circuit is fed from a noisy source, it is clear that the amount of noise that reaches its output will depend on the circuit bandwidth *B*. The circuit itself will, however, add contributions to this noise.
- The crucial quantity in assessing circuit performance is the signal-to-noise ratio (SNR), defined by:

$$\mathrm{SNR} = \frac{S}{N} = \frac{\text{signal power}}{\text{noise power}}$$

Noise

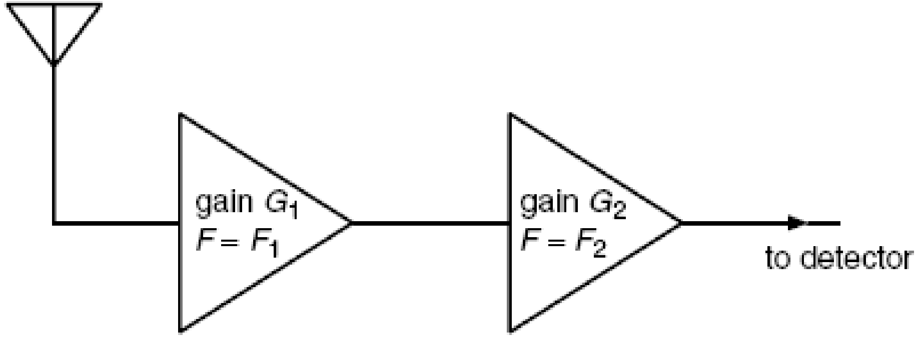
- In a radio receiver, SNR will directly relate to the quality of the demodulated signal.
- The change in SNR through an RF circuit is normally measured in terms of its *noise factor F* (known as the *noise figure* when expressed in dB terms). This is defined by:

$$F = \frac{S_i/N_i}{S_o/N_o}$$

- where S_i and S_o are the signal powers at the input and output, respectively, and N_i and N_o are the corresponding noise powers (limited to contributions from within the circuit bandwidth B).
- The signal level at the receiver antenna terminals can be calculated using the Friis equation, but this signal must compete with a combination of receiver and external noise sources.
- As a signal passes through the circuits of the receiver, the SNR will change through contributions from their various noise sources.

Noise

- In most circumstances, the received signal will be very weak and therefore will need to pass through several stages of amplification.



- If we cascade two stages, the noise factor of the combined device will be given by

$$F = F_1 + \frac{F_2 - 1}{G_1}$$

- If the source has a noise temperature T_s that is different from the ambient value T , the total noise power (referred to the input) is given by:

$$N = kT\,B(F - 1) + kT_sB$$

note that noise powers are additive for uncorrelated noise sources.

Radio Link Budget Example

- A 2km radio link at 2.5 GHz uses receivers with a 10 kHz bandwidth and a noise figure of 10 dB. The system employs polarisation matched half-wave dipole antennas and there is an antenna noise temperature of 100 K.

- Calculate the transmitter power that is required for a 10 dB signal-to-noise ratio.

- The total noise N, referred to the receiver input, is given by:

$$N = (F-1)kTB + kT_A B$$

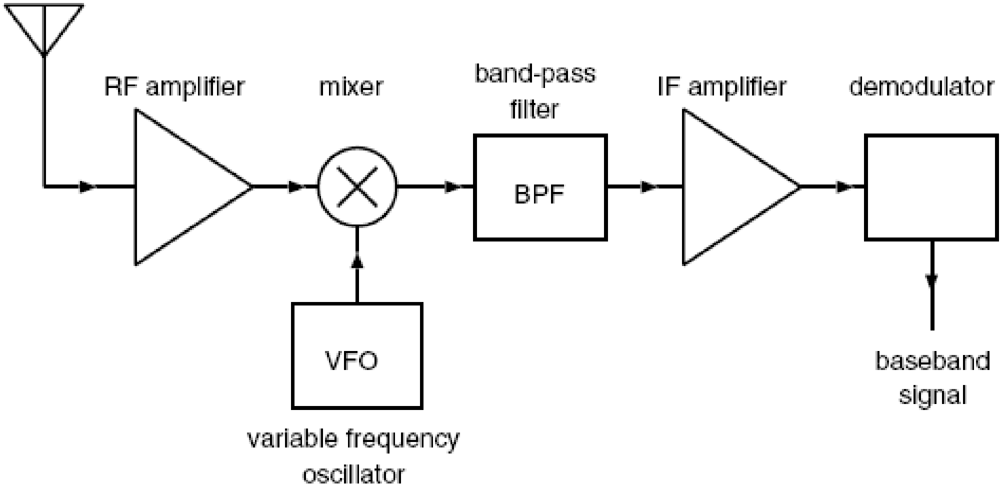
- where $F = 10$, $T = 290$ K, $T_A = 100$K and $B = 10^4$ Hz. This expression includes receiver noise and antenna noise. The value of this noise power is 3.74×10^{-16} W and so the signal power at the receiver will need to be $P_R = 3.74 \times 10^{-15}$ W for a 10dB SNR.
- From the Friis equation, the required transmit power P_T will be:

$$P_T = \frac{P_R}{G_R G_T}\left(\frac{4\pi R}{\lambda}\right)^2$$

- where $G_R = G_T = 5/3$, $R = 2 \times 10^3$ m and $\lambda = 0.12$ m. Consequently, $P_T = 5.9 \times 10^{-5}$ W or -12.3 dBm (dB with respect to 1 mW).

Sensitivity and selectivity

- The strength of the noise depends on the bandwidth of the system. As a consequence, we need to keep the bandwidth of the receiver as low as possible.
- If it is required to operate over a range of frequencies, such a receiver can be impractical due to the difficulty of building high-quality variable frequency filters. Consequently, it is more usual to convert all input signals to a fixed intermediate frequency (IF).
- A receiver based on such principles is known as a superheterodyne and a typical architecture is shown in Figure



Sensitivity and selectivity

- The sensitivity of a receiver is normally defined in terms of the *minimum detectable signal* (MDS), the minimum signal power that can be differentiated from the noise.
- This is usually taken to be the signal that yields a given signal to noise ratio SNR_0 (often taken to be 0 dB).
- For a receiver with noise factor F, and bandwidth B, the MDS is given by:

$$\mathrm{MDS} = [(F - 1)T + T_A]\, kB\, SNR_0$$

where T_A is the antenna temperature and T the ambient temperature.

- Sometimes, the sensitivity is quoted as the signal voltage:

$$v_{\min} = \sqrt{\mathrm{MDS} \times R}$$

that is required to achieve the signal to noise ratio SNR_0 (R is the input impedance of the receiver).

Non-linearity in RF systems

- The introduction of amplifiers and mixers means that there will be non-linear effects, both intentional and unintentional, in the transfer ofsignals from input to the output
- It is assumed that the output voltage vo of an amplifier (or other network) is related to the input voltage v_i through

$$v_0 = k_0 + k_1 v_i + k_2 v_i^2 + k_3 v_i^3 + \cdots$$

- In the case of a sinusoidal input voltage v_i = V cos ωt this will result in an output voltage of the form

$$v_o = \left(k_0 + \frac{k_2}{2}V^2\right) + \left(k_1 + \frac{3k_3}{4}V^2\right) V \cos \omega t + \frac{k_2}{2}V^2 \cos 2\omega t + \frac{k_3}{4}V^3 \cos 3\omega t + \cdots .$$

- the non-linearity has generated a multitude of *harmonics*. Furthermore, the value of *k*3 will normally be negative and so the gain *k*1 + (3k^3/4)V^2 will be reduced as the input power level rises. This compression effect is normally expressed in terms of the 1 dB compression point *P*1 dB

Non-linearity in RF systems

- If the input voltage *vi* is the combination of two sinusoidal signals

$$v_i = V_1 \cos \omega_1 t + V_2 \cos \omega_2 t$$

the output will contain components at frequencies

$$
\begin{aligned}
v_o(t) = {} & k_0 + \frac{k_2}{2}\left(V_1^2 + V_2^2\right) \\
& + \left(k_1 V_1 + \frac{3}{4}k_3 V_1^3 + \frac{3}{2}k_3 V_1 V_2^2\right)\cos \omega_1 t \\
& + \left(k_1 V_2 + \frac{3}{4}k_3 V_2^3 + \frac{3}{2}k_3 V_1^2 V_2\right)\cos \omega_2 t \\
& + \frac{k_2}{2}V_1^2 \cos 2\omega_1 t + \frac{k_2}{2}V_2^2 \cos 2\omega_2 t \\
& + \frac{k_3}{4}V_1^3 \cos 3\omega_1 t + \frac{k_3}{4}V_2^3 \cos 3\omega_2 t \\
& + k_2 V_1 V_2 \cos(\omega_1 + \omega_2)t + k_2 V_1 V_2 \cos(\omega_1 - \omega_2)t \\
& + \frac{3k_3}{4}V_1^2 V_2 \cos(2\omega_1 + \omega_2)t + \frac{3k_3}{4}V_1^2 V_2 \cos(2\omega_1 - \omega_2)t \\
& + \frac{3k_3}{4}V_1 V_2^2 \cos(2\omega_2 + \omega_1)t + \frac{3k_3}{4}V_1 V_2^2 \cos(2\omega_2 - \omega_1)t.
\end{aligned}
$$

Non-linearity in RF systems

- a measure of the intermodulation distortion (IMD) which is the ratio of the output power at the combination frequency to the output power at the fundamental.

$$\mathrm{IMD} = \left(\frac{3k_3 V_1 V_2}{4k_1}\right)^2$$

- For equal input signals ($V1 = V2$), the input power IIP3 for which the IMD has value 1 is known as the third order intercept point,

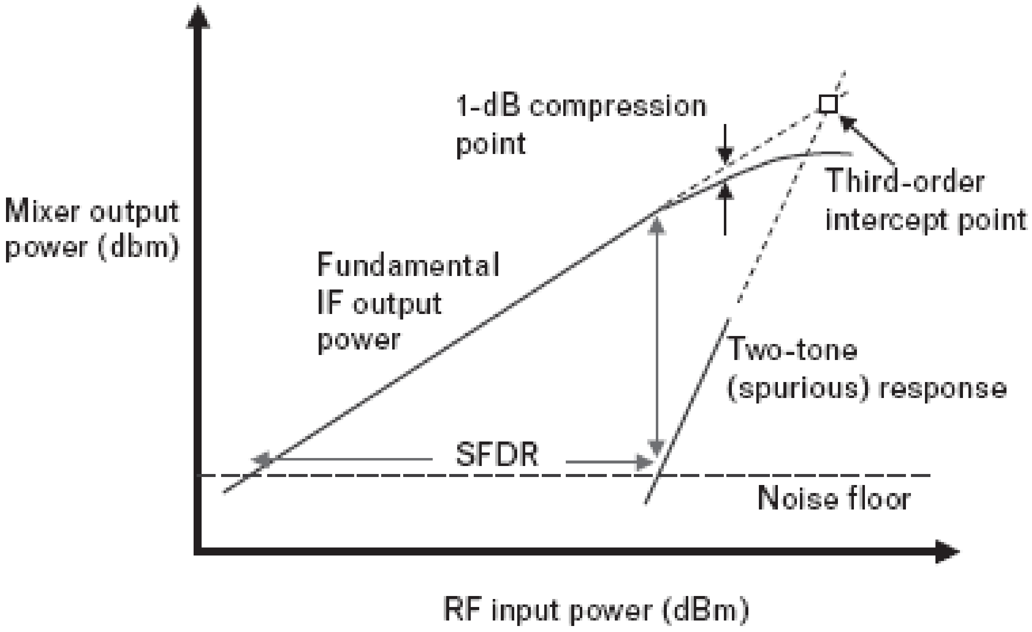
$$\mathrm{IIP3} = |2k_1/3k_3R|$$

where R is the input impedance.

spurious free dynamic range

- A useful practical measure of non-linearity in a receiver is the spurious free dynamic range (SFDR). This is the ratio of the minimum detectable signal to the signal whose third order distortion is just detectable:

$$\mathrm{SFDR} = \left(\frac{\mathrm{IIP3}}{\mathrm{MDS}}\right)^{2/3}$$



Non-linearity in RF systems

- It can be shown that the total third-order intercept point IIP3 of two cascaded devices can be derived from:

$$\frac{1}{\mathrm{IIP3}} = \frac{1}{\mathrm{IIP3}_1} + \frac{G_1}{\mathrm{IIP3}_2}$$

example

- A 100MHz receiver has a 50 input impedance, a 1 dB compression point of 7 dBm (referred to the input), a bandwidth of 10 kHz and a noise figure of 6 dB.

- Find the spurious free dynamic range when the receiver is fed from an antenna with a noise temperature of $T_A = 1000$ K.

- A 1dB compression point of 7 dBm will imply that the non-linear voltage gain $k_1 + (3k_3/4)V^2$, when divided by the ideal voltage gain $k1$, has a value $10^{-0.05}$ (1 dB of compression expressed as a voltage ratio) for an input power of 0.005W (7 dBm expressed in watts). That is:

$$\frac{k_1 + \frac{3k_3}{4}V^2}{k_1} = 10^{-0.05}$$

- when $V^2/(2 \times 50) = 0.005$W.

example

- As a consequence:

$$3k_3/4k_1 = -0.2175$$

- and so the third order intercept point is given by:

$$\mathrm{IIP3} = (1/50)|2k_1/3k_3| = 0.046\mathrm{W}.$$

- The total noise at the input (including receiver noise) is given by:

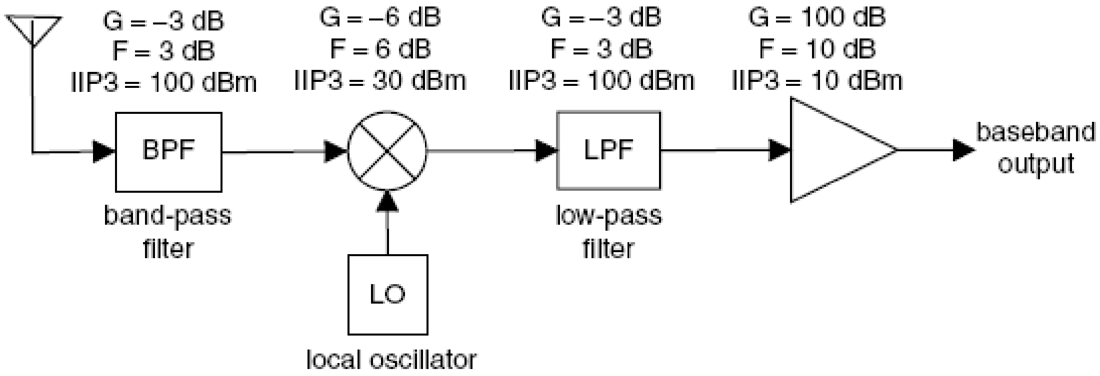
$$\mathrm{N} = (F - 1)kT\,B + kT_{\mathrm{A}}B$$

for which $F = 10^{6/10} = 4$, $T = 290$ K, $T_{\mathrm{A}} = 1000$ K, $B = 10^4$ Hz and $k = 1.38 \times 10^{-23}$ J/K.

- As a consequence, the total noise will be $N = 2.58 \times 10^{-16}$W which is the MDS based on a 0 dB SNR.
- The SFDR will be given by $(\mathrm{IIP3/MDS})^{2/3} = 3.1 \times 10^9$ or 95 dB.

example

- Given the direct conversion receiver calculate the minimum detectable signal (MDS) and dynamic range



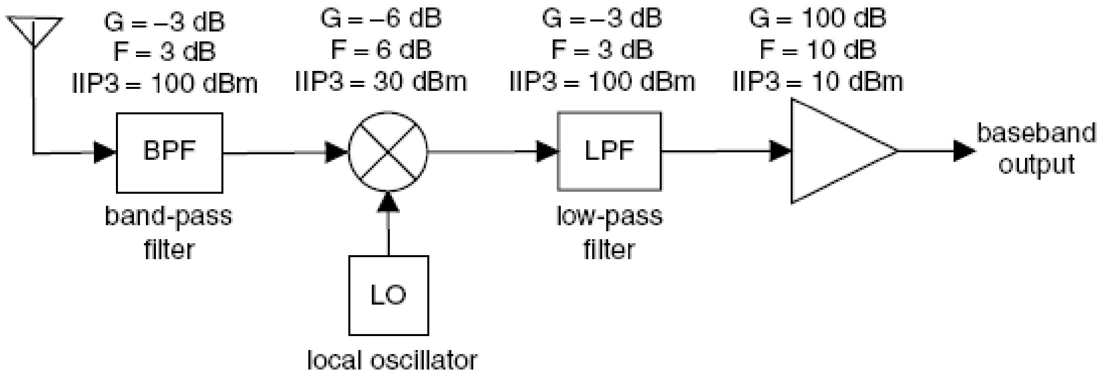
- Firstly, it will be noted that the noise factor *F* of the passive elements is given by 1/*G* (a components which dissipate power will also generate noise).
- The combined gain of the first two stages is −9 dB and, using the expressions for combining noise factors and intercept points, the combined noise figure (linear):

$$F = 2 + (4 - 1)/(1/2) = 8 \text{ (or 9 dB)}$$

- the combined intercept point:

IIP3 =[(1/1010) + (1/2)/103]−1 ≈ 2000mW (or 33 dBm).

example



- Combining the first three stages we obtain a gain of −12 dB,

  a noise factor of *F* = 8 + (2 − 1)/(1/8) = 16 (or 12 dB)

  and an intercept point of IIP3 = [(1/2000) + (1/8)/1010]−1 ≈ 2000mW (or 33 dBm).
- Finally, combining all stages, we obtain a total gain of 88 dB,

  a total noise factor of *F* = 16 + (10 − 1)/(1/16) = 160 (or 22 dB)

  and an intercept point of IIP3 = [(1/2000) + (1/16)/10]−1 ≈ 148mW (or 22 dBm).
- With MDS based on a 0 dB SNR and an ambient T_A,

  MDS = $FkTB$ = 160 × 1.38 × 10−23 × 290 × 3000 =19.2 × 10^{-16} W (or -117dBm)

  SFDR = $[0.148/(19.2 \times 10{-}16)]^{2/3}$ = 1.8 × 10^9 or 93 dB.