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Department of Electrical & Computer Engineering

ELEC 691X/498X – Broadcast Signal Transmission Fall 2015

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Office Hours: Wednesday, Thursday, 14:00 – 15:00

Time: Tuesday, 2:45 to 5:30

Room: H 411

Lecture 7:
Transmission Equipment

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In this lecture we cover the following topics:

- Encoders, Multiplexers and Decoders.
- Modulators and Demodulators.
- Up Converters.
- Down Converters.
- Power Amplifiers.
- Low Noise Amplifiers.
- Transmitter Antennas.
- TV Receiving Antennas.
- Link Budget.

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In previous lectures, we talked about what is needed in an end-to-end television broadcasting system. So, in a sense what we will discuss about in this lecture is not totally new. What is new is that while in previous lectures we were talking about different parts of the broadcasting link separately, from this point on we will consider them as parts of an overall system. We have talked about the techniques and algorithms used to do video encoding/decoding, modulation/demodulation, etc. And putting that knowledge together with what you have learnt about design of digital circuits, you should be able to implement them. So we will not talk about how the equipment used for broadcasting are implemented, but about the specifications of these equipment and how they can be put together to form a transmission chain. We will start by reviewing an end to end broadcasting system. We will start with a terrestrial system. This is simpler than a satellite broadcasting system and, therefore, simplifies the matters. Later we will discuss a satellite broadcasting link. Some parts such as encoder/decoder, modulator/demodulator we have already covered and we know their properties. Some, like antennas and HPA's we will cover briefly on our way. Our goal will be that at the end be able to match our resources with our requirements. This means

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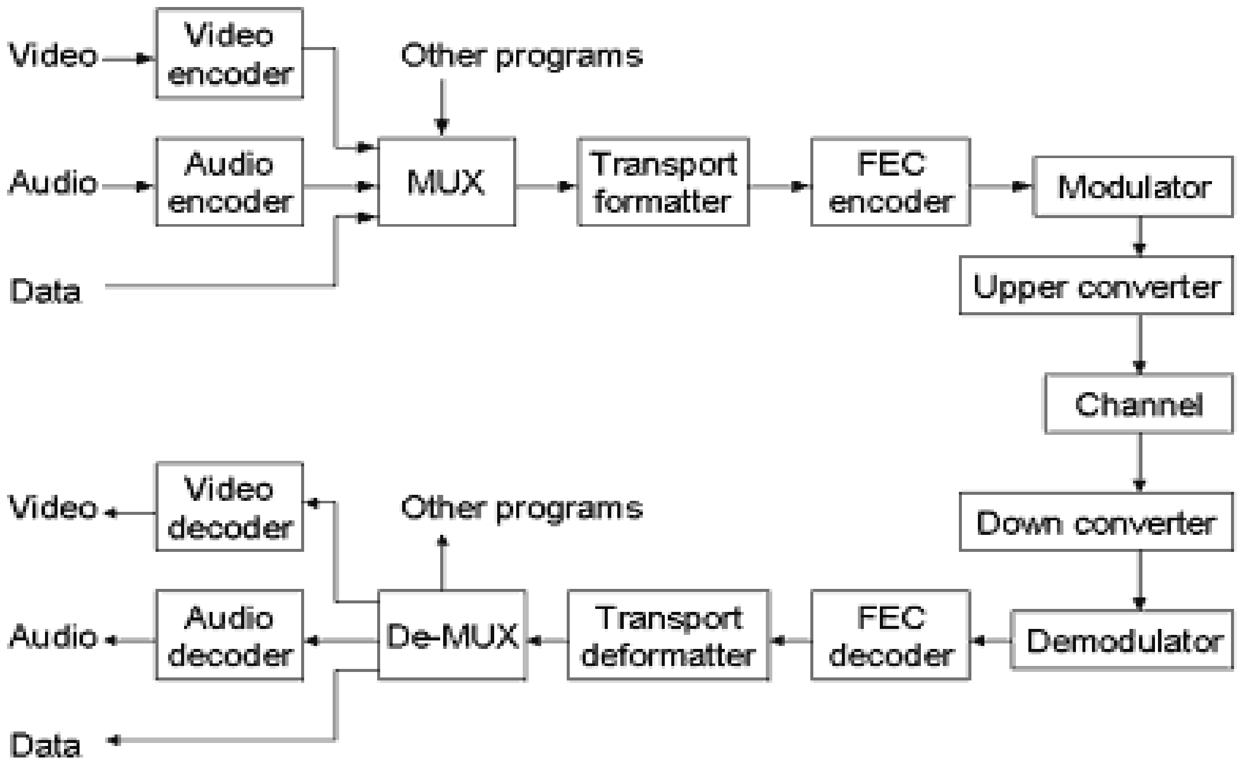
that given the bandwith and power available, we assess the number and quality of TV channels that we can have and if there is some discrepancy whether or not it is possible to close the gap by improving the design.
Following is a block diagram of a TV broadcasting system:



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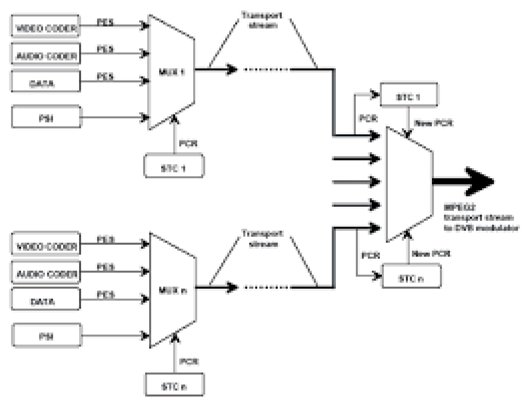
The first piece of equipment is the encoder. As we saw before it consists of a Video Encoder and an Audio Encoder. Multiplexer can combine the Video and Audio outputs with programming data to make a SPTS (Single Program Transport Stream). However, most often, programs are delivered in bundle. That is several programs with the same format, for example sport channels, drama channels or comedy channels can be put together to form a so called **Bouquet** (in Europe) and **virtual sub-channel** (US and Canada).



In this case the multiplexer (MUX) takes in the output of several encoders and combines them into an MPTS (Multiple Program Transport Stream). It regenerates the PSI and may also provide for PID Re-mapping, Service Filtering,

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and PSI/SI Editing or to Insert Electronic Program Guides, Conditional Access, and Other Data. These extra capabilities allow the station to remove a program or do drop and add on permanent of temporary basis. For example a children channel that is viewed only during certain times during the day can be replaced by another program with audiences outside the children's viewing hours.

The Transport Formatter may also be part of the MUX. It generates the ASI (Asynchronous Serial Interface) discussed in Lecture 2.

The next block is the FEC encoder that optionally implements the Reed Solomon (RS) code and convolutional code discussed in Lecture 6. While the block diagram shown divides the functions very finely, the physical location of each function may be implementation dependent. For example while RS and convolutional coding may both be considered channel coding functions RS coding may be done at the output of the MUX as part of forming the transport streams in the ASI while convolutional coding may be integrated with the modulation process and performed in the modulator.

Modulator performs the conversion from a bit stream into a waveform. The output of the modulator will be a **baseband** signal, i.e., a signal centered around zero frequency one half of the symbol rate.

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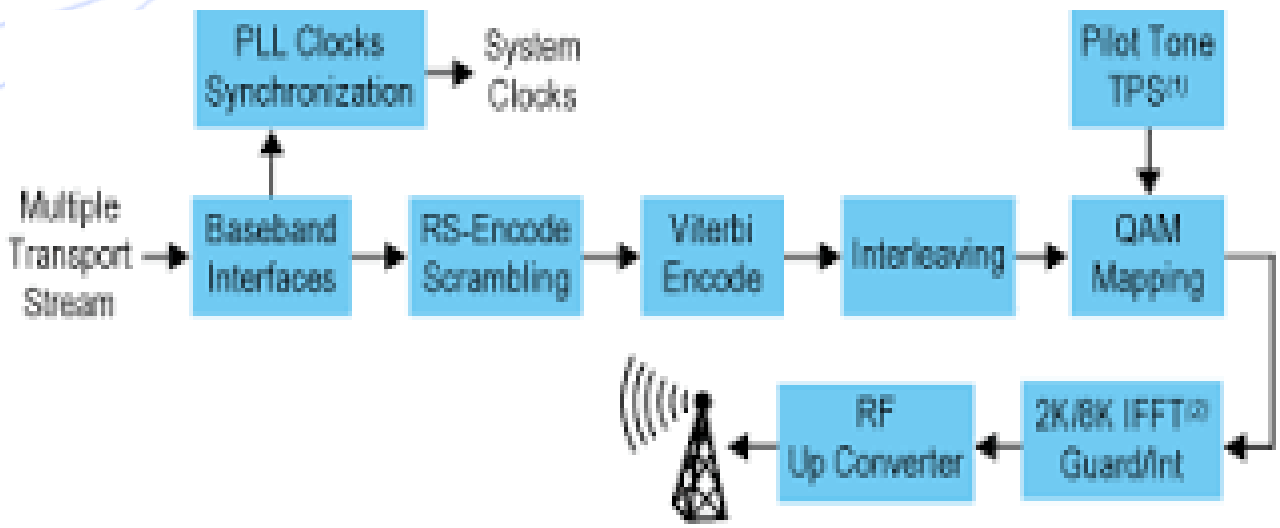
This figure shows the block diagram of a DVB-T modulator:



The two blocks that we have not talked about are the **interleaver** and the inverse Fast Fourier Transform (IFFT). An interleaver is used in order to spread the bits according to a certain pattern throughout the data stream and later return them

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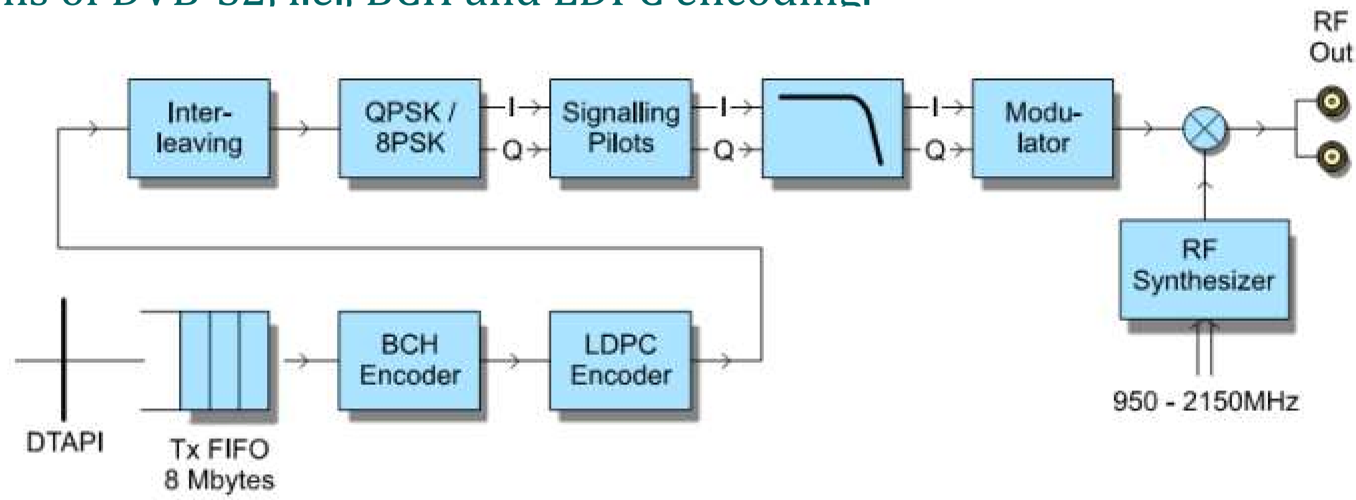
back to the original order at the receiver end by doing de-interleaving. The objective is to combat against the fading by letting the effect of a long fade be spread. That is a burst of errors due to fading of a signal does not affect a whole codeword making the FEC useless.

IFFT is part of the Orthogonal Frequency Division Multiplexing (OFDM).

This figure shows the block diagram of a DVB-S modulator with optional FEC functions of DVB-S2, i.e., BCH and LDPC encoding.



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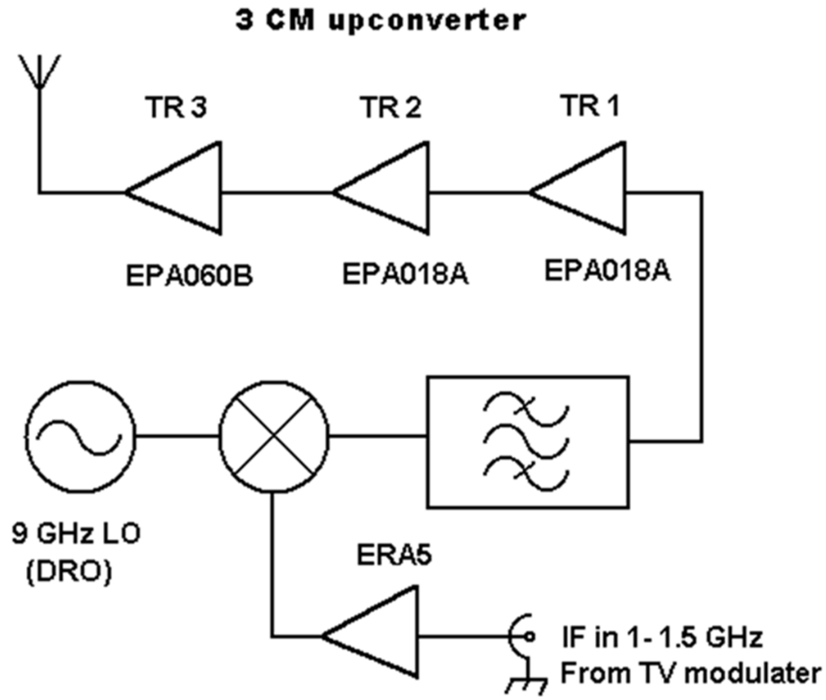
In the above system an upconverter takes the output of the modulator to a frequency range used by the terrestrial communication systems (cell phones). This is called L band. Following diagram shows a Block Upconverter (BUC) translating the signal to Ku-band. A BUC includes upconverter plus the amplifier.



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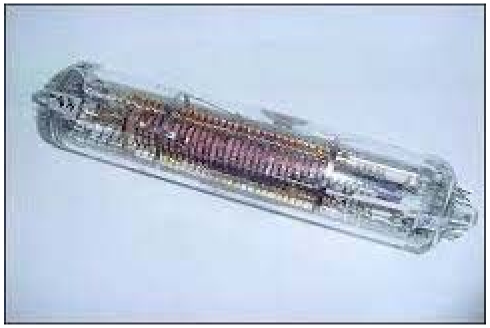
The amplifiers used are called High Power Amplifier (HPA). This is to make them distinct from the amplifiers in different parts of the transmission circuitry, for example , in modulator or demodulator used to make signals strong enough for further processing.

HPA's may be implemented using Travelling Wave Tubes (TWT). IN such a case they are called Travelling Wave Tube Amplifier (TWTA). A TWTA in addition to the tube has power supply and control circuitry required to adjust the gain and frequency.



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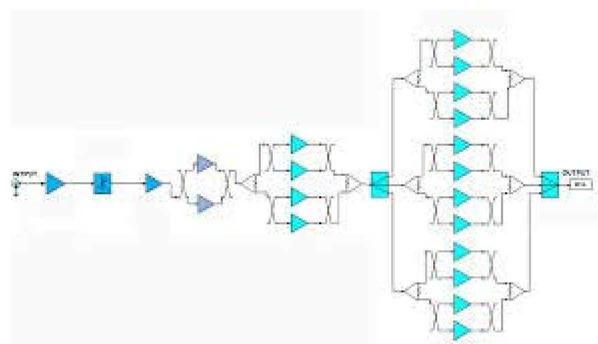
High Power Amplifiers can be also built using Power Transistors. In this case, the amplifier is called Solid State Power Amplifier (SSPA) or Solid State Power Block (SSPB) if it is integrated with an upconverter.

SSPA's are usualy built in multiple stages, co-phasing amplifiers with lower power made by transistors of rating less than the final product.



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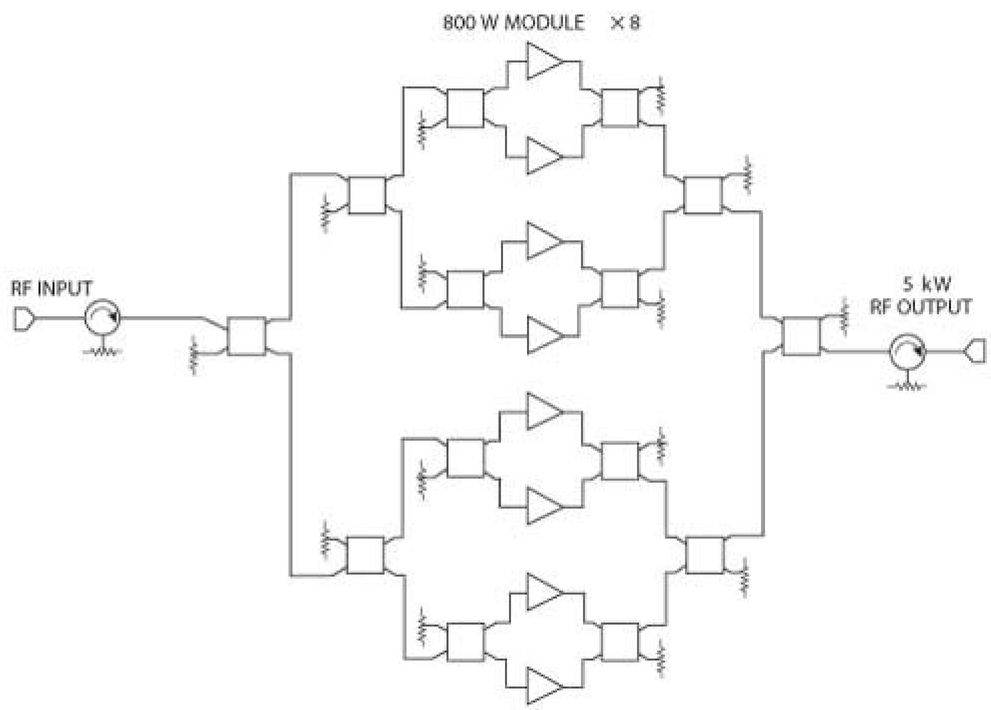
Following is the implementation of a 5 kW SSPA using eight 800 W transistors:



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The rest of equipment on the diagram on Slide 4 are the counterparts of the equipment mentioned above. For example, each encoder has a decoder to undo what the encoder has done and any modulator at the transmit side requires a demodulator at the receiver side. The channel is any medium used to convey the signal in the case of the satellite and terrestrial TV, it consists of a transmit and a receive antenna coupled through the air. The characteristics of the channel and the mathematical model representing it may differ depending on the location and, possibly, the movement of the antennas, objects blocking the electromagnetic field between the two antennas, etc. In this course, we consider stationary antennas and Line of Sight (LOS) path between the two antennas. This is valid when the two antennas "see" each other and there is a single path between them. This model is accurate when the antennas are installed high enough so that one can ignore the ground reflection and also there are not objects blocking, scattering or refracting the electromagnetic rays.

Finally, in order to bring down the spectrum to baseband, we need a down converter after the antenna and before feeding the signal to the receiver. Low Noise Amplifier (LNA) may be integrated with the down converter . The combined unit is called A Low Noise Block (LNB).

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In previous lectures, we discussed the relationship between the Bit Error Rate (BER) and the received $\frac{E_b}{N_0} = \frac{W}{R_b} . \frac{P_r}{N}$ where $\frac{P_r}{N}$ is the ratio of the received signal power to the noise power.

We now try to find $\frac{P_r}{N}$ for a given link consisting of the elements shown in the slide shown on slide 4. What we will do is first to multiply the transmitter power by all the gains such as amplification, antenna gain, etc. and then divide the result by all different attenuations in order to find the power at the receiver (P_r). Then we add all sources of noise in order to come up with the noise power N. Finally, we divide P_r by N to get $\frac{P_r}{N}$. Of course when the quantities are in dB the multiplication and division are replaced by addition and subtraction. This procedure is called **Link Budget** calculation and is quite straightforward and can be done using an spreadsheet program. There are a lot of free software doing this. In fact almost any satellite service provider or equipment manufacturer for terrestrial and satellite systems has one on its website.

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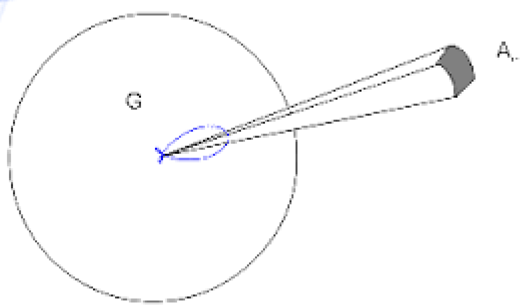
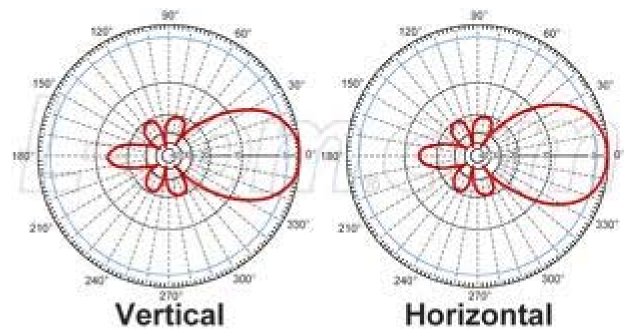
The first thing to consider is the transmit power P_t. This is the power at the output of HPA. This is the power delivered to the transmit antenna. The electromagnetic field leaving the antenna spreads radially and at a distance the power density is $\frac{P_t}{4\pi d^2}$ where $4\pi d^2$ is the surface area of a sphere centered at the transmitter and radius d.





This formula is only valid if the electromagnetic wave travels at all directions, i.e., when the antenna is isotropic. Usually antennas are directive, that is, the radiation is more concentrated in a certain direction. The gain of the antenna is the ratio of the total volume of the sphere to that of the solid angle. The power density of a system using a transmit antenna with gain G_T is $\frac{P_t G_t}{4\pi d^2}$.

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The received power P_r is proportional to the effective area of the receive antenna. So,

$$P_r = \frac{P_t G_t}{4\pi d^2} A_{e,r}$$

The relationship between the gain and the effective area of and antenna (also called antenna aperture) is:

$$G = \frac{4\pi A_e}{\lambda^2}$$

where $\lambda = \frac{c}{f}$

Is the wavelength of the transmitter signal.

So the effective area of the receive antenna is,

$$A_{e,r} = \frac{\lambda^2}{4\pi} G_r.$$

Substituting this in the formula for the received power, we get,

$$P_r = \frac{P_t G_t G_r}{\left(\frac{4\pi d}{\lambda}\right)^2} = \frac{P_t G_t G_r}{L_s}$$

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where L_s is called space loss or path loss and represents the effect of the distance between the transmit and receive antennas. If there are other losses such as those in cables and connectors, we lump them together and denote them L_o for other losses. So,

$$P_r = \frac{P_t G_t G_r}{L_s L_o}$$

Changing the received power into dBW (dB Watt), we have,

$$P_r = P_t + G_t + G_r - L_s.$$

Where P_t and P_r are in dBW or dBm (dB mW), G_t and G_r are in dBi (dB compared to an isotropic antenna) and L_s and L_o are in dB.

$$L_s = 10\log\left(\frac{4\pi d}{\lambda}\right)^2.$$

Note: Decibel (dB) takes the unit of the quantity it is applied to so if power is in Watts, we have dBW, if it is in mW then its decibel value is in dBm. Take 100 Watts of power. It is 20 dBW. But since it is 100,000 mW, it is 50 dBm. The value in dBm is 30 dB higher than the dBW value. Dimensionless entities such as gain are just in dB. One P_r is found, we can find $E_b = \frac{P_r}{R_b}$.

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Example: A transmitter transmits with 50 W power at a frequency of 10 GHz. to a satellite at a satellite at a Geostationary orbit (at an altitude of 36000 km.). Find the received power at the satellite if the Earth station antenna has a diameter of 2 m. and efficiency of $\eta = 0.65$. Assume that the receive antenna at the satellite has a gain of 45 dBi.

Solution: The gain of the transmit antenna is,

$$G_t = \frac{4\pi}{\lambda^2} A_{e,t}$$

where $\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03$ m. and $A_{e,t} = \left(\frac{D}{2}\right)^2 \pi\eta = \left(\frac{2}{2}\right)^2 \pi \times 0.65 = 2.04$.

So, $G_t = \frac{4\pi}{(0.03)^2} \times 2.04 = 28{,}484$ or 44.55 dBi.

$P_t = 10\log(50) \approx 17 dBW = 47\ dBm$.

$L_s = 10\log\left(\frac{4\pi\times36\times10^6}{0.03}\right)^2 = 203.57\ dB$.

Therefore,

$$P_r = 47 + 44.55 + 45 - 203.57 \approx -67\ dBm \text{ or -97 dBW.}$$

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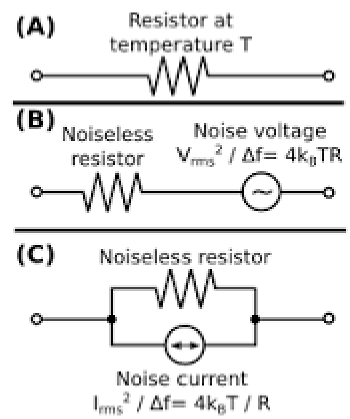
We have talked about how to find the power at the receiver P_r and, therefore, E_b. Now, let's find N_0. The noise generated by a circuit with resistance R at a temperature T and bandwidth W is given by $4k_B TRW$ where $k_B = 1.38 \times 10^{-23}$ is called the Boltzmann constant. This is called the thermal noise. It has a flat spectral density over the frequency band and is distributed according to Gaussian distribution. That is why it is called Additive White Gaussian Noise (AWGN).

Modelling the noise source with a voltage source $\sqrt{4k_B TRW}$ and a resistor T, we find the maximum power that it can deliver to a load is $N = k_B TW$. This happens when the load has a resistance equal to R.

Dividing N by W, we get the noise density $N_0 = k_B T$. T is called the noise temperature.



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Communication links such a broadcasting systems consists of different equipment in cascade. For example, a home TV reception system has antenna connected to LNB, down converter, then to the coaxial cable, the power amplifier, the receiver, etc. Each of these components can be modeled with a gain (or a loss that can be considered as a gain of less than unity).

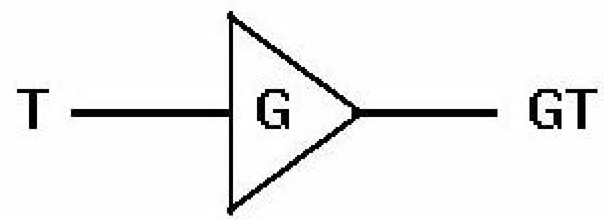

Figure 1. An ideal noiseless amplifier.

It would not be realistic to assume any component to be noise free. Themodel with noise included is,

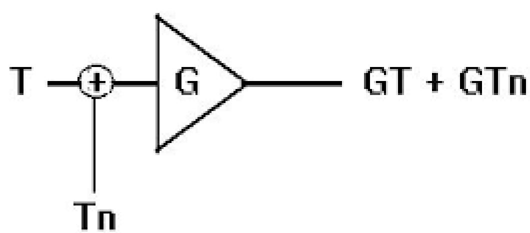

Figure 2. An amplifier with noise temperature Tn.

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Now, assume that two components with Gains G_1 and G_2 and noise temperatures T_1 and T_2 are connected together to a noise source T.

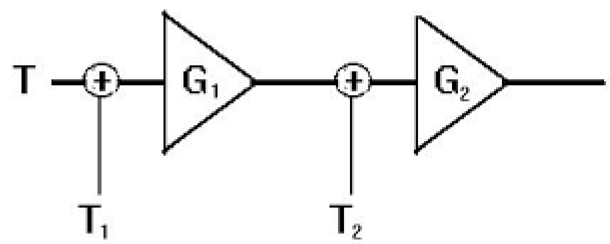

Figure 3. Two cascaded amplifiers.

The overall gain will be G_1G_2 and the noise power added by the system to T will be $[T_1G_1 + T_2]G_2$. Now lets define an equivalent noise temperature for the system. We have,

$$[T_1G_1 + T_2]G_2 = T_{eq}G_1G_2.$$

So, $T_{eq} = T_1 + \frac{T_2}{G_1}$

In general, for n stages, we have,

$$T_{eq} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1G_2} + \cdots$$

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Noise Factor is another quantity used to quantify how noisy a circuit, most often an amplifier, is. It is the ratio of the Signal-to-Noise Ratio (SNR) at the input of a circuit to the SNR at the output of the circuit. So, it can not be less than one,

$$F = \frac{SNR_{in}}{SNR_{out}} \geq 1.$$

Let the input power be S_{in} and the noise power at the input be $N_{in} = k_B T_{in}$.
Then $SNR_{in} = \frac{S_{in}}{N_{in}} = \frac{S_{in}}{k_B T_{in}}$.
Taking the gain and the noise temperature of the circuit as G and T, respectively, we have $SNR_{out} = \frac{GS_{in}}{k_B G(T_{in}+T)}$. Therefore,

$$F = \frac{\frac{S_{in}}{k_B T_{in}}}{\frac{GS_{in}}{k_B G(T_{in}+T)}} 1 + \frac{T}{T_{in}}.$$

Or $T = (F-1)T_{in}$. To have a common base for comparing the different amplifiers, the input (or ambient) noise temperature is fixed at 290 degrees Kelvin. So, T=290(F-1). The noise factor in dB is called the Noise Figure,

$$NF = 10\log(F) = 10\log\left(1 + \frac{T}{290}\right)$$