MODULE 2 – LINK DESIGN:
WEEK 2 & 3

S4: T*ypes of FEC, Computer Aided Design*

S5: Uplink, Saturation flux Density, input backoff

S6: Downlink, TWTA output, Output backoff

S7: Effects of rain, Intermodulation noise

S8 & S9: Problems

FORWARD ERROR CORRECTION

In telecommunication and information theory, forward error correction (FEC) is a system of error control for data transmission, whereby the sender adds redundant data to its messages, also known as an error correction code.

This allows the receiver to detect and correct errors (within some bound) without the need to ask the sender for additional data.

FEC devices are often located close to the receiver of an analog signal, in the first stage of digital processing after a signal has been received.

FEC circuits are often an integral part of the analog-to-digital conversion process, also involving digital modulation and demodulation, or line coding and decoding.

How It Works?

FEC is accomplished by adding redundancy to the transmitted information using a predetermined algorithm. Each redundant bit is invariably a complex function of many original information bits.

- The original information may or may not appear in the encoded output; codes that include the unmodified input in the output are systematic, while those that do not are non-systematic.

Example Of Working Of FEC

An extremely simple example would be an analog to digital converter that samples three bits of signal strength data for every bit of transmitted data.

- If the three samples are mostly zero, the transmitted bit was probably a zero, and if three samples are mostly one, the transmitted bit was probably a one.

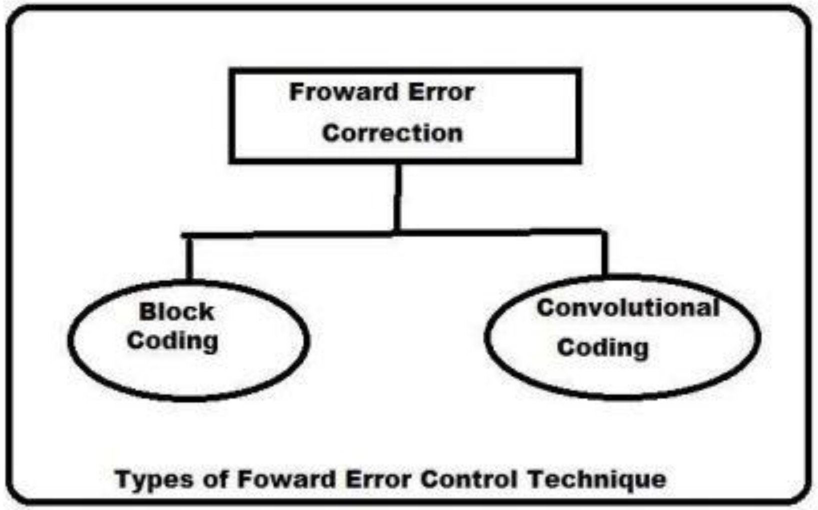
ADVANTAGE AND USE:

The advantage of forward error correction is that a back-channel is not required, or that retransmission of data can often be avoided, at the cost of higher bandwidth requirements on average.

FEC is therefore applied in situations where retransmissions are relatively costly or impossible.

In particular, FEC information is usually added to most mass storage devices to protect against damage to the stored data.

TYPES OF FEC



Froward Error Correction
Block Coding
Convolutional Coding
Types of Foward Error Control Technique

BLOCK CODING:

□Block codes work on fixed-size blocks (packets) of bits or symbols of predetermined size. Practical block codes can generally be hard-decoded in polynomial time to their block length.

□There are many types of block codes, but among the classical ones the most notable is Reed Solomon coding because of its widespread use on the compact disc, the DVD, and in hard disk drives.

□Classical block codes are usually decoded using hard-decision algorithms, which means that for every input and output signal a hard decision is made whether it corresponds to a one or a zero bit.

□Other examples of classical block codes include Go-lay, BCH, Multidimensional parity, and Hamming codes.

CONVOLUTIONAL CODING:

- Convolutional codes work on bit or symbol streams of arbitrary length.

- Convolutional codes are typically decoded using soft-decision algorithms like the Viterbi, MAP or BCJR algorithms, which process (discretized) analog signals, and which allow for much higher error-correction performance than hard-decision decoding.

- They are most often soft decoded with the Viterbi algorithm, though other algorithms are sometimes used.

- Viterbi decoding allows asymptotically optimal decoding efficiency with increasing constraint length of the convolutional code, but at the expense of exponentially increasing complexity.

- A convolutional code that is terminated is also a 'block code' in that it encodes a block of input data, but the block size of a convolutional code is generally arbitrary, while block codes have a fixed size dictated by their algebraic characteristics.

- Types of termination for convolutional codes include "tail-biting" and "bit-flushing".

INTERLEAVING

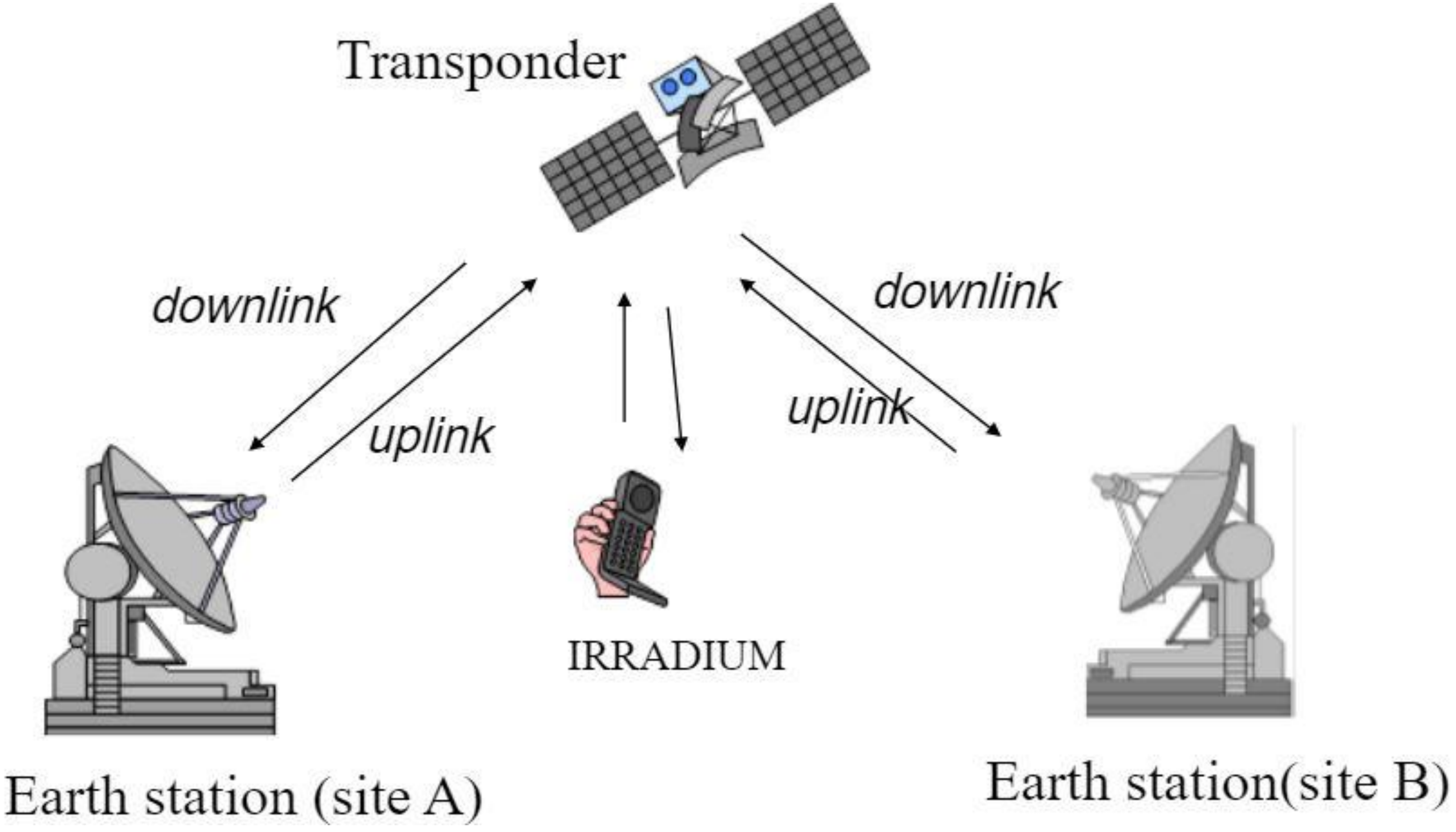
Interleaving is frequently used in digital communication and storage systems to improve the performance of forward error correcting codes.

Many communication channels are not memoryless: errors typically occur in bursts rather than independently. If the number of errors within a code word exceeds the error-correcting code's capability, it fails to recover the original code word.

Interleaving ameliorates this problem by shuffling source symbols across several code words, thereby creating a more uniform distribution of errors

S5: UPLINK, SATURATION FLUX DENSITY,
INPUT BACKOFF
S6: DOWNLINK,
TWTA OUTPUT, OUTPUT BACKOFF
S7: EFFECTS OF RAIN,
INTERMODULATION NOISE
S8 & S9: PROBLEMS

UPLINK & DOWNLINK DESIGN



The Uplink of a satellite circuit is the one in which the earth station is transmitting signal and satellite is receiving it.

Subscript U will be used to denote the specifically the uplink is being considered.

$$[Lp] + [Lu] = [LOSSES]$$

$$[C/N_0]_U = [EIRP]_U + [G/T]_U - [LOSSES]_U - [k]$$

SATURATION FLUX DENSITY

The traveling-wave tube amplifier (TWTA) in a satellite transponder exhibits power output saturation The flux density required at the receiving antenna to produce saturation of the TWTA is termed the saturation flux density. The saturation flux density is a specified quantity in link budget calculations, and knowing it, one can calculate the required EIRP at the earth station.

To show this, consider again Eq. which gives the flux density in terms of EIRP, repeated here for convenience:

$$\Psi_M = \frac{\text{EIRP}}{4\pi r^2}$$

In decibel notation this is

$$[\Psi_M] = [\text{EIRP}] + 10 \log \frac{1}{4\pi r^2}$$

But from Eq. (12.9) for free-space loss we have

$$-[\text{FSL}] = 10 \log \frac{\lambda^2}{4\pi} + 10 \log \frac{1}{4\pi r^2}$$

Substituting this in Eq. (12.40) gives

$$[\Psi_M] = [\text{EIRP}] - [\text{FSL}] - 10 \log \frac{\lambda^2}{4\pi}$$

The $\lambda^2/4\pi$ term has dimensions of area, and in fact, from Eq. it is the effective area of an isotropic antenna. Denoting this by A_0 gives

$$[A_0] = 10 \log \frac{\lambda^2}{4\pi}$$

SATURATION FLUX DENSITY

Since frequency rather than wavelength is normally known, it is left as an exercise for the student to show that with frequency f in gigahertz, Eq. (12.43) can be rewritten as

$$[A_0] = -\,(21.45 + 20 \log f)$$

Combining this with Eq. and rearranging slightly gives the EIRP as

$$[\mathrm{EIRP}] = [\Psi_M] + [A_0] + [\mathrm{FSL}]$$

Equation (12.45) was derived on the basis that the only loss present was the spreading loss, denoted by [FSL]. But, as shown in the previous sections, the other propagation losses are the atmospheric absorption loss, the polarization mismatch loss, and the antenna misalignment loss. When allowance is made for these, Eq. becomes

$$[\mathrm{EIRP}] = [\Psi_M] + [A_0] + [\mathrm{FSL}] + [\mathrm{AA}] + [\mathrm{PL}] + [\mathrm{AML}]$$

SATURATION FLUX DENSITY

$$[\text{EIRP}] = [\Psi_M] + [A_0] + [\text{LOSSES}] - [\text{RFL}]$$

This is for clear-sky conditions and gives the *minimum* value of [EIRP] which the earth station must provide to produce a given flux density at the satellite. Normally, the saturation flux density will be specified. With saturation values denoted by the subscript S, Eq. is rewritten as

$$[\text{EIRP}_S]_U = [\Psi_S] + [A_0] + [\text{LOSSES}]_U - [\text{RFL}]$$

Example An uplink operates at 14 GHz, and the flux density required to saturate the transponder is −120 dB(W/m^2). The free-space loss is 207 dB, and the other propagation losses amount to 2 dB. Calculate the earth-station [EIRP] required for saturation, assuming clear-sky conditions. Assume [RFL] is negligible.

solution At 14 GHz,

$$[A_0] = -(21.45 + 20 \log 14) = -44.37 \text{ dB}$$

The losses in the propagation path amount to 207 + 2 = 209 dB. Hence, from Eq. (12.48),

$$[\text{EIRP}_S]_U = -120 - 44.37 + 209$$

$$= 44.63 \text{ dBW}$$

INPUT BACKOFF

Defi: The level of a signal at the input of an amplifier relative to that level at the input that would result in the maximum possible output level.

used to determine the operating power levels required in a satellite transponder TWTA

As described in Sec. , where a number of carriers are present simultaneously in a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of intermodulation distortion. Such multiple carrier operation occurs with frequency-division multiple access (FDMA) and is described in The point to be made here is that backoff must be allowed for in the link budget calculations.

Suppose that the saturation flux density for single-carrier operation is known. Input backoff will be specified for multiple-carrier operation, referred to the single-carrier saturation level. The earth station EIRP will have to be reduced by the specified backoff (BO), resulting in an uplink value of

$$[\mathrm{EIRP}]_U = [\mathrm{EIRP}_S]_U - [\mathrm{BO}]_i$$

Although some control of the input to the transponder power amplifier is possible through the ground TT&C station, as described in Sec. input backoff is normally achieved through reduction of the [EIRP] of the earth stations actually accessing the transponder.

$$\left[\frac{C}{N_o}\right]_U = [\Psi_S] + [A_0] - [\mathrm{BO}]_i + \left[\frac{G}{T}\right]_U - [k] - [\mathrm{RFL}]$$

DOWNLINK

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Equation (12.38) can be applied to the downlink, but subscript D will be used to denote specifically that the downlink is being considered. Thus Eq. (12.38) becomes

$$\left[\frac{C}{N_o}\right]_D = [\mathrm{EIRP}]_D + \left[\frac{G}{T}\right]_D - [\mathrm{LOSSES}]_D - [k] \qquad (12.53)$$

In Eq. (12.53) the values to be used are the satellite EIRP, the earth station receiver feeder losses, and the earth station receiver G/T. The free-space and other losses are calculated for the downlink frequency. The resulting carrier-to-noise density ratio given by Eq. (12.53) is that which appears at the detector of the earth station receiver.

Where the carrier-to-noise ratio is the specified quantity rather than carrier-to-noise density ratio, Eq. (12.38) is used. This becomes, on assuming that the signal bandwidth B is equal to the noise bandwidth B_N:

$$\left[\frac{C}{N}\right]_D = [\mathrm{EIRP}]_D + \left[\frac{G}{T}\right]_D - [\mathrm{LOSSES}]_D - [k] - [B] \quad (12.54)$$

DOWNLINK

Example A satellite TV signal occupies the full transponder bandwidth of 36 MHz, and it must provide a C/N ratio at the destination earth station of 22 dB. Given that the total transmission losses are 200 dB and the destination earth station G/T ratio is 31 dB/K, calculate the satellite EIRP required.

$$[\text{EIRP}]_D = \left[\frac{C}{N}\right]_D - \left[\frac{G}{T}\right]_D + [\text{LOSSES}]_D + [k] + [B]$$

Setting this up in tabular form, and keeping in mind that $+[k] = -228.6$ dB and that losses are numerically equal to +200 dB, we obtain

Quantity	Decilogs
$[C/N]$	22
$-[G/T]$	−31
[LOSSES]	200
$[k]$	−228.6
$[B]$	75.6
[EIRP]	38

The required EIRP is 38 dBW or, equivalently, 6.3 kW.

OUTPUT BACKOFF DOWNLINK

Where input back-off is employed as described in Sec. , a corresponding output back-off must be allowed for in the satellite EIRP. As the curve of Fig. shows, output back-off is not linearly related to input backoff. A rule of thumb frequently used is to take the output backoff as the point on the curve which is 5 dB below the extrapolated linear portion, as shown in Fig. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output backoff is $[BO]_o = [BO]_i - 5$ dB. For example, with an input back-off of $[BO]_i = 11$ dB, the corresponding output back-off is $[BO]_o = 11 - 5 = 6$ dB.

If the satellite EIRP for saturation conditions is specified as $[EIRP_S]_D$, then $[EIRP]_D = [EIRP_S]_D - [BO]_o$ and Eq. becomes

$$\left[\frac{C}{N_o}\right]_D = [EIRP_S]_D - [BO]_o + \left[\frac{G}{T}\right]_D - [LOSSES]_D - [k]$$

PROBLEMS

Example The specified parameters for a downlink are satellite saturation value of EIRP, 25 dBW; output backoff, 6 dB; free-space loss, 196 dB; allowance for other downlink losses, 1.5 dB; and earth station G/T, 41 dBK^{-1}. Calculate the carrier-to-noise density ratio at the earth station.

solution As with the uplink budget calculations, the work is best set out in tabular form with the minus signs in Eq attached to the tabulated values.

Quantity	Decilogs
Satellite saturation [EIRP]	25.0
Free-space loss	−196.0
Other losses	−1.5
Output backoff	−6.0
Earth station [G/T]	41.0
$-[k]$	228.6
Total	91.1

The total gives the carrier-to-noise density ratio at the earth station in dBHz, as calculated from

For the uplink, the saturation flux density at the satellite receiver is a specified quantity. For the downlink, there is no need to know the saturation flux density at the earth station receiver, since this is a terminal point, and the signal is not used to saturate a power amplifier.

TWTA OUTPUT DOWNLINK

The satellite power amplifier, which usually is a traveling-wave tube amplifier, has to supply the radiated power plus the transmit feeder losses. These losses include the waveguide, filter, and coupler losses between the TWTA output and the satellite's transmit antenna. Referring back to Eq. , the power output of the TWTA is given by

$$[P_{\mathrm{TWTA}}] = [\mathrm{EIRP}]_D - [G_T]_D + [\mathrm{TFL}]_D$$

Once $[P_{\mathrm{TWTA}}]$ is found, the saturated power output rating of the TWTA is given by

$$[P_{\mathrm{TWTA}}]_S = [P_{\mathrm{TWTA}}] + [\mathrm{BO}]_o$$

Example A satellite is operated at an EIRP of 56 dBW with an output backoff of 6 dB. The transmitter feeder losses amount to 2 dB, and the antenna gain is 50 dB. Calculate the power output of the TWTA required for full saturated EIRP.

solution Equation

$$[P_{\text{TWTA}}] = [\text{EIRP}]_D - [G_T]_D + [\text{TFL}]_D$$

$$= 56 - 50 + 2$$

$$= 8 \text{ dBW}$$

$$[P_{\text{TWTA}}]_S = 8 + 6$$

$$= 14 \text{ dBW (or 25 W)}$$

EFFECTS OF RAIN

- The traveling-wave tube amplifier (TWTA) in a satellite transponder exhibits power output saturation
- The flux density required at the receiving antenna to produce saturation of the TWTA is termed the saturation flux density.
- The saturation flux density is a specified quantity in link budget calculations, and knowing it, one can calculate the required EIRP at the earth station.
- To show this, consider again Eq. which gives the flux density in terms of EIRP, repeated here for convenience:
- Up to this point, calculations have been made for clear-sky conditions, meaning the absence of weather-related phenomena which might affect the signal strength. In the C band and, more especially, the Ku band, rainfall is the most significant cause of signal fading.
- Rainfall results in attenuation of radio waves by scattering and by absorption of energy from the wave, as described in Sec.

- Rain attenuation is accompanied by noise generation, and both the attenuation and the noise adversely affect satellite circuit performance.
- Rain attenuation increases with increasing frequency and is worse in the Ku band com- pared with the C band. Studies have shown (CCIR Report 338-3, 1978) that the rain attenuation for horizontal polarization is considerably greater than for vertical polarization.

- As a result of falling through the atmosphere, raindrops are some- what flattened in shape, becoming elliptical rather than spherical.
- When a radio wave with some arbitrary polarization passes through raindrops, the component of electric field in the direction of the major axes of the raindrops will be affected differently from the component along the minor axes.
- This produces a depolarization of the wave; in effect, the wave becomes elliptically polarized
- This is true for both linear and circular polarizations, and the effect seems to be much worse for circular polarization
- Rain falling on a hemispherical radome forms a water layer of constant thíckness. Such a layer introduces losses both by absorption and by reflection.

UPLINK RAIN FADE MARGIN

Rainfall results in attenuation of the signal and an increase in noise temperature, degrading the [CIN] at the satellite in two ways.

The increase in noise, however, is not usually a major factor for the uplink. This is so because the satellite antenna is pointed toward a "hot" earth, and this added to the satellite receiver noise temperature tends to mask any additional noise induced by rain attenuation. What is important is that the uplink carrier power at the satellite must be held within close limits for certain modes of operation, and some form of uplink power control is necessary to compensate for rain fades.

The power output from the satellite may be monitored by a central control station or in some cases by each earth station, and the power output from any given earth station may be increased if required to compensate for fading.

Thus the earth-station HPA must have sufficient reserve power to meet the fade margin requirement.. As an example, for Ottawa, the rain attenuation exceeds 1.9 dB for 0.1 per- cent of the time. This means that to meet the specified power requirements at the input to the satellite for 99.9 percent of the time, the earth station must be capable of providing a 1.9-dB margin over the clear-sky conditions.

DOWNLINK RAIN FADE MARGIN

The results given by Eqs. and are for clear-sky conditions. Rainfall introduces attenuation by absorption and scattering of signal energy, and the absorptive attenuation introduces noise as discussed in Sec. Let $[A]$ dB represent the rain attenuation caused by absorption. The corresponding power loss ratio is $A = 10^{[A]/10}$, and substituting this for L in Eq. gives the effective noise temperature of the rain as

$$T_{\text{rain}} = T_a \left(1 - \frac{1}{A}\right)$$

Here, T_a, which takes the place of T_x in Eq. , is known as the *apparent absorber temperature*. It is a measured parameter which is a function of many factors including the physical temperature of the rain and the scattering effect of the rain cell on the thermal noise incident upon it (Hogg and Chu, 1975). The value of the apparent absorber temperature lies between 270 and 290 K, with measured values for North America lying close to or just below freezing (273 K). For example, the measured value given by Webber et al. (1986) is 272 K.

The total sky-noise temperature is the clear-sky temperature T_{CS} plus the rain temperature:

$$T_{\text{sky}} = T_{\text{CS}} + T_{\text{rain}}$$

Rainfall therefore degrades the received $[C/N_o]$ in two ways: by attenuating the carrier wave and by increasing the sky-noise temperature.

COMBINED UPLINK & DOWNLINK

The complete satellite circuit consists of an uplink and a downlink, as sketched in Fig . Noise will be introduced on the uplink at the satellite receiver input. Denoting the noise power per unit bandwidth by P_{NU} and the average carrier at the same point by P_{RU}, the carrier-to-noise ratio on the uplink is $(C/N_o)_U = (P_{RU}/P_{NU})$. It is important to note that power levels, and not decibels, are being used here.

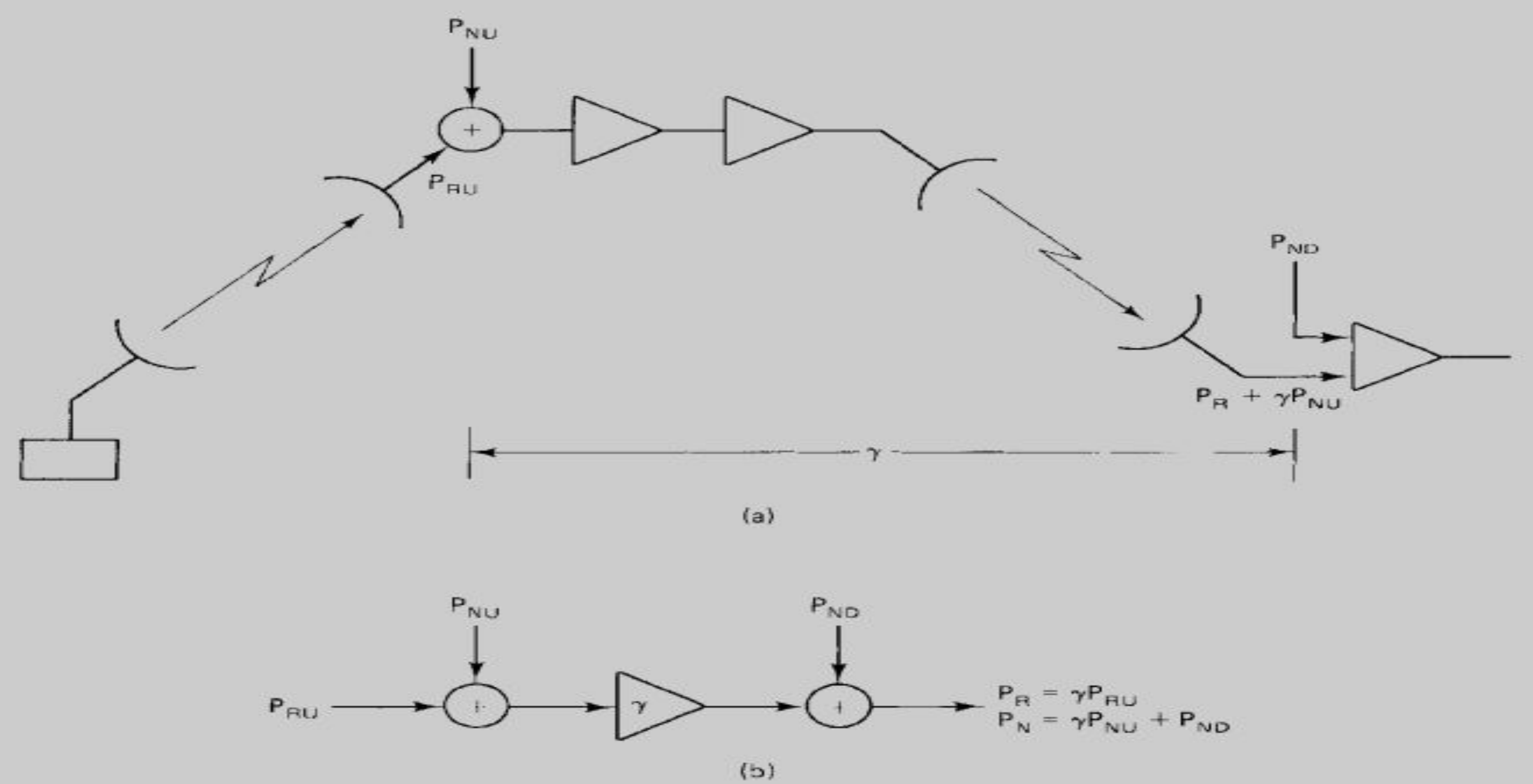


Figure (*a*) Combined uplink and downlink; (*b*) power flow diagram for (*a*).

COMBINED UPLINK & DOWNLINK

The C/N_o ratio for the downlink alone, not counting the γP_{NU} contribution, is P_R/P_{ND}, and the combined C/N_o ratio at the ground receiver is $P_R/(\gamma P_{NU} + P_{ND})$. The power flow diagram is shown in Fig. The combined carrier-to-noise ratio can be determined in terms of the individual link values. To show this, it is more convenient to work with the noise-to-carrier ratios rather than the carrier-to-noise ratios, and again, these must be expressed as power ratios, not decibels. Denoting the combined noise-to-carrier ratio value by N_o/C, the uplink value by $(N_o/C)_U$, and the downlink value by $(N_o/C)_D$ then,

$$\begin{aligned}
\frac{N_o}{C} &= \frac{P_N}{P_R} \\
&= \frac{\gamma P_{NU} + P_{ND}}{P_R} \\
&= \frac{\gamma P_{NU}}{P_R} + \frac{P_{ND}}{P_R} \\
&= \frac{\gamma P_{NU}}{\gamma P_{RU}} + \frac{P_{ND}}{P_R} \\
&= \left(\frac{N_o}{C}\right)_U + \left(\frac{N_o}{C}\right)_D
\end{aligned}$$

PROBLEMS

Example - - For a satellite circuit the individual link carrier-to-noise spectral density ratios are: uplink 100 dBHz; downlink 87 dBHz. Calculate the combined C/N_o ratio.

solution

$$\frac{N_o}{C} = 10^{-10} + 10^{-8.7} = 2.095 \times 10^{-9}$$

Therefore,

$$\left[\frac{C}{N_o}\right] = -10 \log (2.095 \times 10^{-9}) = 86.79 \text{ dBHz}$$

Example - - illustrates the point that when one of the link C/N_o ratios is much less than the other, the combined C/N ratio is approximately equal to the lower (worst) one. The downlink C/N is usually (but not always) less than the uplink C/N, and in many cases it is much less. This is true primarily because of the limited EIRP available from the satellite.

INTERMODULATION NOISE

Intermodulation occurs where multiple carriers with nonlinear characteristics. In satellite communications systems, this most commonly occurs in the traveling-wave tube high-power amplifier aboard the satellite, Both amplitude and phase nonlinearities give rise to intermodulation products.

Third-order intermodulation products fall on neighboring carrier frequencies, where they result in interference. Where a large number of modulated carriers are present, the inter- modulation products are not distinguishable separately but instead appear as a type of noise which is termed intermodulation noise.

$$\frac{N_o}{C} = \left(\frac{N_o}{C}\right)_U + \left(\frac{N_o}{C}\right)_D + \left(\frac{N_o}{C}\right)_{\mathrm{IM}}$$

The carrier-to-intermodulation-noise ratio is usually found experimentally, or in some cases it may be determined by computer methods. Once this ratio is known, it can be combined with the carrier-to-thermal-noise ratio by the addition of the reciprocals in the manner.

Denoting the intermodulation term by (C/N)IM and bearing in mind that the reciprocals of the C/N power ratios (and not the corresponding dB values) must be added.

PROBLEMS

Example For a satellite circuit the carrier-to-noise ratios are uplink 23 dB, downlink 20 dB, intermodulation 24 dB. Calculate the overall carrier-to-noise ratio in decibels.

solution From Eq.

$$\frac{N}{C} = 10^{-2.4} + 10^{-2.3} + 10^{-2} = 0.0019$$

Therefore,

$$\left[\frac{C}{N}\right] = -10 \log 0.0019 = 17.2 \text{ dB}$$

In order to reduce intermodulation noise, the TWT must be operated in a backoff condition as described previously. Figure shows how the $[C/N_o]_{IM}$ ratio improves as the input backoff is increased for a typical TWT. At the same time, increasing the backoff decreases both $[C/N_o]_U$ and $[C/N_o]_D$, as shown by Eqs and ( ). The result is that there is an optimal point where the overall carrier-to-noise ratio is a maximum. The component $[C/N]$ ratios as functions of the TWT input are sketched in Fig. The TWT input in dB is $[\Psi]_S - [BO]_i$, and therefore, Eq. ( ) plots as a straight line. Equation ( ) reflects the curvature in the TWT characteristic through the output backoff, $[BO]_o$, which is not linearly related to the input backoff, as shown in Fig. . The intermodulation curve is not easily predictable, and only the general trend is shown. The overall $[C/N_o]$, which is calculated from Eq. ( ), is also sketched. The optimal operating point is defined by the peak of this curve.

PROBLEMS:

1.Under clear sky conditions, the downlink [C/N] is 30dB. The effective noise temperature of the receiving system being 450k. If rain attenuation exceeds 2.5 dB for 0.2 percent of the time, calculate the value below which [C/N] falls for 0.2 percent of the time. Assume T_a = 295k.

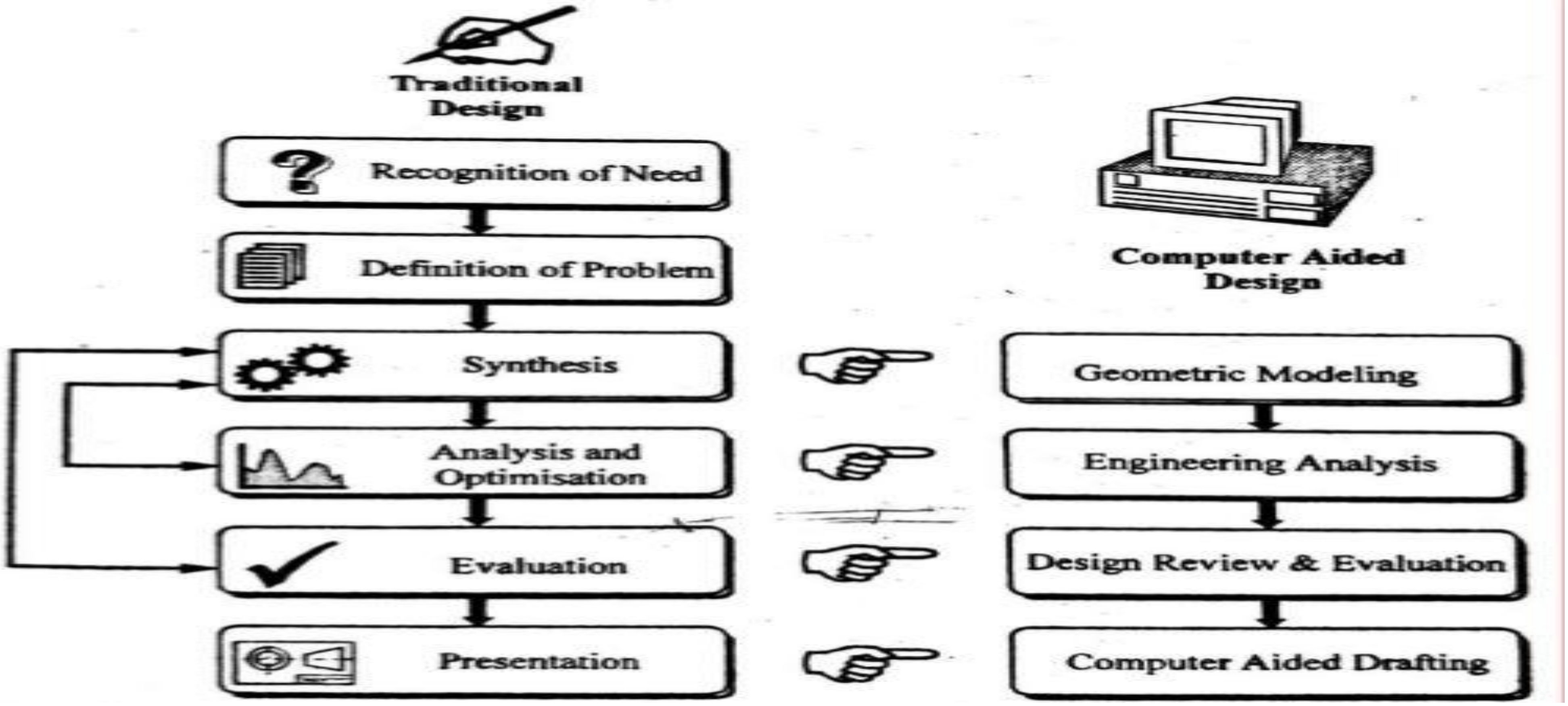
2.For a satellite circuit the individual link carrier-to-noise spectral density ratios are: uplink is 197 dB Hz; downlink is 189 dBHz. Calculate the combined C/No ratio.

3.A satellite is operated at an EIRP of 68 dBW with an output backoff of 9 dB. The transmitter feeder losses amount to 5 dB, and the antenna gain is 59 dB. Calculate the power output of the TWTA required for full saturated EIRP.

4.A satellite TV signal occupies the full transponder bandwidth of 46 MHz, and it must provide a C/N ratio at the destination earth station of 24 dB. Given that the total transmission losses are 220 dB and the destination earth station G/T ratio is 33 dB/K, calculate the satellite EIRP required.

5.An uplink operates at 16 GHz, and the flux density required to saturate the transponder is -125 dB9 (W/m^2). The free space loss is 209 dB, and the other propagation losses amount to 4dB. Calculate the earth-station [EIRP] required for saturation, assuming clear-sky conditions. Assume [RFL] is negligible.

COMPUTER AIDED DESIGN

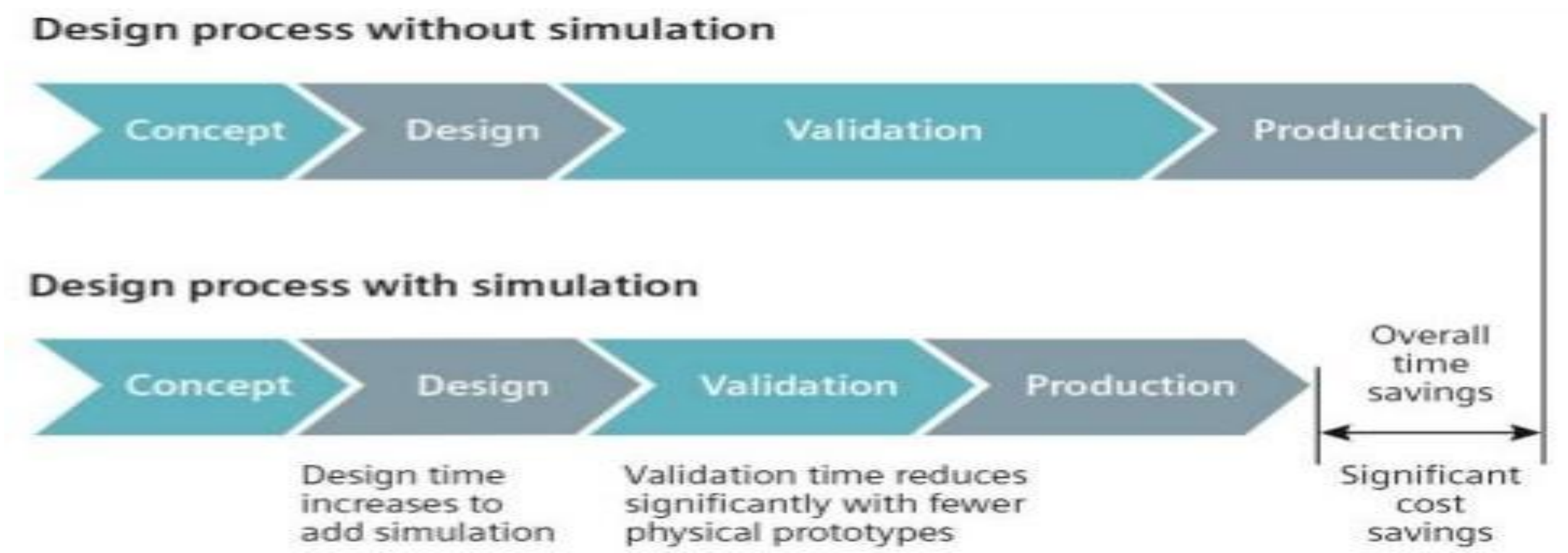


COMPUTER AIDED DESIGN PROCESS

COMPUTER AIDED DESIGN

- CAD is the use of computers to aid in the creation, modification, analysis, or optimization of a design.

- CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.



COMPUTER AIDED DESIGN ARCHITECTURE