Link Budget Design

The radio link between the mobile station and the base station is best described by a link budget. This link budget shows the system gain and loss and is determined by a number of factors. The objectives of calculating link budget are;

a) To determine the tolerable RF loss between the base station and the subscriber unit.

b) To provide a quick overview of power, gain and losses of the system.

c) To ultimately ensure that uplink and downlink are balanced. An example of a simplified link budget for a GSM class - 4 mobile networks is presented in Table

Transmitting End	Unit	BTS	MS	EQUATIONS
RF output power	dBm	43	33	A
Body loss	dB	0	2	B
Combiner Loss	dB	3	0	C
Feeder loss	dB	2	0	D
Connector Loss	dB	2	0	E
Transmitter Antenna Gain	dBi	17.5	0	F
EIRP - Peak	dBm	53.5	31	G = A + F - (B + C + D + E)

Receiving End	Unit	MS	BTS	EQUATIONS
Required Rx sensitivity	dBm	-103	-107	H
Rx Antenna Gain	dBi	0	17.5	I
Diversity Gain	dB	0	3	J
Connector Loss	dB	0	2	K
Body Loss	dB	2	0	L
Feeder Loss	dB	0	2	M
Interference Degradation Margin	dB	3	3	N
Isotropic Rx Power (50% Coverage Probability)	dB	-98	-120.5	O = H - (I + J) + (K + L + M + N)
* Fade Margin (90% Coverage Probability)	dB	4.3	4.3	P
Required Rx Power	dBm	-102.3	-124.8	Q = O – P
Maximum Permissible Path loss	dB	155.6	155.8	R = G – Q

- **Note :** Value of Fade Margin is taken from the example discussed at the end of the chapter for 90% coverage probability.

The power should be preferably referred with respect to a milliwatt (dBm).

Tx Power from a base station

Common values of Tx power are 50, 25, 20 or 10 Watts which corresponds to 47, 44, 43 or 40 dB respectively. If these values are specified at the top of the cabinet this implies that the combiner losses are already included.

Tx Power from subscriber unit

The general trend is for the subscribers to use less power transmitting mobile phones as time moves on for obvious reasons. Therefore the link budget calculations must take all these classes of mobiles into consideration. Table (1.2) presents the current mobile classes in GSM 900 and DCS 1800 bands. The low transmitting power of the mobiles also help in reducing interference.

CLASS	GSM 900	DCS 1800
1	20 w (43 dBm)	1 w (30 dBm)
2	8 w (39 dBm)	0.25 w (24 dBm)
3	5 w (37 dBm)	4 w (36 dBm)
4	2 w (33 dBm)	
5	0.8 w (29 dbm)	

Combiner loss

Cavity combiners provide low losses typically 1.5 dB for a five cavity combiner. Hybrid combiners provide 3 dB and 6 dB for 2 and 4 carriers respectively. The available power of the BTS and the required number of carriers make it possible to use hybrid combiners in most of the cases.

Duplexer loss

This is only applicable for systems having common transmit and receive antenna. The typical loss for aduplexer is about 1 dB.

Feeder loss

Feeder loss at the base station is usually around 2 to 4 dB. For mobile installations it is very common to have2 dB loss. (Typically for a 7/8 inch cable the attenuation is 4.2 dB per 100 metres).The table - (1.3) below gives the typical values of cable loss for different BTS antenna heights from the ground level.

Morphology	Typical BTS Antenna height in meters.	Loss in dB for LDF - 50 A 7/8 inch foam 50 Ω	
		900 Mhz	1800MHz
Dense Urban	35	1.47	2 to 2.3
Urban	35	1.47	2 to 2.3
Suburban	45	1.89	2.6 to 2.9
Rural	60	2.52	3.5 to 3.9

Antenna Gain

Typical antenna gain for a directional antenna are 14 dBi to 19 dBi . Typical antenna gain for omnidirectionalantennas are 6 to 8 dBi. The mobile antenna might have very small gain, no gain or even negative gain. Butfor link budget calculations we assume a mobile antenna of no gain (0 dBi).

Tx EIRP

An EIRP of 50 dBm or a few dBm above is very common at the base station.

Diversity Gain

The typical value for the diversity gain at the base station is 3 dB.

Receiver Sensitivity

Sensitivity in a receiver is normally taken as the minimum input signal required to produce a specified output signal having a specified signal-to-noise ratio and is defined as the minimum signal-to-noise ratio times the mean noise power .Typically received sensitivity of MS and BTS are -102 dBm and - 107 dBm respectively.

Balancing Radio Link Budget

It is important to ensure a balanced radio link budget in order to

a) Avoid unnecessary transmission of RF power that may reduce the efficiency of frequency reuse.

b) To get similar quality in uplink and downlink. The balanced link budget can only be obtained for one class of subscribers. The uplink is usually the worse path due to the lower power transmitted by the mobiles. Here the balance is usually obtained by

a) Higher sensitivity of the base station.b) Using Receiving Diversity at the base station.

c) Reducing the base station transmitted power.

Fade Margin

Normal coverage predictions calculate a mean value for a predicted area. This implies only 50 % of the places inside the area will be above the predicted level. Therefore in order to ensure coverage with a certain probability a safety margin is required. The calculation for fade margin is discussed below.

In Building Coverage

Planning for mobiles operating inside the buildings must include an attenuation factor. For In Buildingcoverage the typical value of Fade Margin would be 15 to 20 dB.

In Car Coverage

For subscriber units operational inside the cars without an external antenna the typical value of Fade Margin at900 MHz is 2 - 3 dB and at 1800 Mhz it is about 3 - 4 dB.

Fade Margin Calculation

Due to terrain variations like hills, buildings, vegetation or any other obstruction and inbuilding or incar usage of the MS, there are multiple reflections or multipath propagation which accounts for the additional loss in the received signal (fading of received signal strength). To account for this Fade Margin is added in the link budget.

Calculation of Fade Margin

For the calculation of fade margin we define the following parameters.

Propagation Index (γ)

This is also known as attenuation constant γ .This can be theoretically computed using the formula applicable for the specific propagation model chosen for the cell site. Or else we can obtain RSS (Received Signal Strength) at various points at a desired distance from the BTS using drive tests and plot RSS Vs Distance. From the slope between any two points after one mile intercept point on the graph plotted, we can obtain the propagation constant.

Standard Deviation (σ)

σ can be assumed based on experience or computed from measured values of RSS using statistical formula . These measurements are done by CW drive tests.

Area Probability

This is the fraction of the total area within which the RSS will be above a specified threshold.

Edge Probability

This is the probability of getting an RSS of a particular level at the edges of the cell. Based on σ and γ , we can calculate the Edge probability and Fade Margin by using what are called Jake's curves and Jake's tables.

Calculation of Edge Probability & Fade Margin

From the value of σ and γ we calculate

$\rho=\sigma/\gamma$

From the Jake's curves given in figure -(1.1) we can find out the Edge Probability for a desired coverage probability. Then with the help of the computed Edge probability we refer to the Jake's table - (1.4) to find out the correction factor. The measured or the calculated standard deviation from the CW propagation test is then multiplied by the correction factor. The result gives the Fade Margin which is then added to the required sensitivity in the Link Budget Calculation. By adding this Fade Margin to the Link

Budget we can guarantee the required coverage probability and computed edge probability.

Example:
Let us take up on an example for computing edge probability and fade margin for better understanding of the same. Say the coverage probability and received signal strength threshold set by a customer is that 90% of the total area should have signal strength better than - 90 dBm. The steps for computing edge probability and fade margin are as follows:

Step 1:
Calculate ρ with the help of σ and γ . Here γ, the propagation index and σ the standard deviation are computed from CW propagation measurement and the values found are γ = 3.5 and σ = 7.

Step 2:
Thus $\rho=\sigma/\gamma = 7 / 3.5$
$\rho= 2$

Step 3:
We have to now calculate the edge probability for a given coverage probability using Jake's curves . Jake's curves is a graph of Coverage Probability as Y axis Vs σ / γ i.e. ρ . as its X axis. Itgives an edge probability P EDGE for every Coverage Probability and its corresponding ρ .

Step 4:
For the example under consideration $\rho = 2$ and the Coverage Probability is 0.9. Thus from the Jake's curves we find out that the edge probability is 0.73. The literal meaning is that 73 % of the cell boundary area (Edge) would have signal strength better than -90 dBm.

Step 5 :
We have to compute the correction factor for the fade margin. With the help of the edge probability computed, we have to look up on the Jake's table (Table 1.4) to find out the correction factor. For an Edge probability of 0.73 which lies between 0.7291 and 0.7324 the correction factor is 0.615.

Step 6:
Fade margin is calculated by multiplying the correction factor with the standard deviation (σ).
Thus Fade Margin is FM = σ x Correction Factor FM = 7 x 0.615 = 4.305

Thus fade margin is found to be 4.305 for the cited example. As mentioned earlier this Fade Margin is added to the link budget calculations to guarantee the required coverage probability and computed edge probability.