whether the system is likely to be de-sensitised compared to its design value by that noise. Noise is discussed in further depth in Chapter 13.

5.5.8 Sensitivity and Noise

We determined minimum sensitivity in the absence of noise in the previous section. In many cases, the system will not operate at the minimum sensitivity but will instead be de-sensitised by noise. We will be looking at noise and interference in Chapter 13, but in the mean time it is important to recognise that in this case, the receiver will require a signal strength that is above the combined noise plus interference. For mobile elements, this will probably change as the subscriber moves around the service area, but for fixed installations, the noise and interference present can be measured or predicted as long as the interferers and their characteristics are known. When ground clutter attenuation is used to represent ground usage in the propagation model, then a portion of this can be attributed to typical noise values found in those environments.

This works in the following manner; if an equivalent figure of, say, −70 dBm (referenced to a dipole antenna) is predicted as the median value for a particular location and the clutter loss is 15 dB, then the value stored by the planning tool will be $-70 - 15 = -85$ dBm. This value can then be compared to the minimum equivalent signal value required, which will be the receiver sensitivity plus the fade margin (and possible shadowing margin, for point-to-area models) to determine whether the signal level is high enough to provide an acceptable service. So if we use the value of −108 dBm, with a 10 dB fade margin (and no shadowing loss), to give a minimum acceptable value of −98 dBm, the predicted value is −85 dBm, giving a margin of $(-85)-(-98) = +13$ dB, so the network does offer an acceptable service at this location since the margin is positive.

The wanted value will depend on the service; thus a digital system may require a minimum value of E_b/N_o whereas an analogue system will require a given signal-to-noise ratio. It is also important to note that the sensitivity is always quoted against a required performance target; it makes no sense on its own. Thus 'a signal-to-noise ratio of 12 dB to achieve a raw BER of 10^{-3}' makes sense, whereas 'E_b/N_o of 12 dB' makes no sense unless it is further qualified. There must always be the concept of a certain value input that will lead to a certain value output, where the input value may be a power level or a signal-to-noise ratio and the output may be SINAD, output power, BER and so on.

5.6 Building a Link Budget

5.6.1 Introduction

Link budgets can be constructed in different ways to specify link characteristics or to calculate an unknown value to be used then in the design process. In general, the process involves the same basic considerations; determine the point in the link process for which the answer is required, and then calculate from either the transmitter or receiver end to compute the required value. For the following examples we will use a simplified form of Figure 5.11 to illustrate the principles, shown in Figure 5.14. If the path includes more elements from Figure 5.11, then it is only necessary to account for the additional losses and gains of each part.

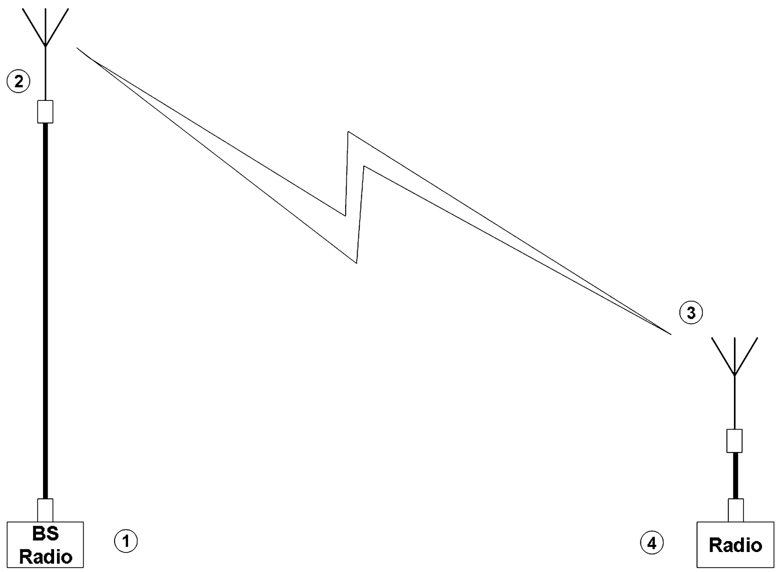

Figure 5.14. Simple path illustration.

5.6.2 Link Loss Calculation to Determine Level at Receiver

To determine the power at the transmitting antenna, the nominal power output by the transmitting radio is modified by the losses in gains due to the equipment between the radio and antenna, and then the gain or loss of the transmitting antenna relative to a standard antenna (typically a dipole) is included. If we then know the path loss for a given path, we can include the effects to determine the level of the received level at the receiver. This is illustrated by example in Table 5.7.

Table 5.7. Calculation to determine level at receiving radio.

Example link budget			
Transmitter elements	Value	Units	Calculation
(A) Nominal power at radio output	41.5	dBm	
(B) Total Tx feeder loss	3	dB	
(C) Total Tx connector loss	1	dB	
(D) Transmit antenna gain (reference a dipole)	2.5	dBd	
(E) Effective radiated power	40	dBd	A − B − C + D
(F) Path loss	135	dBd	
(G) Level at receiver antenna	−95	dBd	E − F
(H) Receiver antenna gain	−3	dBd	
(I) Total Rx conector loss	1	dB	
(J) Total Rx feeder loss	0.5	dB	
Level at receiver input	−99.5	dBm	G + H − I − J

The losses for feeders and connectors in this illustration are shown as positive, so they must be subtracted from the available input levels, since the power available at their output must be lower than on the input side. The receiver antenna gain is shown as a negative value, but this negative value must be added to the input power otherwise a double negative would be a positive, and thus the antenna loss would incorrectly be calculated as a gain. This is typical of path budgets; it is always important to determine which values should be added and which should be subtracted. In practice, it is often useful to draw out a diagram of the link in the form of Figure 5.14 for simple links, or like Figure 5.11 for more complex links.

There is another potential pitfall as well; does the path loss refer to a median value or is it something else? Does the calculated path loss include the required fade margin for the wanted availability, or has this not been added (in which case it must be)? Thus, another key aspect of link analysis is to determine the exact origin of each term to ensure that all terms are accounted for, and none are double-counted.

If all is well, then the figure for received signal level in dBm can be compared with some desired threshold value to determine whether the link will work or not (as a binary decision), the margin above or below the required threshold in dB, the probability of successful operation (PSO) or the expected BER or SINAD as required.

Of course, in many cases we will not know the path loss but will instead wish to know the maximum allowable loss that can be tolerated in the system before the performance falls below that considered acceptable.

5.6.3 Link Budget to Determine Maximum Allowable Loss

If we need to determine the maximum path loss that can be tolerated in a link to achieve a given minimum acceptable performance, then we can calculate the effective radiated power from the transmitter, calculate the level required at the receiving antenna and take the difference between the two, as illustrated in Table 5.8.

In this case, the calculation at the transmitter end is the same, but we calculate back from the receiver radio to determine the equivalent signal required at the antenna. Note that in this

Table 5.8. Calculation to determine maximum allowable path loss.

Example link budget			
Transmitter elements	Value	Units	Calculation
(A) Nominal Power at radio output	41.5	dBm	
(B) Total Tx feeder loss	3	dB	
(C) Total Tx connector loss	1	dB	
(D) Transmit antenna gain (reference a dipole)	2.5	dBd	
(E) Effective equivalent radiated power	40	dBm	A – B – C + D
Receiver elements			
(F) Receiver sensitivity	−104	dBm	
(G) Total Rx connector loss	1	dB	
(H) Total Rx feeder loss	0.5	dB	
(I) Receiver antenna gain	−3	dBd	
(J) Minimum required signal level	−99.5	dBm	F + G + H – I
Maximum tolerable path loss	139.5	dBd	E – J

Table 5.9. Loss required at street level to meet required performance; the tolerable path loss must be defined in terms of the wanted availability or another system performance metric (such as dynamic sensitivity for digital systems).

Factor	Value	Units
Maximum tolerable path loss at antenna	139.5	dBd
Body loss	6.5	dB
Building penetration loss	20	dB
Fade margin for required availability	10	dB
Street level median loss value from prediction	103	dBd

case, we need to add the connector and feeder losses to the required sensitivity in order to determine the signal required at the output of the antenna. The antenna has a -3 dB gain, which is a 3 dB loss, so we need 3 dB more at the input to the antenna. Thus in this case, the antenna gain is subtracted (resulting in a net addition) from the figure at the antenna output. As can be seen, the calculation of link budget is not in itself difficult, it is just necessary to ensure that terms are combined in the right way.

It is important to be careful about the path loss calculated. This must be the maximum path loss when including the effects of fading for the required availability. Also, if the system under consideration needs to take into account such as body loss, building penetration or both, then these need to be accounted for before the median field strength calculated by a propagation model can be compared to it. This is illustrated in Table 5.9, which shows the correction to apply to obtain the equivalent maximum tolerable path loss as calculated by a prediction model that calculates a median loss for 50 % of locations at street level, assuming the loss figures used.

5.6.4 Link Budget to Determine MMOFS

For practical use in a planning tool, we may be interested in the equivalent field strength that is required at the antenna taking into account all effects between the antenna and the receiver input. This is often referred to as the median minimum operating level (MMOL) for conducted power level or MMOFS (median minimum operating field strength). To this value, we will need to add the additional margin required to give the wanted degree of performance. Many tools will report the results of path profile or coverage predictions in terms of field strength, and thus it will be necessary to compute the equivalent value needed in the correct form. The required value is illustrated in Figure 5.15. The required median field strength required is obtained by adding the losses and gains between the receive antenna (including its own loss or gain value in the direction of the transmitter) and the receiver and converting to the equivalent field strength.

When the wanted value in dBm has been calculated, it needs to be converted into an equivalent field strength. For an impedance of $50\,\Omega$ (which is the typical value for most mobile radio systems), this can be determined by the following equation:

$$\text{Field strength (dB}\mu\text{V/m)} = \text{Power (dBm)} + 20\log f + 77.2 \qquad [25]$$

where f is the frequency in MHz

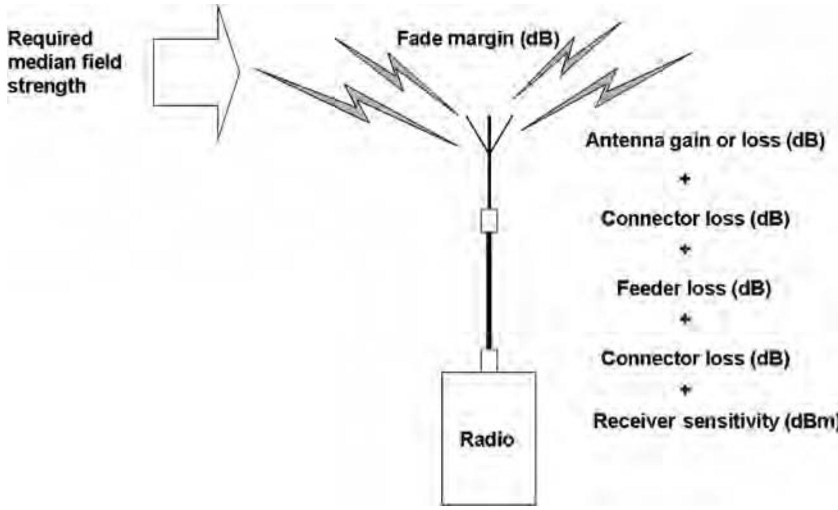

Figure 5.15. Required field strength at the receiving antenna.

An example is shown in Table 5.10, for a frequency of 390 MHz. Note that the mobile antenna has loss, not gain (we have shown it in a different way in this example because this is the way it can be expressed in some link budgets, and we want to reinforce the need to check the meaning of each term).

This is effectively one part of the link budget, broken down into a form that allows us to configure one part of the planning tool. This is typical, and it is often the case that different parts of the link budgets are stored in different parts of the planning tool. For example all of the aspects relevant to the transmitter may be stored in the characteristics of each individual base station (in case there are differences), whereas the mobile element is not explicitly modelled (since coverage plots effectively assume that the mobile moves throughout the entire service area) and is therefore modelled by setting a global characteristic such as the field strength value, plus some representation of antenna height above local ground.

Table 5.10. Equivalent field strength required at antenna.

Example	Units	Calculation
(A) Unfaded radio receiver sensitivity (dBm)	−111	
(B) Connector loss (dB)	0.5	
(C) Feeder loss (dB)	2	
(D) Connector loss (dB)	0.5	
(E) Mobile antenna ***loss*** (dBd)	6	
(F) Equivalent power required @ antenna (dBm)	−102	A + B + C + D + E
(G) Fade margin required (dB)	10	
Value to be converted to field strength (dBm)	−92	F + G
Equivalent field strength @ 390 MHz (dBμV/m)	37.0	Equation [25]

5.6.5 *Other Factors in Link Budgets*

Depending on the technology in use and the structure of the link, there may also be other elements in a link budget. This may include such elements as follows:

- Additional connector and feeder losses.
- Amplifier gains on transmit side or on receiver side (in which case receiver noise figure may need to be adjusted).
- Combiner losses.
- Interference and noise at the receiver, which will de-sensitise the receiver threshold (see Chapter 13).
- Processing gain for CDMA systems such as UMTR UTRA and CDMA 2000.

These features will all manifest themselves as either gains or losses, and if in doubt it is usually a good idea to draw the link out on paper and work through it to ensure that elements are being accounted for correctly and not double-counted. Additional information for some technologies such as TETRA, GSM and UTRA is also available in the specifications, which usually contain sample link budgets.

It is also worth bearing in mind that a link budget may need to be constructed for each *type* of subscriber to account for differences in antennas used, feeder and connector losses and the sensitivity of the radios, and that it will be necessary to build a link budget for both the uplink and downlink direction. Most modern technologies are designed to provide balanced links (so that the losses in each direction are the same), but this may not be representative of reality. This is due to the different environments in which the base station and mobile are likely to be found, in which the noise floor may be different. Thus even though the theory of path reciprocity (path loss is the same between any two antennas, irrespective of which end is regarded as the transmitter) holds true, in practice it may be necessary to adjust the figures to reflect the true situation. Also, it will be necessary to determine link budgets for each type of service to be offered if required receiver sensitivity changes between these services.

> *The fundamental factor to bear in mind is that if the link budgets are calculated incorrectly, then every other activity that occurs in the design process is in error.*

5.7 Expressing the Link Budget in a Planning Tool

In some simple planning tools, there may be a dialogue screen in which the link budget is entered in a single area, but for tools that allow handling of multiple sites with different characteristics, it is often the case that elements of the link budget have to be entered in different places in the tool. Thus, for example:

- Elements of the link budget relevant to the base station are entered in the dialogue box for each station on an individual basis.
- Environmental aspects, such as building penetration loss, may be entered in a dialog screen applicable to the propagation model and used globally for simulations.