APPENDIX B
UNITS OF OPTICAL POWER

Optical power can be expressed either in linear units [such as watt (W), milliwatt (mW) or microwatt ($\mu\mathrm{W}$)] or in dB units [such as dB, dB-milli (dBm) or dB-micro ($\mathrm{dB}\mu$)]. The unit dBm is dB with respect to milliwatt. The unit $\mathrm{dB}\mu$ is dB with respect to microwatt. The various units of optical power will be explained in this appendix. The majority of optical power meters give the user an option for displaying the optical power using one of these units.

An optical power P expressed in Watts, can also be expressed in dB using the following expression:

$P_{dB} = 10\log P$ [P is in Watts] (1)

An optical power P expressed in mW or $\mu\mathrm{W}$, may be expressed in dBm or $\mathrm{dB}\mu$, respectively, using:

$P_{dBm} = 10\log P$ [P is in mW] (2)

$P_{dB\mu} = 10\log P$ [P is in $\mu\mathrm{W}$] (3)

Example 1:

Express $4\ \mathrm{mW}$ in: a) Watts and $\mu\mathrm{W}$ b) dB c) dBm d) $\mathrm{dB}\mu$

Solution:

a) 4 mW = $0.004\,W$ = 4000 μW

b) $P_{\mathrm{dB}} = 10\log 0.004 = -23.979\ \mathrm{dB}$

c) $P_{dBm} = 10\log 4 = 6.021\ \mathrm{dBm}$

d) $P_{dB\mu} = 10\log 4000 = 36.021\ \mathrm{dB}\mu$

Notice that the difference between P_{dB} and P_{dBm} is $30\ \mathrm{dB}$. Also the difference between P_{dBm} and P_{dBu} is $30\ \mathrm{dB}$. The reason is that $30\ \mathrm{dB}$ corresponds to a *factor* of 1000 in linear units.

Example 2:

Express 13 dBm in: a) mW b) W and $\mu\mathrm{W}$ c) dB and $\mathrm{dB}\mu$

Solution:

a) $P = 10^{13/10} = 10^{1.3} = 19.95\ mW$

b) $P = 19.953\ mW = 0.019953\ W = 19953 \mu W$
c) 13 dBm = 13 - 30 = -27dB & 13 dBm = 13+30 = 43 dBμ

In many EE 420 laboratory experiments, we will be required to calculate optical power loss. Consider for instance the situation illustrated in Figure 1, where a given optical beam is incident on a *lossy* optical element. The input optical power is P_i and the output optical power is P_o. Since the optical element is lossy, it follows that $P_o < P_i$.

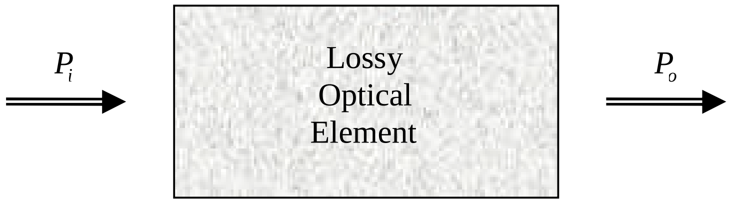

Figure 1: Input and Output Optical Powers through a Lossy Optical Element.

For a *linear* element, it is well-known that the output optical power is proportional to the input optical power, i.e. $P_i / P_o = \eta$, where η is some constant. This constant is larger than unity, simply because $P_i > P_o$. The parameter η can be used to represent the loss of the element. When η increases, the loss of the optical element also increases. For instance, when $\eta = 3$, then $P_o = P_i / 3$ and therefore, only one third of the incident optical power is available at the output end of the element.

The element loss can also be expressed using the dB measure, using the expression:

$$\text{dB}_{Loss} = 10 \log \eta = 10 \log \frac{P_i}{P_o} \qquad (4)$$

Where P_i and P_o are expressed in the *same linear* units. For instance, if P_i is expressed in mW, then P_o must also be expressed in mW.

The loss in dB can also be expressed as the difference between the power levels in dB, as shown next. Using equation (4), and assuming that P_i and P_o are expressed in Watt, we have:

$$\text{dB}_{Loss} = 10 \log \frac{P_i}{P_o} = 10 \log P_i - 10 \log P_o = P_{idB} - P_{odB} \qquad (5)$$

In a similar fashion, it is easy to show that:

$$\text{dB}_{Loss} = P_{idBm} - P_{odBm} \qquad (6)$$

$$\text{dB}_{Loss} = P_{idB\mu} - P_{odB\mu} \qquad (7)$$

Notice that in expressions (5), (6) and (7), *both* the input and output power levels are expressed in the *same* dB units, such as dB, dBm or dBμ. In addition, the dB_{Loss} is always expressed in dB, *even if* the power levels are expressed in dBm or dBμ. It is *meaningless* to express the power loss in dBm or dBμ. For instance, the difference between 10dBμ and 3dBμ is given by:

$10\text{dB}\mu - 3\text{dB}\mu = 7\text{dB}$ (i.e. $10\text{dB}\mu - 3\text{dB}\mu \neq 7\text{dB}\mu$)

Example 3:

With reference to Figure 3 above, assume that $P_i = 10\ mW$ and $P_o = 0.5mW$. Calculate:

a) $\eta = \frac{P_i}{P_o}$ b) the element loss in dB using two different methods.

Solution:

a) $\eta = \frac{P_i}{P_o} = \frac{10}{0.5} = 20$

b) Method 1: $\text{dB}_{\text{Loss}} = 10\log 20 = 13.01\,\text{dB}$

Method 2: $P_{idBm} = 10\log 10 = 10\ \text{dBm}$

$P_{0dBm} = 10\log 0.5 = -3.01\,\text{dBm}$

dB_{Loss} =10 dBm - (- 3.01 dBm) = 13.01 dB (the same answer as above).