When \( rs > a \) equation (4.3.5) becomes,

$$P_{LED, Step} = \frac{2\pi B_0}{\int_0^{r_s} [n^2(r) - n_2^2] r\,dr}$$

**Power coupled to graded index fiber**

In graded index fiber, the index of refraction varies radially from fiber axis. Numerical aperture for graded index fiber is given by,

$$P_{LED, Step} = 2\pi^2 r_s^2 B_0 n_1^2 \Delta \left[ 1 - \frac{2}{a + 2} \left( \frac{r_s}{a} \right)^a \right]$$

Is source radius \( rs \) is less than fiber core radius \( a \) i.e. \( rs < a \), the power coupled from surface emitting LED is given as –

For coupling maximum power to fiber, the refractive index of the medium separating source and fiber must be same; otherwise there will be loss of power. The power couple is reduced by factor,

$$R = \left( \frac{n - n_1}{n + n_1} \right)^2$$

where,

- \( n \) is the refractive index of medium.
- \( n_1 \) is the refractive index of fiber core.
- \( R \) is the Fresnel reflection or reflectivity.

**Lensing Schemes for Coupling Improvement**

When the emitting area of the source is smaller than the core area of fiber, the power coupling efficiency becomes poor. In order to improve the coupling efficiency miniature lens is placed between source and fiber. Micro lens magnifies the emitting area of source equal to core area. The power coupled increases by a factor equal to magnification factor of lens.

Important types of lensing schemes are:

1. Rounded – end fiber.
2. Spherical – surfaced LED and Spherical-ended fiber.
3. Taper ended fiber.
4. Non imaging microsphere.
5. Cylindrical lens,
6. Imaging sphere.

Fig. 4.4.1 shows the lensing schemes.

There are some drawbacks of using lens.
1. Complexity increases.
2. Fabrication and handling difficulty.
3. Precise mechanical alignment is needed.

**Equilibrium Numerical Aperture**

The light source has a short fiber fly lead attached to it to facilitate coupling the source to a system fiber. The low coupling loss, this fly lead should be connected to system fiber with identical NA and core diameter. At this junction certain amount of optical power approximately 0.1 to 1 dB is lost, the exact loss depends on method of connecting. Also excess power loss occurs due to non propagating modes scattering out of fiber. The excess power loss is to be analyzed carefully in designing optical fiber system. This excess loss is shown in terms of fiber numerical aperture.
Numerical aperture at input light acceptance side is denoted by NAin. When light emitting area LED is less than fiber core cross-sectional area then power coupled to the fiber is NA = NAin.

If the optical powers of measured in long fiber lengths under equilibrium of modes, the effect of equilibrium numerical aperture NAeq is significant. Optical power at this point is given by,

\[ P_{eq} = P_{50} \left( \frac{NA_{eq}}{NA_{in}} \right)^2 \]

Where,

P50 is optical power in fiber at 50 m distance from launch NA.

The degree of mode coupling is mainly decided by core – cladding index difference. Most optical fibers attain 80 – 90% at their equilibrium NA after 50 m. Hence NAeq is important while calculating launched optical power in telecommunication systems. 4.8 Fiber Connectors. Connectors are mechanisms or techniques used to join an optical fiber to another fiber or to a fiber optic component.

Different connectors with different characteristics, advantages and disadvantages and performance parameters are available. Suitable connector is chosen as per the requirement and cost.

Various fiber optic connectors from different manufactures are available SMA 906, ST, Biconic, FC, D4, HMS-10, SC, FDDI, ESCON, EC/RACE, LC, MT.
Three different types of connectors are used for connecting fiber optic cables. These are –
1. Subscriber Channel (SC) connector.
2. Straight Tip (ST) connector.
3. MT-RJ connector.

SC connectors are general purpose connections. It has push-pull type locking system. Fig. 4.8.1 shows SC connector.

![Fig. 4.8.1 SC connector for fiber cable](image)

ST connectors are most suited for networking devices. It is more reliable than SC connector. ST connector has bayonet type locking system. Fig. 4.8.2 shows ST connectors.

![Fig. 4.8.2 ST connector for fiber cable](image)

MT-RJ connector is similar to RJ45 connector. Fig. 4.8.3 shows MT-RJ connector.

![Fig. 4.8.3 MT-RJ connector for fiber cable](image)

Principles of Good Connector Design

1. Low coupling loss.
2. Inter-changeability – No variation is loss whenever a connector is applied to a fiber.
3. Ease of assembly.
4. Low environmental sensitivity.
5. Low cost – The connector should be inexpensive also the tooling required for fitting.
6. Reliable operation.
7. Ease of connection.
8. Repeatability – Connection and reconnection many times without an increase in loss.

Connector Types

Connectors use variety of techniques for coupling such as screw on, bayonet-mount, puch-pull configurations, butt joint and expanded beam fiber connectors. Butt Joint Connectors.

Fiber is epoxied into precision hole and ferrules are used for each fiber. The fibers are secured in a precision alignment sleeve. But joints are used for single mode as well as for multimode fiber systems. Two commonly used butt-joint alignment designs are:

1. Straight-Sleeve.
2. Tapered-Sleeve/Biconical.

In straight sleeve mechanism, the length of the sleeve and guided ferrules determines the end separation of two fibers. Fig. 4.8.4 shows straight sleeve alignment mechanism of fiber optic connectors.

In tapered sleeve or biconical connector mechanism, a tapered sleeve is used to accommodate tapered ferrules. The fiber end separations are determined by sleeve length and guide rings. Fig. 4.8.5 shows tapered sleeve fiber connectors.
Connector Return Loss

At the connection point of optical link low reflectance levels are desired since the optical reflections can be a source of unwanted feedback into the laser cavity. Due to this unwanted feedback the optical frequency response may degrade, also it generates internal noise within the source affecting overall system performance. Fig. 4.8.6 shows the connection model.

![Fig. 4.8.6 Tapered sleeve connector](image)

The return loss for the index-matched gap region is given by,

\[ R_l = -10 \log \left(2R \left[1 - \cos \left(\frac{4\pi n_1 d}{\lambda}\right)\right]\right) \]

Where,

- \( D \) is the separation between fiber ends.
- \( n_1 \) is index-matching material.
- \( R \) is reflectivity constant.