# Lasers and Optical Communication Systems

Simona Castrase
Department of Electronics,
Faculty of Electrical Engineering and Information Technology
University of Oradea, Romania
Armatei Române St., no.1, phone: 0259/432830
scastrase@uoradea.ro

***Abstract*** ***– Recent advances in lasers suggest potential applicationsto communication systems. An assessment of these potentialities is particularly difficult because of the incomplete state of knowledge, but certain threads of thought are begining to form quite clearly and its is mainly such aspects that can discuss. For communication systems requiring several millions of speech channels, optical communication could well prove to have economic advantages. A smaller scale, an optical guide could provide communication channels at a cost competitive with another systems. Communication using beamed optical transmission is another alternative.***

***Keywords:*** ***Electromagnetic wave, communication systems, fibre guide.***

## I. FUNDAMENTAL DESIGN FACTORS

### A. Signal power

At radio or microwave frequencies the efficiency of generating oscillations is of the order 50 per cent, and the powers which can be generated range from kW to MW. The efficiency and maximum power of sources at present available decline rapidly in the millimetric spectrum, so that the band above about 100 Gc/s is at present of limited value for communication purposes. It is difficult to say, at present, whether the reasons are fundamental or are a function of the present day technology.

In the optical band, with the advent of lasers, appreciable powers and improved efficiencies become possible. The efficiecies of present lasers are well below 50 per cent, and although peak powers of the order of megawatts possible, the generation of optical frequencies with average power of the order of watts is still a difficult engineering task.

### B. Frequencies stability

The frequencies stability (or coherency) is another feature of source that determines its usefulness for communication purposes. At radio or microwave frequencies the short term frequency stability can be commonly of the order of 1 part to $10^{10}$ or better, and over long periods of time the frequency can be easily kept constant to a fraction of a cycle per second. These figures can be related to the effective line width of the source, and for high-grade lasers the percentage line width can be as goodas, or better than, those achievable at microwave frequencies. At optical frequencies implies a line width of some tens of kilocycles per second, and this alone imposes definite limitations on many modulation methods. The same feature also renders an efficient exploitation of bandwidth impossible, but clerly this need not be a limitation of the system.

This high carrier frequency associated with the optical band is advantageous for at least two reasons: (1) in antenna design in that high directivity can be readily realised, and (2) because potentially very large bandwidths become possible[2].

### C. Noise

Noise is fundamental design parameter. At radio and microwave frequencies the minimum noise per unit bandwidth is given by kT(-204dbW at room temperature). This is an approximation and more exact expression is:

$$N(f) = \frac{hf}{\exp\frac{hf}{kT} - 1} + hf$$

where the first term represents black body radiation and reduces to kT in the microwave spectrum, and the second term represents quantum noise. At optical frequencies quantum noise is some 20 dB higher than thermal noise. Thus other factors being equal, we are some 20 db worse off at optical frequencies than microwave frequencies[2].

## II. FREE SPACE OPTICAL COMMUNICATON SYSTEM

Communication systems can be divided into two classes : (1) those utilising a guided path ( such a coaxial cable or waveguide) and (2) those utilising radiation in free space ( for ex. microwave links) [1].

Free space propagation at optical frequencies is attractive in that much smaller and lighter antenna are needed to realise a given directivity than for microwave frequencies. This increased antenna gain can be traded for transmitter power or larger repeater spacing, but the advantages so gained are not as large as might appear at first, principally because of the added quantum noise. For equal signal to noise ratio, the geometric mean of the transmitter and receiver antenna diameter decreases with wavelength , but only with the 4th root of the wavelength.

To take full advantage of the increased antenna gain it is necessary, at optical frequencies, to improve the tracking accuracy of the equipment by an order of magnitude above those in common use to day.

If used for inter-satellite or space communications the tracking problems are very severe indeed, and unless these problems can be solved the advantages offered by highgain antenna at optical frequencies are more of an embarrassment than profit. For the applications where high directivity cannot be put to advantege the optical system has, from a technical point of view, little to offer.

For terrestrial applications, a high directivity optical link appears to have many advantages but for the variable and unpredictable optical properties of the troposphere. The atmosphere is virtually opaque for large parts of the spectrum, but even in selected windows the shimmer of the air on a clear hot day and complete black-out in bad weather conditions are serious short comings (fig.1) [1].

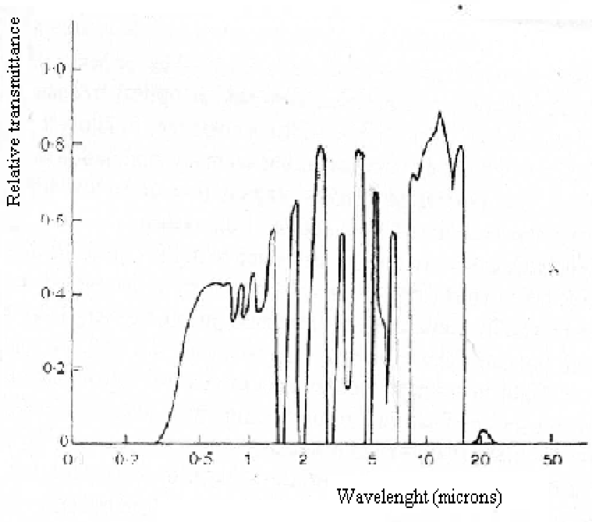

Fig.1.

A commercial future may exist for short haul terrestrial systems, offering very cheap service of limited reliability. Such links would be truly portable and would not add to the congestion in free space, already apparent in the radio and microwave spectrum.

For these reasons it is difficult to envisage, at present, any large scale application of free space optical links, except possibly in the form of balloon relay system, using a network of ballons suspended above the weather affected layer of the atmosphere. Signals could be freely propagated over thousands of miles using relay stations mounted on balloons spaced by hundreds of miles and be substantially unaffected by varying atmospheric conditions[7].

## III. PERFORMANCE FIGURES OF OPTICAL WAVEGUIDES

### A. Electromagnetic wave beams

Three knows types of structure belonging to this class are: (1) Iris wave beam, (2) Lens wave beam, (3) Mirror wave beam [2].

The systems differs fundamentally from the well-known beam transmission as employed, for ex. in microwave links, in that the lens are in the Fresnel zone of their neighbours. The decrease the signal strength with the square of distance is therefore prevented. The modes have the general form:

$$\psi_{mn} = f_{mn} \cos n\varphi \cdot \exp \gamma_n z$$

where $f_{mn}$ is a function Laguerre polynomialis and $\gamma_n$ is the propagation coefficient of the mode, which for the lower order modes differs but slightly from the free space propagation coefficient. This mode has maximum energy concentration an dis therefore of greatest practical interest.

Under ideal conditions the wave beam structures have theoretical attenuation figures which can be below 1dB/km. With suitable elements they can be used for the whole optical spectrum down the frequencies in the millimetric band. In the millimetric band their use is restricted, because of the large aperture and small spacing of elements needed to avoid excessive attenuation due to diffraction.

Diffraction loss is only one different processes by which the signal is attenuated. Apart from launching loss, the signal is attenuated by reflection at the lens surfaces and absorption in the lens material. For typical installations the reflection and absorption losses are the main causes of attenuation, and amount to about 1dB/km. Smaller attenuation figures can be realised if larger lens spacings are utilised, but then larger lenses must be used to counteract diffraction loss and the system becomes more sensitive to changes of direction.

Although gas lenses may solve some problems connected with wave beams, the fundamental problems, such as inability to negotiate any resonable bends and system degradation due to statistical variations among the lens elements, remain.

### B. Fibre guides

A fibre guide is an example of a dielectric rod waveguide, scaled to optical frequencies, its diameter being of the order of microns. Propagation of electromagnetic waves along dielectric cylinders has been investigated many years ago. Waves can be propagated in a variety modes, most of wich are mixed modes and all modes excepted the HE mode, exhibit a low frequency cut-off. Thus for fibres a fraction of a wavelength in diameter only the HE mode can propagate. The fibre can be considered suitable for transmission over long distance[3].

For large diameter fibres (10 to 100 μm diameter), the velocity of propagation for rays inclined at a small angle to the axis is substantially, and the conditions of propagation are similar those found in the reflecting pipe, except that the fibres can be bent to a relatively small radius of curvature without significant losses. Since the transmission takes place almost entirely within the fibre material, the attenuation of the wave is substantially equal to the absorption coefficient of the fibre material. For small diameter ( less than 0,1 μm), most of the energy is carried outside the fibre in the form of a surface wave and very little within the fibre. Consequently, the velocity of propagation is close to *c* and the attenuation is small.

At optical frequencies both single and multimode operation is possible. Fibres, particularly as multimode guides, have been in use for a long time, but with attenuation of the order of 1 dB/m their use has been restricted to transmission over short distances. Single mode guides would have much smaller attenuation (less than 10dB/km), but there are difficulties associated with the manufacture, handling and support of thin fibres in long lengths. In addition the optical properties of many materials can be significantly degraded by the process of drawing into thin fibres[4].

At present, optical fibres are unsuitable for transmission over long distances, mainly because of excessive attenuation in the fibre material, or the inability to support sub-micron fibres. These are largely technological material problems and hopes of solving the outstanding problems are good[5].

### C. Gas guides

A dielectric rod and a fibre guide are only two particular ambodiments of class 2 waveguides. To realise a guiding effect, it is not necessary to have a sharp boundary between the dielectric guiding medium and free space. A gradual decrease in the value of the permittivity in the transverse plane of the guide, i.e a transverse gradient in permittivity is sufficient.

Such pipes could serve us efficient guides of optical waves. The chief advantage of gas guides ist hat unlike fibre guides they are fundamentally low-loss guides, because of the negligible absorption of optical waves in gases, such as $CO_2$. At the same time, because of the low refractive index of gases, gas guides are not nearly as efficient in negotiating bends as dielectric fibre guides[3], [5].

### D. Optical microguide

If we could support a thin optical fibre without touching the surface of the fibre then the surface wave propagation would be undisturbed and a low attenuation optical guide would become possible. This is precisely what an optical microguide achieves. In its simplest form the optical microguide consists of a thin film of a suitable dielectric mounted in a supporting structure.

The light energy is launched on the film by directing a parallel beam of light (polarised in the plain normal to the dielectric film) edge on and along the film. The film thickness is a fraction of the wavelength of light (say 500Å) and the film width is such as to admit freely a beam of light tipically some 10,000 wavelengths wide.

The mode supported by the film is subtantially a plane surface wave, which is symmetrical with respect to the mid-plane of the film. Since most of the energy is carried in the space outside the film, the attenuation of the wave is considerably smaller than indicated by the extinction coefficient.

The expression representing the surface wave carried by the microguide is:

$$\exp(-ax)\,\exp(-\alpha-j\beta)z$$

where *z* is measured along the film and *x* is measured from and perpendicular to the surface of the guide. The decay coefficient *a* is given by:

$$a=\omega^2\mu_o\varepsilon_o\left(1-\frac{1}{n^2}\right)d$$

and the attenuation by:

$$\alpha=8\pi^3\left(\frac{d}{\lambda}\right)^2\frac{1}{n^2\lambda}\left(1-\frac{1}{n^2}\right)\tan\delta$$

where *n* is the refractive index and *δ* the loss-tangent of the film material.

The thicker the film the less the transverse spread of the field, but the thinner the film the lower the attenuation of the guide. The film can be twisted without any noticeable loss of energy, and the combination in one plane and twist enables the guide to negotiate bends in any plane[6].

One of the many alternative ways of supporting the thin film uses a confocal system of cylindrical lenses, as illustrated in fig.2, but the guide can only be bent in one plane and to overcome this, the construction shown in fig.3 is proposed.

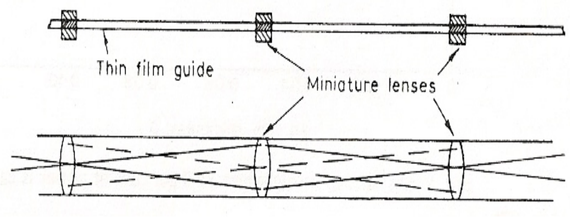

Fig.2

The film is mounted within a circular protective tube, in the shape of a helix, and such a guide would be suiteble for negotiating bends in any plane provided that the radius of curvature remains large in comparision with the lay of the helix.

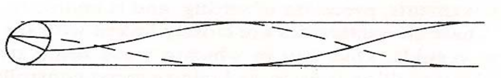

Fig.3

In principle, arbitrarily small atteniation figures may be achieved even with existing materials, but in practice films thinner than 0,1 μ are likely to present technological difficulties, and for this reason a microguide operating in the 1 to 10μ range with an attenuation of the order of a few dB/km .

## IV. CONCLUSIONS

Some advantages of optical communication system are: open optical communication system would exploit that part of the electromagnetic spectrum which is vacant and therefore would not add the congestion in free space; bandwidth is plentiful, communication capacity is large; with open systems, antenna of very high directivity are easily realised.

The intrinsic advantages are: quantum noise (20dB above thermal); high tolerance on many components; with open terrestrial systems unpredictable characteristics of the troposphere.

It appears that compact short range low-capacity open systems can be realized, but such systems are limited due to weather. Guided communication systems are in their infancy, but if some of technological problems are solved, then a large field will be opened for the communication engineer to explore.

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