The premises of laser inter-satellite communication system

MARKÉTA SMEJKALOVÁ MAZÁLKOVÁ
Department of Communication and Information Systems
University of Defence
65 Kounicova, 612 00 Brno
CZECH REPUBLIC
Marketa.Mazalkova@unob.cz

Abstract: This paper involves analysis, optimization and design principles for mathematical and engineering models of subsystem and system level development of spaceborne and ground receiver free-space laser communication terminals communicating to and from distant planetary and Earth-orbiting spacecraft. Research opportunities in this area include development of laser beam acquisition, tracking and pointing techniques and algorithms, development of computer aided analysis link budget for the free space channel, systems engineering (analysis and design) of optical transmission development of high efficiency flight qualifiable solid-state lasers, fast fine-pointing mirrors high update-rate acquisition and tracking cameras and very low-noise high-quantum efficiency receiver.

Key-Words: Laser; satellite; communication; system; analysis; optimization; technology

1 Introduction

The complete results of the research are included in [1]; the main parts of the research study are analysis, optimization and conception design methodology of laser inter-satellite communication system (LICS). In this paper, there are the basic design-parameters for an effective technological implementation of transmitting and receiving units for duplex transfers and signals processing in communication, acquisition and tracking links in LICS topology between two GEO satellites [2].
This paper presents partial result of computer implementation of parametric correlation for analysis and optimization in MATLAB programme.

2 The premises of laser inter-satellite communication system parameters

The basic assumption of analysis is laser communication equation (LCE). This equation expresses the dependences of different parameters, such as source power and gains and losses parameters during signal transfer. These parameters provide relevant data for technological implementation design. Based on the background and receiver noise, as well as the type of signal modulation which is to be detected, a required signal is generated. The ratio of received signal to required signal is the system link margin. Identifying these gains and losses requires intimate knowledge of the system design, including the internal constraints, design choices and knowledge of the external factors, including range, data rate, and required signal criteria. Basic parameters are presented by transmitting and receiving units and transfer for three links – acquisition, tracking and communicating.
The laser communication equation (LCE) can be written as

$$P_{t(dB)} = P_{r(dB)} - \left(G_{t(dB)} + \sigma_{ur(dB)} + L_{wf(dB)} + \right) \left(+ L_{t(dB)} + L_{R(dB)} + G_{r(dB)} + L_{r(dB)}\right) \quad (1)$$

where:

P_t - the transmitting signal power (dB)

P_r…the receiving signal power (dB)

G_t…the effective transmitting antenna gain (dB)

G_r…the receiving antenna gain (dB)

L_t…the efficiency loss associated with the transmitter (dB)

L_r…the efficiency loss associated with the receiver (dB)

L_R…the free space range loss (dB)

σ_{ur}…the transmitter pointing loss (dB)

L_{wf}…the transmitting Strehl loss (dB)

A… data from information source

A1…coded and modulated optical signal

B1…optical signal before detection

B…data for user.

LICS parameters premises are optimized by computer programme, the premises consider two satellites in an orbit. For satellites at an altitude *h* above the Earth's surface and traversing circular orbits, the range between satellites is given as

$$R = \sqrt{2.(R_z + h)^2 + 2.(R_z + h)^2.(1 - \cos(\beta))}$$

(m, m, m,^{0}) (2)

where:

R_z…the Earth radius

β…the orbital angle between two satellites (for GEO, β =120°)

h…the altitude above the Earth's surface.

The free space range loss can be simply written as

$$L_R = 10\log_{10}\left[\frac{\lambda}{4\pi R}\right]^2 \text{ (dB)} \quad (3)$$

where:

λ…wave length, for real cases it is in dimension 780nm - 860nm.

3 Mathematical and physical implementation analysis and optimization of inter-satellite communication system in MATLAB

Bearing in mind the main research objective, partial goals have been defined. These goals include mathematical and physical analysis of basic parameters and characteristics for LICS design that is required for communication and control signals transfer between GEO satellites. This analysis is also needed for LICS technological basis design. Finally, it is also necessary for computer implementation of several-parametric correlation into analysis and optimization in MATLAB programme. Analysis and optimization is given by the graphical outputs that enable LICS parameters optimization occurring in actual situation.

The original research study [1] is over 90 pages long, so it is impossible to mention all relevant data in this paper. It includes a programme for the input parameters design, for the input and output losses, as well as free space losses.

Basic mathematical and physical description aforesaid system aspects are dealt with in research study [1] and they serve as a starting point for computer implementation of several-parametric correlation programme.

The equations which were used in the calculations and in graphical outputs of parametric correlations of LICS system optimization are given at the end of this paper.

The original programme has been prepared in MATLAB. The programme is able to calculate selected several-parametric correlations and to convert them into graphical outputs. We are able to indicate optimal values of selected system transfer parameters according to specified criteria

4 The results

The graphic outputs from the original programme of optimization design in MATLAB are in the research study. There are graphical outputs which should be used for comparison of three links. The graphical outputs for acquisition, communication and communication-track link iteration are shown in the next figures.

We can see curves for the dependences of required signal level and efficiency. Behaviour of curves for required signal level is moving by exchanging values of efficiency.

The chosen graphical results from computer support of suggested laser satellite communication system optimization of multi-parametrical correlations.

Acquisition link

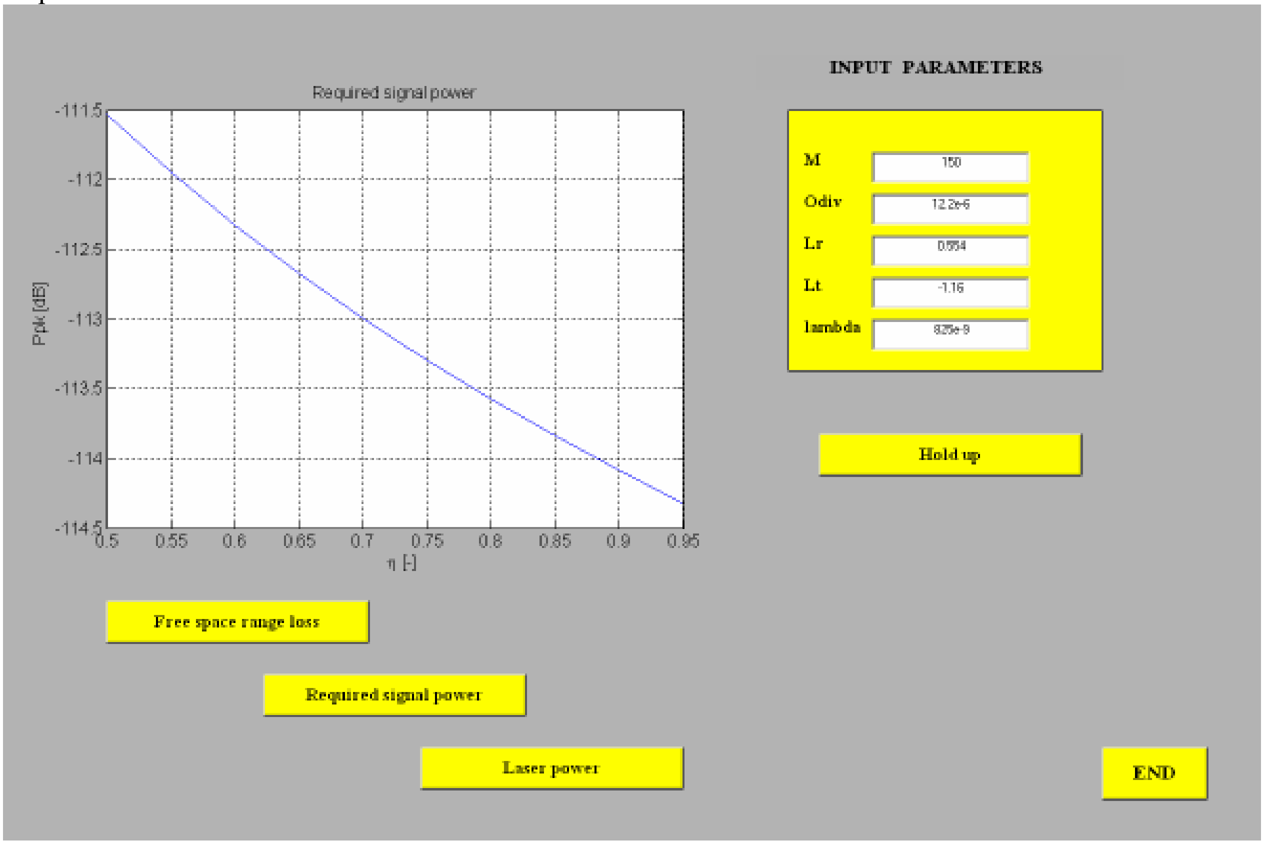

Fig. 1 Required signal level dependent on efficiency for acquisition link

Trucking link

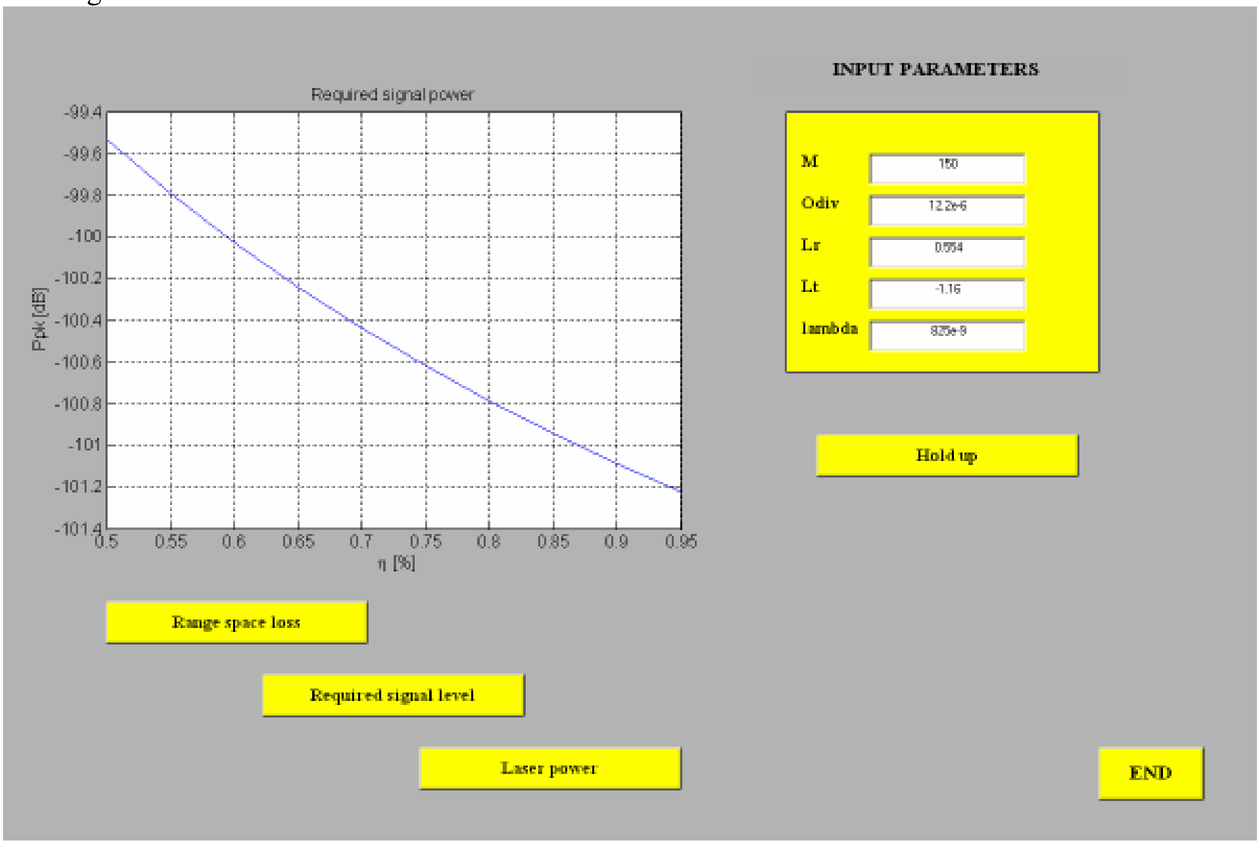

Fig. 2 Required signal level dependent on detector efficiency for trucking link

Communication link

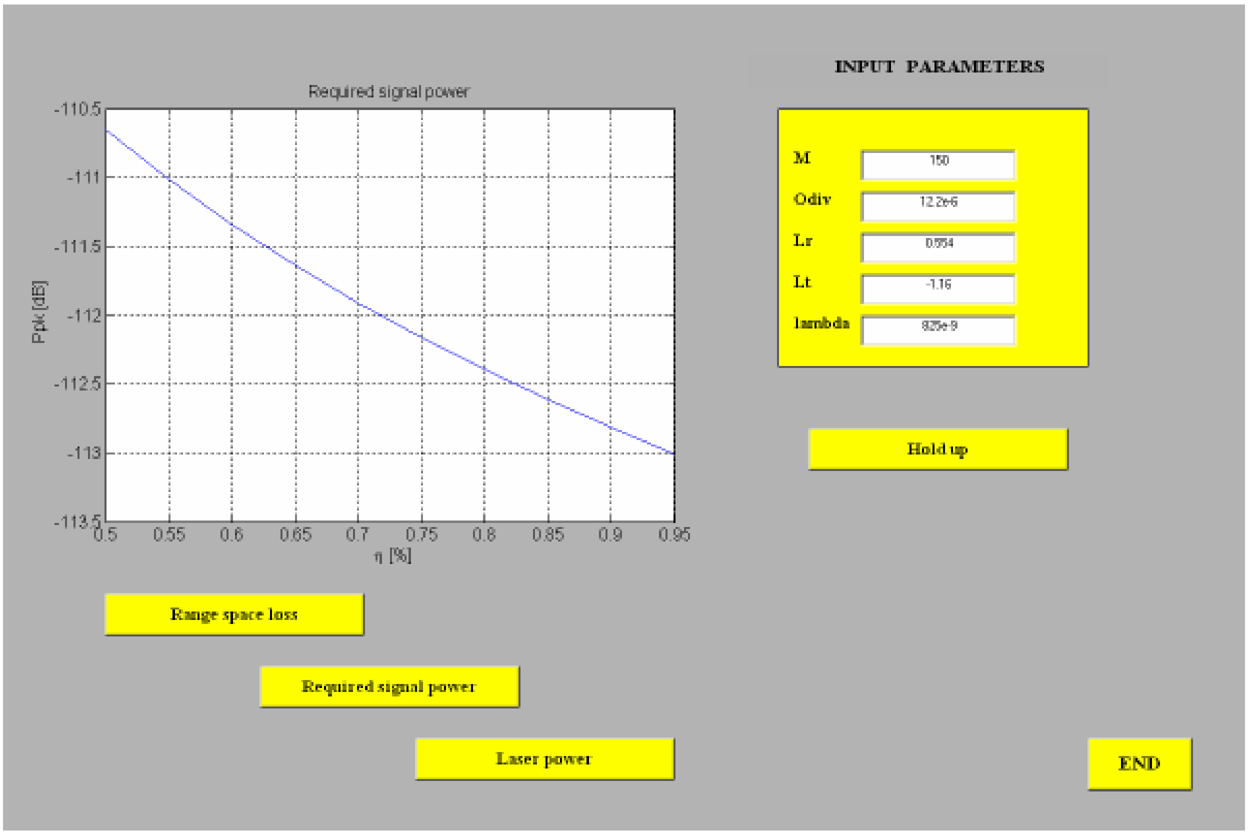

Fig. 3 Required signal level dependent on detector efficiency for communication link

Comparison of acquisition, tracking and communication link

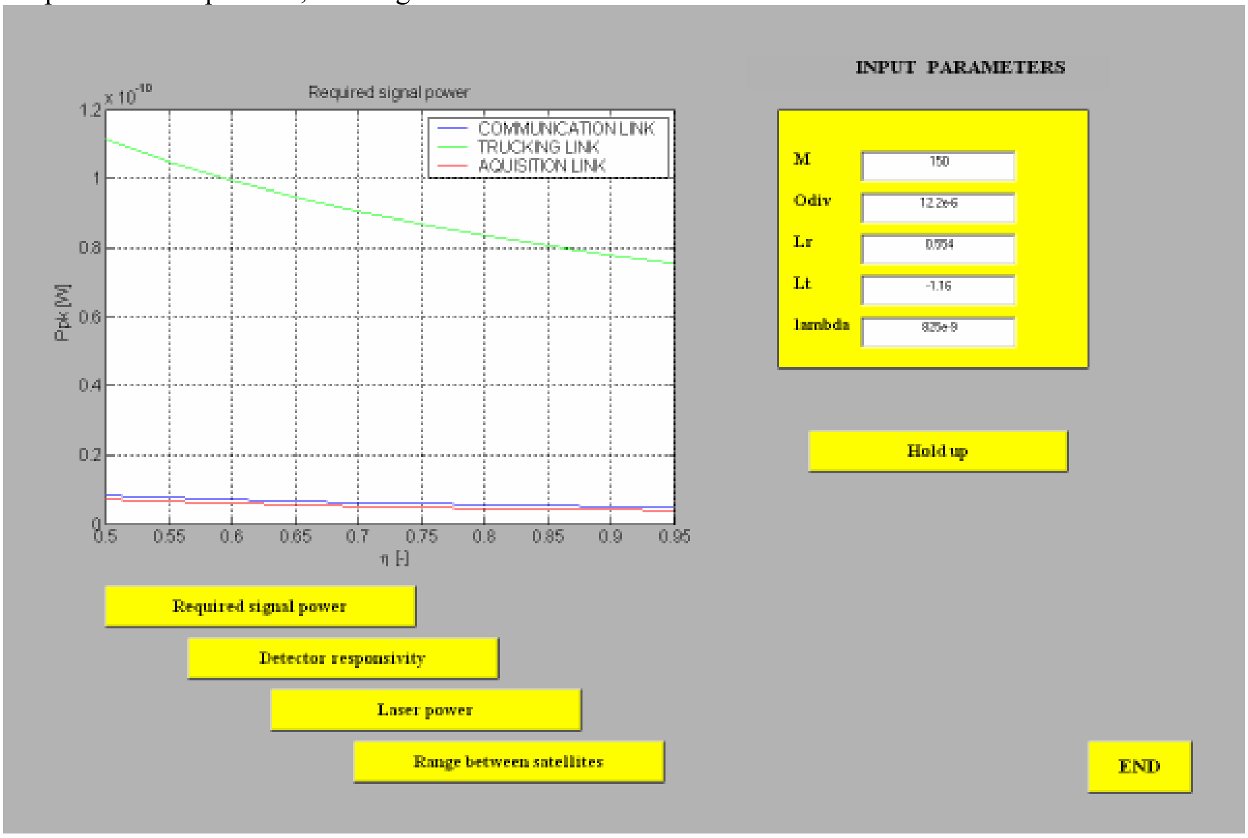

Fig. 4 Required signal level dependent on detector efficiency

As you can see in Fig. 4 - required signal level dependent on detector efficiency for communication, tracking and acquisition links of LICS. This figure is for a comparison of three links. It is the most important for whole system optimization. The curves are differentiated by colours (red-acquisition link, green-tracking link, blue-communication link).

5 The conclusion

Following the parametric correlations computer analyses, basic parameters premises were calculated. These premises serve as input data for effective decisions concerning optimal technological implementation of LICS application. Analysis and optimization supported by computer programme allow making cost-effective decision in designing individual parameters in laser inter-satellite communication system.

The Acronyms

GEO	geosynchronous Earth orbit
lambda	wavelength
LEO	low Earth orbit
LICS	Laser inter-satellite communication system
LICE	laser communication equation
Lr	the efficiency loss associated with the receiver
Lt	the efficiency loss associated with the transmitter
M	avalanche gain
Odiv	divergence angle

Reference:

[1] Mazálková, M.- Titl, M.: Analýza a optimalizace koncepce laserového družicového komunikačního systému. Výzkumná zpráva. Univerzita obrany Brno, 2005.

[2] Lambert, S.G.-Casey, W.L.: Laser Communications in Space. Artech House, Inc., 1995.

[3] Titl, M.: Systémové aspekty návrhu laserových kosmických komunikačních systémů. Podklady přednášek předmětu “Optické komunikace”. VA, K-302, Brno