

بناء نظام برمجي لتصميم وصلة اتصالات لاسلكية تعمل بالترددات V/UHF والمايكرولية

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المستخلص:

تم في البحث الحالي بناء نظام برمجي يمكن استخدامه في تصميم وصلة اتصالات تعمل بالترددات V/UHF والمايكرولية باستخدام نظام Mathcad ولغة Visual Basic. النظام البرمجي المقدم يستثمر القوة في التعامل مع المعادلات الرياضية والرسوم البيانية التي يتمتع بها Mathcad من جهة والأدوات القوية للرأفة والوصل بين الصفحات التي توفرها لغة Visual Basic من جهة أخرى. يقوم النظام بحساب لمعادلات الرياضية والإحصائية التي تستخدم لحل مسائل تصميم وصلة الاتصالات اللاسلكية لمديات الترددات المذكورة آنفا. من مزايا هذا النظام البرمجي طريقة عرضه للنتائج حيث يتم عرضها بالطرق العديدة وعلى شكل رسوم بيانية مختلفة وهذه الطرق مهمة جدا للمصممين الذين يعملون في هذا المجال. كما يمتاز البرنامج بقدرته على إظهار رسائل إلى مستخدمه تعلمه فيما إذا كان تصميمه النهائي مقبول عمليا من عدمه.

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A Computer Program Construction
Applied To V/UHF and Microwave Wireless Communication Link
Planning

By

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Abstract:

A communication link design computer program is constructed using MathCad and Visual Basic package for wireless V/UHF and Microwave frequency bands. The new program exploits the powerful mathematical and graphical tools exists in MathCad and the powerful tools of Visual Basic in interface page applications. The new computer program presented in this paper is based on theoretical and some statistical expressions applied in this field and therefore it can be used in solving design problems. Examples of applying the program are given for two cases, V/UHF and Microwave links. One of the features of this program is its way of results presentation, which are presented in numerical, text and graphical modes that are relay needed in such applications. Another important features of the new computer program is its capability of showing messages to tell the designer whether the overall design process is applicable or not.

1. Introduction

Communication design link is needed particularly for installing new communication links. In this paper V/UHF and Microwave links are considered. It is well known that such designs depends on many parameters such as full information about both transmitter, receiver and the medium between them [1,2,3,4]. The final goal of the communication link design is to receive a signal with a certain strength such that can be detected by the receiver with good reliability and acceptable outage time.

The design constrains of V/UHF and Microwave propagation are different and therefore each one is taken separately in the analysis although they have similarities in most of the calculations concerning path attenuation and link budget.

In this paper a computer program is built which uses two packages namely Mathcad and Visual Basic. One of the reasons of applying these two packages and combine theme in one computer code is to exploit the powerful mathematical and graphical tools that exist in Mathcad and powerful of the interface page tools exists in Visual Basic. The main advantage of the new computer code presented in this paper is that it offers a full interaction with the design procedures, that means one can immediately notice the effect of changing any parameter on the design process.

Examples on the design of typical communication links using the new computer code are shown for the two cases, i.e., V/UHF and Microwave links. The results are presented in numerical, text and graphical modes, which helps the designer in fast decision-making.

2. Theoretical Background:

The wireless communication link consists of transmitter(including the antenna), medium (space, ground and obstacles) and the receiver (including the antenna) as illustrated in fig. (1)

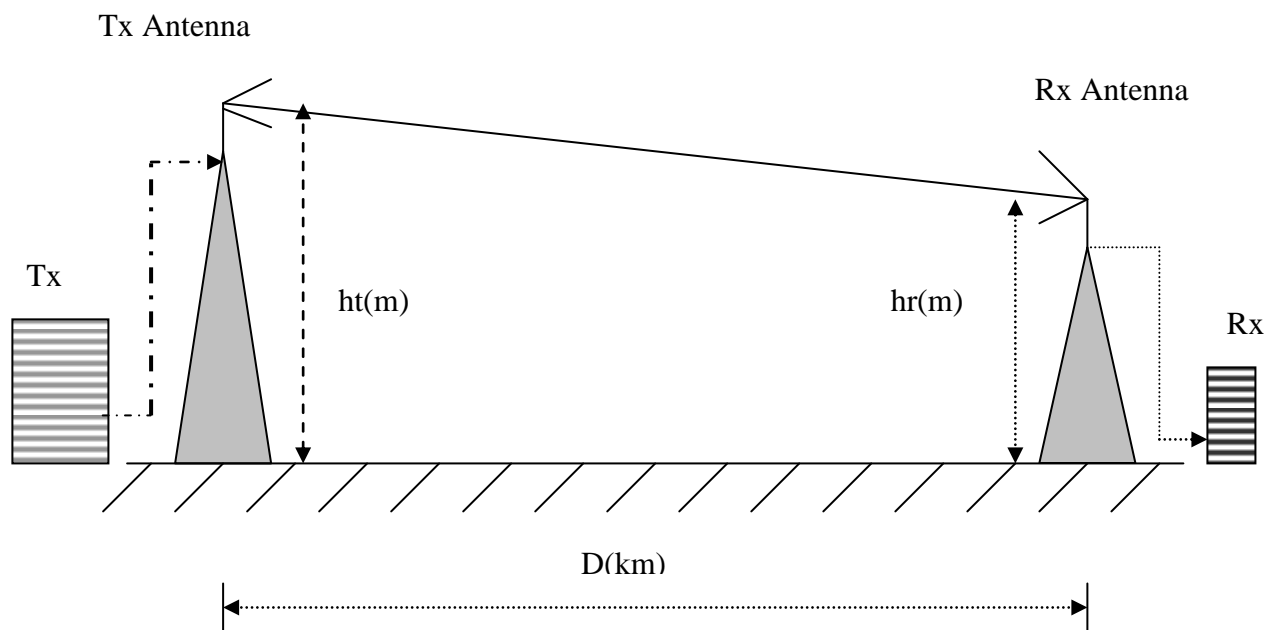


Fig.(1) Schematic diagram of a communication link

2.1 Performance of a communication Link

The performance of a communication link is mainly depends on the following parameters:

2.1.1 Transmitter:

- (1) Operating carrier frequency
- (2) Transmitter output power (usually given in dBm) P_T (dBm)
- (3) Transmitter antenna gain G_T (in dB)
- (4) Feeder cable losses in dB (the cable between the transmitter and the antenna, connector losses are included)
- (5) The height of the transmitting antenna above local ground (in meter)

2.1.2 Receiver:

- (1) Receiver sensitivity (minimum detectable signal level) in dBm

- (2) Receiver antenna gain in dB
- (3) Feeder cable losses in dB (cable that connects the receiving antenna to the receiver, connector losses are also included)
- (4) Receiver antenna height above local ground

2.1.3 The medium between the transmitter site and the receiver site

For wireless communication links the transmitted electromagnetic wave is mainly affected by the conditions of the atmosphere as well as the ground conditions such as topographical conditions between transmitting and receiving sites. These factors can statistically be determined by calculating the effective earth's radius (k), which may take different values for different regions, and the normal value of k is $4/3$. Therefore if more realistic results are needed, then actual values of k should be provided as well as actual terrain variation along the path between the transmitter and the receiver should also be defined accurately. Therefore diffraction losses due to the obstruction of the **Line Of Sight (LOS)** with ground or with obstacles on the ground may occur and can be calculated.

2.1.4 Free Space Loss.

This type of loss depends mainly on the transmitting frequency and the range between the transmitter site and the receiver site. The cause of this loss is due to natural wave expansion when emerging from the transmitter till it reaches the receiver.

3. Mathcad Code Construction

Fig.(2) shows the flow-chart of all processes performed starting with the interface page construction using Visual Basic and Mathcad computer code instructions.

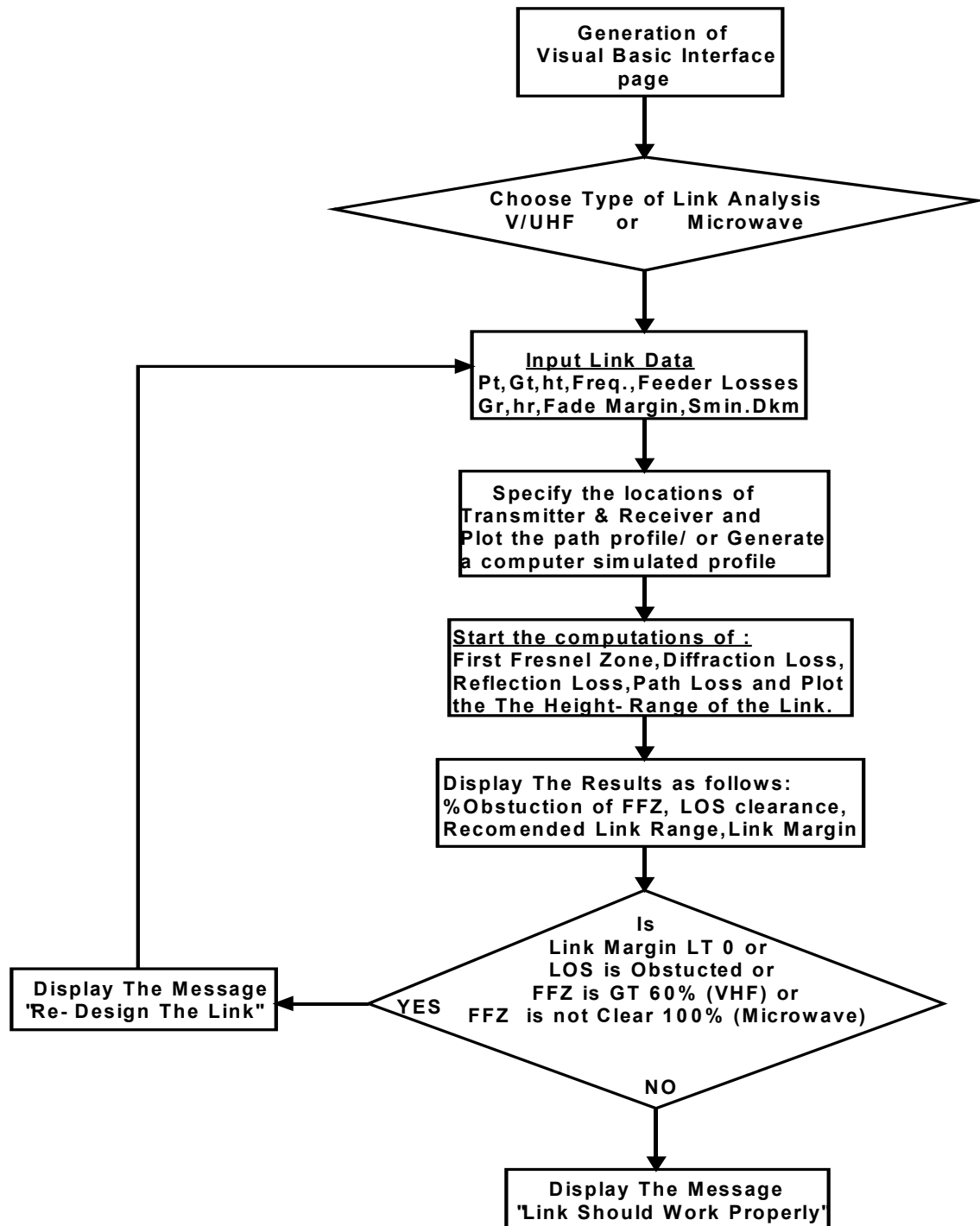


Fig.(2) Flow Chart illustrating the sequence of calculations.

3.1 Input Data From Visual Basic Software:

$PT_{dBm} := in0$ $h1 := in1$ $D_{Km} := in2$
 $F_{MHz} := in3$ $GT_{dB} := in4$ $GR_{dB} := in5$
 $FeederLosses_{dB} := in6$ $Smin_{dBm} := in7$ $h2 := in8$
 $FadeMarginUVHF_{dBm} := in9$

Where:

PT_{dBm} : output power of the transmitter
 f_{MHz} : operating frequency
 GT_{dB} : transmitter antenna gain (dB)
 D_{km} : ground distance between Tx and Rx
 $h1$: height of the transmitting antenna above local ground
 $FeederLosses_{dB}$: Total cable losses between Tx/Rx and their antennas
 GR_{dB} : Receiver antenna gain (dB)
 $FadMarginUVHF_{dBm}$: Fade margin of U/VHF
 $Smin_{dBm}$: Minimum detectable receiver signal
 $h2$: height of the receiving antenna above local ground

3.2 The instruction used to set Default Values

$PT_{dBm} := \text{if}(PT_{dBm} = 0, 33, PT_{dBm})$ $h1 := \text{if}(h1 = 0, 30.1, h1)$
 $D_{Km} := \text{if}(D_{Km} = 0, 10.0, DKm)$ $h2 := \text{if}(h2 = 0, 16.1, h2)$
 $f_{MHz} := \text{if}(f_{MHz} = 0, 450, f_{MHz})$ $GT_{dB} := \text{if}(GT_{dB} = 0, 3.0, GT_{dB})$
 $GR_{dB} := \text{if}(GR_{dB} = 0, 3.0, GR_{dB})$
 $Smin_{dBm} := \text{if}(Smin_{dBm} = 0, -114, Smin_{dBm})$
 $FadeMarginUVHF_{dBm} := \text{if}(FadeMarginUVHF_{dBm} = 0, 18, FadeMarginUVHF_{dBm})$
 $FadeMargin\mu W_{dB} := 10$

3.3 instructions used to define constants and unit conversion

$PT_{mwatt} := 10^{\frac{PT_{dBm}}{10}}$ $\lambda := \frac{300}{f_{MHz}}$ $a := 6370 \text{km} (\text{Earth Radius})$

$$PT_{watt} := P_{Tmwatt} \cdot 10^{-3}$$

3.4 Average Height Above Mean Sea Level Simulation:

In this paper a general ground is assumed and not restricted to a particular one and hence a simulation of terrain is needed. If actual information does exist then actual data points can replace the data generated by this simulation process easily. The following shows how this simulated data is generated and is shown in fig. (3)

$$ypp(x) := \frac{1}{2}(\cos(2x)^2 + \sin(3x)^2 + \cos(x) + \sin(4x)) + 2$$

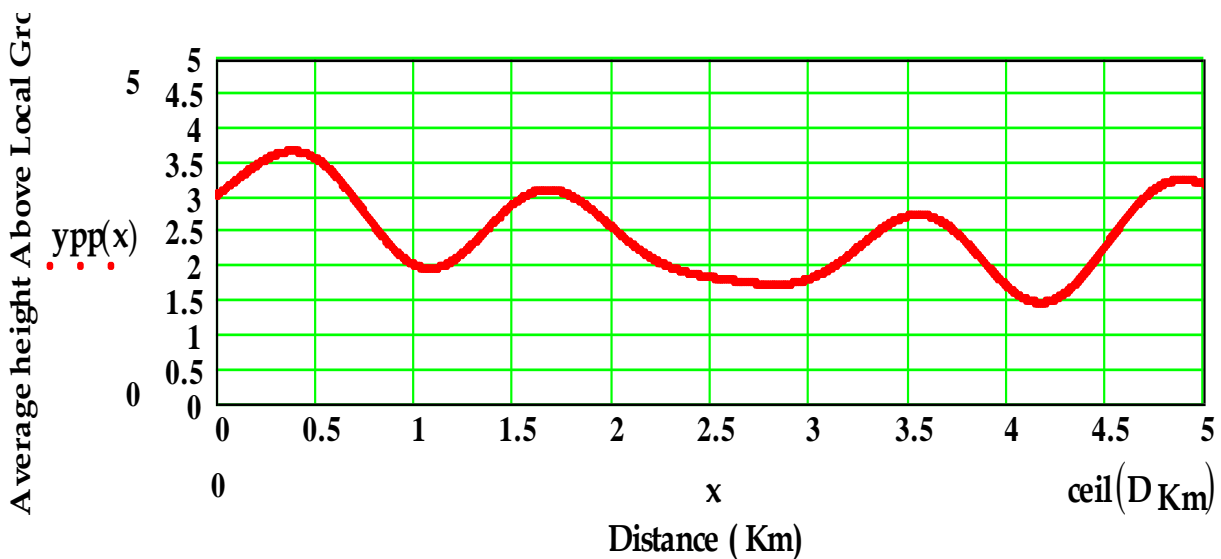


Fig. (3) Generated terrain data

3.5 Fresnel Zones Determination:

One of the very important performance test done on communication link analysis is that whether the first Fresnel zone is obstructed or not and if it is obstructed then what is the percentage area of obstruction? The following instructions show how these are calculated. Fig. (3) shows an example of the first Fresnel zone shape projected on the path. Also it shows the LOS as well as the Earth’s bulge (for the case of k=4/3). Fig. (4) also shows the simulated terrain along the path.

$$h11:=h1+ypp(t) \quad h22:=h2+ypp(D_{km}) \dots\dots\dots(1)$$

$$ht(x) := \frac{x \cdot (D_{km} - x)}{2 \cdot k \cdot a} \cdot 1000, \quad m := \frac{h22 - h11}{D_{km}} \dots\dots\dots(2)$$

$$yp(x) := ht(x) + ypp(x) \dots\dots\dots(3)$$

$$y(x) := m \cdot x + h11 \quad rf(x) := 547 \cdot \sqrt{\frac{x \cdot (D_{km} - x)}{f_{MHz} D_{km}}} \dots\dots\dots(4)$$

$$rf1(x) := rf(x) + y(x) \dots\dots\dots(5)$$

$$RLOS_{km} := 3.57 \sqrt{k} (\sqrt{h11} + \sqrt{h22}) \dots\dots\dots(6)$$

where:

h11 : height of transmitter antenna above sea level.

h22 : height of receiver antenna above sea level.

ht(x) : Earth's bulge

m : the slop of the LOS.

ypp(x) : Earth's bulge above sea level.

y(x) : LOS equation.

rf(x) : First Fresnal Zone radius.

RLOS_{Km} : radius of LOS.

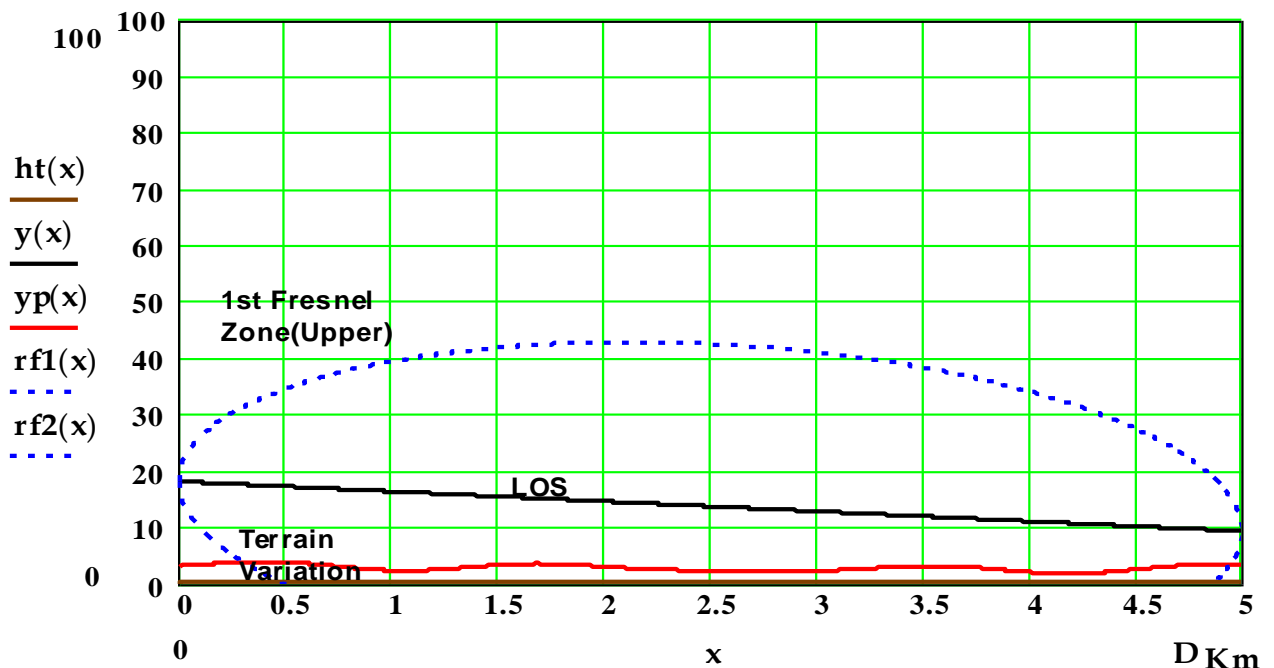


Fig. (4) First Fresnel Zone, Line of Sight (LOS) and terrain height above Mean Sea Level.

3.6 Diffraction Loss:

When Line Of Sight (LOS) is obstructed by an obstacle or passes near an obstacle, the strength of the received signal will suffer an attenuation which depends on the location (distance) of the obstacle from

the transmitting/receiving antenna, the depth of the penetration, the distance between the antennas and the operating frequency Fig. (4). The following computer code is used to calculate this type of loss (diffraction loss).

3.6.1 Computer Code to Determine the maximum terrain height and its location.

```

Mayd:= | ym ← 0 .....(7)
        | dm ← 0
        | for x ∈ 0, .01 .. D Km
        |   | Δy ← yp(x) - ym
        |   | if Δy ≥ 0
        |   |   | ym ← yp(x)
        |   |   | dm ← x
        | ( ym )
        | ( dm )

```

Maximum Terrain Height **Mayd₀ = 3.7** At distance from left **Mayd₁ = 0.4 km**

$$\delta H_m := y(\text{Mayd}_1) = \text{Mayd}_0$$

Minimum clearance with LOS **δHm = 13.5 meters**
 If Positive → LOS not Obstructed
 If negative → LOS Obstructed

$$dt1 := \begin{cases} \frac{D_{km}}{2} & \text{if } \text{Mayd}_1 = 0 \vee \text{Mayd}_1 \geq D_{km} \\ \text{Mayd}_1 & \text{Otherwise} \end{cases} \dots\dots\dots(8)$$

3.6.2 Diffraction Loss Calculations:

Electromagnetic wave may obstructed by an obstacle and hence the received signal will be attenuated. Once the distance of obstruction is determined, then one can use the following equations to calculate the diffraction loss in dB

$$w1(\delta 1_m, dt) := \sqrt{2} \left[\frac{\delta H_m}{\sqrt{\frac{\lambda \cdot dt \cdot (D_{K_m} - dt) \cdot 1000}{D_{K_m}}}} \right] \dots\dots\dots(9)$$

$$Az1_{dB} := |20 \cdot \log(ET(w1(\delta H_m, dt)))| \dots\dots\dots(10)$$

Where:

$$ET(w) := \left| \frac{0.5 + C(w) + j \cdot (0.5 + S(w))}{\sqrt{2}} \right| \dots\dots\dots(11)$$

and

$$C(t) := \int_0^t \cos\left(\frac{\pi}{2} \cdot \lambda^2\right) d\lambda \quad S(t) := \int_0^t \sin\left(\frac{\pi}{2} \cdot \lambda^2\right) d\lambda \dots\dots\dots(12)$$

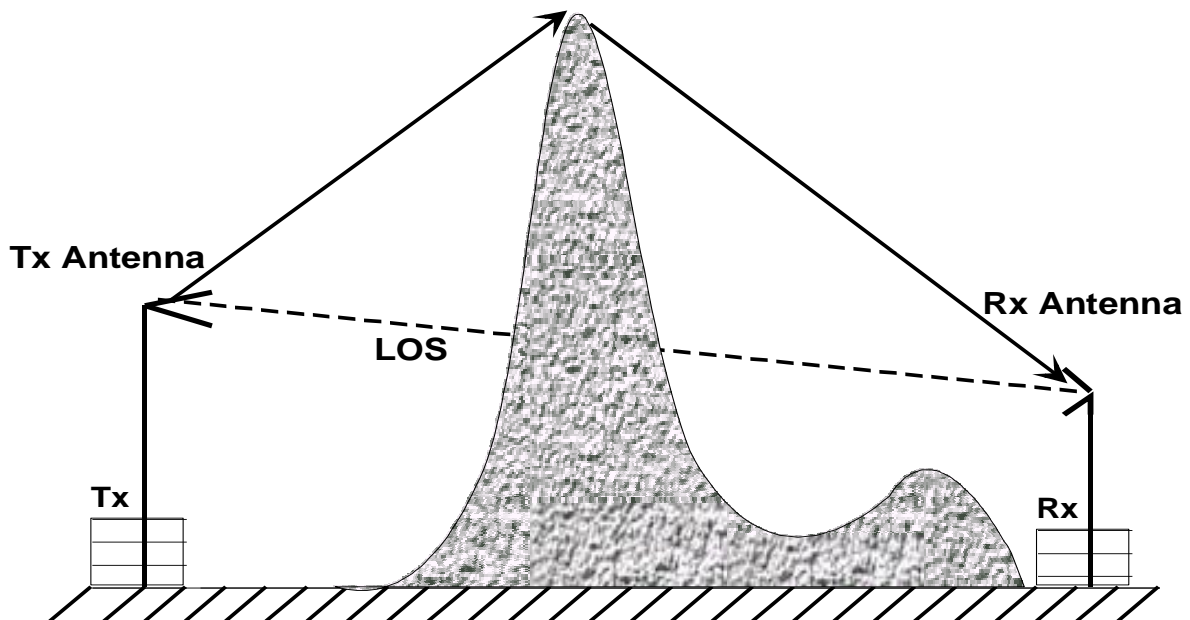


Fig.(5) Electromagnetic wave obstruction and received by diffraction

3.7 Computer code for LOS clearance and first Fresnal zone obstruction percentage determination

$$\text{LineOfSight tStatus} := \begin{cases} \text{"CLEAR"} & \text{if } \delta H_m > 0 \\ \text{"OBSTRUCTED"} & \text{otherwise} \end{cases} \dots\dots\dots(13)$$

$$\% \text{FFZObstruction} := \frac{\text{rf}\left(\frac{D_{\text{Km}}}{2}\right) - \delta H_m}{2 \cdot \text{rf}\left(\frac{D_{\text{Km}}}{2}\right)} \cdot 100 \dots\dots\dots(14)$$

$$\% \text{FFZObstruction} := \begin{cases} 0 & \text{if } \% \text{FFZObstruction} \leq 0 \\ \% \text{FFZObstruction} & \text{otherwise} \end{cases} \dots\dots\dots(15)$$

3.8 Path Loss and Recommended Link Range Calculations:

3.8.1 V/UHF Links:

Free space Loss and height Gain in dB

$$\text{PL1} := 96.372 + 20 \cdot \text{Log}(f_{\text{MHz}}) - 20 \cdot \log(h1 \cdot h2) \dots\dots\dots(16)$$

Power received in dBm (Excluding Path Loss)

$$\text{PrVUHFdBm} := \text{PTdBm} + \text{GTdB} - \text{FeederLossesdB} - \text{PL1} - \text{FadeMarginUVHFdBm} - \text{Az1dB} \dots\dots\dots(17)$$

Notes on Fade Margin: In the planning of a communication system, it is customary to take into account a fade margin since it relates to the reliability of the wireless communication links. The value of the fade margin is very critical particularly for data transmission applications. In this paper 18 dB and 10 dB values are used for V/UHF and microwave links respectively as default values which gives 99% link reliability. Other values of fade margins may be used if required.

Power received in dBm(Excluding path loss):

$$\text{PrNdBm} := \text{PT}_{\text{dBm}} + \text{GT}_{\text{dB}} + \text{GR}_{\text{dB}} - \text{FeederLosses}_{\text{dB}} - \text{PL1} - 40 \log(D_{\text{Km}} \cdot 1.609) - \text{Az1dB} \dots\dots\dots(18)$$

Link Margin (Budget):

$$\text{LinkMargindB} := \text{PrNdBm} - \text{Smin}_{\text{dBm}} \dots\dots\dots(19)$$

$$DVUHF_{km} := 10^{\frac{PrVUHF_{dBm} - Smin_{dBm}}{40}} \times 1.609 \dots\dots\dots(20)$$

$$RecommendedRange_{km} := DVUHF_{km} \dots\dots\dots(21)$$

A:=”Redesign the Link”

B:=”Link should work Properly”

$$Message := \begin{cases} B & \text{if } (\%FFZObstruction < 60 \wedge LinkMargin > 0) \dots\dots(22) \\ A & \text{otherwise} \end{cases}$$

3.8.2 Microwave Links;

$$Lo_{dB} := 20 \log(D_{km}) + 20 \log(f_{MHz}) + 32.44 \text{ (free space loss calculation).. } (23)$$

$$PL_{Microwave} := 20 \log\left(\frac{\lambda}{4\pi}\right) \dots\dots\dots(24)$$

$$Pr_{\mu wave1_{dBm}} := PT_{dBm} + GT_{dB} + GR_{dB} - FeederLosses_{dB} + PL_{Microwave} - Az1_{dB} \dots\dots(25)$$

$$D_{microwave_{\mu W_{km}}} := 10^{\frac{(Pr_{\mu wave1_{dBm}} - Smin_{dBm})}{20}} \times 10^{-3} \dots\dots(27)$$

$$Pr_{\mu wave_{dBm}} := Pr_{\mu wave1_{dBm}} - FadeMargin_{\mu W_{dBm}} \dots\dots\dots(26)$$

$$PPr_{\mu dBm} := PT_{dBm} + GT_{dB} + GR_{dB} - FeederLosses_{dB} - Lo_{dB} - FadeMargin_{\mu W_{dBm}} - Az1_{dB} \dots\dots(28)$$

$$LinkMargin_{dB} := 1.259 \dots\dots(29)$$

$$RecomendedRange_{km} := D_{microwave_{\mu W_{km}}}$$

A:=”Re Design The Link”

B:= ” Link Should Work Properly”

$$Message : \begin{cases} B & \text{if } (\%FFZObstruction < 0 \wedge LinkMargin_{dB} > 0) \\ A & \text{otherwise} \end{cases}$$

4. Examples On Path Link Design With MathCad Code :

4.1 V/UHF Path Link Case Study Design (Example 1) :

A communication Link is operating in UHF frequency band (450 MHz) is taken as an example. All the information concerning this link are shown as input data. The results are given which shows the status of the design that is whether it “operational” or needs to repeat the process of the design by changing some of the parameters to make the link to operate satisfactorily. This process may be repeated many times till it reaches proper results. The results contain numerical as well as text messages helping the designer to make quick and right decisions to setup the design parameters and this is as shown in fig.(6).

VHF/UHF and Microwave Link Analysis

-----Mathcad Input Data-----

$D_{\text{Km}}=5$ $f_{\text{MHz}}=450$ $PT_{\text{dBm}}=33$ $S_{\text{min dBm}}=-114$

$GT_{\text{dB}}=3$ $\text{FadeMarginUVHFdBm}=18$ $k=4/3$

$GR_{\text{dB}}=3$ $h1=15$ $h2=6.0$ $\text{FeederLossesdB}=3.8$

-----Results-----

$\%FFZO\text{obstruction}=27$ $\text{LineOfSightStatus}=\text{”CLEAR”}$

$R_{\text{LOS Km}}=30$

$\text{RecommendedRange km}=4.9$ (provided first Fresnel zone obstruction $\leq 60\%$).

$\text{LinkMargin}_{\text{dB}}=1.3$

Message =”Link Should Work Properly.”

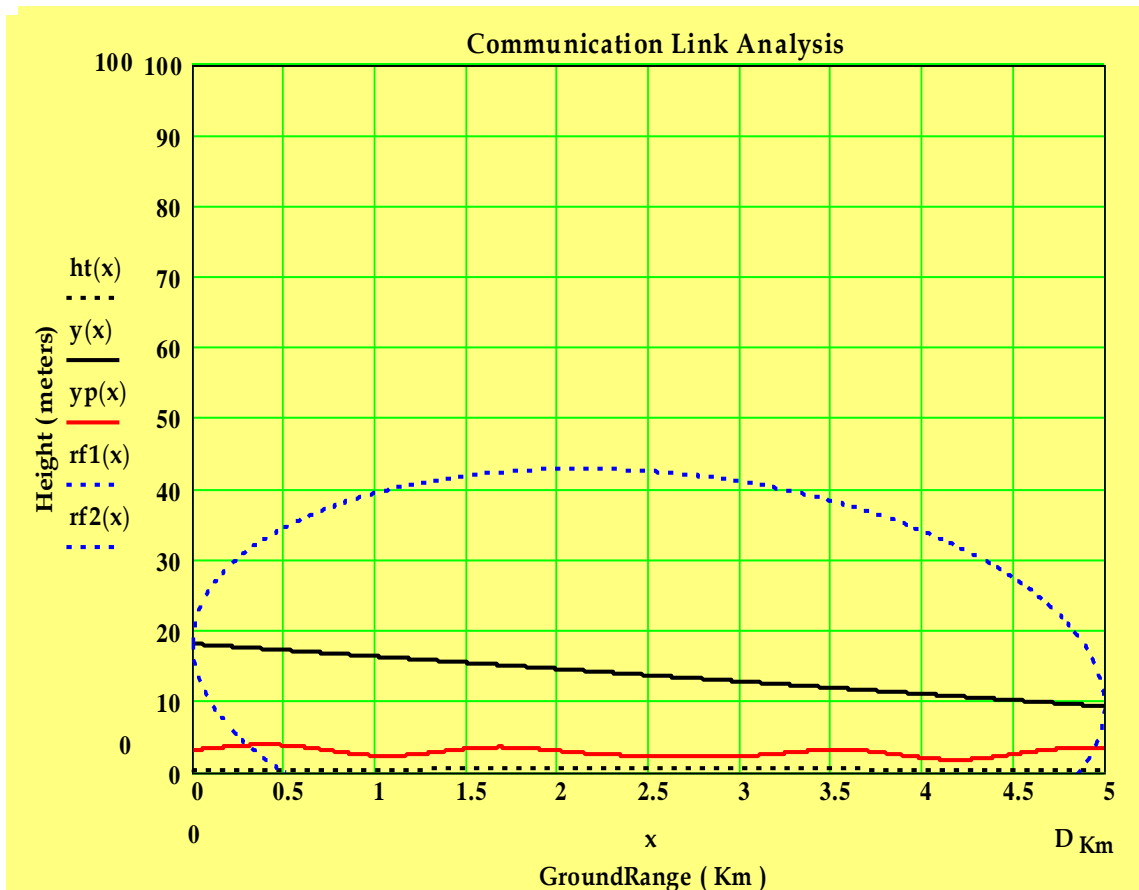


Fig.(6) Height-Range Coverage Diagram MathCad work sheet results of example (1)

4.2 Microwave Path Link Case study design example (2).

A communication is operating at microwave frequency band (2450 MHz) is taken as another example. Results are shown in fig. (7).

Microwave Link Analysis

-----Mathcad Input Data-----

$D_{Km}=6$ $f_{MHz}=2450$ $PT_{dBm}=15$ $Smin_{dBm}=-85$
 $GT_{dB}=8$ $FadeMargin_{UVHF_{dBm}}=10$ $k=4/3$
 $GR_{dB}=24$ $h1=15$ $h2=10$ $FeederLosses_{dB}=6$

-----Results-----

$\%FFZObstruction=0$ $LineOfSightStatus = "CLEAR"$
 $RLOS_{Km}=32.2$
 $RecommendedRange_{Km}=6.1$ (provided first Freznal zone obstruction $\leq 60\%$).
 $LinkMargin_{dB}= 0.1$

Message = "Link Should Work Properly."

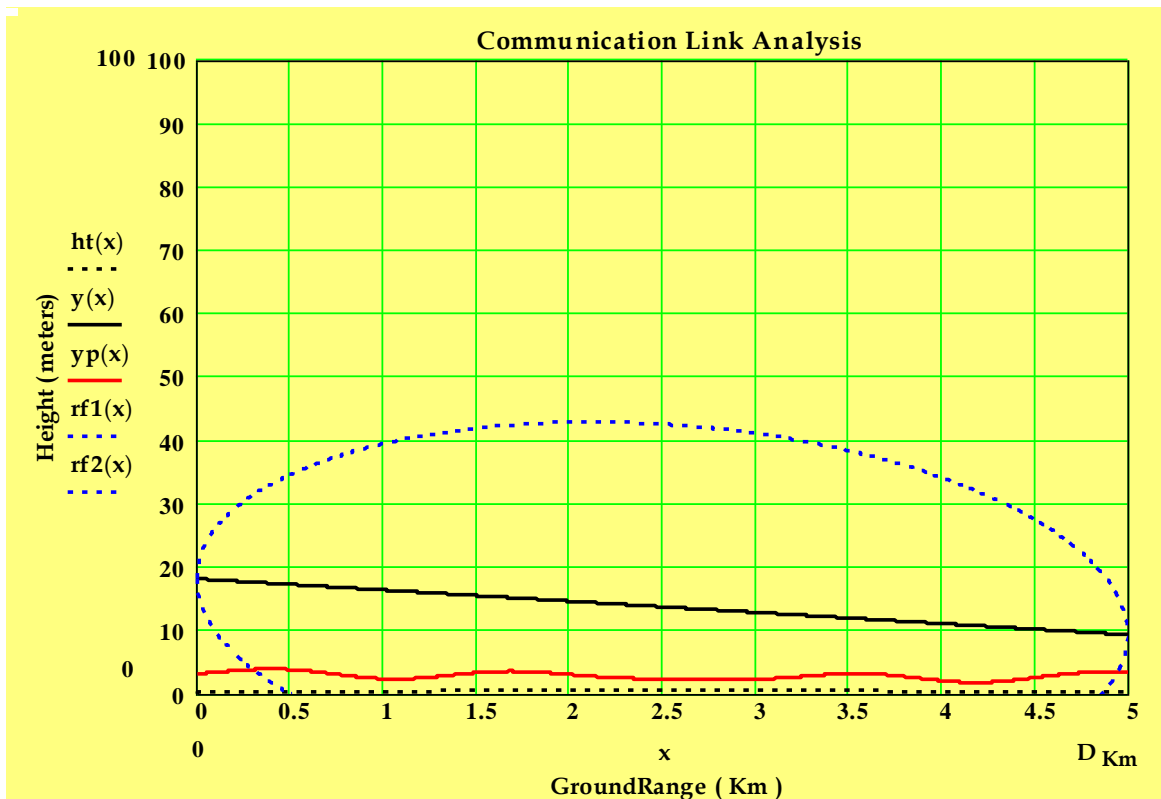


Fig.(7) Height-Range Coverage Diagram / MathCad worksheet results of example (2)

5. Construction of Visual Basic Interface Page with MathCad Code

Figs.(8) and (9) shows a sample of Visual Basic Interface page. The page shows all information needed in communication link design and more over it shows text as well as graphical MathCad results. It is clear from these interface page that one can change any parameter without the need to enter and alter the MathCad code instructions. Another facility is that , one can even enter the MathCad instruction codes through Visual Basic page, and navigate and change any instruction in MathCad codes. As a result, combining Visual Basic and MathCad codes in one code might help designers to interact with the combined new computer code to obtain more clear and immediate visualization of the effect of changing any of the design parameters and this process is frequently needed in such design problems.

6. Discussion and Conclusions:

In wireless communication links operating in V/UHF and microwave frequency bands, the transmitted electromagnetic wave will be affected by the surrounding medium and arrived at the receiver side with attenuation in signal level. As it is shown above that there are many parameters responsible for the signal attenuation. Designers always look for optimum methods and in communication link design these parameters are related with each other as shown in the above examples. Therefore, with the application of the computer program presented in this paper, it is shown that the results are presented in different ways, i.e, numerical, text and graphical modes. The different modes of result presentations, will help in better visualizing the problem and making quick and optimum solutions. In fact the results presented in examples (1) and (2) came from number of computer trails till it settled to those shown in the work sheet results.

It is worth noting that, in this paper, fade margins are assumed to have values of 18 dB for V/UHF and microwave links respectively to operate in 99% of the time. Designers have the options to change these values via the interface page and get the required results.

One of very important criteria in the design of the communication link is the first Fresnal zone percentage of the obstruction. Therefore, one of the features of this computer code presented in this paper is the graphical presentation of the Fresnal zone with the Line Of Sight status.

Without these, information the design would be incomplete and may give impractical results.

VHF/UHF Link Analysis

-----MathCad Input Data-----

$k = \frac{4}{3}$ **Eff. Earth's Radius Factor**

Results

%FFZObstruction = 27 LineOfSightStatus = "CLEAR" RLOS_{Km} = 30
 RecommendedRange_{km} = 4.9 <====Provided First Fresnel Zone Obstruction < or = 60%.

LinkMargin_{dB} = 1.3 **Message = "Link Should Work Properly."**

Coverage Distance(Km)
5.0

Frequency (MHz)
450

Tx O/P Power (dBm)
33

Tx Ant. Height (meters)	Rx Ant. Height (meters)
15	6.0

GT(dB)
3.0

GR(dB)
3.0

Total Feeder Losses (dB)
3.8

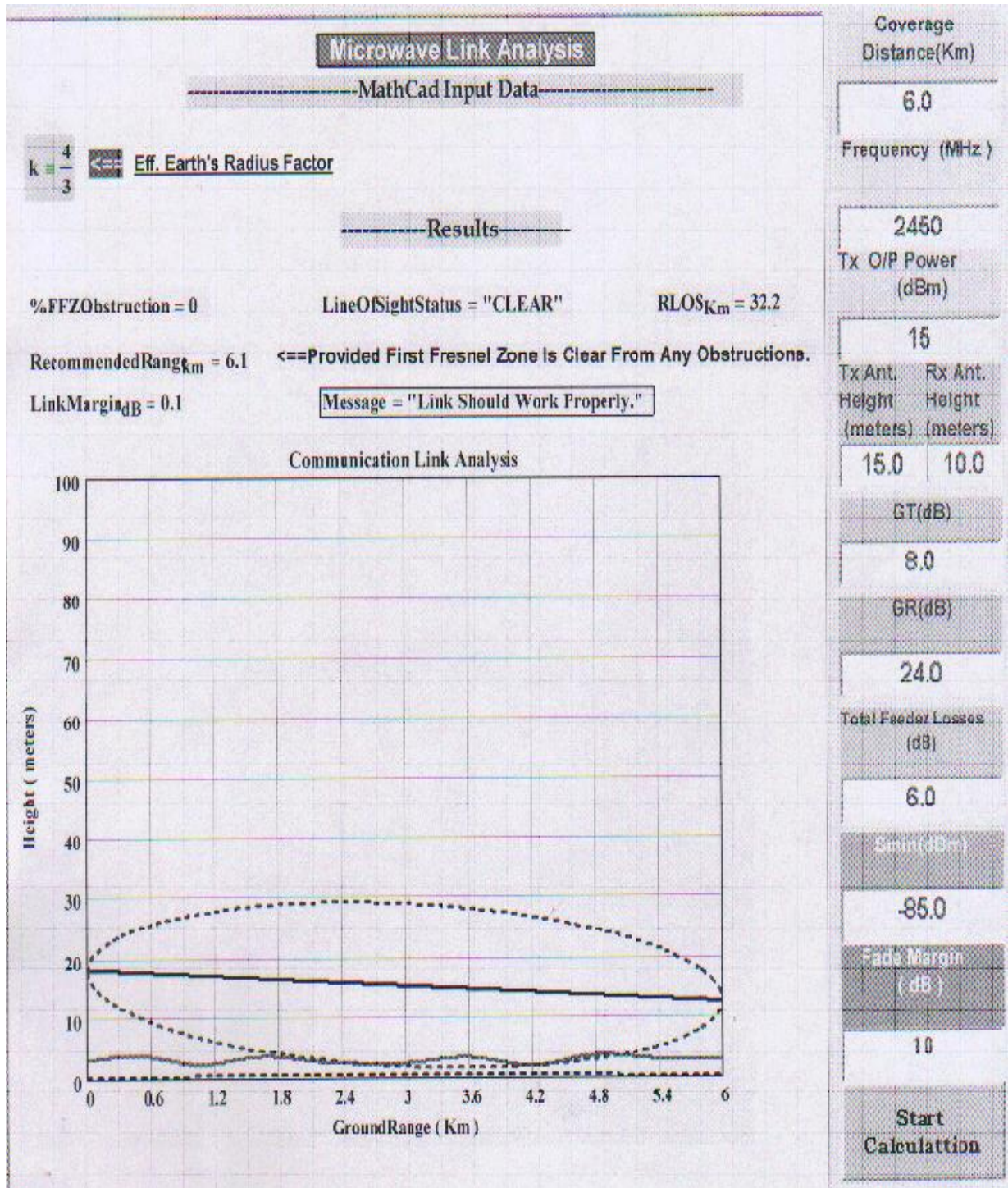
Smin(dBm)
-114

Fade Margin(dB)
18

Start Calculation

Communication Link Analysis

**Fig.(8) Height-Range Coverage Diagram / Visual Basic Interface
Page (V/UHF Link Example)**



**Fig.(9) Height-Range Coverage Diagram / Visual Basic Interface
Page (Microwave Link Example)**

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