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# DESIGN OF DIGITAL MICROWAVE RADIO LINK BY MATLAB

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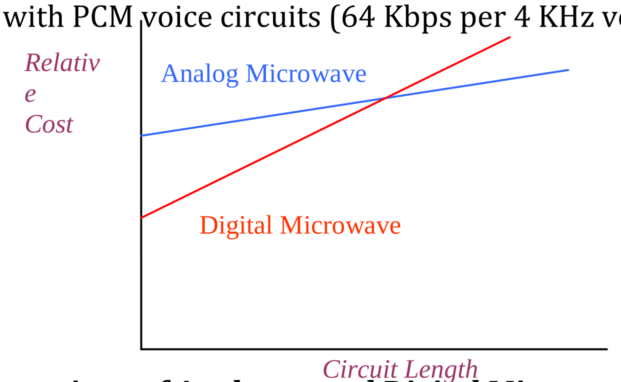
**Abstract:**

*Generally, Digital microwave radio (DMR) offers solving for connecting, it provides enable and grow communication networks for public and private networks to a wide range of applications and for environments. The principle of DMR system and design parameters, influencing factors for its performance have been presented. The performance calculations of the system are developed, and the design steps to satisfy quality and reliability objectives have been given. Typically, to design any DMR Link needs to committee of engineers and technicians to scan the earth between two sites that will establish this system, then study of geometry properties of this region and the height of obstacles if exist to design the height towers, power and another parameters, that may happen mistakes which need to solve it after finishing of establishment system and it needs to a big time and hard work. Developing a computer program using MTLAB has been suggested to obtain tower heights at different sites of the link in the first, then getting performance calculation, system configuration that satisfies the reliability and quality objectives specified by ITU. The results proves that the lowest time and easy way have been achieved by using the Matlab software program. Comparison between of the developed software with other sources (such as Alcatel Company which established a system of DMR between Libya and Algeria countries) has been discussed. The results confirms capability of using software program to design and test any DMR system.*

**Key Words:** DMR, Matlab Software, Digital Microwave, LOS & C/N

**Introduction:**

It is true to say that the future of almost all communications mediums is in the transmission of digits. In general, digital transmission offers the end user better quality and the provider more capacity for a given transmission resources [1]. A DMR link is similar to an analogue microwave link with the exception of calculating the desired $C_{min}/N$. For digital links, the required carrier power is a function of the desired performance (i.e. probability of error) and the noise power [1]. In the recent years, the development of a digital modulation radio increased for telecommunication radio system, since it is used for the private and government sectors, and the demand for new types of services is also increasing. An electronic digital switching is used for voice and data switching. The new central office switching equipment is a computer based machine that is vastly superior to the earlier electro-mechanical switching. These switching operate with PCM voice circuits (64 Kbps per 4 KHz voice channel).




**Comparison of Analogue and Digital Microwave Radio Costs [2]**

Since the trunk connections to the switches are digital signals, the lowest multiplexing costs are achieved by utilization of digital transmission. DMR tend to cost more than FM radios but the overall transmission cost, including multiplexing costs is usually lower than analog transmission systems. The figure above shows comparison of the relative transmission costs of analog and digital microwave radio systems [2].

DMR offers significant advantages over analog transmission. DMR with regeneration per repeater has no build-up of noise and the system noise performance is independent of the number of hops, where as the total noise in analog system builds up as the log of the number of repeaters [3].

**Line of Sight (LOS) Propagation [4]:**

The propagation of any two antennas consists of LOS path with other waves that comes from ground or any other surface which parallels the earth's surface and a sky waves that comes from the components of signal reflected off the troposphere or ionosphere, a waves that reflected off obstacle in the terrain, and a ground reflected path. The existence and advantages of these modes depend on the link geometry, the operating frequency, terrain and distance between both antennas. For frequencies mode is the predominant mode available for use; the other modes may cause interference with the stronger LOS path. Line-of-sight links are limited in distance by the curvature of the earth, obstacles along the path, and free space loss. Average distances for conservatively designed LOS links are 30 to 48 Km.

**Path Profile [5]:**

In path profile we must take into considerations all obstacles along the Line-Of-Sight radio path including trees and vegetation, earth curvature, and fresnel zone.

Path profile is performed according to the following steps [5]:

1. Get obstacle information from topo-graphical maps scale 1:25,000 or 1:50,000, to now the height and position for earth obstacle.
2. Setup a graph paper and indicate obstacle height on Y-axis and the distance from both sites on X-axis. Trace all obstacles as shown in figure 1. Where $d_{A1}$ represent the distance from the A site to the first obstacle and $d_{A2}$ it is from the A site to the 2nd obstacle, and the same for the other site, since $d_{B1}$ it is the distance from the B site to the first obstacle and which is the second obstacle for A site, so $d_{B2}$ is the distance from the B site to the second obstacle so it is first obstacle for A site. $h_1$ and $h_2$ are the heights for both obstacle respectively [3].

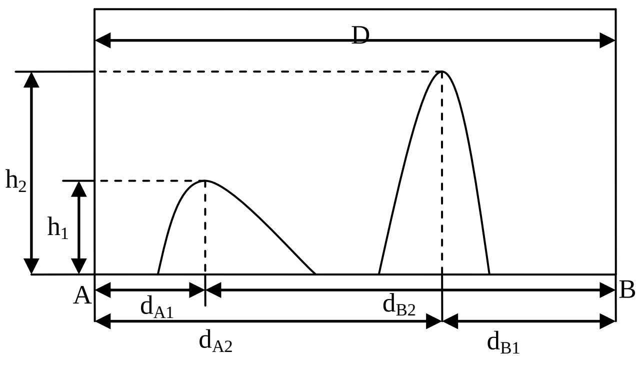



**Figure 1: Obstacle between the Two Sites**

**3. Determine Earth Curvature (E.C) [5]:**

Earth curvature or it is called earth bulge in some books, since it is the bending density of the earth and it is the ratio of the effective earth radios to the true earth radius. In order to draw the line of sight straight in a path profile, the ray bending due to variation in K-value is added to the terrain height. The modification of the terrain height is given by:-

$$\mathbf{E.C} = \frac{\mathbf{0.078 d_1 d_2}}{\mathbf{k}} \quad \text{In meter} \qquad (1)$$

Where k is the K-value as shown in figure 2 and the other parameters have their previous definition.

The value of k in Libya is taken greater than 1, typically k=4/3.

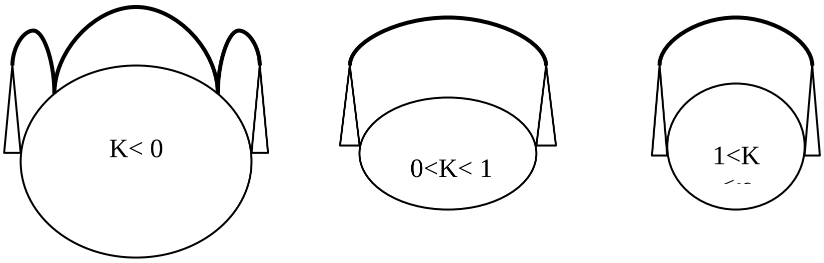


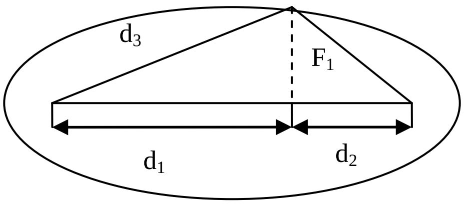

**Figure 2: Various Forms of Atmospheric Reflection [3]**

It is clear from figure 2 that the heights are obtained when 0<k<1.

### 4. Determine Fresnel Zone Clearance [5]:

An EM wave front has expanding properties as it travels increases or decreases of signal level of reflection or phase transmission will occurred.

The first Fresnel zone is defined as the locus of points where $d_3-(d_1+d_2) = \lambda/2$. This equation describes an ellipse, but for practical applications the radius $F_1$ may be approximated by the formula:-




$$\mathbf{F_1} = \mathbf{17.3}\sqrt{\frac{\mathbf{d_1.d_2}}{\mathbf{f.d}}} \quad \text{Meter} \qquad (2)$$

In general the $n^{th}$ Fresnel zone radius (when $d_3-(d_1+d_2) = n\lambda/2$) is given by:-

$$\mathbf{F_n} = \mathbf{17.3}\sqrt{\frac{\mathbf{n d_1 d_2}}{\mathbf{f.D}}} \qquad (3)$$

Where f =frequency (GHz).

D = path length (Km) ($D=d_1+d_2$).

$d_1$= distance from transmitter to a given point along the path (Km).

$d_2$=distance from receiver to the same point along the path (Km).

The impact of diffraction and reflection on the radio waves can be seen easily by using the model developed by A. fresnel for optics. Fresnel accounted of the diffraction of light by assuming that the cross section of an optical wave front is divided into zones of concentric circles separated by half- wave lengths [4]. Optimum clearance of on obstacle defined as 0.6 of ($1^{st}$ fresnel zone clearance).

5. Setup table showing obstacle distances $d_1$& $d_2$ and calculated E.C and $F_1$ for each obstacle as shown below:-

| Obstacle location | $d_1$ | $d_2$ | E.C | Fresnel zone Radius |
|---|---|---|---|---|
| Obstacle #1<br>Obstacle #2<br>~ | ~<br>~<br>~ | ~<br>~<br>~ | ~<br>~<br>~ | ~<br>~<br>~ |

6. For each obstacle add it's earth curvature E.C, $0.6F_1$ it is height, and in case of vegetation and trees between the heights add an average value of 12 meters for trees and 3 meters for average growth as shown in fig 3.

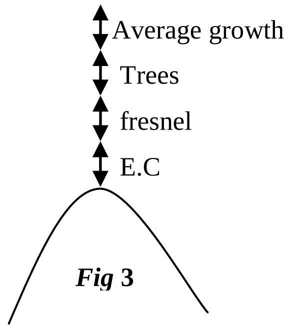


***Fig* 3**

7. Repeats step 6 for each obstacle and draw the results on a graph paper. Then draw straight line connecting the top heights obtained in step 6 for each obstacle as shown in fig 4. More than one possibility may result, and the best choice minimum tower heights are selected.

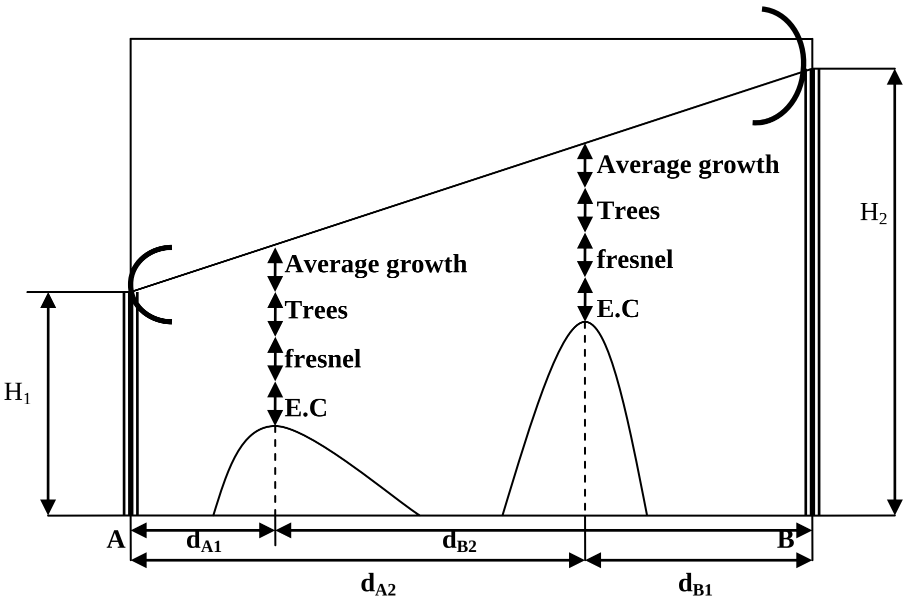



**Figure 4: Radio system performance Design [6]**

1. Determine C/N Requirement

We can determine C/N by assuming certain BER, and then from bit rate, and BW, C/N is obtained.

2. Get receiver noise figure, and noise power as

$$N=KTBF \quad (4)$$

Where

N = is the noise power.

F = is the noise figure.

B = is the receiver BW.

T = is effective noise temperature.

3. Get $C_{min}$ that is required receiver carrier level then

$$C_{min}=N_{total} + C/N \quad (5)$$

4. Get transmit power, use given value or assumed, value

5. Get system gain ($G_s$) as

$$G_s= P_t - C_{min} \quad (6)$$

6. Repeater spacing

$$G_s = P_t - C_{min} \geq F + L_s + L_f + L_b - G_t - G_r \quad (7)$$

Where F is Hope fade margin (dBs) of a non-diversity system required meeting the reliability objective, and it is have the following expression

$$F = 30\log D + 10\log 6ABf - 10\log(1-R) - 70 \quad (8)$$

Where :- (1-R) is the reliability objective.

A is roughness factor and it is equal (4) for very smooth terrain, equal (1) for equal average terrain with some roughness, and equal (1/4) for very rough terrain.

B is factor to covert worst month probability to annual prob. Since it is equal (1/8) for mountainous or very dry area, equal (1/4) for average terrain with some roughness, equal (1/2) for hot or humid areas, and equal (1) on worst month basis.

$L_s$ = is the free space loss

$$L_s = 92.4 + 20\log D + 20\log f \quad (9)$$

For f in GHz, and D in Km

$L_f$ = is feeder loss, and $L_b$ is branching loss.

$G_t$,$G_r$ is the gain of transmitter and receiver respectively.

**Note**: If we have (R=99.9%) that is give (1-R) =0.001, then (-10log (1-R)) =+30dBs. But if the (R=99.99%), then (-10log (1-R)) =+40dBs.

Therefore F is increased by 10 as a result of improving reliability by adding extra "9" to the decimal point. This extra 10dBs on fade margin will require extra 10dBs in power to keep a constant $G_s$ (system gain) or in other words to meet C/N requirement which again is being selected to satisfy the desired BER.

**Link Calculation Procedure [4]:**

The following assumptions are made:-

1. An adequate path clearance is provided on the path under consideration.
2. Rain attenuation and atmospheric absorption have been ignored, which is appropriate for frequencies below 10GHz. These two effects are easily added for use of higher frequencies.
3. As often the case, antenna size is the final design parameter. Hence antenna size is calculated from other design parameters whose values are already selected.

   The procedure shown can be rearranged to make any design parameter the last value to be determined. Often iteration is required in order to determine the best combination of design values. The following design changes are commonly made to meet performance objectives:-

- Increase transmitter power.
- Use lower loss transmission line.
- Use lower noise receiver.
- Add diversity path to the unprotected path.
- Increase antenna spacing for existing space diversity or frequency spacing for existing frequency diversity.
- Increase antenna size.
- Add an amplitude equalizer or, for greater improvement, add an adaptive transversal equalizer.

**Design of Tower Heights:-**

The methodology of program is, in the first will calculate the Fresnel zone ($F_R$) and earth curvature (E.C), then increase 12 meters for trees and 3 meters for average growth to the E.C, $F_R$, height of obstacle, then will again the process for all obstacles, by the breath of the time the program will find the bigger height of obstacles, then it works to find all possible of ways to send and receive the signal with ensure don't crossing the path any obstacle. In the last, the program will choosing the lowest cost of the towers.

**The Link Design and Parameters:**

In the beginning, when the program execution will ask to insert the input data, then it will star to calculate the required data automatically. When calculated the outage by program, it will calculate the unprotected probability of outage and compared with Severely Error Second (SES) for availability case or Degraded Minutes (DM) for quality case. If the probability less than it, the program will tell that "Here we get a good performance" otherwise the program will using all the possible solutions such as (space diversity, frequency diversity, combine diversity, equalization,….etc) until getting a good performance and then, the program will tell "Here we get a good performance". If still the probability bigger than SES, then it well tell that "You must change design parameters".

**Results & Discussion:**

- **Determination of Tower Heights:-**

**Scenario 1:-**

A system of digital radio link that established among three sites and two hops; the data available is given in table 1

TOWER DESIGN (Two Hop)

Radio frequency (f) = 6 GHz. K= 4/3

**FIRST HOP**

Path length (D) = 30 Km

- Site A = 30m over MSL

First obstacle:-

Distance ($d_{A1}$) =10 Km

Height ($h_1$) =45 m

Second obstacle:-

Distance ($d_{A2}$) = 15Km

Height ($h_2$) = 60 m

Third obstacle:-

Distance ($d_{A3}$) =20 Km

Height ($h_3$) =40 m

- Site B =40m over MSL

**SECOND HOP**

Path length (D) =60 Km.

- Site B = 40m over MSL.

First obstacle:-

Distance ($d_{B1}$) =20 Km.

Height ($h_1$) =40 m.

Second obstacle:-

Distance ($d_{B2}$) =35 Km.

Height ($h_2$) =35 m

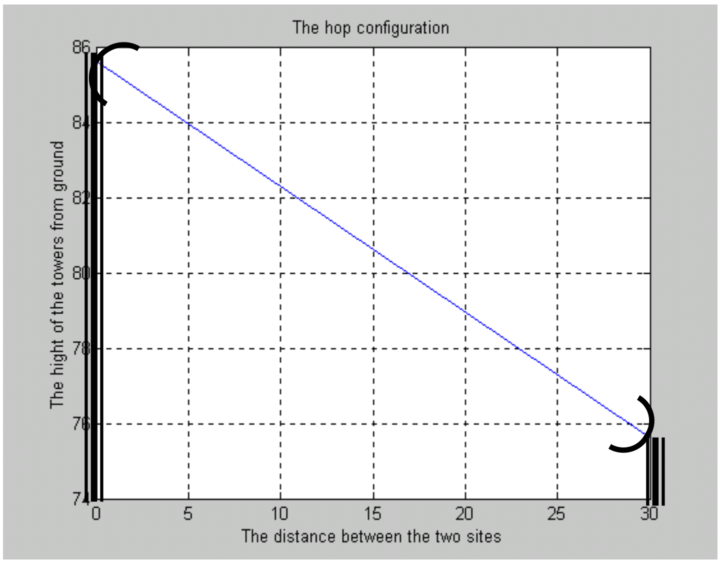
Third obstacle:-

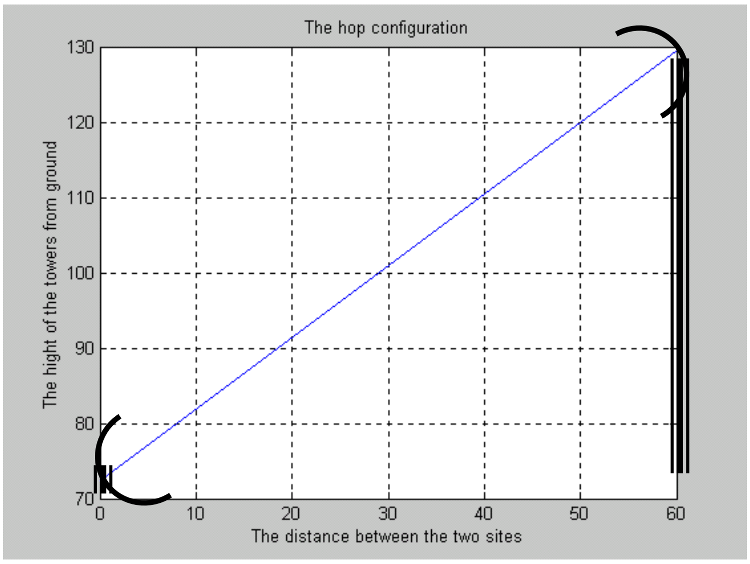
Distance ($d_{B3}$) = 50 Km.

Height ($h_3$) =50 m.

- Site C =30m over MSL.

***The Developed Program Results:***




**Comparison between the Results of This Program and Other Results of Sources**

| ***Results of The Computer Program*** | ***Results Obtained By Manual Calculation*** |
|---|---|
| Hop #1<br>$h_1$= 85.6326m<br>$h_2$=75.6326m | Hop#1<br>$h_1$=85m<br>$h_2$=75m |
| Hop#2<br>$h_1$=72.2966m<br>$h_2$=129.4162m | Hop#2<br>$h_1$=73m<br>$h_2$=128.8m |

***Note: -*** From the comparison table it is clear that the two results are almost identical.

- **Link Design And Performance Calculation:**

To perform link design and performance calculation, we will consider two examples one system uses M-PSK modulation, and other system uses M-QAM modulation respectively, as shown below:-

**Scenario 2:**

A system of digital microwave radio link between two sites firs called repeater B and another called Harash is utilizing Q-PSK modulation technique and it has the following data:-

Bit Rate (R) =34 Mbps
Radio Frequency (f) = 2.203 GHz
Path Length (D) = 79 Km
Power Options ( $P_t$) =30 dBm
Antenna Diameter Options (Dia) =3.7 m
Antenna Efficiency Options (eff) =0.5
W/G Loss Factor Options (W/G) =3.4983799E-02 dB/m
Receiver Noise Figure Options (NF) = 4 dB
Antenna Spacing (SD) = 20 m
Frequency Spacing (FD) = 6.6090003E-02 GHz
**Modulation Type:**
The Spectral Efficiency (Se) = 1.7 bps/Hz
CQ =1E-03
Wx=3.090946
***QPSK***
RF-Channel Bandwidth (BW) =20 MHz
**CCIR Outage Objectives:**

1. Availability (BER=1.0E-03) Objectives (SES)= 1.7064001E-03%
2. Quality ( BER=1.0E-06) Objectives (DM) = 1.264E-02 %

**Path Losses:**
Site (A) Repeater ***B***
Transmitter line losses

a. antenna Height Above Ground (HT) =149m
b. horizontal Transmission Line Length (U) = 10 m

Site (B) ***Harash***
Receiver Line Losses

a. Antenna Height Above Ground ( Upper Antenna if SPACE DIVERSITY is Used ) (HR) =212 m

b. Horizontal Transmission Line Length ( C) =10 m
Branching Loss (Lb) =4.7dB
Atmospheric Absorption Losses (Lg) =0 dB
Miscellaneous Losses (Lm) =0 dB
Terrain Factor (a) =1
Climate Factor (b) =0.25
Modulation Implementation Loss (MIL) = 2 dB
Dispersive Fade Margin (DFM) = 39.9 dB
Interference Fade Margin (IFM) = 57.5 dB
The AEQ Improvement Factor (AEQIF) = 1.5
Combiner Hysteresis Loss (H) = 3 dB
CQ = 1E-06
WX = 4.744944
Modulation Implementation Loss (MIL) = 2 dB
Dispersive Fade Margin (DFM) = 37.8 dB
Interference Fade Margin (IFM) = 55.5 dB
**The Requirement:**

1. $E_b/N_o$.
2. RSLm.
3. $G_s$.
4. PUL.

5. The link performance and configuration.

**Scenario 3:**

A system of digital microwave radio link between two sites, first called sim sim and another called vert designed ( 16-QAM modulation technique is selected) and it has the following data:-

Bit Rate (R) = 140 Mbps
Radio Frequency (f) = 6.77 GHz
Path Length (D) = 92.4 Km
Power Options (Pt) =30 27.0 dBm or (0-3 dBW)
Antenna Diameter Options (Dia) =3.7 m
Antenna Efficiency Options (eff) =0.5
W/G Loss Factor Options (W/G) =4.4771198E-02 dB/m
Receiver Noise Figure Options (NF) = 4 dB
Antenna Spacing (SD) = 5 12 m
Frequency Spacing (FD) = 0.2708 0.3385 GHz

**Modulation Type:**

The Spectral Efficiency (Se) = 3.5 bps/Hz
CQ =1.3333334E-03
Wx=3.004823

***16-QAM***

RF-Channel Bandwidth (BW) =40 MHz

**CCIR Outage Objectives:**

3. Availability (BER=1.0E-03) Objectives (SES)= 1.9958401E-03%
4. Quality ( BER=1.0E-06) Objectives (DM) = 1.4784001E-02 %

**Path Losses:**

**Site (A) Sim *Sim***

Transmitter line losses

c. antenna Height Above Ground (HT) =26 m
d. horizontal Transmission Line Length (U) = 19 m

**Site (B) *Vert Pre***

Receiver Line Losses

c. Antenna Height Above Ground ( Upper Antenna if SPACE DIVERSITY is Used ) (HR) =29 m

Branching Loss (Lb) =4.5 dB
Atmospheric Absorption Losses (Lg) =0 dB
Miscellaneous Losses (Lm) =0 dB
Terrain Factor (a) =4
Climate Factor (b) =0.125

**AVAILABILITY CALCULATIONS (BER=1.0E-03)**

Modulation Implementation Loss (MIL) = 3 dB
Dispersive Fade Margin (DFM) = 26.8 dB
Interference Fade Margin (IFM) = 57dB
The AEQ Improvement Factor (AEQIF) = 6.6
Antenna Spacing (S) =12 m
Combiner Hysteresis Loss (H) = 0 dB

**QUALITY CALCULATIONS (BER=1.0E-06)**

CQ= 1.3333333E-06
WX= 4.689944
Modulation Implementation Loss (MIL) = 3 dB

Dispersive Fade Margin (DFM) = 24.1 dB
Interference Fade Margin (IFM) = 54.3 dB

**The Requirement:**

6. $E_b/N_o$.
7. RSLm.
8. $G_s$.
9. PUL.
10. The link performance and configuration.

***Comparison among of our Program and Other Sources:***

***Q-PSK (Availability)***

| | Outage Time (%) | | |
|---|---|---|---|
| **Source** | **Computer Output** | **Alcatel ATFH** | **Another Program[7]** |
| **Unprotect System** | 123.0E-4 | 95.96E-4 | 124.4E-4 |
| **With Adaptive Equalization** | 82.0E-4 | | 82.93E-4 |

***Q-PSK (Quality)***

| | Outage Time (%) | | |
|---|---|---|---|
| **Source** | **Computer Output** | **Alcatel ATFH** | **Another Program [7]** |
| **Unprotect System** | 278E-4 | 272.54E-4 | 280.7E-4 |
| **With Space Diversity** | 44.5E-4 | | 44.68E-4 |

***16-QAM (Availability)***

| | Outage Time (%) | | |
|---|---|---|---|
| **Source** | **Computer Output** | **Alcatel ATFH** | **Another Program[7]** |
| **Unprotect System** | 3584E-4 | 1649E-4 | 3574E-4 |
| **With Space Diversity & Equalization** | 14E-4 | 6.5E-4 | 14.32E-4 |

***16-QAM (Quality)***

| | Outage Time (%) | | |
|---|---|---|---|
| **Source** | **Output Computer** | **Alcatel ATFH** | **Another Program[7]** |
| **Unprotect System** | 6789E-4 | 3250E-4 | 6783E-4 |
| **With space Diversity & Equalization** | 52E-4 | 39.3E-4 | 51.6E-4 |

**Conclusion:**

In the recent years, the development of a digital modulation radio is increased for telecommunication radio system, since it used for the private and government sectors, and the demand for new types of services is also increasing. DMR it provides enable and grow communication networks for public and private networks to a wide range of applications and for environments. Design DMR link by MAtlab software and compare among own results and other results have been done. The results were symmetrical, the results of the developed computer program conform to the result obtained from other sources. Modulation techniques which are widely used in digital microwave radio are Q-PSK and M-QAM. The steps of path profiles are :-

a. Get obstacle information from topo-graphical maps.

b. Setup a graph paper and indicate obstacle height on Y-axis and the distance from both sites on x-axis.
c. Determine Earth Curvature.
d. Determine Fresnel Zone Clearance.
e. Setup table for obstacle distances, clearance and fresnel zone.
f. For each obstacle add its earth curvature E.C, 0.6F1, 12 for trees and 3 for the growth.
g. Repeats step (f) for each obstacle and draw the results on a graph paper.

Diversity is used to improve the performance of the radio which is affected by objective fading the terrain, atmosphere, and precipitation. Availability objective is used to measure the availability of the link such as the BER performance when it isn't greater than 1E-03 for a specified period. It is specified as severely errored seconds (SES). The quality objective of a link is the percentage of time the BER is more $10^{-6}$. It is specified as degraded minutes (DM). The results of the developed computer program package conforms to the results obtain by the other references.

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