1 Introduction

The aim of this project is designing Private Mobile Radio (PMR) Digital Network around Veles city in Macedonia. The specification of the project is introduced in section 2.In section 3 the geographical location and climate of the Veles has be discussed. For designing this network, 2 types of networks are considered one is UHF network and other one is microwave network. These concepts have been reported in section 4. These are 3 systems in this networks, repeaters, mobile units, and 28 GHz radio. These are introduced in section 5. Analyzing the network which is designed is discussed in section 6, including selection of stations' locations and Fresnel Ellipsoid. Last section of this report is allocated to conclusion.

2 Project Definition

In this project, the Private Mobile Radio (PMR) Digital Network is designed in the area of 100 km × 100 km square around the Veles city in Macedonia. The frequency of operation is 465 MHz and modulation type is ETSI Digital Mobile Radio (DMR). The interconnection between repeaters is point-to-point microwave links at 28 GHz. Repeater stations use Motorola SLR5500, and vehicular terminals use Motorola DM4000E. Vehicular terminals are communicating with each other by means of repeaters and base stations.

3 Geographical location and climate of Veles city

Veles city is located in 41.7165° N, 21.7723° E. This city is surrounded by mountains in west, south, north-east, and north-west. Other areas are smooth ground. Figure 1 shows the geographical location of the Veles city in Macedonia. As expected, the number of the base stations in mountain parts is higher for better coverage.

The climate of this city is Veles is 234m above sea level. The climate in Veles is warm and temperate. Veles has a significant amount of rainfall during the year. This is true even for the driest month. This climate is Cfa (i.e., Humid subtropical climate) according to the Köppen-Geiger climate classification. In Veles, the average annual temperature is 13.9 °C. Precipitation here is about 627 mm per year. So, continental sub-tropical is selected as type of the climate in the software and in the other word for this project. Figure 2 shows the type of climate in the area of study. Clearly, it is shown that the most part of the area has Cfa class climate.

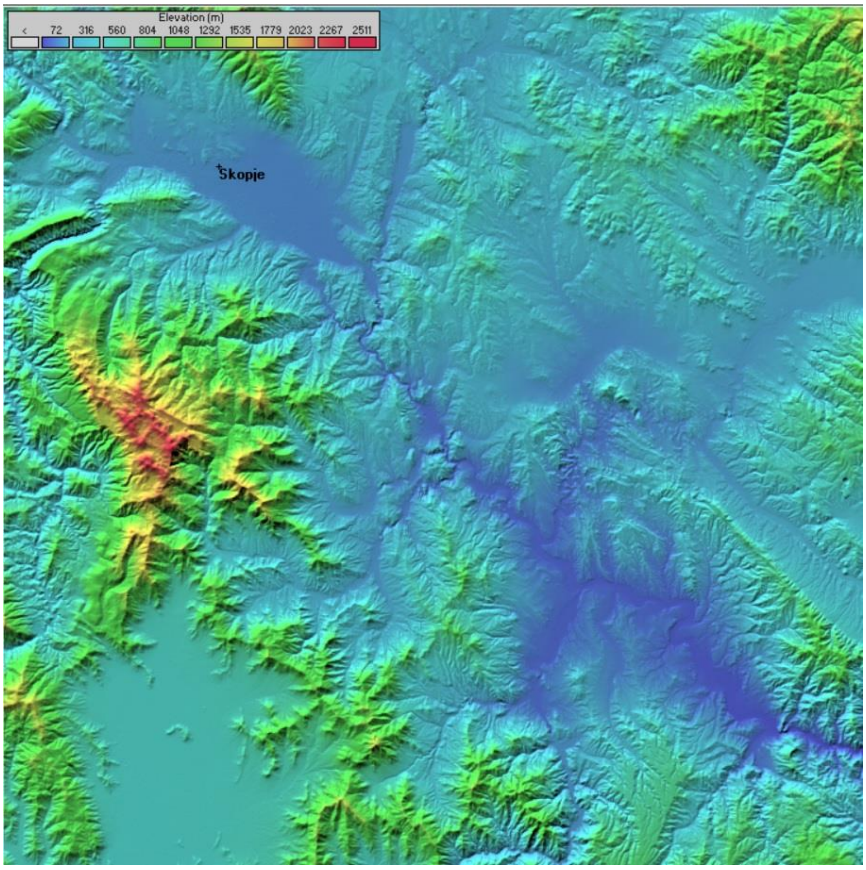

Figure 1. Geographical location of Veles city

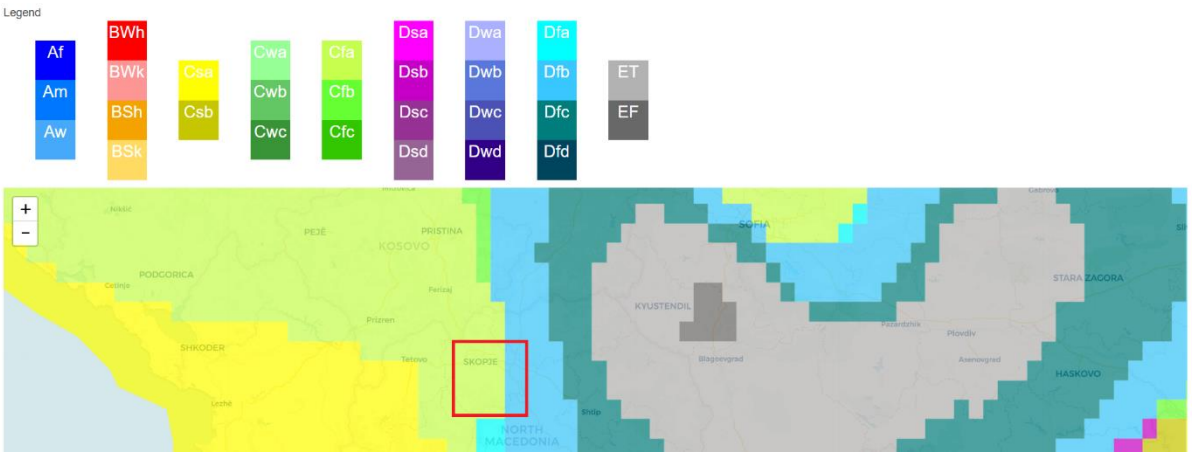

Figure 2. The climate class of area of study

*Source: https://www.plantmaps.com/koppen-climate-classification-map-europe.php

4 Network Definition

In this scenario, 2 networks are defined. One is microwave network working at 28 GHz (SHF Band) for interconnecting the repeaters point-to-point microwave link is used; and a UHF network working at 465 MHz for radio coverage of the local areas in the target region.

For both network, 28 GHz, and UHF network the vertical polarization is selected. As mentioned before, continental sub-tropical is selected as type of the climate. The topology of the networks is based on voice communication.

For the microwave network, the design is based on making sure that radio visibility between repeaters is satisfied. This is point-to-point microwave link. This basically means that the first Fresnel ellipsoid must be free to guarantee full radio visibility. Each repeater will be interconnected with at least two other repeaters to allow better routing.

For the UHF network, all the antennas for base stations are considered to have Omni-directional pattern. In this case, first Fresnel ellipsoid is no longer considered but the focus is on single and combined radio coverage of base stations.

5 Systems

There are 3 types of systems are defined in this project including Repeaters, Mobile Units, and 28 GHz radio. By using Repeaters, the signals are rebroadcasted in frequency carrier of 465 MHz in the area which Mobile units exist. So, it is necessary that the repeaters communicate with each other's.

5.1 Repeaters

In this project, Motorola SLR5500 is selected for repeaters. In Motorola SLR5500 datasheet, in the table of general specifications, the RF output power is between 1 to 50 watts so for this project 40 watt is considered as transmit power. For Receiver Threshold, in the table of Receiver of this datasheet, Sensitivity is equal to 0.22 µV, for being safe and covering the worst condition, 0.44 µV is selected.

For antenna specification, an omnidirectional antenna is selected. After testing some antennas in the area of study, the best choice is BAN0155R which works in the frequency of desired (465 MHz). The gain of this antenna is 6.5 dBi. The reasonable antenna height is few meters up to 50 to 70 meters based on the different areas, different heights are selected. The cable in this case after some experience, the best choice is coaxial cable RT 50/20. In datasheet of RT 50/20 for frequency of 465 MHz the approximate loss is 10 dB per 100 meters.

5.2 Mobile Units

Motorola DM4000E is selected for Mobile Units. Like section 5.1 it is required to select the best number for transmit power and receiver sensitivity from the datasheet. The transmit power can be selected from 1 to 40 watts. 40 watts is selected, it does not matter to use maximum power because mobile unit works much less than Base Station unit. In the datasheet for receiver there is 2 sensitivity types, one is analog and the other one is digital. Since, the type of modulation in this project is digital so the digital sensitivity is selected which is 0.16

μV, because of safety purpose 0.32 μV is selected. 0.32 μV can satisfy both digital and analog sensitivity.

The Antenna type is omnidirectional. It is not expected much gain so 0 dBi is chosen. The height of antenna is in order of the height of vehicle so 1.5 m can be good choice.

5.3 28 GHz Radio

Datasheet of PTP 820S is used. For transmit power, from transmitter table in the case of 28 GHz and QPSK modulation because of transmitting voice and since not much bandwidth is necessary, 18 dBm is selected. For Receiver Threshold, in the table of receiver by focusing on 18 GHz, -94.5 dBm is seen and by considering the margin, -88.5 dBm is chosen.

In the case of antenna specifications, in 28 GHz, antenna is highly directive but omnidirectional type is selected because in THP 03 275 S, the HPBW is 2.2 degree so for connecting to each repeater, an antenna is needed so it is equivalent to selecting omnidirectional type. For antenna gain: In the section of Electrical Characteristics, antenna operates in 27.5 to 29.5 GHz so, 28 GHz is in the middle of this band therefore, gain mid band which is 38 dBi is chosen. The antenna Height is same height of the UHF network.

6 Analysis of the network

6.1 Selecting locations of the stations and covered area

Analysis of the network started with locating the first station on the top of the highest mountain in the area of study and by use of single polar radio coverage, the locations which are not covered found. After that by putting the second station on top of the highest mountain in one of the locations that is not covered by station 1, and then analyzing is provided in the area not covered by station 1 and 2 by means of combined cartesian radio coverage. Again, not covered locations are found. This process should be continued until reaching an acceptable coverage percentage for example 95 percents. In this project for this purpose, considered 11 stations to cover the area. Figure 3 to 13 show the single polar radio coverage of each station.

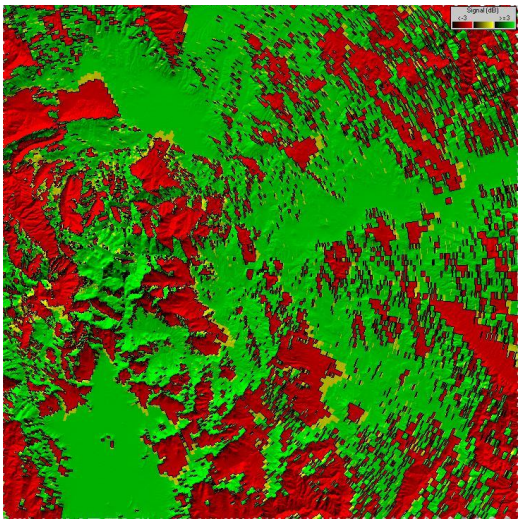

Figure 3. Single polar coverage of station 1

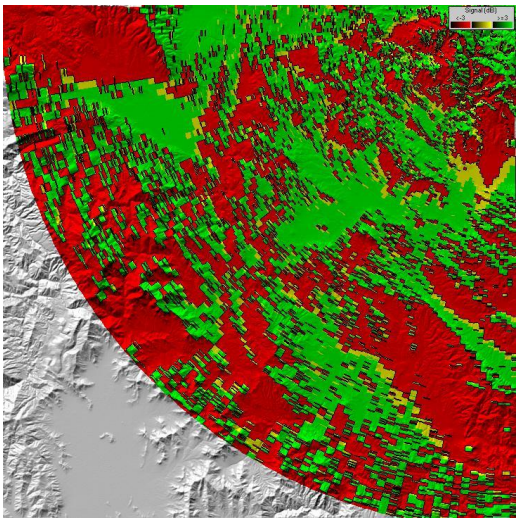

Figure 4. Single polar coverage of station 2

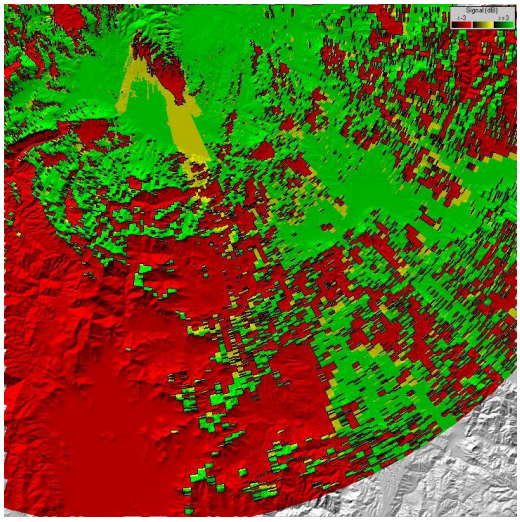

Figure 5. Single polar coverage of station 3

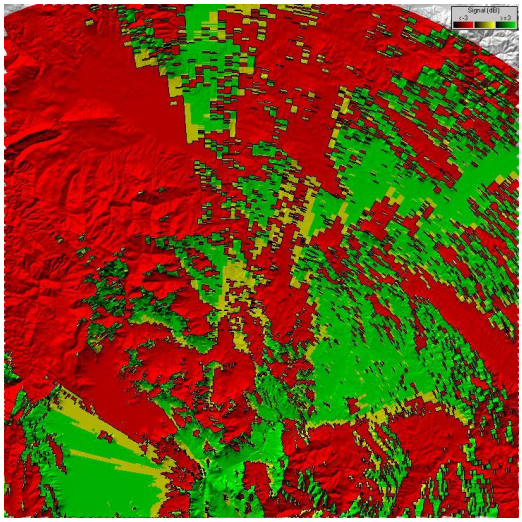

Figure 6. Single polar coverage of station 4

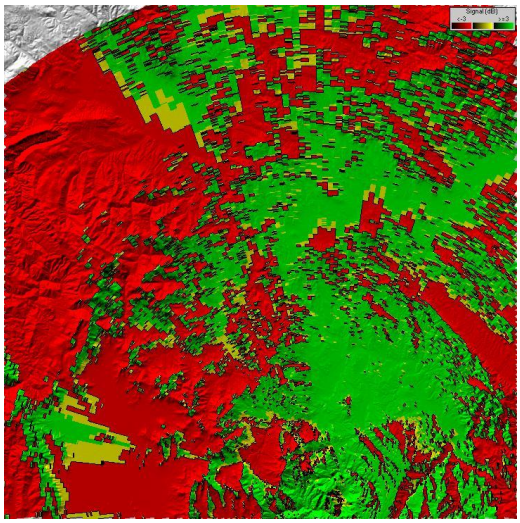

Figure 7. Single polar coverage of station 5

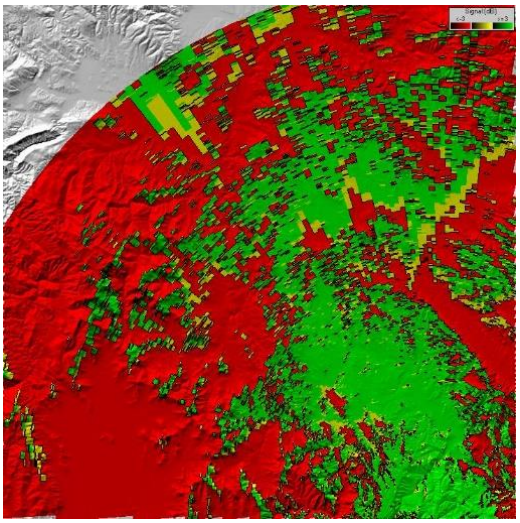

Figure 8. Single polar coverage of station 6

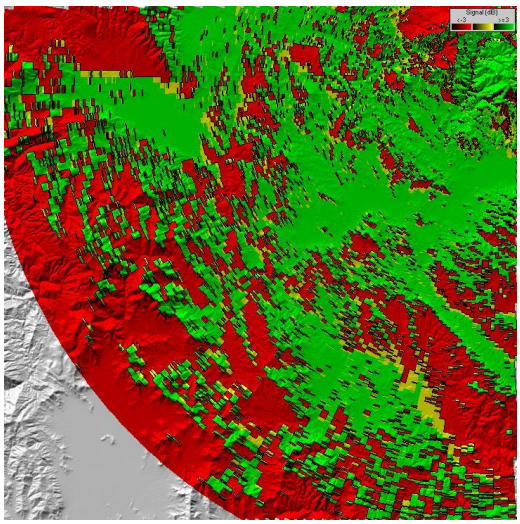

Figure 9. Single polar coverage of station 7

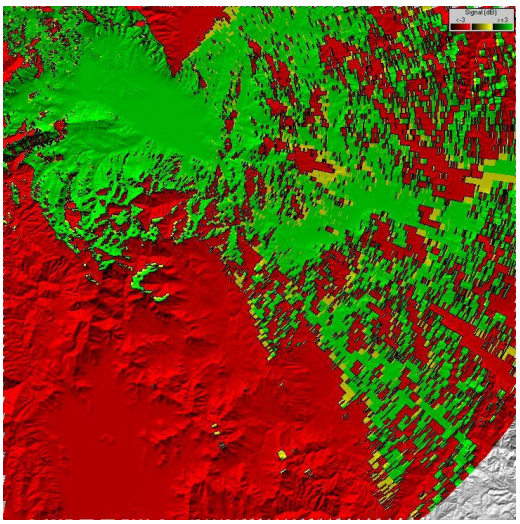

Figure 10. Single polar coverage of station 8

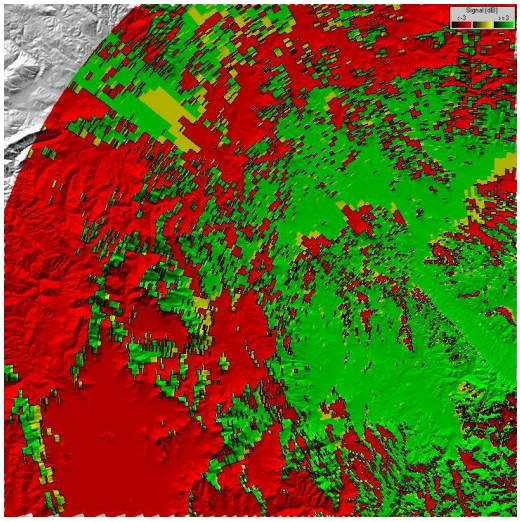

Figure 11. Single polar coverage of station 9

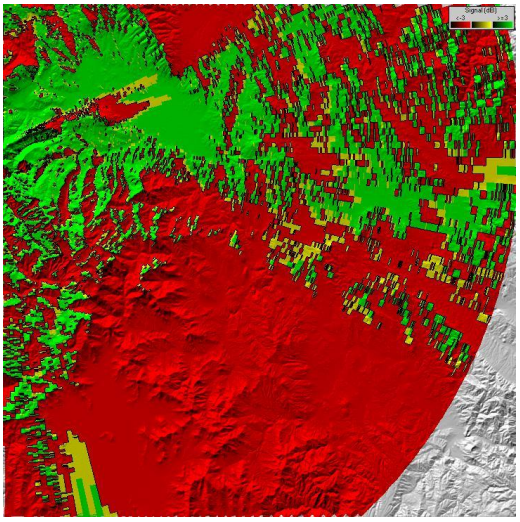

Figure 12. Single polar coverage of station 10

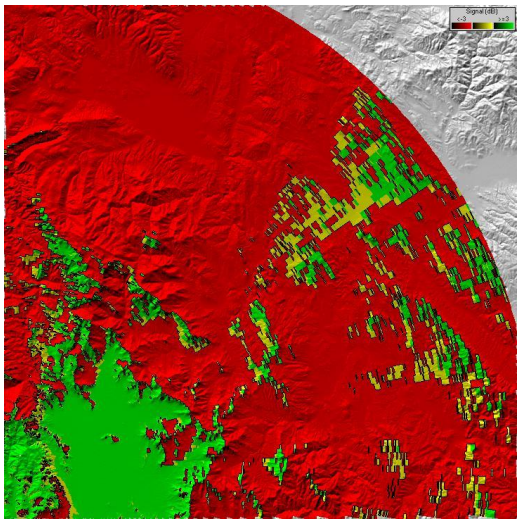

Figure 13. Single polar coverage of station 11

Figure 14 shows the final position of stations in the area.

Figure 15 shows the total coverage which is provided by all stations. The green color shows covered area, yellow is threshold and red is not covered area.

By using Google Earth map the residential areas are found and shown by red circles in figure 16.

By using Google earth, the areas which are not covered and guessed to be residential area are marked and examined which they are residential or not. Covering of residential areas are crucial. Figure 17 shows the marked areas. In this figure, 6 places are marked, and the brown and yellow circles are examined to show that they are not residential areas. Figure 18 to 23 show the location of marked areas and figures 24 and 25 show the brown and yellow circles, respectively.

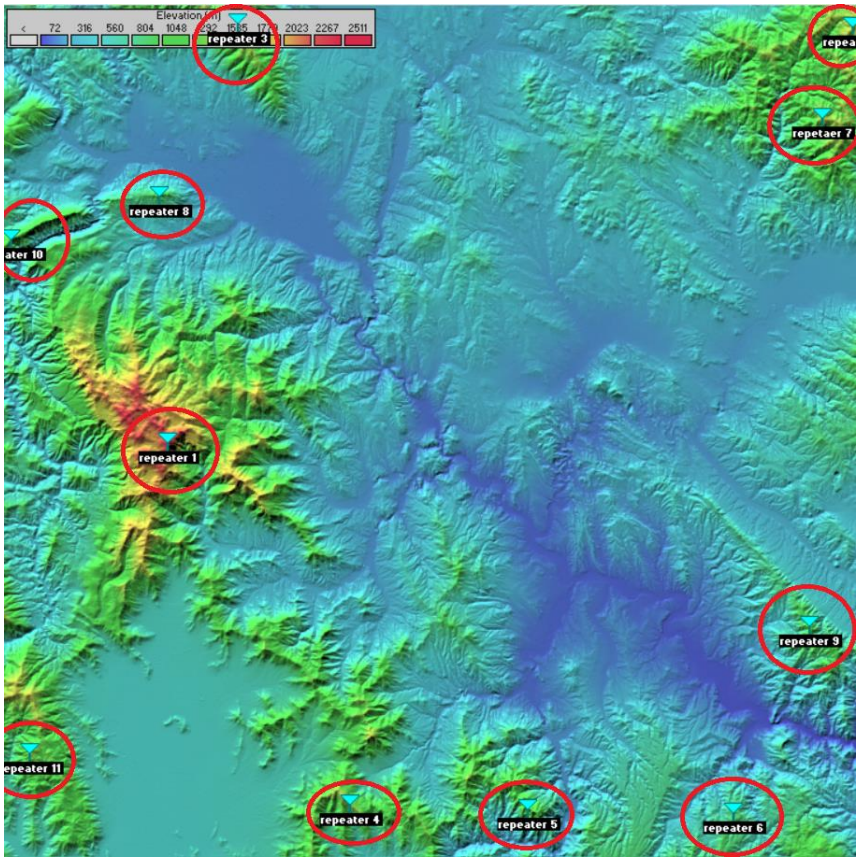

Figure 14. Location of the stations

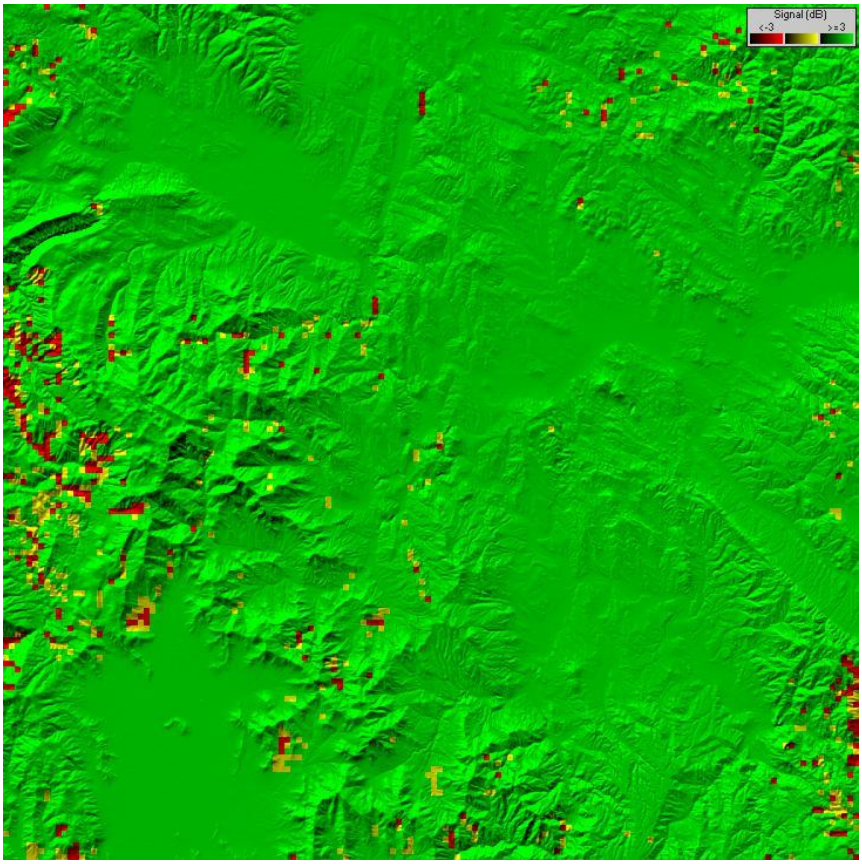

Figure 15. Total covered area by all stations

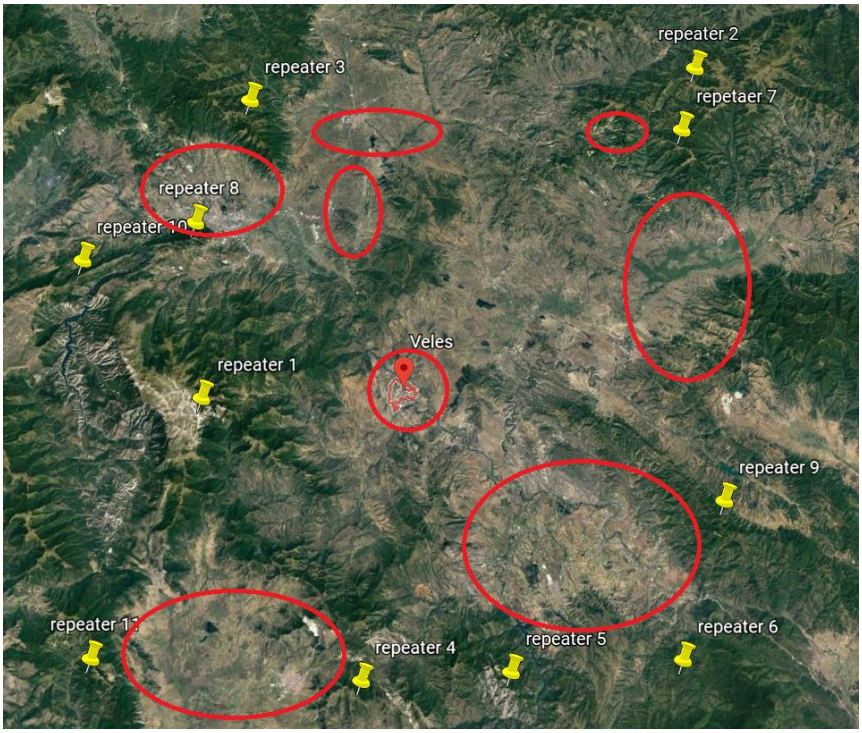

Figure 16. Residential areas

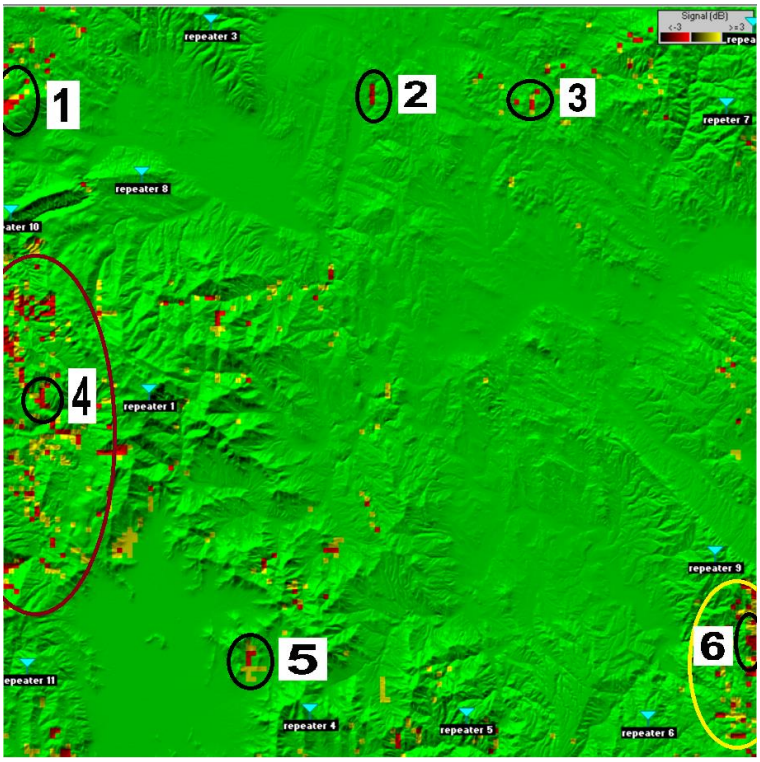

Figure 17. marked areas.

Figure 18. marker 1

Figure 19. marker 2

Figure 20. marker 3

Figure 21. marker 4

Figure 22. marker 5

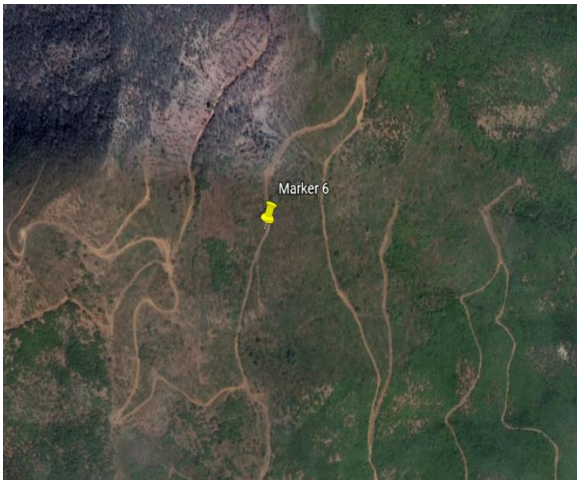

Figure 23. marker 6

Figure 24. Brown circle area of figure 17

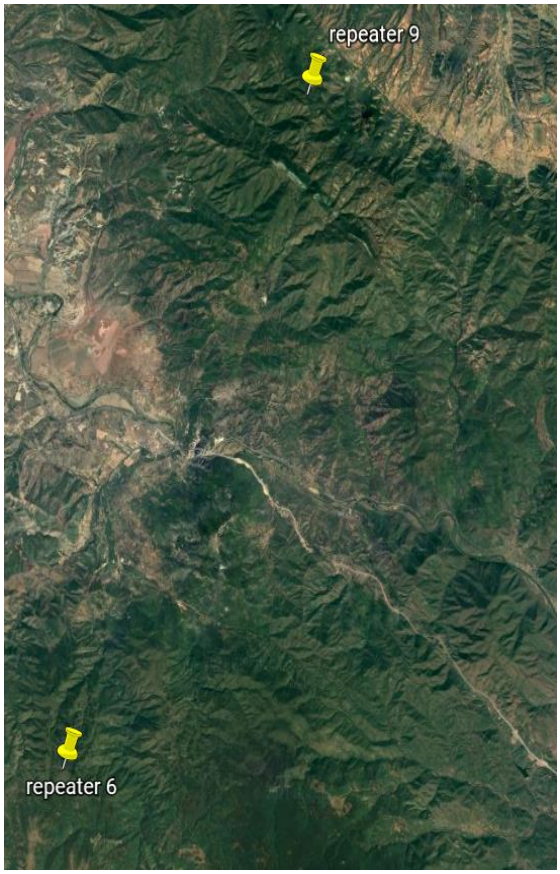

Figure 25. Yellow circle area of figure 17

6.2 Fresnel Ellipsoid

To dimension the point-to-point microwave links connecting the repeaters, the Radio Link tool was used. It is a tool made available by Radio Mobile that allows checking the state of the first Fresnel ellipsoid between any pair of repeaters: the height of each tower can be modified until a suitable solution is found. The minimum height for each antenna is selected and then gradually increased them one by one to make sure the first Fresnel ellipsoid is free and provide required radio coverage. To check the state of all the links the Network Report tool was employed. It collects in a symmetric matrix the state of each link between all the possible pairs of repeaters. The state is represented by the number 50 plus the signal margin in dB, with respect to the sensitivity. Very intuitively, if the element ij is marked green, the link between repeaters i and j is working, otherwise the element is marked red. Resulted very useful to make sure that each repeater had at least two working interconnections. Figure 26 and 27 shows free first Fresnel ellipsoid and not free one. Figure 28 shows the state of each link between 2 pairs of repeaters by matrix and figure 29 shows the link states on map.

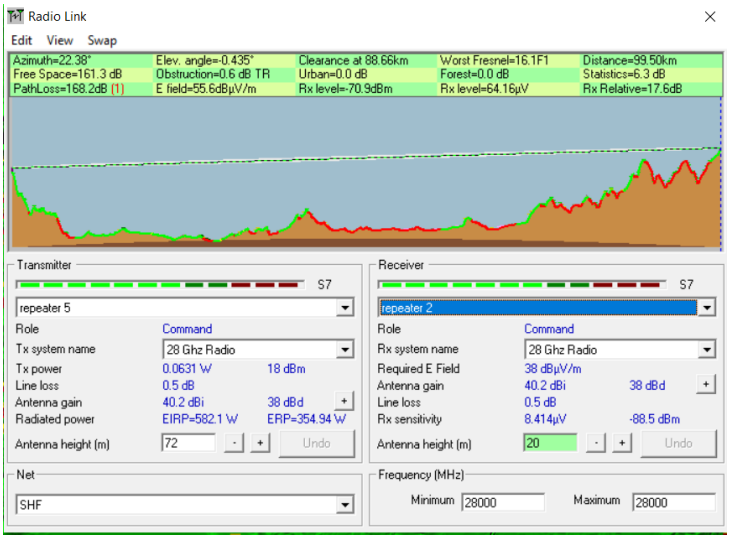

Figure 26. Free first Fresnel Ellipsoid

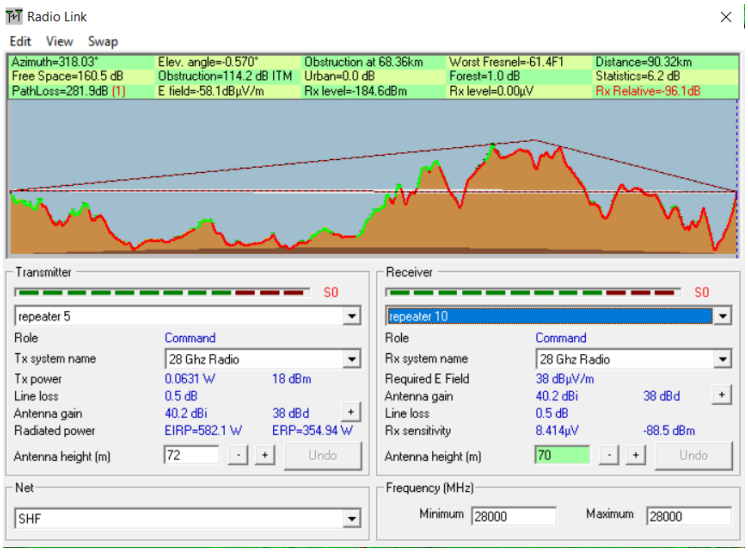

Figure 27. Not free first Fresnel Ellipsoid

SHF
Topology Voice
28000.0 MHz

Net members:	#	01	02	03	04	05	06	07	08	09	10	11	Role:	System:	Antenna:
repeater 1	01		69	75	74	72	69	69	79	70	79	76	Command	28 Ghz Radio	20.0m
repeater 2	02	69		70	68	68	68	86	70	72	68	66	Command	28 Ghz Radio	20.0m
repeater 3	03	75	70		70	58	67	72	81	68	77	01	Command	28 Ghz Radio	61.0m
repeater 4	04	74	68	70		82	01	69	01	73	01	77	Command	28 Ghz Radio	70.0m
repeater 5	05	72	68	58	82		81	70	01	75	01	06	Command	28 Ghz Radio	72.0m
repeater 6	06	69	68	67	01	81		69	01	80	01	01	Command	28 Ghz Radio	70.0m
repetaer 7	07	69	86	72	69	70	69		69	73	69	66	Command	28 Ghz Radio	20.0m
repeater 8	08	79	70	81	01	01	01	69		69	83	01	Command	28 Ghz Radio	70.0m
repeater 9	09	70	72	68	73	75	80	73	69		01	01	Command	28 Ghz Radio	63.0m
repeater 10	10	79	68	77	01	01	01	69	83	01		01	Command	28 Ghz Radio	70.0m
repeater 11	11	76	66	01	77	06	01	66	01	01	01		Command	28 Ghz Radio	50.0m

Quality = 50 + signal margin in dB

Figure 28. Link states matrix

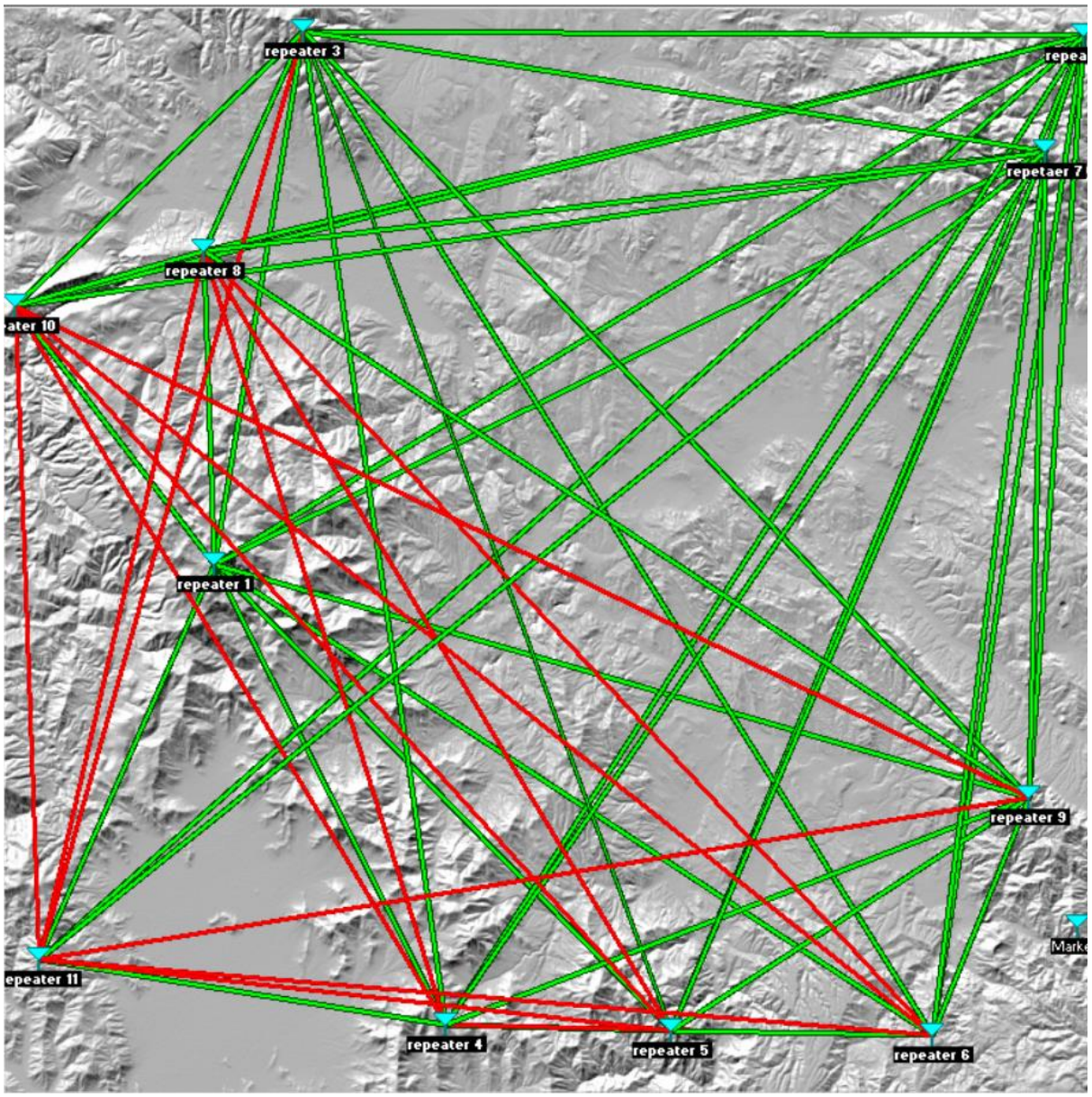

Figure 29. Link states on map

7 Conclusion

Veles city is surrounded by mountains in west, south, north-east, and north-west. As expected, the number of stations to cover these areas are more and this concept is clearly obtained in the selection of the station's locations. 100 percent coverage is hard and costly. For better coverage, the number of stations should increase and also antennas, cables and all materials in the network must be improved. In this situation, at least the residential areas should be covered. After analyzing the network, some locations are not covered so in this project first the residential areas are found from Google Earth then those not covered which guessed that they are located in residential areas have been found by Google earth and noticed that they are out of cities and villages and almost located in the mountains. By tradeoff between the cost and complexity of the network 11 stations are located in this area.

Appendix

Motorola SLR5500 datasheet

GENERAL SPECIFICATIONS			
	VHF	**UHF**	**300 MHz**
Frequency Range	136-174 MHz	400-470 MHz	300-360 MHz
Channel Capacity	64		
RF Output Power	1-50 W		
Dimensions (H x W x D)	44 x 483 x 370 mm		
Weight	8.6 kg		
Input Voltage (AC)	100-240 Vac, 47-63 Hz		
Current (standby), 110 / 240 V	0.18 / 0.25 A		
Current (transmitting), 110 / 240 V	1.5 / 0.9 A		
Input Voltage (DC)	11.0-14.4 Vdc		
Current (standby)	0.7 A		
Current (transmitting)	9.5 A		
Operating Temperature Range	-30 to +60 °C		
Humidity	RH of 95%, non-condensing at 50 °C		
Max Duty Cycle	100%		
FCC Description	ABZ99FT3094	ABZ99FT4096	-
IC Description	109AB-99FT3094	109AB-99FT4096	-
Digital Vocoder Type	AMBE+2™		
Battery Charger Capacity	12 V, 3 A		
Connectivity	Tx (N female), Rx (BNC female), USB A receptacle, 2x Ethernet		
Supported System Types	Digital Conventional, IP Site Connect, Capacity Plus (Single Site and Multi-Site), Capacity Max, Analogue Conventional, MPT 1327		
RECEIVER			
Frequency Range	136-174 MHz	400-470 MHz	300-360 MHz
Channel Spacing	12.5 / 20 / 25 kHz		
Frequency Stability	0.5 ppm		
Sensitivity, 12dB SINAD	0.22 uV		
Sensitivity, 5% BER	0.22 uV		
Selectivity (TIA603D), 12.5/20/25 kHz	55 / 83 / 83 dB	55 / 80 / 80 dB	55 / 80 / 80 dB
Selectivity (TIA603), 12.5/20/25 kHz	68 / 83 / 83 dB	68 / 80 / 80 dB	68 / 80 / 80 dB
Selectivity (ETSI), 12.5/20/25 kHz	63 / 70 / 70 dB		
Intermodulation Rejection (TIA603D/ETSI)	82 / 73 dB		
Spurious Rejection (TIA603D/ETSI)	95 / 90 dB		
Audio Distortion	< 1%		
Transmitter Hum and Noise, 12.5/20/25 kHz	-45 / -45 / -50 dB		
TRANSMITTER			
Frequency Range	136-174 MHz	400-470 MHz	300-360 MHz
RF Output Power	1-50 W		
Max Duty Cycle	100%		
Channel Spacing	12.5 / 20 / 25 kHz		
Frequency Stability	+/- 0.5 ppm		
Intermodulation Attenuation	40 dB		
Adjacent Channel Power (TIA603D), 12.5/20/25 kHz	62 / 78 / 78 dB		
Adjacent Channel Power (ETSI), 12.5/20/25 kHz	62 / 78 / 78 dB		
Conducted Spurious Emissions	-36 dBm < 1 GHz, -30 dBm > 1 GHz		
Modulation Fidelity (4FSK)	FSK Error 5%, FSK Magnitude 1%		
Audio Response	TIA603D		
Audio Distortion	< 1%		
Receiver Hum and Noise, 12.5/20/25 kHz	-45 / -45 / -50 dB		
Rated System Deviation, 12.5/20/25 kHz	±2.5 / ±4.0 / ±5.0 kHz		

Motorola DM4000E datasheet

	Numeric Model				Alphanumeric Model			
Model Number	DM4401e / DM4400e[1]				DM4601e / DM4600e[1]			
Band	VHF	300MHz	UHF Band 1	UHF Band 2	VHF	300MHz	UHF Band 1	UHF Band 2
GENERAL SPECIFICATIONS								
Frequency	136-174 MHz	300-360 MHz,	403-470 MHz	450-527 MHz	136-174 MHz	300-360 MHz,	403-470 MHz	450-527 MHz
Low Power Output	1-25 W	–	1-25 W	–	1-25 W	–	1-25 W	–
High Power Output	25-45 W	1-40 W	25-40 W	1-40 W	25-45 W	1-40W	25-40 W	1-40W
Channel Spacing	12.5, 20[2], 25 kHz							
Channel Capacity	99				1000			
Dimensions (H x W x D)	53 x 175 x 206 mm							
Weight	1.8 kg							
Power Supply (Nominal)	12 V							
Max Current Drain, Standby	0.8 A							
Max Current Drain, Receive	2 A							
Transmit Current Draw, Low Power	11 A	–	11 A	–	11 A	–	11 A	–
Transmit Current Draw, High Power	14.5 A	14.5 A	14.5 A	12 A	14.5 A	14.5 A	14.5 A	12 A

TRANSMITTER SPECIFICATIONS	
4FSK Digital Modulation	12.5 kHz Data: 7K60F1D and 7K60FXD, 12.5 kHz Voice: 7K60F1E and 7K60FXE, Combination of 12.5 kHz Voice and Data: 7K60F1W
Digital Protocol	ETSI TS 102 361-1, -2, -3
Conducted/Radiated Emissions (TIA603D)	-36 dBm < 1 GHz, -30 dBm > 1 GHz
Adjacent Channel Power	60 dB (12.5 kHz channel), 70dB (20[2] / 25 kHz)
Frequency Stability	± 0.5 ppm
RECEIVER SPECIFICATIONS	
Analog Sensitivity (12dB SINAD)	0.18 uV
Digital Sensitivity (5% BER)	0.16 uV
Intermodulation (TIA603D)	70 dB
Adjacent Channel Selectivity, (TIA603A)-1T	60 dB (12.5 kHz channel), 70 dB (20[2] / 25 kHz)
Adjacent Channel Selectivity, (TIA603D)-2T	45 dB (12.5 kHz channel), 70 dB (20[2] / 25 kHz)
Spurious Rejection (TIA603D)	70 dB

BAN0155R

Type	BAN0155	BAN0155R (reflector)
Frequency [MHz]	400÷435	
	435÷470	
Impedance	50 Ω	
V.S.W.R.	<1.35	
Gain [dBi]	4.5	6.5
HPBW		
E-plane	±12.5	
H-plane	±180	±120
Polarization	Vertical	
Input connector	N female	
Max power	300 W	

PTP 820S

TRANSMIT POWER

	Frequency (GHz)									
Transmit Power (dBm)	6	7	8	10-11	13-15	18	23	24 UL HP	26	28-38
QPSK	29	28	28	27	24	22	20	18	21	18

RECEIVE SENSITIVITY

		Frequency (GHz)												
Modulation	Channel Spacing	6	7	8	10	11	13	15	18	23	24	26	28-31	32	38
QPSK		-96.5	-96.0	-96.0	-95.5	-96.5	-95.5	-94.5	-96.0	-95.0	-94.5	-94.5	-94.5	-94.0	-94.0

THP 03 275S

Electrical Characteristics

Frequency range	27.5 - 29.5 GHz
Gain, low band	37.2 dBi
Gain, mid band	38.0 dBi
Gain, top band	38.5 dBi
Return Loss	17.7 dB
VSWR	1.3
HPBW	2.2 deg
Front to back ratio	64 dB
Isolation	NA
XPD	30 dB
Electrical Compliance	Class 3B
	ETSI 302 217

References

Radio Mobile Handbook; A VHF to microwave propagation simulation program By Roger Coudé, VE2DBE

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https://www.britannica.com/science/humid-subtropical-climate

https://www.plantmaps.com/koppen-climate-classification-map-europe.php