Appendix A

Theoretical part of the assignment

RADIO LINK SYSTEMS
Nokia MetroHopper 58 GHz

1. GENERAL VIEW OF RADIO LINK SYSTEMS

Radio link system is a stationary or semi stationary duplex radio connection [1]. Radio link provides transmission access trough usage or radio relay stations or satellites.

Radio link systems can be divided into four different classes by the frequency that is used: visual-, satellite, scattering and ionosphere links [2].

Ionosphere links can be used in high frequency (HF) band, where it is possible to have very long distance connections (more than 4000 km over one hop). In the HF-band the transfer rate is usually not more than few kilobits per second.

Scattering links take advantage of the scattering caused by the non homogeneity of the troposphere. This scattering causes radio signal to turn back to the earth. At the UHF-band it is possible to have ca 1000km connection at the transfer rate around tens of megabits per second. Since the scattering changes randomly with the changes of the troposphere, the scattering links is that they are unstable.

While using satellite links the radio wave reflects from the satellite back to the earth. The satellite must be on close to earth orbit. The link attenuation is determined by the free space attenuation when the frequency is below 10 GHz. At higher frequencies also the rain effect and absorption attenuation must be taken account.

Visual communication links are used at the UHF (300 MHz - 3GHz), SHF- (3 - 30 GHz) and EHF-bands (30 - 300 GHz). The available capacity of these link systems increases as the frequency increases but at the same time the distance of the link decreases due to the effect of attenuation. Below 10 GHz the maximum distance of the link is 60 - 80 km because of the curvature of the earth. At higher frequencies attenuation due to the rain limits the link distances to be shorter and at the 58 GHz the maximum distance is ca l km.

In this laboratory work we look at the millimeter waves links (EHF-band).

1.1 The use of radio link systems

Radio link systems are used for digital communication at the areas where there are no cables or the use of the cables is expensive and difficult. Data transfer over the radio waves is simple especially if the connection is needed for a short period of time. Traditionally radio link systems are used by military, government corporations and private phone companies [3]. Nowadays radio links are also being deployed by medium sized companies such as telecom operators and there is also EHF-radio link systems on the market that are used as point-to-multipoint broadband internet solutions.

There are certain benefits and drawbacks in the radio link systems which are useful to know when designing a data transfer system [4].

Benefits of radio links

- fast to set up
  - only need to set up both ends
  - useful at catastrophic situations
- fits well in hard geography
  - lakes
  - mountains
- mobile possibility
- easy to increase capacity
- independent of competitors
  - rented cables
- no costs of digging
- network is easy to change and improve data easy to encrypt
- BTS location useful also for radio links BTS locations independent of the existing backbone network

Drawbacks of the radio link systems

- fading of the radio signal
  - limits to the distance and transfer rates
  - weather effects
  - BER
- limited transfer capacity
  - limited number of channels
  - disturbance of other systems
  - short distance
- licensing fees
  - takes time to acquire a license
- need for line of sight
- effect of the terrain
  - tall towers
- need to plan
- increase of capacity is limited (compared to fiber)
- high speed connections complicated

1.2 Radio parts of digital radio link systems

The main functions of radio parts in digital radio link systems are frequency conversion, filtering, and signal amplification.

In the transmitter a radio a baseband signal is modulated to a radio frequency. The modulated baseband signal is directed to an antenna and with its help to the free space. The modulated signal level is usually relatively low; in order to achieve high transmission power the signal is strengthened before its transmission. The modulator, local oscillator from which a baseband signal is obtained and terminal amplifier are one of the most important basic parts of the transmitter.

In the receiver the coming signal is snatched from the air by an antenna. In order to select the correct signal from the air the correct frequency band is filtered out. After propagation in the air the signal is usually extremely weak. Before its detection it should be amplified, demodulated to the baseband filtered and amplified again. The receiver repeats the operations of the transmitter but in opposite direction (figure 1).

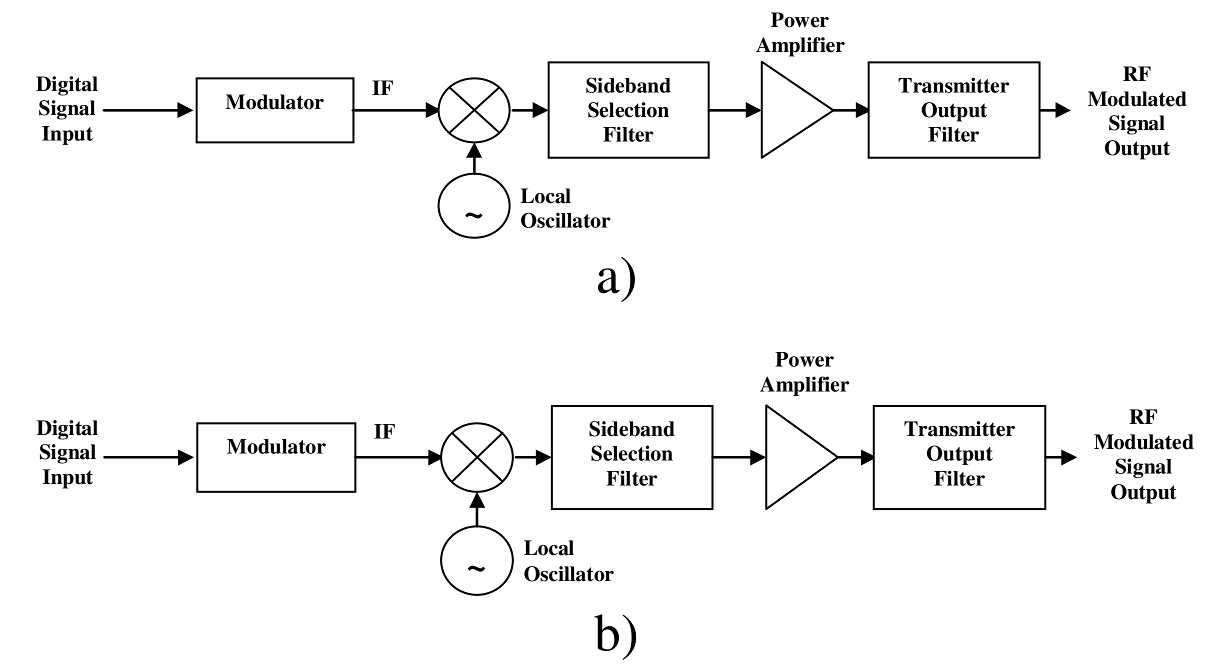


Figure 1. Block diagram of a) transmitter and b) receiver

1.3 Two way connection in a radio link system

Two-way connections in the radio link systems can be implemented either as full duplex or half duplex.

In the FDD connection (Frequency division duplex - full duplex) a separate frequency is used for transmission and reception and the data transfer takes place in both directions at the same time. The frequencies differ from each other by the duplex space. Among others full duplex connections are: TDMA, FDMA and CDMA cellular systems.

In TDD connection (Time division duplex - half duplex) two stations alternate transmitting with the same frequency in step with a certain period. The relation of the TX/RX burst determines effective symbol speed.

1.3.1 Modulation methods

The radio communication systems can transmit only on certain reserved frequencies. The process of transforming the baseband information signal to the radio frequency is called modulation. (figure 2) [7].

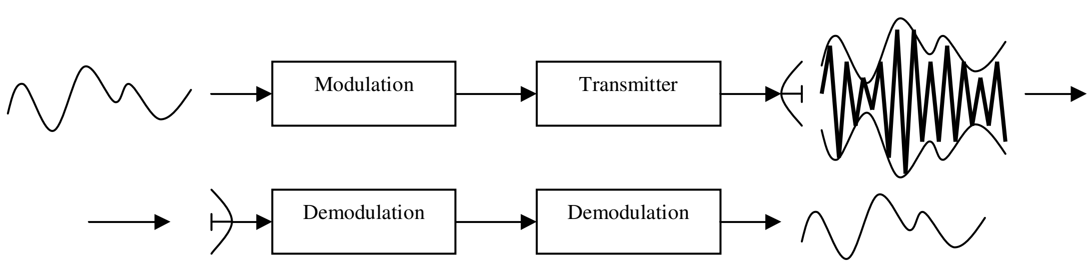


Figure 2. Modulation and demodulation

1.3.1.1 Modulator and demodulator

In a transmitter the modulator modulates the signal in the desired way and the demodulator of the receiver distinguishes a carrier wave and extracts the baseband signal from the observed waveform. Figures 3 and 4 show the functional block diagrams of a modulator and demodulator. [8]

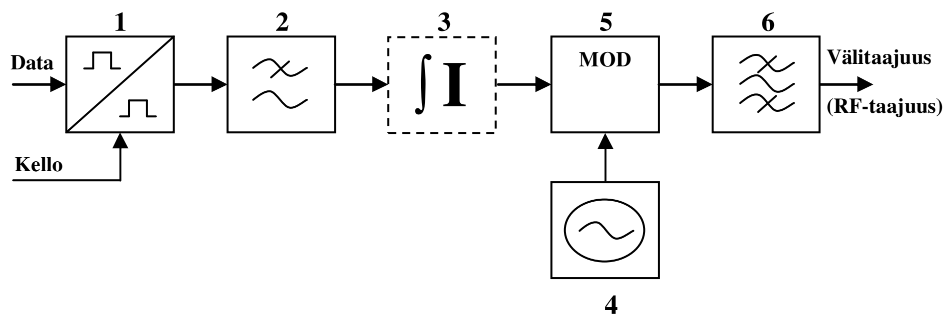


Figure 3. Block diagram of a modulator

Tasks of a modulator:

1. Coding of data and D/A-transfer 2. Filtering of the baseband signal
2. Predistortion (not always present)
3. Generation of a carrier wave
4. Modulation
5. Filtering of the modulated signal

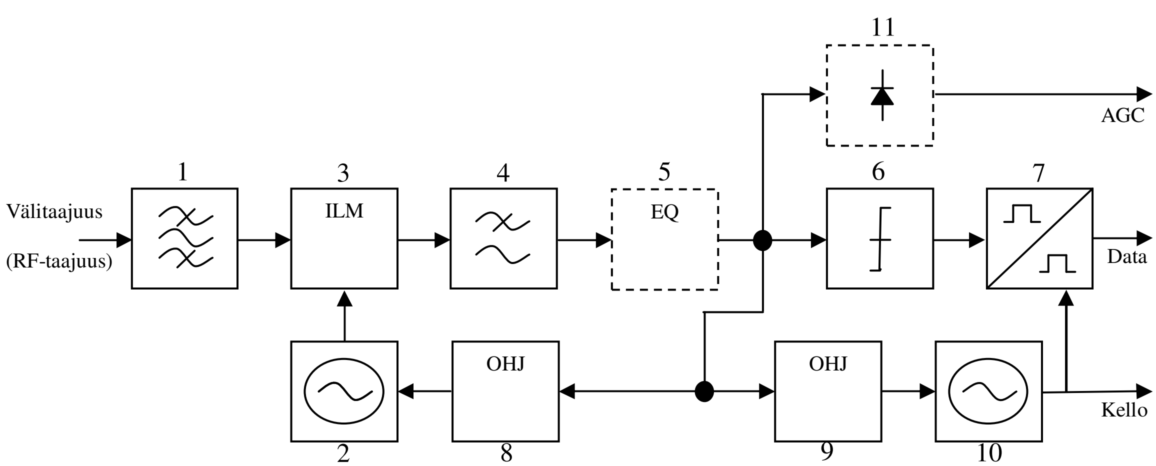


Figure 4. Block diagram of a demodulator

Tasks of a demodulator:

1. Filtering of an incoming signal
2. Generation of a reference carrier wave (if using coherent detection) 3. Detection to baseband frequency
3. Filtering of baseband signal
4. Adaptive correction (not always present)
5. Decision making
6. Decoding
7. Control of a reference carrier wave
8. Control of a c1ock frequency
9. Generation of a c1ock signal
10. Generation of AGC (not always present)

1.3.1.2 Modulation methods

The modulation for radio interface could be selected from numerous options. The can be classified for example whether they are linear or nonlinear, or whether they are analog or non analog. The analogous modulation methods are for example amplitude (AM), frequency (FM) and phase modulation (PM) and they are still used widely for example in the radio broadcasting. However, the use of digital methods is increasing all the time with the digital time. The digital modulation method is used particularly in systems which are meant mainly to the data transfer.

There are several advantages compared to analogous with digital modulation methods: [9]

- In general digital transmission can stand lower signal to noise ratio. Since can add coding to the input bit stream we could correct errors even for very low SNR values. If the signal from the analog source is directly modulated to the carrier frequency errors due to the noise can not be corrected. In order to have low distortion the transmission requires high SNR values.
- Higher frequency reuse. Since the crosstalk is manifested only usually as the noise better noise resistance of encoded digital data stream carries directly over to better frequency reuse factor.
- It is possible to regenerate a digital signal so the faultless transfer is possible even on long connections.
- The algorithm for error detection can be effectively used as an advantage in which case the faultless transfer in practice is reached.

The time division multiplexing of several signals to the frequency at the same time is moderately easy. Often is used a combination of the TDMA (Time Division Multiple Access) and the FDMA (Frequency Division Multiple Access), in which case:

- The encryption of the information is easy.
- The new information services can be easily integrated into the system.

The digital methods also contain disadvantages:

- In low SNR case in general a digitalized data requires broader bandwidth than the bandwidth needed for analog transmission, but the matter can be revised with the compression of the signal and by using multistage modulation methods.
- The timing is difficult because a two co phase clock signals must be generated for the receiver and for the transmitter. Furthermore, the frame synchronization must be in order.

The digital transmission methods can further divided coherent or incoherent demodulation. In an incoherent demodulation attention is paid only to the amplitude information of the signal. In a coherent demodulation attention is also paid to the phase information of the signal. Then the receiver must generate a local oscillator signal which must be synchronized to a carrier frequency and phase. Incoherent demodulation is independent of the phase mistakes. The usage of the phase information makes coherent transmissions more noise resistant. By tracking the phase the information can be inserted into phase and due to that the amount of transmitted information per symbol can be increased.

1.3.1.3 Digital modulation methods in radio link systems

Most general digital modulation methods are ASK (amplitude shift keying), FSK (frequency shift keying) and PSK (phase shift keying). From those ASK is used only in the simplest links. FSK and PSK with their several are more widely employed. One common linear modulation method QAM (quadrature amplitude modulation) combines the amplitude and phase modulation.

MSK (minimum shift keying) [10]
In the laboratory work we are using MetroHopper system produced by Nokia corporation. It operation at 58 GHz. In such high frequencies it is very challenging to control signal amplitude and therefore this particular radio link system uses MSK modulation, which is the special case of FSK. The separation of the frequencies $|f_2 - f_1|$ of MSK is a half of the inverse value of the bit length T_b. For example the separation of frequencies will be 0.5 MHz when in that case the transmission rate is 1 Mbit/p. The smallest frequency difference 180° phase difference is obtained during one bit between the signals which frequencies are ovat f_2 and f_1. With respect to the carrier phase the modulated phase is on ±90°. This minimal possible phase difference and from stems the name MSK.

Because of the phase continuity of MSK the spectrum side lobes of it are significantly lower that the side lobes of ASK or PSK spectrum. In Figure 5 the spectrum of MSK has been presented. MSK spectrum curves more mildly than QPSK and thus fewer disturbances are being produced outside the used band. [11]

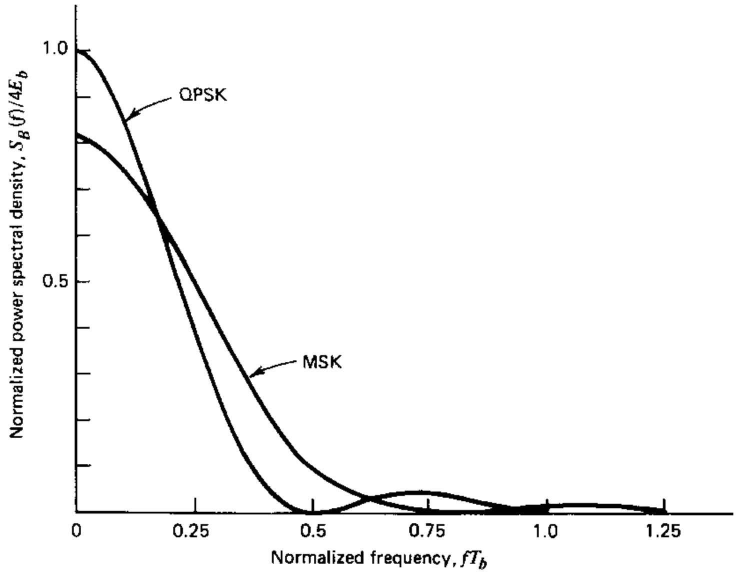


Figure 5. Spectrum of MSK and QPSK modulated signals

Figure 6 shows the waveforms of MSK: modulated signal, phase curve (the trellis figure) and data signal. The phase of MSK changes linearly (in that case the frequency will be constant) during the symbol and when a symbol changes, the changes in the frequency are abrupt

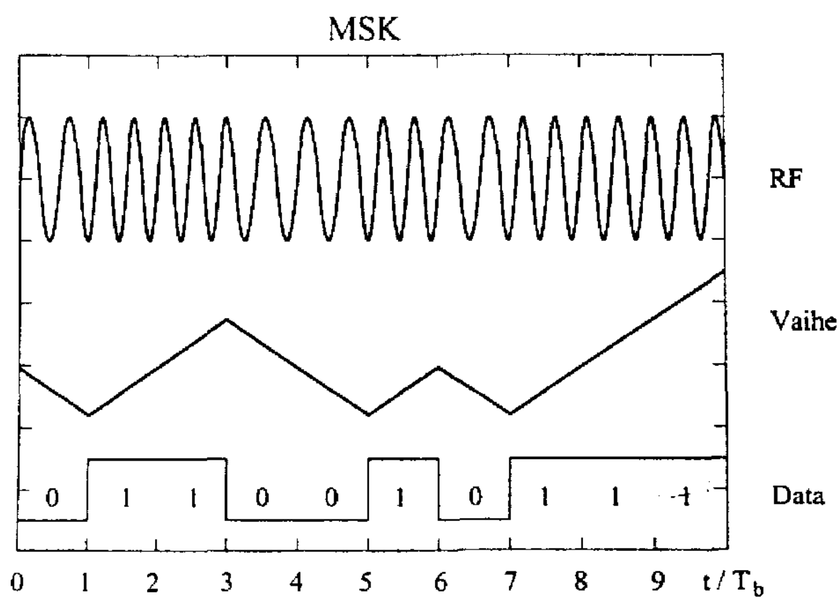


Figure 6. Waveform of MSK

The bit error ratio of MSK is obtained from a formula [12]:

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right), \qquad (1)$$

where E_b / N_o denotes the signal to noise ratio and

$$erfc(u) = 2Q\left(\sqrt{2}u\right), \tag{2}$$

The bit error ratio can be obtained as

$$BER = Q\left[\sqrt{2\frac{E_b}{N_o}}\right], \tag{3}$$

Let' s mark signal-to-noise ratio with *K* and we finally obtain the bit error ratio of MSK

$$BER = Q\left[\sqrt{2\kappa}\right], \tag{4}$$

EXAMPLE: Calculate 16-MSK bit transfer rate in an AWGN-channel (Additive White Gaussian Noise), when the bit error rate is

a) $BER = 10^{-3}$
b) $BER = 10^{-6}$

Attenuation of AWGN-channel is $A_s = 110$ dB, power of the transmitter $P_{TX} = 5$ dBm and the one-sized power spectrum of the noise reduced to the receiver $N_0 = 1.32*10^{-20}$ W/Hz.

SOLUTION:

In the 16- MSK modulation method a symbol rate R_s is a quarter of the bit rate R_b, or $R_s = \frac{R_b}{4}$.

a)

$BER \le 10^{-3}$ is calculated from the Q-function to be about 3.1. This value is obtained from the Q-function table (Appendix 1).

$$Q \approx \frac{1}{\sqrt{2\pi x^2 e^{x^2}}}$$

MSK's bit error rate is obtained from a formula

$$BER = Q\left[\sqrt{2\kappa}\right]$$

Attenuation in the channel is $A_s = 110dB \Rightarrow A_s = 1 \cdot 10^{11}$

$$Q\left[\sqrt{2\kappa}\right] \approx 10^{-3} \Rightarrow \sqrt{2\kappa} = 3.1$$

$$\Rightarrow \sqrt{2\frac{E_{RX}}{N_0}} = 3.1 \Rightarrow 2\frac{E_{RX}}{N_0} = 9.61$$

$$\Rightarrow \frac{E_{RX}}{N_0} = 4.805$$

Because $E_{RX} = \frac{P_{TX}}{R_s A_s}$, the equation can be presented as

$$\frac{P_{TX}}{R_s A_s N_0} = 4.805$$

Insert $R_s = \frac{R_b}{4}$

$$\frac{4P_{TX}}{R_b A_s N_0} = 4.805$$

From here the bit rate R_b is solved after changing the transmission power to be in watts

$$5dBm = 10\log\left(\frac{x}{1mW}\right) \Rightarrow$$

$$x = 10^{0.5} \cdot 1mW = 3.16mW$$

Final bit rate is R_b

$$R_b = \frac{4P_{TX}}{4.805 \cdot A_s \cdot N_0} = \frac{4 \cdot 3.16mW}{4.805 \cdot 1^{11} \cdot 1.32 \cdot 10^{-20}} = 1.99Mbit/s$$

b)

Solution to the part b is calcualted similarly as in part a.

$BER \leq 10^{-6}$ is given from Q-funktion value about 4.8.

$$Q\left[\sqrt{2\kappa}\right] \approx 10^{-6} \Rightarrow \sqrt{2\kappa} = 4.8$$

$$\Rightarrow \sqrt{2\frac{E_{RX}}{N_0}} = 4.8 \Rightarrow 2\frac{E_{RX}}{N_0} = 23.04$$

$$\Rightarrow \frac{E_{RX}}{N_0} = 11.52$$

Bit rate R_b is

$$R_b = \frac{4P_{TX}}{11.52 \cdot A_s \cdot N_0} = \frac{4 \cdot 3.16mW}{11.52 \cdot 1^{11} \cdot 1.32 \cdot 10^{-20}} = 831.23kbit/s$$

The MSK modulation method (and also other basic digital modulation methods) and its mathematical interpretation have been shown in the Simon Haykin's book Communication Systems 3'd edition.

1.3.1.4 Comparison of modulation methods

The choice of a modulation method usually is a compromise between their different properties. The choice is always restricted by the frequency band, system properties, and costs. For example in a mobile phone system multipath propagation causes deep fades, therefore the modulation methods that are based on the change of the signal amplitude (AM ASK) are not very suitable. Other property of a mobile system multipath propagation poses problems of its own, because of the cost requirements it can not be combated by complex equalizers. Comparable stability of the radio link channels allows a convergence of complex equalization methods. However at the high frequencies it is difficult to control the signal amplitude and to make linear power amplifiers. That constraint forces us to at millimeter band nonlinear modulations like FSK. (FM, PM, FSK, MSK, GMSK all are versions of it). Since signal envelop of such modulation does not change we can use more efficient non-linear amplifiers of the class C, E and F. The amplifiers of this kind use less power

1.3.2 Transmitter amplifier

In a transmitter to the antenna precedes a power amplifier (TX amplifier). Typical required amplification is about 40 dB leading to the output power at the amplifier output to be about +30 dBm (at 2GHz). [13]
The transmitter amplifier consists of several consecutive amplifier stages in which the amplification increases towards the end. The last stages are typically made by using high power GaAs-FET transistors. At frequencies less than 2 GHz and with small output power also bipolar transistors are used. [13]
Additionally to amplification the most important characteristic of the amplifier is its linearity. Nonlinearity creates cross multiplications components into spectrum and thereby widens the spectrum (rises side lobes).

1.3.3 Automatic gain control AGC

The analog digital (A/D) converter at the receiver has an optimal working point. Attenuation in the link could wide range of values. The average signal level at the (A/D) converter input is kept constant by and automatic gain control (AGC). The stabilization of the average value can be implemented in two different ways: either the strongly attenuated signal is amplified or too strong signal is limited. In transmitter side AGC is used for stabilizing the signal transmission level and due that protects the TX amplifier input from too high signal level. AGC is necessary in the systems where information is inserted into signal amplitude (the radars QAM, AM) but it is often used also in other systems as mentioned to keep average to A/D input constant.

AGC measures the signal power at the RF-frequency at the antenna output by using a diode. Example of scheme implementing such measurement is on figure 7. The circuit on figure 7 corresponds to the content of the block 11 in figure 4.

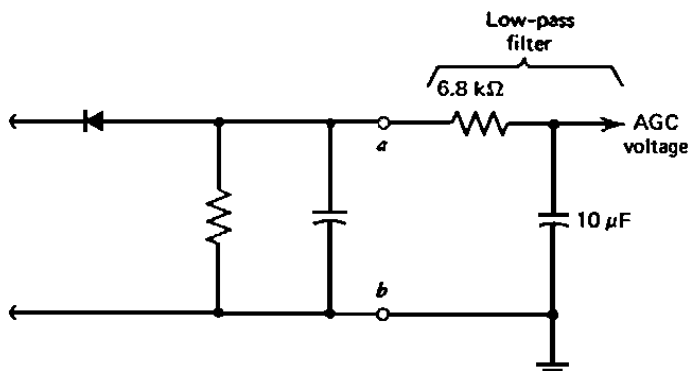


Figure 7. AGC scheme, diode detector

The output voltage from AGC that drives the amplifier gain is related to the received signal power. The relationship between the signal power and AGC voltage in MetroHopper system is given in table 1. [14]

Table 1. Relationship between AGC-voltage and received signal power

Rx signaaliteho	AGC-jännite
0 dBm	0,0 V
-10 dBm	0,5 V
-20 dBm	1,1 V
-30 dBm	1,6 V
-40 dBm	2,2 V
-50 dBm	2,6 V
-60 dBm	3,3 V
-70 dBm	3,8 V
-80 dBm	4,4 V
-90 dBm	5,0 V

1.3.4 Power feed at high frequencies

Additionally to amplifiers and antenna one critical part in a radio system are feeding cables. The task of a feeding cable is to connect the transmitter output and antenna or antenna, and the receiver input. Critical for those connection is minimization of reflections and distortions. As a feed cable usually is used a coaxial cable (under 3 GHz) or wave pipe (more than 3 GHz).

Coaxial cable can be characterized as a low-pass filter. Accordingly to this model the is useful up to its limiting frequency. The upper limit frequency can be calculated from diagram 5. [15]

$$f_{ck} = \frac{c_0}{\pi\sqrt{\varepsilon_r}\left(r_0 + r_i\right)}, \qquad (5)$$

in f_{ck} = upper limit frequency, c_0 = light speed, ε_r = relative bioelectricity constant of an insulator, ε_r = inside radius of the outer conduct, r_i = outside radius of the inner conduct.

Also waveguide operates as a low-pass filter in which the energy proceeds on the frequencies which are lower than the lower limit frequency. Ion the waveguide exist also an upper limit frequency above which appear higher waveforms. Figure 8 shows the different cross sections of waveguides and the useful frequency bands in diagrams 6 - 9 in different waveguide types. [15]

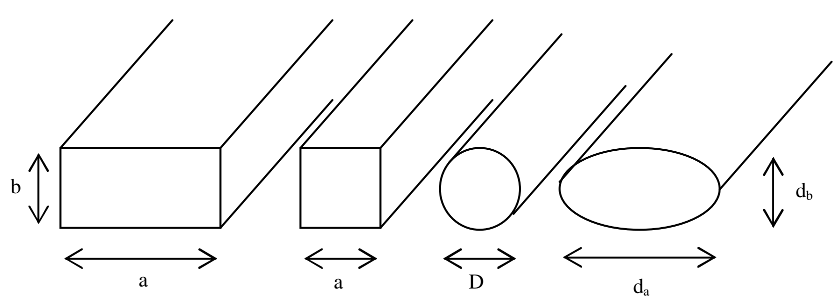


Figure 8. Cross sections of typical waveguides

Rectangle $$f = \frac{c_o}{2a} \leftrightarrow \frac{c_o}{a} \qquad (6)$$

Square $$f = \frac{c_o}{2a} \leftrightarrow \frac{c_o}{2a} \qquad (7)$$

Circle $$f = \frac{c_o}{1,706D} \leftrightarrow \frac{c_o}{1,306D} \qquad (8)$$

Elliptic $$f = \frac{c_o}{1,68d_a} \leftrightarrow \frac{c_o}{1,063d_a}, \text{ kun } \frac{d_b}{d_a} = 0,6 \qquad (9)$$

The deviations from the characteristic impedance, which appear in the feed cables, cause reflections which weaken the quality of the transfer. The homogeneity of the feed cable is described by the relation of the standing wave (SWR). It has been defined as the relation of the sum and separation of the proceeded and reflected wave as shown in formula 10. [16]

$$SAS = \frac{1+|\rho_L|}{1-|\rho_L|}, \qquad (10)$$

in which ρ_L is a reflection factor. The SWR for a fixed feed cable is $SWR = 1$.

1.3.5 Antennas

The antenna emits the electrical signal to the radio wave. The antenna shape defines the direction and relative amplification of the radiation. In the radio link system we attempt to use antenna that concentrates the signal to as narrow beam as possible.

Figure 9 shows a radiation pattern of an antenna similar to one in MetroHopper. The amplification of this antenna in main lobe is 43 dB and between 90-270° smaller than -20 dB. [18].

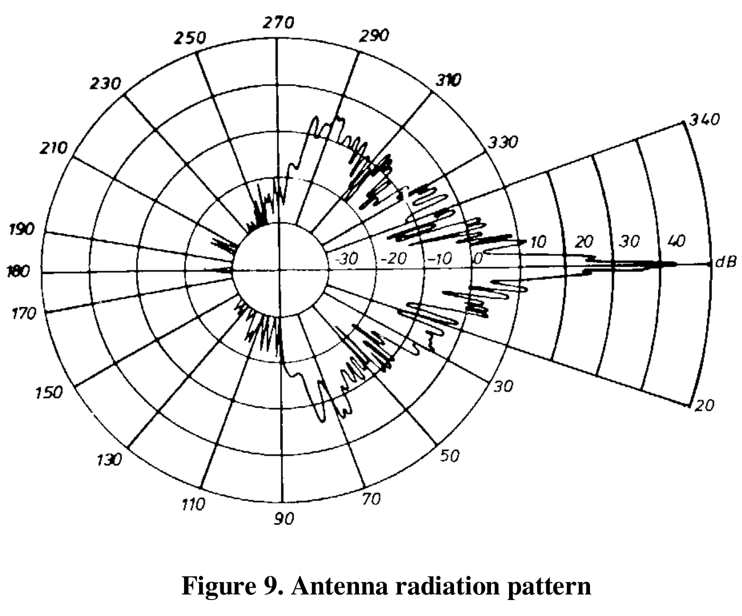


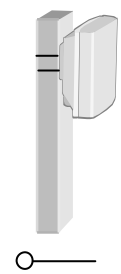
Figure 9. Antenna radiation pattern

The antenna structure depends on its operational frequencies. On low frequencies it is customary to use antenna a dipole antenna. At frequencies over 2 GHz the simple wire based structures are not very efficient. At those frequencies are used: luminous tags, lens, corrugated tube or micro-slope antenna and antennas which are based on dielectric cables are used generally. The antennas of the millimeter wave range have been discussed in the book, Millimetriaaltotekniikka. [20]

1.4 Network elements

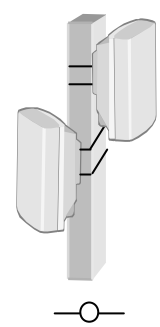
Network elements of the radio link system refer to the elements of the data communications network, in other words to the devices which form the relation in the network and which can be connected by radio links. The radio link provides the glue that allows to combine different system elements together in numerous variations. The radio links inside the network can be connected as: terminal stations, repeaters and branchers. The connection between the network units, radio link, can be generated with the direct connection, with the help of the passive mirror or by using active components, in other words repeaters.

1.4.1 Terminals



The simplest structure of a radio system is to use two terminal stations between which there is a data transfer system, for example radio link. The information signal is provided to the input interface of the radio link and it is moved with the help of the radio link to the second station.

1.4.2 Active repeatars



The tendon of the radio link can be lengthened with the help of repeaters. The repeater receives the signal, demodulates it and corrects the possible errors. In the transmitter the signal will be regenerated and sent towards the following receiver. The active repeater can also forward the signal without regenerating it. In such configuration it does not correct possible errors since it only amplifies the received signal. The benefit is that the received signal has neither to be demodulated nor generated again. Such so structure is cheaper the regeneration system.

The repeater can be used to change the direction of the signal. Such need may arise because of the obstacles in terrain. Usually the radio link stations are chained according to the so-called zig-zag principle (figure 10). The zig-zag allows minimizing disturbances from neighboring links. If the interference level can not be reduced otherwise also the channel or whole carrier frequency in neighbouring links should be changed. With the help of the repeaters the link can be entrenched to be as long as needed.

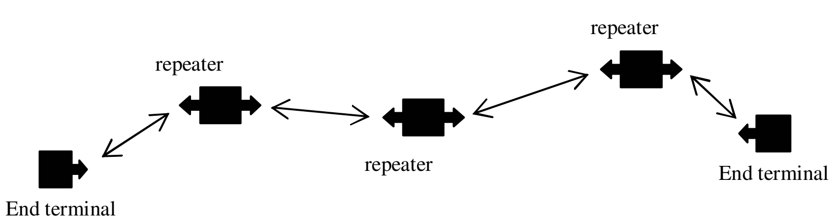


Figure 10. Example of zig-zag connected ratio relay line.

1.4.3 Passive repeaters

The passive repeater functions like active repeater except that the signal neither is processed in any way nor it is amplified. The passive repeater consists of the reception antenna transmission antenna and waveguide between them. The passive repeater can be used to direct the output signal in the desired direction. As such they are suitable in places where the use of the passive mirror is impossible and active repeater is too expensive. The antennas of passive repeater have to provide good directionality and high gain.

1.4.4 Passive mirrors

Passive mirror refers to the component from which the radio signal is made to change its direction "by bouncing". The passive component does not process a signal in any way so the changing of the direction is based on the reflection material. The angles of reflection are determined to the way to be reflected, optical, so the angle of descent and angle of dispart are always as big according to the law of Snell. In the reflection a part of the effect wears out to the mirror so the connection length always becomes shorter when a passive mirror is used. The passive mirror can be used to circle the difficult sections of the terrain, for example in mountains. (Figure 11).

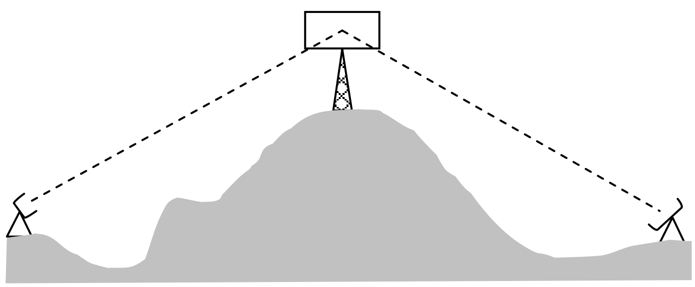
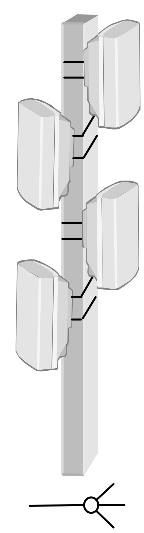


Figure 11. Usage of passive mirrors in mountains

1.4.5 Diplexers



Sometimes data stream contains information to two different destinations or in other way two different destinations are sending two the same end user. The operation of splitting the streams and combining them together are called multiplexing and demultiplexing. These operations are performed in a unit called diplexer. If used in a radio link the diplexer helps to direct data towards different directions. If data from two different sources is multiplexed the final link should possess higher capacity than both of the incoming links.

1.5 Backup connections and network topologies

Usually radio systems have a certain lifetime after which the faults start to appear. The radio link network can break also for other also reason than from the device failure. The strong seasonal attenuations may cause to a certain links to be affected with high attenuation such that it will loose connection. The attenuation can come, for example its rain, from snow, dust, jamming etc.
In order to protect connections from the equipment faults the radio links have usually backup connections.

The backup of the connection can be carried out in many ways. The surest way is a so-called hot backup in which a exist backup devices for every device in the network, these backup equipments take over the operation in case the primary unit brakes down. This way is sure against the device failures but it does not give a protection against local attenuations. The ultimate solution is the so-called link-by-link backup. This method is extremely expensive because two of all devices are needed. In the connections which require an absolute certainty this method is used, however.

1.5.1 Network topologies

The disturbances due to the local signal attenuations can be overcome by utilizing different network topologies. The network is built so that, when a fault hits one link, the communications can be routed to the right place along the second alternative route. This of course reduces the data the whole transfer capacity, but takes care of the fact that the information goes with every part of a net for that also time when the faulty unit is changed or repaired. Figure 12 shows the typical network topology solutions, [19] and in table 2 they are compared.

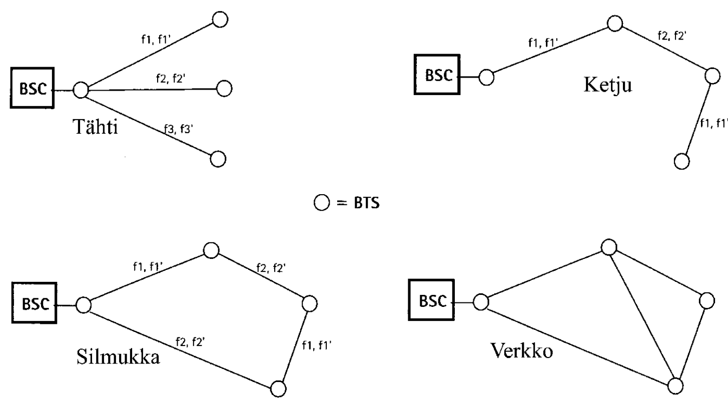


Figure 12. Typical network topologies. Loops provide alternative connections well.

Table 2. Comparison of most general network topologies

Star topology	
+ easy to plan	- Distance between the concentrator (for exampel Base Station Controlles BSC) and user (for example Base Station Subsystem BTS) is limited
+ easy to extend	- Unefficient microwave channel utilization
+ if one link is faulty only one end user is lost	- Unefficient link capacity utilization

Chain – topology	
+ more efficient link capacity usage	- If one link is out the whole chain is impacted
	- First link has to have an alternative backup

Loop – topology	
+ effective protection against device failures and local attenuations	- network planning and setup is more complex than with previous technologies
+ Efficient microwave channel usage	- difficult to add new capacity
+ link outage time minimized, the outage is invisible towards to end user	- more links needed, more expensive
+ increase lengths of individual hops	- capacity in the loop should be constant
+ routing is simple and can easily be done automatically	- hard to protect from local attenuations
+ no hurry to replace the failed link	
+ easy to maintain, failed device is easy to located	

Networ ktopology
Individual nodes can be reached along mulitple alternative paths
Typical topology for internet

1.6 Planning of Radio link systems

Attention has to be paid carefully to the planning of the radio link system to avoid different attenuations and obstac1es. In the course material of the course S-72.3220

2. METROHOPPER – 58 GHZ RADIOLINK SYSTEM

MetroHopper is a radiolink system produced by Nokia Corporation which functions in a 58 GHz frequency band. It has been made for the data transfer in so-called last kilometer of densely populated areas where is no cabling ready and cabling is expensive. MetroHopper is able to transfer 4 x 2 Mbit/s in point to point connections almost everywhere where line of sight is available. MetroHopper belongs to the Hopper radiolink series of Nokia and is compatible to the GSM network elements.

2.1 Special characteristics of 58 GHz frequency band

MetroHopper uses the 58 GHz frequency band which causes a few special characteristics to the radio system. The use of the millimeter wave range almost always requires a line of sight connection. The attenuation of the atmosphere and attenuation caused particularly by the oxygen are strong in this frequency band. This frequency is also sensitive to the rain, in case of dense rain the whole can be lost. Figure 13 shows the attenuation of the clear atmosphere in the frequency band 10-400 GHz at the see level (A) and at the 4 km height (B) [20].

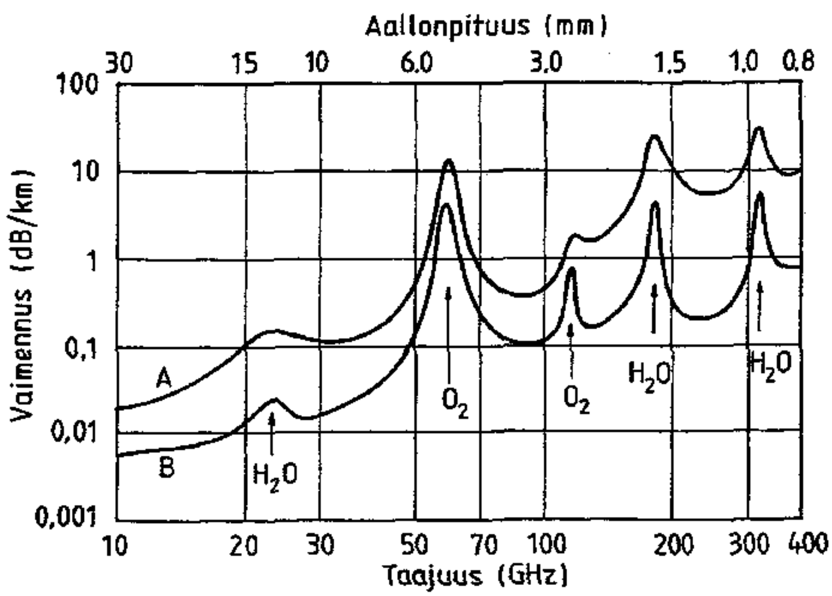


Figure 13. Atmosphere attenuation at 10 - 400 GHz: at the see level (A), at height 4 km (B)

On a 58 GHz frequency there is the attenuation maximum of oxygen from which the special characteristics of the frequency band result (strong attenuation, a short connection length, a good disturbance tolerance).

Attention must also be paid in a 58 GHz frequency band to the effect of the weather for the attenuation of the signal. Figure 13 shows the additional attenuation caused by a rain and fog. [21]

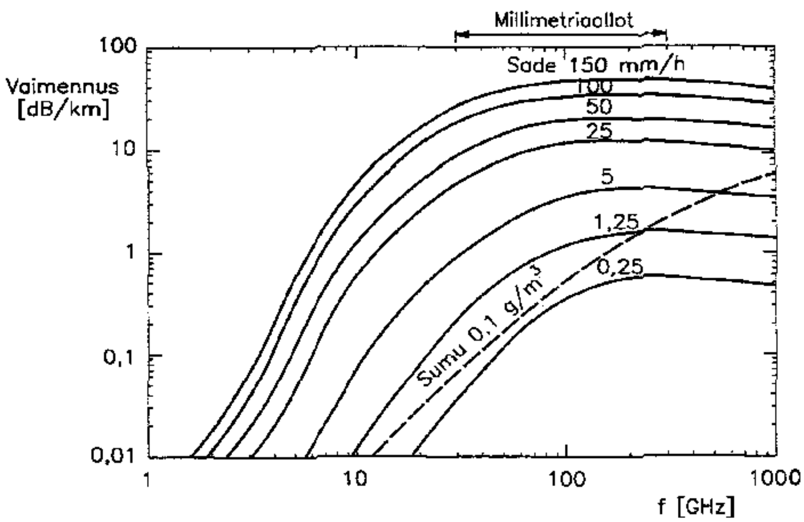


Figure 14. Attenuation at different frequencies caused by fog (dotted line) and rain (continuous line)

The diameter of raindrops defines the size of the wavelength at which case drops start to act as antennas and sprinkle the radio waves. The strong rain attenuates the electric field, more than 10 dB for 1 km at the 58 Ghz. The effect of the snowfall depends on the water content of snowflakes, the dry snowfall attenuates less than sleet. The fog consists of small drops of water, the diameter of which is smaller and therefore the wavelength where its impact is starts to be visible. Because of the size of elements the fog does not cause at 58 GHz as big attenuation as a rain. Additional attenuation is caused also by dust and smoke.

Due to these attenuation factors a possible length of the connection of the radio link is about few kilometers. The benefit of the high attenuation is decrease of the reuse distance. If the links are located far enough due to the strong decay another radio link system is unlikely to be disturbed. Due to this hundreds of MetroHopper systems can be placed on area of square kilometer [22]. Because the 58 GHz radio systems do not really disturb each other the use of the frequency band is quite a efficient and planning is easy. On that reason the the frequency band has been standardized to be used without coordinated frequency planning [23]. ETSI, however, have standardized the channel space of the frequency band and the maximum power levels.

2.2 Structure of MetroHopper

MetroHopper consist an indoor unit, an outdoor unit, and Felxbus-cable (Figure 15)

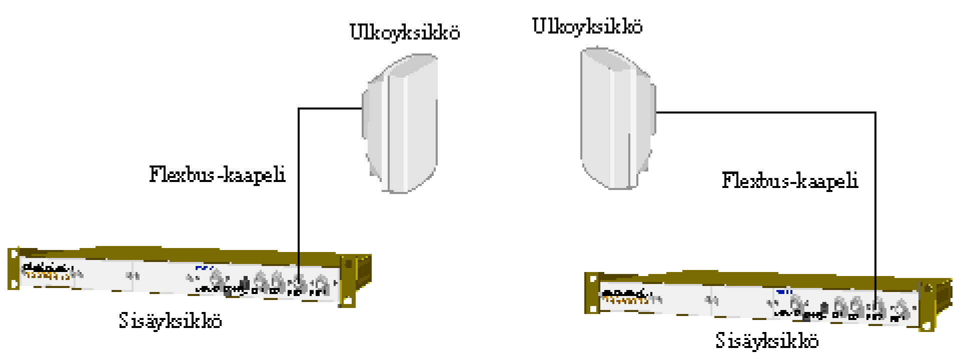


Figure 15. Structure of Nokia's MetroHopper

2.2.1 Indoor unit

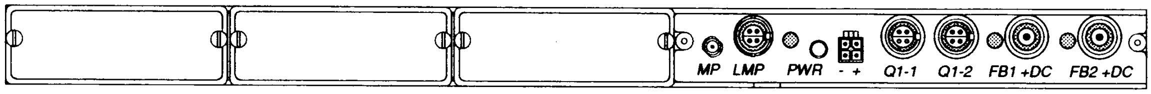


Figure 16. FIU 19 indoor unit

The operation of MetroHopper is directed with an FIU 19 indoor unit which is in accordance with figure 16 and is dimensioned to fit into 19 inches rack [24]. The indoor and outdoor units are connected by a Flexbus cable.

2.2.1.1 Plug-in connectors

One indoor unit is able to control tree so called plug-in units. To the plug-in connectors is connected actual incoming data stream. FIU 19 is able to make connections for three 4 x 2 Mbit/s plug-in units. Independently how many units are connected to it on radio interface MetroHopper is transferring a constant 4 x 3 Mbitls. To the plug-in positions one could connect also extra Flexbus connections. On figure 17 is described one 4 x 2M plug in unit. [25] To this one plug-in unit one could connect four 2 *Mbit/s* incoming data streams using SMB connectors. The connection impedance is 75Ω and it follows ITU-T recommendation 0.703.

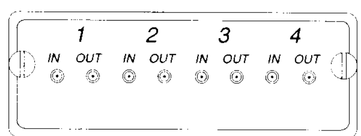


Figure 17. 4 x 2M Plug in - unit

2.2.1.2 Measurement point (MP)

From the MetroHopper system different test signals can be taken out and they can be directed to the interface of the MP connector. An oscilloscope is connected to the MP connector for interpretation of the signals.

2.2.1.3 Local Management Port (LMP)

The MetroHopper system is controlled via MetroHopper Manager program. A control computer is connected to the LMP gate for the local control. MetroHopper can also be controlled from the Q1-1 and Q1-2 connector

2.2.1.4 Power supply

FIU 19 uses 48 V as power supply voltage.

2.2.1.5 Network Management Interface (Q1-1 ja Q1-2)

Multiple FIU 19 indoor units can be controlled from place. For accessing the same control unit they should combined over the bridge. The necessary bridge connections can be configured by using MetroHopper control program. MetroHopper can be connected also to a Nokia GSM Bases Station Subsystem (BSS) trough Q-connector. In this configuration BSS has also control over MetroHopper.

2.2.1.6 Flexbus Interface (FB1 ja FB2) – Flexbus-liitäntä

FIU 19 is connected to the outdoor unit with a Flexbus cable which is connected to FB 1 or FB2 connector. Without separate plug-in unit FIU 19 is able to have control over two outdoor units. The outdoor unit gets its operating voltage from the FB connection.

2.2.2 Flexbus-cabel

Between the FIU 19 2 Mbit/s inputs and Flexbus connector at the output is a cross-connection table.
The indoor and outdoor units are connected by a two directional Flexbus cable which transfers from 1-16 2 Mbit/s signals, and also the signals required for the control of units. The cable provides also power for the outdoor unit. The information signal in the Flexbus cable is digital and maximum length is around 300 m.

2.2.3 Outdoor unit

The outdoor unit contains an integrated antenna and MetroHopper functionality. Thanks to this solution it has been possible to minimize the length of the waveguide and due to the that attenuation between the TX power amplifier and antenna. Thanks to such structure the MetroHopper is very light and easy to install.

The antenna of MetroHopper is the type of integrated flat panel which has been developed in the Radiolaboratory at HUT (the doctoral thesis of Tomas Sehm). The version used in the final product has undergone further developments and fine tuning. At least its appearance deviates from the prototype of the antenna developed by Sehm, such as from picture 18, it is perceived. [26]

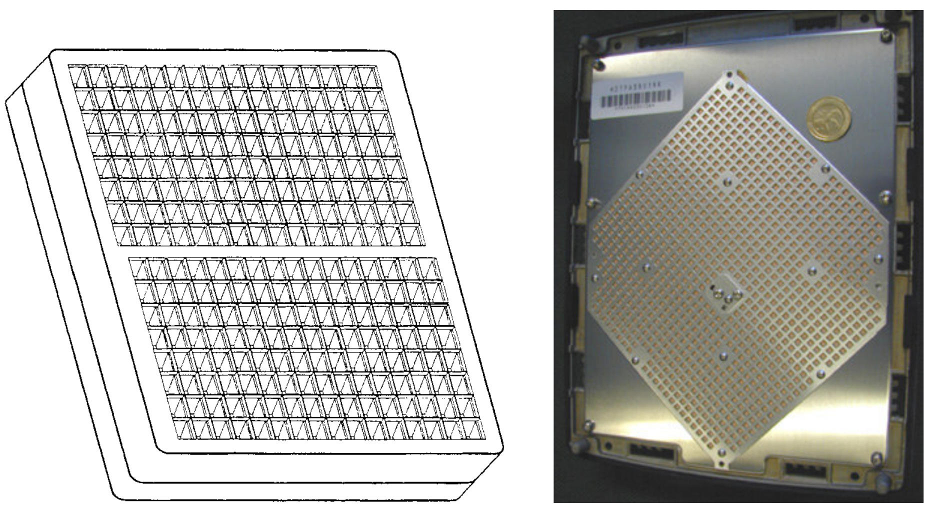


Figure 18. 58GHz:n antenna from Sehm thesis (left) and antenna of the MetroHopper (right)

More information about the antenna is found in the doctoral thesis of Tomas Sehm "Development of Low-Profile Radio Link Antenna for Millimeter Waves".

Nokia measurements indicate the amplification of the antenna to be 34 dBi and its 3 dB slope is 1.5° width in the direction of the main slope. The antenna is well directing and amplifying. As seen in the figure 19 the radiation pattern of the antenna satisfies EN 300 408 specification. [27]

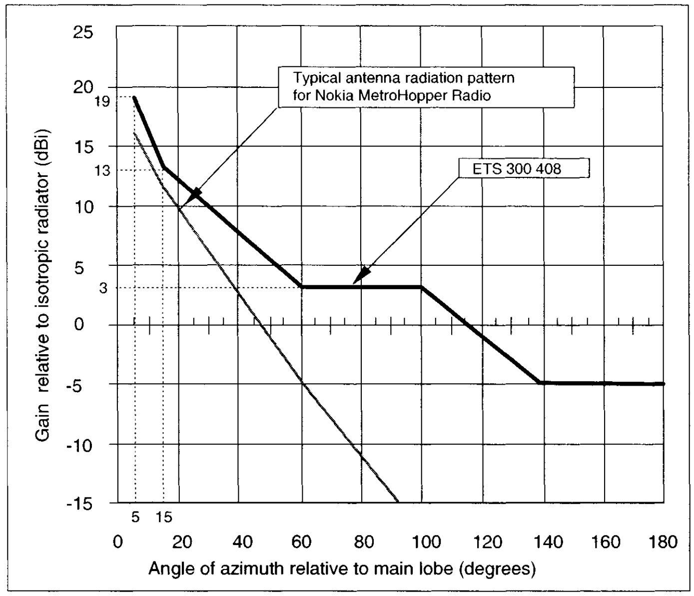


Figure 19. Radiation patter antenna of MetroHopper and limits posed by EN 300 408 specification

MetroHopper is using horizontal polarization. The power is supplied from the inside unit over Floxbus cable.

2.3 Technical details of the radio system

The most important technical details of the MetroHopper are listed in table 3. [28]

Table 2. Technical parameters of MetroHopper

Frequencies and channels	
Used frequencies	57.200 – 58.200 GHz
Channel spacing	100 MHz
Duplexing method	TDD
Channel selection	Manual or automatic
Polarization	Horizontal polarization

Modulation	
Modulation method	MSK

Power levels and BER	
Transmission power	5 dBm
Maximum receivable signal strength	-20 dBm (BER = 10^{-3})
BER 10-3	-71 – -75 dBm
BER 10-6	-69 – -73 dBm

Transfer capacity	
Transfer capacity	4 x 2 Mbit/s

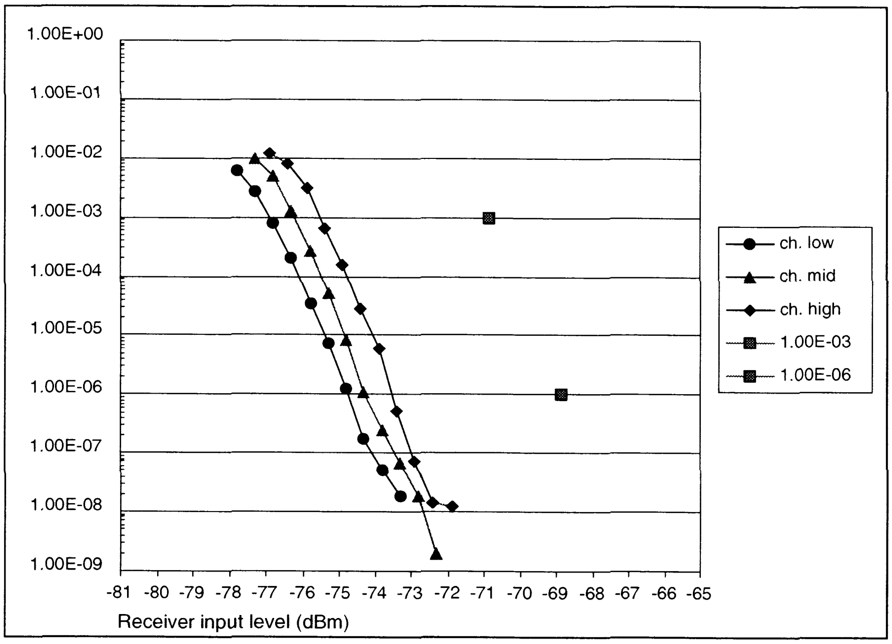


Figure 20.shows BER of MetroHopper as the function of the attenuation. [29].

From the picture it is perceived that only when the received power level is about -73 dBm number of the errors starts to increase significantly. The limits posed by the standard, 10-3 and 10-6, have been marked with boxes.

2.4 Health risk caused by the radion of MetroHopperin

The high frequencies of the radio links, the directing antennas and the possible high power raise the question of the health hazards of the radiation. In Finland The Finnish Ministry of Social Affairs and Health has decided to restrict field intensities such that the health risk is non existent. In a 58 GHz frequencies the maximum limit to the power density of an electric field and magnetic field is 10 W/m^2. Together with antenna amplification the transmit power should not exceed 17 dBm. Over this level the power starts to classified as dangerous. The transmit power of MetroHopper is 5 dBm so there is no danger.

2.5 Applications of the MetroHopper

MetroHopper makes a short and reliable, 4 x 2 Mbit/s connection possible almost everywhere. A 58 GHz frequency band allows designing a tight MetroHopper network where the length of the individual hop is short. The typical purpose of use to the MetroHopper radio link system is the connecting of the wireless network nodes. For example the transfer of the data between GSM repeater to the concentrator. The MetroHopper unit can be connected to the point to point connection, as a repeater or as a diplexing station.

3. INTERFACES IN THE RADIO LINK SYSTEM

Standard transfer rates in a radio link are defined accordingly to PDH and SDH. All the PDH signals and SDH signals up to 155 Mbit/s are in princip1e tranferrab1e in the radio1ink systems. The interface in a radio link is a definition of the transfer format and physical specification needed for connecting two network elements. The interfaces for different transfer speed are defined in ITU-T recommendation G.703. The interface of Nokia MetroHopper is 2 Mbit/s according G.703 to which at 1east PCM, GSM and SDH can be connected in Communications 1aboratory.

4. STANDARDS AND LICENCES

The use of radio links implies the compliance with numerous standards. The standards specify the requirements on radio equipments, structures of interfaces, levels of electromagnetic emission, limits to the environmental effects, operating principles of devices and also the usage of the radio waves. To the telecommunication equipment standards and recommendations are given by ITU- T (worldwide), ETSI (European) and by the Telecommunications Administration Centre, THK (Finnish). Furthermore, THK controls the regulation and grants the licenses of the operation of radio sets. Table 4 shows the standards fulfilled by the Nokia MetroHopper 58 GHz [30].

In the Communications laboratory we possess the operation permit to MetroHopper which is in accordance with appendix 3. The permission has been given to the teaching use so that one end of the link should be located in the laboratory but the other end can be freely located in Otaniemi area. With the permission granted by THK a 58 GHz area the device can be used in any part of Finland when one informs THK about the use. [31] In the operation permits of radio sets and in the searching of them for additional information is found on the WWW pages of THK (http://www.thk.fi) and in the THK notice YY 1.2 from the year 1998: "Luvanvaraisten radiolähettimien yleiset lupaehdot"

Taulukko 3. Standards followed by MetroHopper

Signals (ITU-T)	Name of the standard
G.703	Physical/electrical characteristics of hierarchical digital interface
G.704	Synchronous frame structures used at primary and secondary hierarchical levels
G.823	The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy
G.826	Error performance parameters and objectives for international, constant bit rate paths at or above primary rate
G.921	Digital sections based on the 2048 kbit/s hierarchy

Radio transmission (ETSI)	Name of the standard
EN 300 408	Parameters for radio-relay systems for the transmission of digital and analogue video signals operating at around 58 GHz which do not require co-ordinated frequency planning

Environment	Name of the standard
ETS 300 019-1-1 Class 1.2	Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Storage.
ETS 300 019-1-2 Class 2.3	Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Transportation.
ETS 300 019-1-3 Class 3.2	Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Stationary use of at weatherprotected locations.
ETS 300 019-1-4 Class 4.1	Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Stationary use of at non-weatherprotected locations.
ETS 300 019-1-4 Class 4.1E	Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Stationary use of at non-weatherprotected locations – extended.
ETS 300 385	Radio equipment and systems (RES); EletrcoMagnetic Compatibility (EMC) standard for digital radiolinks and ancillary equipment with data rates around 2 Mbit/s and above.
EN 55022	Limits and methods of measurement of radio interference characteristics of information technology equipment.
EN 60801-2	Electromagnetic compatibility for industrial-process measurement and control equipment – Part 2: Electrostatic discharge requirements.
ENV 50140	Electromagnetic compatibility – Basic immunity standard – Radiated, radio frequency, electromagnetic field; Immunity test
ENV 50141	Electromagnetic compatibility – Basic immunity standard –Conducted disturbances induced by radio frequency fields.
ENV 50142	Electromagnetic compatibility – Basic immunity standard –Surge immunity test.
IEC 801-4	Electromagnetic compatibility for industrial-process measurement and control equipment – Part 4: Electrical fast transient – burst requirements.

5. CONTROL, ALARMS AND INTERNAL TESTS

The radio link systems are controlled from a remote location or at the site. Control at the site is often difficult therefore it is customary to concentrate the supervision of several radio links or of radio systems at one spot, for example into the control room. There is a led lighting in the control room or the system gives the alarm if there is a fault in some part of the system. It is possible also to control the system by using data transfer over radio links. Such remote control allows to reduce expensive on site repairs and tunings. If the problem cannot be identified: for example as exceptional weather conditions if a connection is cut off, one has often to visit the site.

The supervision of systems has been made very versatile. For example from the radio links lot of monitoring data is collected continuously. Additionally to monitoring data radio link units provide explicit alarm and fault reports. In MetroHopper the alarms are divided on the basis of seriousness into into four c1asses: critical, major, minor and warming. The alarms are not only signaled to the control software but many of them are reported also by numerous signaling LEDs.

The condition of the radio link can be tested by running internal tests. In internal test the equipment executes a test sequence and identifies its operational condition. Furthermore, there is often a test interface in the systems to which the desired signals can be directed. From test points one can observe the internal signal for example with the help of the oscilloscope. Usually for the time test is run the connections in the radio interface is lost.

5.1 Control, alarms and internal tests

MetroHopper Management program is a flexible tool for controlling MetroHopper. The parameters obtained from the program can be divided into measurements, error counters, signal quality statistics, and alarms. All the measured can be followed by using follow-up windows. Into those windows program continuously updates the measurements results. The minimum updating time is 10 s. All the measured can be collected into log files. Additionally to the management program MetroHopper has also 3 alarm LED.

Table 5. Measurements

Measurements
Flexbus 1 ja 2: BER
Flexbus 1 ja 2: Power status
PRBS2: BER
PRSBF: BER
Power supply: +3.3V, +5.0V, -5.0V ja Supply voltage
Radio Interface: Rx level, Rx level min ja max

Error counters
Flexbus 1 ja 2:
Frame sync lost
Bit error count
PRBS2: Bit error count
PRBSF: Bit error count

Signal quality statistics Accordingly to ITU-T:n recommendation G.826:
Total Time (TT)

Available Time (AT)
Errored Second (ES)
Severely Errored Second (SES)
Background Block Error (BBE)
Errored Block (EB)

5.1.1 Signaling LEDs and alarms

In the FIU 19 indoor unit of MetroHopper are three LEDs indicating about the function of the device. The rightmost LED is indicating the operation of FIU 19 unit and two others are related to the operations of Flexbusses. The meanings of LEDs are explained in talbe 6 and 7. [32] [33].

Table 6. Explantions of the signalling lights of FIU 19 inside unit

LED color	Meaning
Red	One or more datalines not working.
Yellow	Indoor and/or outdoor unit has active alarm. However, data is transferred over the link.
Green	Units are working properly, no alarms. Blinking green indicates that there is connection to the node manager.

Table 7. Explanation of alarm LEDs for Flexbus

LED color	Meaning
Switched off	Flexbus does not carry supply voltage or data transmission is off.
Blinking green	DC voltage in on, data transmission is off.
Green	DC voltage is on and Metro hopper is transmitting.

All the MetroHopper alarms can be found in appendix 4.

5.1.2 Ineternal tests of MetroHopper

The internal tests of MetroHopper consist: the loopbacks, forced controls, and connections that have been formed to the test interface of the indoor unit.

5.1.2.1 Loopbacks

Internal loopbacks programmable and with the help of defined signals can be directed to the desired places. Figure 21 shows all the loop connections of MetroHopper and their explanations are in table 8. [34].

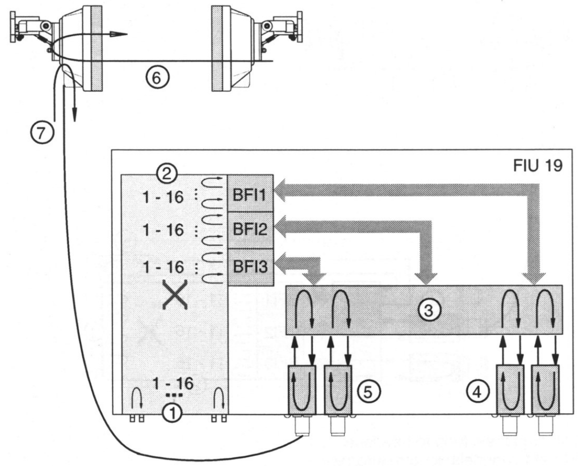


Figure 21. Loopbacks in MetroHopper

Table 8 . Explanations of the loopbacks of MetroHopper

Number	Name	Explanation
1	2M IF	Loopbacks at the 2 Mbit/s interface of hte Plug-in unit.
2	BFI 2M Channels	Loopbacks at the cross-connection of 2Mbit/s signals that are directed to Flexbus.
3	Flexbuses	Loopbacks to the Flexbus interface of indoor unit.
4	FB1 ja FB2	Loopbacks from Flexbus interface back to the device.
5	FB3 ja FB4	Loopbacks from Flexbus interface back to the device.
6	Outdoor Unit	Loopback from one outdoor unit to another.
7	Outdoor Unit	Loopback from outdoor unit to indoor unit.

5.1.2.2 Forced controls

A forced control is an operation in which a part of MetroHopper is compelled to do something in the desired way. For example the colors of the LEDs can be reprogrammed. Such reprogramming helps to test whether all operations are flawless.

5.1.2.3 Measurement points

The measuring point of FIU 19 to indoor units can be directed from the device, several signals. With the help of signals for example the correction of the system is facilitated. The possible signals are: [35]

- 2M TX data
- Flexbus 2M RX data (signals from the cross-connect)
- 2M PRBS (pseudo-random binany sequence)
- 2M AIS (alarm indication signal)
- Flexbus 2M TX clock
- Flexbus 2M RX clock

6. REFERENCES

[1] Antti Räisänen, Arto Lehto: Radiotekniikka. Otatieto 1992.
[2] Arto Lehto: S-26.105 Radiojärjestelmän osat opetusmoniste. Edita Oy kevät 2001 set 6.
[3] Antti Räisänen, Arto Lehto: Radiotekniikka. Otatieto 1992.
[4] Harri Lahti: S-26.140 Tietoliikenteen radiolaitteet I opetusmoniste. Edita Oy kevät 2001 set. 1.
[5] S-26.140 Tietoliikenteen radiolaitteet I opetusmoniste. Edita Oy kevät 2001 set 3. 15 pages.
[6] Tero Tuoriniemi: S-26.140 Tietoliikenteen radiolaitteet I opetusmoniste. Edita Oy kevät 2001 set 3
[7] Arto Lehto: S-26.105 Radiojärjestelmän osat opetusmoniste. Edita Oy kevät 2001 set 1.
[8] S-26.140 Tietoliikenteen radiolaitteet I opetusmoniste. Edita Oy kevät 2001 set 3.
[9] Arto Lehto: S-26.105 Radiojärjestelmän osat opetusmoniste. Edita Oy kevät 2001 set 1.
[10] Arto Lehto: S-26.105 Radiojärjestelmän osat opetusmoniste. Edita Oy kevät 2001 set 1.
[11] Simon Haykin: Communication systems 3ed. John Wiley & Sons USA 1994.
[12] Simon Haykin: Communication systems 3ed. John Wiley & Sons USA 1994.
[13] Petri Mikkonen: S-26.105 Radiojärjestelmän osat opetusmoniste. Edita Oy kevät 2001 set 3.
[14] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 3.3.4.8.
[15] Pentti Teppo: Siirtojärjestelmät tietoliikennetekniikassa. Gummerus 1982.
[16] Antti Räisänen, Arto Lehto: Radiotekniikka. Otatieto 1992.
[17] Pentti Teppo: Siirtojärjestelmät tietoliikennetekniikassa. Gummerus 1982.
[18] Pentti Teppo: Siirtojärjestelmät tietoliikennetekniikassa. Gummerus 1982.
[19] Harri Lahti: S-26.140 Tietoliikenteen radiolaitteet I opetusmoniste. Edita Oy kevät 2001 set 1.
[20] Arto Lehto, Antti Räisänen: Millimetriaaltotekniikka. Otatieto 1997.
[21] Arto Lehto, Antti Räisänen: Millimetriaaltotekniikka. Otatieto 1997.
[22] Nokia Telecommunications: Nokia MetroHopper Radio, Product Overview. Nokia Telecommunications dokumentti C3551200SE_CO 1998-1999
[23] ETSI Standardi ETS 300 408: Transmission and Multiplexing (TM); Parameters for Radio-relay systems for the transmission of digital signals and analogue video signals operating at around 58 GHz, which do not require co-ordinated frequency planning. ETSI March 1996
[24] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 3.1.6.1.
[25] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 3.1.6.1.
[26] Tomas Sehm: A High-Gain 58-GHz Box-Horn Array Antenna with Suppressed Grating Lobes. IEEE Transactions on Antennas and Propagation, Vol. 47, No. 7, July 1999
[27] Nokia Telecommunications: Nokia MetroHopper Radio, Product Overview. Nokia Telecommunications dokumentti C3551200SE_CO 1998-1999 s.30
[28] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 5.0.8.1.
[29] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 5.0.8.1.
[30] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 5.0.8.9.
[31] Telehallintokeskuksen www-sivu: Radiolinkkien käyttö taajuusalueella 57,2 - 58,2 GHz : http://www.thk.fi/suomi/radio/radiolinkit58.htm
[32] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 4.0.4.2.1.
[33] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 4.0.4.2.3.
[34] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 4.0.5.3.1.
[35] Nokia Networks Oy: Nokia MetroHopper Radio User Manual. Nokia Networks 2000, 4.0.5.3.3.