GSM-R Project

Jernbaneverket
Utbygging

☐	Godkjent
☐	Godkjent m/kommentarer
☐	Ikke godkjent Revider og send inn på nytt
☐	Kun for informasjon
Dato:	Sign:

Tunnel System Guidelines

03D	Endringer i.h.t kommentarer på rev02C	17.03.2004	GBH	GBH	BE
02C	Endringer i.h.t. kommentar sendt fra JBV 11.11.2003	18.11.2003	GBH	GBH	S.Storø
01C	Inkluderer linkbudsjettbeskrivelse	06.11.2003	GBH	GBH	S.Storø
00C		29.10.2003	GBH	BE	BE
Revision		Dato:	Utarb. av	Kontr. av	Godkj. av

Title **Tunnel System Guidelines**	Målestokk: Utarbeidet av: **SIEMENS AS**	
Prosjekt: **GSM-R** SoL ID: **00 Generelt GSM-R prosjektet** Site ID: **NA** Delsys.: **Tunnel**	Erstatning for: FDV nummer: TE.800007-000	Antall sider 23 + 0 vedl
Jernbaneverket	Dokumentnummer: **GSM-00-A-20006**	Revisjon **03D**

CONTENT

1. Introduction

The tunnel coverage system is the sub-system which extend the coverage of the network to provide coverage inside the tunnel. In Norway this is an important part of the GSM-R network because of the high number of tunnels.

The main target of the document is to describe the main equipment involved and principles of the tunnel system design. The document will serve as a network plan for the sub-system tunnel as well as guidelines for tunnel system design. Typical tunnel scenarios and design solutions will be described. These solutions are not absolute and should be considered as guidelines. Every tunnel has it's own specific characteristics and needs a specially adapted solution.

2. Tunnel system overview

The GSM-R network is designed to provide coverage along the railway. The base stations mainly provide coverage in the areas outside the tunnels. In order to cover the tunnels, a repeater system can be used. In down link, after receiving signal from a near by base station (often referred to as donor base station) , the repeater simply amplifies the received signal and sends it inside the tunnel, and vice versa in up link. A repeater is just a way to extend the coverage area of a base station cell and does not give any extra capacity to the network. In order to enhance the capacity, a base station must be installed in the tunnel.

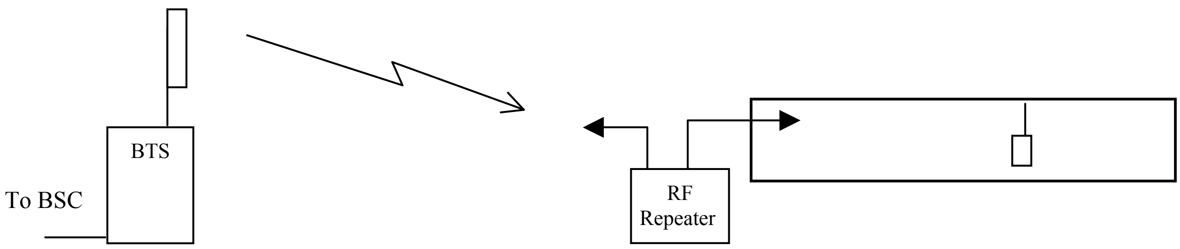

Figure 1: Donor base station and a simple tunnel system

The main components of the repeater system are:

- The pick up antenna: The antenna is directed towards the donor base station antenna in order to pick up the BTS-signal.
- Repeater: This unit amplifies the signal to and from the base station.
- Tunnel antenna/Radiating cable: Positioned inside the tunnel in order to distribute the signal there.
- Repeater OMC: Monitors the repeaters in the network.

3. General System Architecture

3.1 RF-Repeater

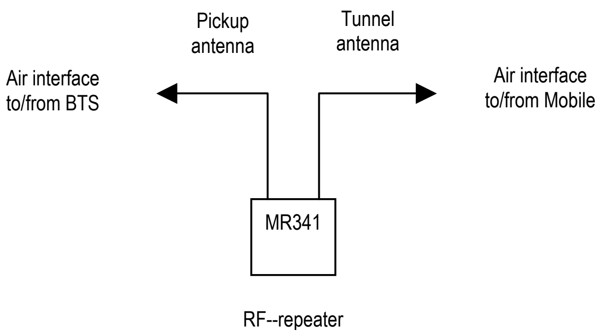

Figure 2: Radio Frequency Repeater

The RF-Repeater picks up the signals from the serving BTS in the particular area and amplifies the selected channels to cover the tunnel for the mobiles. The repeater input is connected to the pickup antenna, while the output is connected to the tunnel antenna or radiating cable.

3.2 Optical System

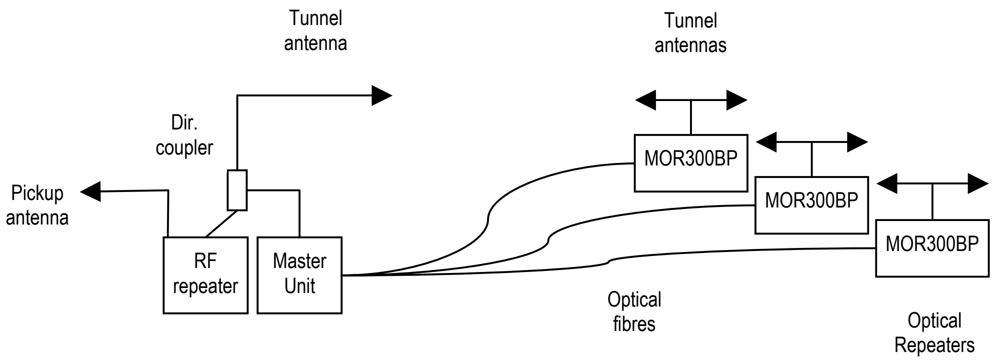

Figure 3: Optical repeater system

The system can be described in five functional blocks:

- Connection to the base station / RF-repeater
- Master Unit
- Fibre Network
- Fibre Optical Repeater (FOR) / Remote Unit (MOR300BP)
- Radiating System (antenna or radiating cable)

3.2.1 Connection to the base station / RF-Repeater

The master unit can be fed either from a BTS output or a RF-repeater output. A directional coupler is connected to this output and passes the signals on to the master unit, via an RF-cable. The master unit does not require very high input signal, so the main part of the signal power either has to be terminated in a dummy load or, as the figure suggests, in an antenna/radiating cable.

3.2.2 Master Unit

The Master Unit converts the signals from RF-signals into optical light for transmission over fibre. The System can be remotely controlled through a modem in the Master Unit.. Hence, the OMC can supervise the system, and alarms or warnings are forwarded to the OMC.

3.2.3 Fibre Network

The Fibre Network is connecting the Remote Units to the Master Unit via single mode fibres. The transmission is analog and therefore not comparable to a digital data transmission. High Return Loss (HRL) fiber optic connectors are used. There is a budget of typical 10 dB allowed optical loss, which is equal to 20 dB electrical loss. Several kilometers can be overcome, still satisfying this criteria.

3.2.4 Fibre Optical Repeater (FOR) / Remote Unit (MOR300BP)

The Remote Units converts the fibre optical signal to RF-signal and vice a versa. They are situated at different transmission locations from which they transmit the RF-signal to the coverage area. They are connected to the Master Unit via optical fibres.

3.2.5 Radiating System

The Remote Units feed either a radiating cable or an antenna system.

3.3 Operation and Maintenance Centre 3.30(OMC)

The Mikom OMC 3.30 is a monitoring system for the repeater system in the GSM-R network. The repeaters are connected to the OMC, via the core network, by a repeater integrated GSM-R modem. It is possible to run Mikom OMC on a single PC or on a network. Several users can have full access to the database and the modem control. For more details se the reference [2].

4. Equipment Description

For more detailed descriptions of the equipment see Reference [2] and the equipment data sheets. The equipment described in this chapter are standard equipment or just examples of models that can be used. Of course there might be a need for other vendors and other types of equipment to adapt the solutions to special circumstances.

4.1 Repeater equipment

4.1.1 RF-Repeater MR341-R:

This repeater is a channel selective repeater that covers the GSM-R band.

Figure 4: The RF-repeater (MR341-R)

Technical data	***MR341-R***
Frequency Range	UL: 876 - 880 MHz; DL: 921 - 925 MHz
Max gain	85.0 dB (at 2 ch), 81.5 dB (at 4 ch)
Output power per channel	32.5 dBm (at 2 ch), 29.0 dBm (at 4 ch)
Number of channels in standard cabinet	2
Power Consumption	20W + 25W/ch
Power supply	48 V DC
Weight	approx. 14 kg
Height, Width, Depth	445 x 255 x 167 mm

Table 1: MR341-R specifications

4.1.2 Master Unit MOR3xxB:

The Master Unit is “broad band” meaning that it covers a wide frequency band (370MHz...2.2GHz).

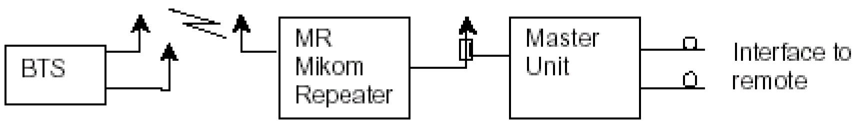

Figure 5: Master unit connected via directional coupler to the RF-repeater

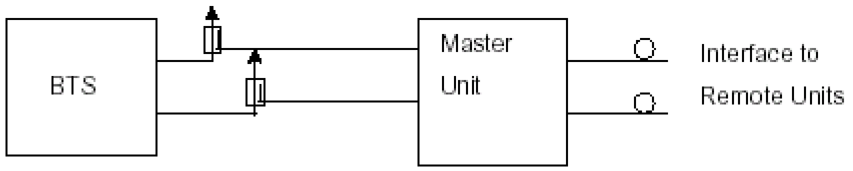

Figure 6: Master unit connected via directional coupler to the BTS

Technical data	*MOR3xxB*
Frequency Range	370 MHz ... 2.2 GHz
RF-input power range at BTS port	+50 dBm ... -10dBm
Power consumption	Depends on application. 1RU: ~50W, 4RU:~67W, 8RU: ~108W
Power supply	48 V DC
Weight kg	106 kg (max config)
Height, Width, Depth	(1200x600x600) mm

Table 2: Master unit specifications

The master unit is preferably delivered in a cabinet from the factory. This 19" rack has outer measurements of 1200mm x 600mm x 600mm (H x W x D), and has a total of 24U available inside.

The equipment has cabling in front. The example layout in figure Figure 7 shows a configuration for 1 to 4 remote units. The maximum configuration with this cabinet is 24 remote units.

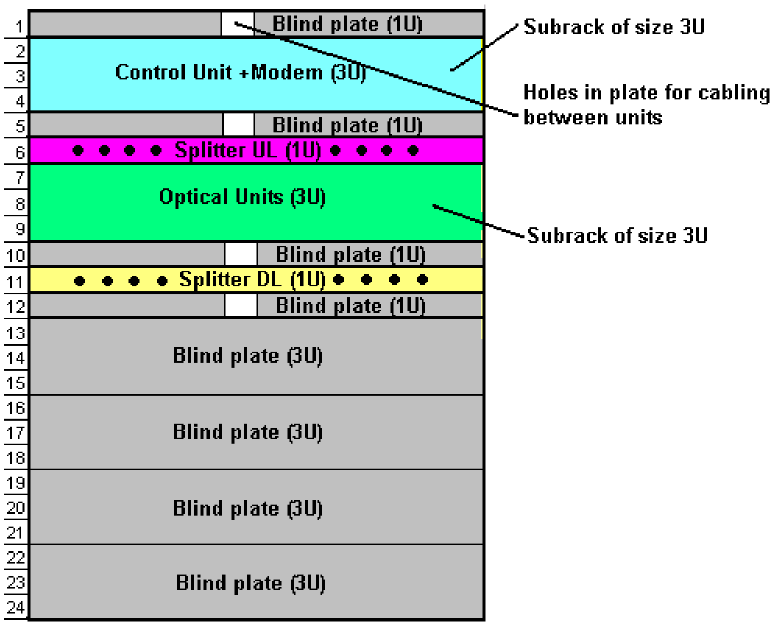

Figure 7: Example of master unit rack layout.

4.1.3 Remote Unit MOR300BP:

This is a broad band unit covering UL 876 – 915 MHz, DL 921 – 960 MHz. Hence it covers both the GSM-R, E-GSM and GSM900 bands.

Figure 8: The fibre optical repeater (MOR300BP)

Technical data	*MOR300BP*
Frequency Range	UL: 876 - 880 MHz; DL: 921 - 925 MHz
Gain UL/DL	50 dBm min
Output power per channel	27 dBm (at 2 ch), 23.5 dBm (at 4 ch)
Power consumption	90 W
Power supply	48 V DC
Weight	aprox. 14 kg
Height, width, Depth	445 x 255 x 167*/185

(* without mounting brackets)

Table 3: Remote unit specifications

4.2 Antennas

The different antennas that will be used in the tunnel system design are listed below. These antennas are chosen based on mechanical and electrical features.

4.2.1 Pick up antennas

The DB842H35E-SY antenna will be used as a standard. The DB844H35E-ST will be used when the situation requires higher gain.

Model	*Pol.*	*Gain [dBi]*	*Front-to-back Ratio [dB]*	*Horizontal bw [deg]*	*Vertical bw [deg]*	*Weight [kg]*	*Size (HxWxD) [mm]*
DB842H35E-SY	V	14.5	40	35	30	6.4	610x610x318
DB844H35E-SY	V	17.6	40	35	15	12.7	1219x610x318

Table 4: Pickup antenna specifications

4.2.2 Hand over antennas

Model	*Pol.*	*Gain [dBi]*	*Front-to-back Ratio [dB]*	*Horizontal bw [deg]*	*Vertical bw [deg]*	*Weight [kg]*	*Size (HxWxD) [mm]*
K 730 677	V	9	25	65	70	1.2	264x258x103
K 742 192	V	11	25	65	55	5.7	300x155x785
K 730 368	V	15.5	25	65	13	6	1294x258x103
K 735 727	V	16.5	24	20	33	10	492x992x190

Table 5: Handover antenna specifications

4.2.3 Tunnel antennas

Model	*Pol.*	*Gain [dBi]*	*Front-to-back Ratio [dB]*	*Horizontal bw [deg]*	*Vertical bw [deg]*	*Weight [kg]*	*Size (HxWxD) [mm]*
T-ASD1-824/960 (AH900T)	Circ	10	10 (UL) 13 (DL)	32	32	13.6	510x?x1859

Table 6: Tunnel antenna specifications

4.3 Feeders and radiating cables

The cable models below will be used as a standard. Andrew is the supplier of these cables.

4.3.1 Radiating Cable

Model	*Dimension*	*Attenuation [dB/100m]*	*Coupling loss, at 95% prob. [dB]*
RCT6-LTC-3	1-1/4"	890MHz: 3.6 (1.08dB/100ft = 3.54dB/100m) (380-400 MHz: 2.0)	67 (80)

Table 7: Radiating cable specifications

4.3.2 Feeder Cables

Model	*Dimension*	*Attenuation [dB/100m]*
FSJ4-50B	1/2"	11.1
LDF4-50A	1/2"	6.85
LDF5-50A	7/8"	3.87
LDF6-50A	1-1/4"	2.76

Table 8: Feeder cable specifications

4.3.3 Radiating Cable Termination ("dummy load")

If the radiating cable is not terminated in an antenna, it must have a 50Ω termination in the end. An example of such a dummy load is

- Suhner 657816-50-0-3, 1W, 7/16 male

4.3.4 RF-repeater/BTS-output Termination ("dummy load")

If a BTS or a RF-repeater feeds a master unit through a directional coupler, and the main output signal is not needed, then there is a need for a 50Ω termination capable of handling higher power than the one in 4.3.3. This is also the case when a hybrid coupler is used close to the RF-repeater/BTS. Two examples of such a dummy loads are:

- Suhner 6506.41.A, 6W, 7/16 male
- Suhner 6525.41.AB, 25W, 7/16 male

4.4 Splitter/coupler/combiner

The described models should be viewed as examples of the type of equipment that will be used. The vendor and models will not necessarily be as stated here.

4.4.1 Power Splitters

The splitting of the RF signal from one to two outputs can be done symmetrically (even splitting) or asymmetrically (uneven splitting).

- Mikom 145024: 2-way symmetrical splitter MPD1-2, 3dB, 7/16
- Mikom 145025: 2-way asymmetrical splitter MPD1-2, 7dB, 7/16
- Mikom 145026: 2-way asymmetrical splitter MPD1-2, 16dB, 7/16

4.4.2 Directional Coupler

In case of an optical repeater system, a directional coupler is connected to the BTS / RF-Repeater output in order to pass part of the signal on to the master unit.

- Mikom 143866: MFC716, 20dB, 7/16
- Mikom 146962: MFC716,10dB, 7/16

4.4.3 Hybrid Combiner

The Hybrid combiner is used to combine two repeater outputs onto one common cable/antenna.

- Kathrein K637067: 3-dB Coupler (hybrid), max 350W at one input, max 500 at two inputs, 7/16

4.5 Optical Fibre Network

The main optical fibre network elements are described below

4.5.1 Optical Fibre

The optical fibre cable consists of 48 single mode fibres.

- Samsung: Loose Tube, Dry Core, Single Jacket, All-Dielectric, Flame Retardant, Halogen Free Cable (SMF 48)

4.5.2 Optical Coupler

The optical coupler is used to combine signals from two master units into one optical repeater (Remote Unit):

- Oplink Communications DWFC 0150P001111: Dual Window, Single Mode Wideband Fiber Coupler, 1x2, 1310/1550nm, 50/50 (Symmetrical).

4.6 Power supply

During a power breakdown, the power supply configurations are designed to supply minimum 100W/250W, for at least 8 hours. For DC-power redundancy there are two rectifier modules in both solutions, each one has a capacity of 700W. This means that the DC power capacity is limited by the batteries (redundancy requirement in case of main power fallout) and not the rectifiers.

4.6.1 Power Supply for Repeater In Shelter

The rectifiers and batteries are installed in a rack with the following dimensions 900mm x 600mm x 400mm (H x W x D).

Figure 9: Rectifier and batteries in rack inside shelter.

4.6.1.1 Repeater Installation without Master Unit

Repeater in shelter Rectifier 100W	
Number	***Module***
2	Rectifier module Flatpack 700 (700W)
1	Control module MPSU 3000 2 U
1	Subrack
1	Distribution Unit (Battery: 1 x 100A, Load: 4 x 6A)
1	Cabinet 900x600x400, 18U with door
4	Battery 32Ah
1	Battery cables

Table 9: 100W Power system specifications.

4.6.1.2 Repeater Installation with Master Unit

Repeater in shelter Rectifier 250W	
Number	***Module***
2	Rectifier module Flatpack 700 (700W)
1	Control module MPSU 3000 2 U
1	Subrack
1	Distribution Unit (Battery: 1 x 100A, Load: 3 x 6A and 1 x 16A)
1	Cabinet 900x600x400, 18U with door
4	Battery 55Ah
1	Battery cables

Table 10: 250W Power system specifications

4.6.2 Power Supply for Repeater in Tunnel

The rectifiers and batteries are installed in a rack with the following dimensions 600mm x 600mm x 350mm (H x W x D). This is originally a IP66 cabinet, which after modifications including air valves, has been reduced to IP56.

Figure 10: Rectifier and batteries in rack inside a tunnel

Repeater in shelter Rectifier 100W	
Number	***Module***
2	Rectifier module Flatpack 700 (700W)
1	Control module MPSU 3000 2 U
1	Subrack
1	Distribution Unit (Battery: 1 x 100A, Load: 4 x 6A)
1	Rittal Cabinet 600x600x350
4	Battery 32Ah
1	Battery cables

Table 11: 100W Power system specifications in tunnel.

5. Design Requirements

The tunnel system design requirements are described in the *GSM-R System Contract, Attachment E7- Tunnel Systems.* A brief overview will be presented here.

5.1.1 Frequency

All tunnel system elements shall as a minimum be configured to operate within the UIC frequency band for GSM-R:

Uplink:	876 – 880 MHz
Downlink:	921 – 925 MHz

5.1.2 Coverage and quality

All tunnels not being covered from BTSs outside shall have a tunnel system to provide in-tunnel coverage when there is a train in tunnel.

With a coverage probability of at least 95% in each location interval (length: 100m), the measured coverage level shall be greater than or equal to –82 dBm at 1.5 m height above ground. This applies to tunnels of all lengths.

Many tunnels shorter than or around 100m are likely to have sufficient coverage without a repeater solution. For tunnels where this is considered likely, there has been an agreement to wait for drive test verification of the coverage, in order to avoid building unnecessary repeater systems. The drive tests will be performed during SAT SOL. The same applies for avalanche covers of all lengths.

The RxQual value for tunnel systems shall be 3 or lower.

The following network performance requirements shall be satisfied:

- Dropped call rate shall not exceed 1%
- Radio network congestion shall not exceed 1%
- Handover success rate shall be at least 99%

5.1.3 Redundancy concept

There is no tunnel coverage redundancy requirements for tunnels shorter than 1000m. The following redundancy criteria apply to tunnels longer than 1000m only.

The repeaters shall be fed from two different BTSs. These BTSs shall provide donor signal at each end of the tunnel. If a tunnel system element fails, the coverage gap in the tunnel shall be no longer than 100m. A coverage cap is defined as measured signal level lower than –82 dBm.

5.1.4 Capacity dimensioning

If tunnel system is fed from cell on BTS for which radio planning is performed by Company, all capacity in cell shall be made available in tunnel system. In case a BTS is part of the tunnel system, the traffic calculations shall be based on 1 % grade of service (GoS) and the Erlang B formula. The tunnel system shall always as a minimum be configured with 2 TRXs per cell due to redundancy requirements. For further details on this issue, see the system contract.

5.1.5 Initial Tuning

Siemens is responsible for the design verification and shall perform initial tuning and optimisation of the tunnel system. For further details, see contract.

6. Design approach

Based on the cell plan from the radio planning group and the characteristics of the tunnel, every tunnel will need a customized design. Important tunnel parameters are:

- Length
- Profile
- Structure
- Curvature

Important coverage related issues are:

- Secure coverage level better than -82dBm, with train in the tunnel.
- Secure safe handovers in all situations
- Secure coverage in the area outside the tunnel, which are often difficult to reach from the BTS.
- Follow the redundancy criteria.

Chapter 6.1 describes the four main categories of tunnel systems designed for this project, while chapter 6.2 gives examples of customized solutions that will be used in the project. In the following drawings the terms *RFR, MU* and *FOR* have been used, meaning respectively *Radio Frequency Repeater*, *Master Unit* and *Fibre Optical Repeater (Remote Unit).*

6.1 Main design categories

6.1.1 Tunnel System Type 1 (length < ~100m)

Many tunnels shorter than or around 100m are likely to have sufficient coverage without a repeater solution. For tunnels where this is considered likely, there has been an agreement to wait for drive test verification of the coverage, in order to avoid building unnecessary repeater systems.

In case there is a need for repeater solution, the same solution as in chapter 6.1.2 will apply.

6.1.2 Tunnel System Type 2 (length < ~300m)

For tunnels at this length, a solution with 1 RF-repeater and 1 tunnel antenna will normally be sufficient to comply with the coverage requirements, even with a train in the tunnel. The tunnel antenna to be used in the project has relatively strong back lobe. As a result of this, it can be positioned some distance into the tunnel (50-100m) and still cover the whole tunnel. If it is necessary to provide coverage outside the tunnel (e.g. in relation to HO), the use of radiating cable ending in a handover antenna might be required.

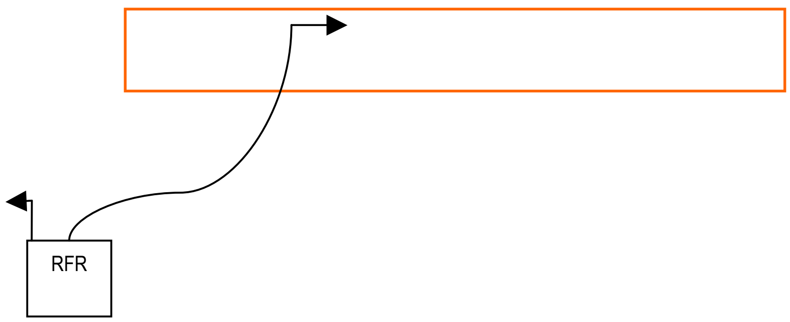

Figure 11: Typical solution in tunnels shorter than ~300m

6.1.3 Tunnel System Type 3 (length < ~1000m)

For longer tunnels than above it will be difficult to fulfill the coverage criteria with only one tunnel antenna. The solution shown in the figure below includes 1 RF-repeater and radiating cable through the tunnel. This will in most cases be a cheaper and also better and more predictable solution than to use 1 RF-repeater and tunnel antenna in each end of the tunnel.

Figure 12: Typical solution in tunnels up to ~1000m

6.1.4 Tunnel System Type 4 (length < ~1200m)

A tunnel longer than ~1000m will require 2 RF-repeaters to fulfil the redundancy requirement. At a radiating cable length > ~1100m, the signal will soon drop below -82 dBm. With an allowable coverage gap in the redundant case of 100m, a tunnel of ~1200m can be covered by 1 RF-repeater in each end of the tunnel and radiating cable between them.

Figure 13: Typical solution in tunnels up to ~1200m

6.1.5 Tunnel System Type 5 (length > ~1200m)

For tunnels longer than ~1200m, there will be a need for a repeater site inside the tunnel. This will require an optical system. The tunnel can be covered either by tunnel antennas or radiating cables. The antenna solution requires shorter distance between the fibre optical repeaters than the radiating cable solution. The tunnel characteristics and the cost in each case will decide the solution to choose.

6.1.5.1 Optical system with distributed antennas

The solution described includes 2 x RF-repeater with pickup antennas, 2 x master units, n x fibre optical repeaters and n x tunnel antennas. In the redundant case when one of the mid-repeaters fail, the solution in Figure 14 will lead to a distance of approximately 1000m between the operating repeaters. If one of the RF-repeaters fails, there will be approximately 200m to cover (100m coverage gap is allowed according to contract). The big difference is that now there will be an antenna on only one side of the MS, resulting in a possible high train blocking effect. In addition the fibre optical repeater (MOR300BP) has considerably lower output power than the RF-repeater (~12 dB lower after power splitting).

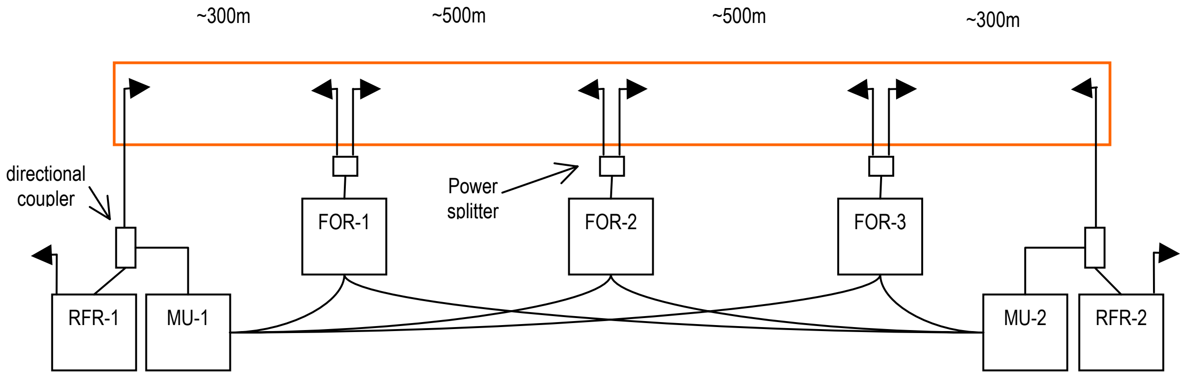

Figure 14: Typical optical solution with distributed antennas

6.1.5.2 Optical system with radiating cable

The solution described includes 2 x RF-repeater with pickup antennas, 2 x master units, n x fibre optical repeaters and (n+1) x radiating cables. In the case when one of the repeaters fail, the solution in will lead to a distance between the operating repeaters of approximately 1600m. That is each repeater must cover at least 750m (100m coverage gap). According to link budget calculation the requirements will be fulfilled in this case.

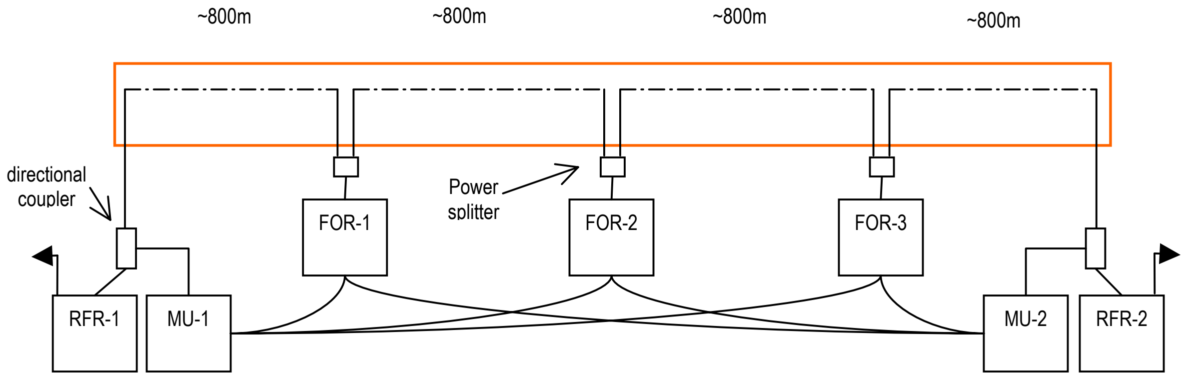

Figure 15: Typical optical solution with radiating cable

6.2 Examples of customized tunnel solutions

The standard solutions in chapter 6.1 will not always be the optimal solution. In this chapter some examples of customised solutions.

6.2.1 Overlap-/HO-antenna

Overlap antenna

Very often the area right outside the tunnel is in a coverage shadow from the BTS. To cover this "extension" of the tunnel, a *overlap antenna* can be introduced as a part of the tunnel system, as in Figure 16.

Handover antenna

In some cases there are more than one BTS that covers the area outside the tunnel. It might be difficult to know which BTS will be serving, or it might actually vary depending on the situation (e.g. train direction). In other cases the serving BTS is different on the different sides of the tunnel. All these situations might lead to unpredictable handover behaviour and in many cases a handover around the tunnel entrance. Due to the possible sudden drop in serving BTS signal in such cases (train moving in or out of the tunnel), dropped calls might occur. To avoid this situation the extension of coverage from the tunnel system to the area outside the tunnels can be necessary. This can be done by a handover antenna like Figure 16 shows. The solution is equal to the overlap antenna solution described above.

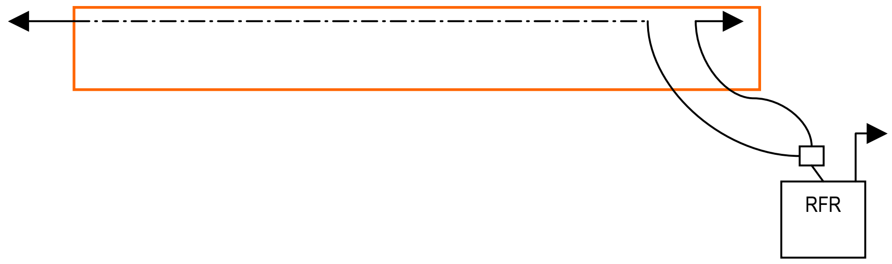

Figure 16: Example of overlap antenna and hand over antenna

6.2.2 Combined antenna/radiating cable solution

If the same BTS is covering both sides of a tunnel, that is there is no need for special handover concern, combining radiating cable and tunnel antenna can be a more cost optimal solution. This can be applicable to tunnels which is to long for a pure antenna solution.

Figure 17: Example of combining antenna and radiating cable.

6.2.3 One tunnel system covering more tunnels

When tunnels are situated close to each other, it can be cost effective to include more tunnels in the same tunnel system design. See Figure 18 and Figure 19.

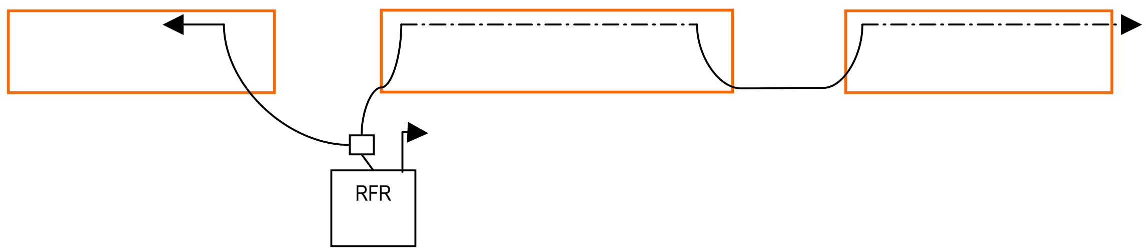

Figure 18: One tunnel system covering three tunnels

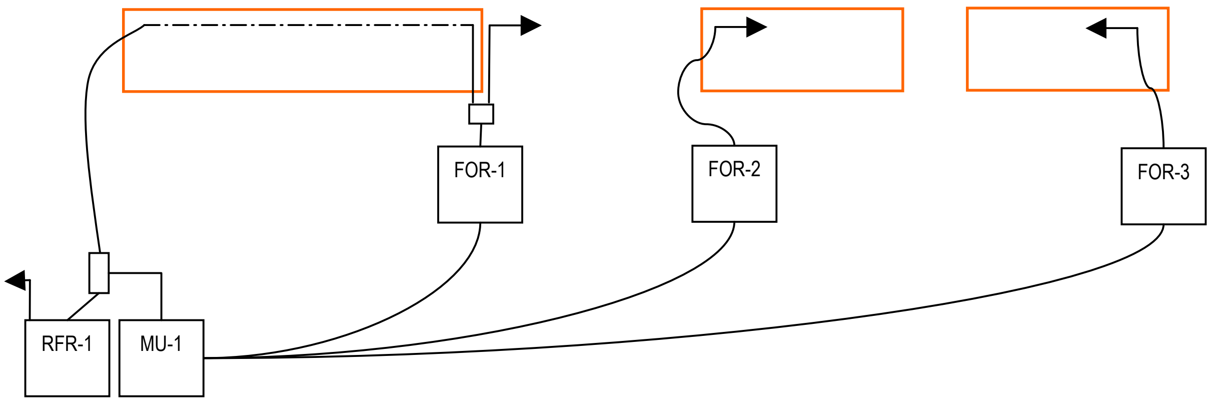

Figure 19: One optical tunnel system covering three tunnels

6.3 Antenna and radiating cable positioning

The positioning of the antenna should typically be placed in a position where line of sight in both directions are at its best. This usually means in the outer side of a curve. At the same time caution must be taken to avoid feedback to the pickup antenna. Isolation between the input and the output of the repeater must be > 100 dB for full utilization of the repeater. Both antenna and radiating cable should preferably not be mounted lower than ~4.5m above the track. One must avoid mounting the antenna in a way that it points directly into an obstacle. Obstacles close to the antenna will have an unpredictable, but surely negative effect on the signal propagation.

On a fibre optical repeater site inside a tunnel there will usually be a power splitting to lead the signal in both directions. When using antennas, these should in general not be mounted next to each other. In fact it is possible to stretch the distance between the antennas in the "Tunnel System Type" in chapter 6.1.5.1. by placing the antennas on each of the FOR's 50-100m apart. This is possible due to the strong back lobe of the tunnel antenna.

6.4 Handovers

Through the design process care is taken to avoid faulty handovers in relation to the tunnel systems. However, in a redundant case (when one repeater element fails), the design will not avoid all faulty handovers and possible dropped calls. In tunnels longer than 1000m, the design will in most cases include a controlled handover area in the end, middle or beginning of the tunnel. If one repeater element fails, the signal level will in most cases still be strong enough to hold the call. But if one of the RF-repeaters fails, a faulty handover resulting in a dropped call might occur, even if the received signal level is higher than the sensitivity. This can happen if there is not enough time to perform the handover (e.g. when the train enters or exits the tunnel).

6.5 Link budget

A link budget is a calculation made to estimate the signal loss and signal gain in a chain of network elements. In the radio planning process this is necessary in order to predict the signal level at a certain place with a certain distance to the radiating element (antenna/radiating cable). In the case of an outdoor antenna, the calculation will include a signal propagation model that estimates the loss of power "through air". In addition certain margins will apply to the calculation (penetration loss, fade margin, body loss...)

6.5.1 General Explanation to the Link Budget

This explanation refer to the link budget in Figure 20. All gain and loss values in the link budget are taken from the data sheets for the RF-equipment. There is no prediction model involved and the values are based on factory testing.

The ***white cells*** in the table are either calculated from other cells or should be kept at the fixed value. The ***yellow cells*** have the values meant to be defined by the user, while ***pink cells*** show the most interesting design results.

The ***green cell*** is the calculated minimum BTS signal needed at the pickup antenna, in order for the repeater system to fulfil the requirements set by the designer. This value is the input value to the *Final Tunnel Design* document.

The upper left table describes the ***pickup path***, with the gain of the pickup antenna and the cable loss from the antenna to the RF-repeater. The green cell calculates the value needed to give the output power defined in the third row (Pout MR341...) of the ***mobile path*** table. This table describes the loss from the repeater to the first radiating element (antenna or RC). The first cell in the mobile path table is used to reduce the needed output power (Pout MR341...), which again reduces the needed signal at the pickup. (green cell). The next three tables, ***in case of radiating cable, in case of antenna solution , in case of antenna solution,*** will be used depending on what solution was chosen. For the radiating cable the signal level at a distance of 3m from the cable is given, while for an antenna only the EiRP (Emitted isotropic Radiating Power).

The radiating cable table and the overlap/handover table are connected and can be used together, while the antenna solution table does not depend on the other two. Only the main elements (main feeders, splitters, repeaters, antennas/RC's) will be included in the calculation. Elements such as connectors and jumpers have been considered to have a too small influence. In case these elements will have a significant impact, they will be included in the splitter or cable loss.

6.5.2 Link Budget for Tunnel Antenna Solution

In the case of antenna solution in a tunnel, a signal level prediction is difficult. Every tunnel has its own characteristics and there are no general models that can be applied for every tunnel. With different kinds of trains in the tunnel the situation becomes even more complex. For such solutions gaining experience through measurements on live networks (or test networks) are crucial. A link budget will be used only to calculate the EiRP (Emitted isotropic Radiating Power).

Example:

The link budget in Figure 20 could be the situation for the leftmost tunnel in Figure 18. The pickup antenna gain is 14.5dBi. There is 15m superflex cable between pickup antenna and the RF-repeater, resulting in a 1.7dB loss. The maximum repeater gain for MR341 is 85dB and the maximum output power is 32dBm. With 85m of 7/8" feeder to the tunnel antenna, the feeder loss is 3.3dB. There is an additional splitter loss (due to a symmetrical splitter) of 3.0dB. With a tunnel antenna gain of 10dBi, the resulting EiRP is 35.7dBm. By setting the RC-length to 0 and the overlap/HO antenna gain to 0, these tables will not be considered. As the signal level in the tunnel is hard to predict, we would usually want to have maximum output (32dBm) from the repeater. The resulting *minimum DL input signal at pick-up* is -65dBm.

Figure 21 shows an example of a link budget for a fibre optical repeater (FOR) in a situation like in Figure 14. In this link budget the output power of the FOR must be inserted depending on the number of channels to amplify.

LINK BUDGET FOR MR341 - RADIATING CABLE OR ANTENNA

Pick-Up path (from DL field strength @ antenna to input repeater)

Calculated minimum DL input signal @ pick-up antenna	-65,8	dBm
Pick-Up antenne gain	14,5	dBi
1/2" Superflex feeder length	15	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	1,7	dB

Mobile path (from DL output repeater to Mobile)

Reduce repeater gain (always positive value)	0,0	dB
Maximum repeater gain	85,0	dB
Pout MR341 @ 2 channels	32,0	dBm
1/2" Superflex feeder length	0	m
1/2" feeder length	0	m
7/8" feeder length	85	m
1-1/4" feeder length	0	m
Sum feeder loss	3,3	dB
Splitter loss towards Antenna or Radiating cable	3,0	dB

In case of Radiating cable

Longitudinal loss	3,6	dB/100m
Length of Radiating Cable	0	m
Longitutinal loss for the selected length of cable	0	dB
Coupling loss at 2m, 95% (default 67dB)	0	dB
Distance Cable to Receiving Antenna (default 3m)	3	m
Coupling loss at desired	0,0	dB
Minimum DL level	-82	dBm
DL level at end of Radiating Cable	0,0	dBm
Margin (Fading, Body loss, Interference...)	0,0	dB

In case of Overlap/HO antenna

1/2" Superflex feeder length	0	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	0,0	dB
Overlap/HO antenna gain	0	dBi
EIRP Overlap/HO antenna	0,0	dBm

In case of Antenna sollution

Tunnel antenna gain	10	dBi
EiRP Tunnel antenna	35,7	dBm

Figure 20: Link budget for RF-repeater and tunnel antenna solution

LINK BUDGET FOR MOR300 - RADIATING CABLE OR ANTENNA

In case of Radiating cable

Longitudinal loss	3,6	dB/100m
Length of Radiating Cable	0	m
Longitutinal loss for the selected length of cable	0	dB
Coupling loss at 2m, 95% (default 67dB)	0	dB
Distance Cable to Receiving Antenna (default 3m)	3	m
Coupling loss at desired	0,0	dB
Minimum DL level	-82	dBm
DL level at end of Radiating Cable	0,0	dBm
Margin (Fading, Body loss, Interference...)	0,0	dB

In case of Antenna sollution

Tunnel antenna gain	10	dBi
EiRP Tunnel antenna	29,9	dBm

Mobile path (from DL output repeater to Mobile)

Pout MOR300 (2ch = 27dBm, 4ch = 24dBm)	24,0	dBm
1/2" Superflex feeder length	10	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	1,1	dB
Splitter loss towards Antenna or Radiating cable	3,0	dB

In case of Overlap/HO antenna

1/2" Superflex feeder length	0	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	0,0	dB
Overlap/HO antenna gain	0	dBi
EIRP Overlap/HO antenna	0,0	dBm

Figure 21: Link budget for fibre optical repeater and antenna solution

6.5.3 Link Budget for Radiating Cable Solution

In case of a radiating cable solution the situation is quite different from the antenna case. A mobile station will have close to a constant distance to the radiating cable through the whole tunnel, and the signal level can be calculated quite accurate based on datasheet information. In the design the values for 95% probability will be used. That means that the values used for the radiating cable should hold (the real value should be better than the given value) for at least 95% of the cases/positions.

Example:

The link budget in Figure 22 could be the situation for the two tunnels to the right in Figure 18. There is a 30m ½" feeder from the RFR to the RC in the first tunnel, and there is a 110m 1-1/4" feeder between the RC's in the two tunnels. The resulting feeder loss is 5.1dB. Then there is an additional splitter loss (due to a symmetrical splitter) of 3.0dB. If the first tunnel is 500m and the second tunnel is 200m long, the total length of the RC is ~700m. In the end of the last tunnel there is an overlap antenna with 9dBi gain which is fed from the RC by a 5m superflex feeder. Let's say that the overlap antenna needs to cover ~200m outside the tunnel due to some obstruction. The free space loss is ~78dB for 200m. With an EiRP of -1dBm from the overlap antenna, the area should be covered with a 3dB margin (no other margins considered) [-1dB - 78dB - -82dB = 3dB]. Hence there is no need for maximum output power from the RFR. By adjusting the "reduce repeater gain" to get the wanted margins, the minimum input signal (green cell) is recalculated. The link budget also shows that at the end of the last RC there is a signal level of -78.1dBm which is sufficient to fulfil the coverage criteria.

Figure 23 shows an example of a link budget for the fibre optical repeater 1 or 3 (FOR-1 or FOR-3) in Figure 15. The redundancy concept requires that there is no more than 100m coverage gap (signal level < -82dBm) if an element fails. The link budget assumes that FOR-2 fails. Then FOR-1 and FOR-3 each has to cover 750m in towards FOR-2. The link budget shows that there will be a margin of 6.1dB and the solution is safe.

LINK BUDGET FOR MR341 - RADIATING CABLE OR ANTENNA

Pick-Up path (from DL field strength @ antenna to input repeater)

Calculated minimum DL input signal @ pick-up antenna	-73,8	dBm
Pick-Up antenne gain	14,5	dBi
1/2" Superflex feeder length	15	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	1,7	dB

Mobile path (from DL output repeater to Mobile)

Reduce repeater gain (always positive value)	8,0	dB
Maximum repeater gain	85,0	dB
Pout MR341 @ 2 channels	24,0	dBm
1/2" Superflex feeder length	0	m
1/2" feeder length	30	m
7/8" feeder length	0	m
1-1/4" feeder length	110	m
Sum feeder loss	5,1	dB
Splitter loss towards Antenna or Radiating cable	3,0	dB

In case of Radiating cable

Longitudinal loss	3,6	dB/100m
Length of Radiating Cable	700	m
Longitutinal loss for the selected length of cable	25,2	dB
Coupling loss at 2m, 95% (default 67dB)	67	dB
Distance Cable to Receiving Antenna (default 3m)	3	m
Coupling loss at desired	68,8	dB
Minimum DL level	-82	dBm
DL level at end of Radiating Cable	-78,1	dBm
Margin (Fading, Body loss, Interference...)	3,9	dB

In case of Overlap/HO antenna

1/2" Superflex feeder length	5	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	0,6	dB
Overlap/HO antenna gain	9	dBi
EIRP Overlap/HO antenna	-0,8	dBm

In case of Antenna sollution

Tunnel antenna gain	0	dBi
EiRP Tunnel antenna	0,0	dBm

Figure 22: Link budget for RF-repeater, radiating cable and overlap antenna

LINK BUDGET FOR MOR300 - RADIATING CABLE OR ANTENNA

In case of Radiating cable

Longitudinal loss	3,6	dB/100m
Length of Radiating Cable	750	m
Longitutinal loss for the selected length of cable	27	dB
Coupling loss at 2m, 95% (default 67dB)	67	dB
Distance Cable to Receiving Antenna (default 3m)	3	m
Coupling loss at desired	68,8	dB
Minimum DL level	-82	dBm
DL level at end of Radiating Cable	-75,9	dBm
Margin (Fading, Body loss, Interference...)	6,1	dB

In case of Antenna sollution

Tunnel antenna gain	0	dBi
EiRP Tunnel antenna	0,0	dBm

Mobile path (from DL output repeater to Mobile)

Pout MOR300 (2ch = 27dBm, 4ch = 24dBm)	24,0	dBm
1/2" Superflex feeder length	10	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	1,1	dB
Splitter loss towards Antenna or Radiating cable	3,0	dB

In case of Overlap/HO antenna

1/2" Superflex feeder length	0	m
1/2" feeder length	0	m
7/8" feeder length	0	m
1-1/4" feeder length	0	m
Sum feeder loss	0,0	dB
Overlap/HO antenna gain	0	dBi
EIRP Overlap/HO antenna	0,0	dBm

Figure 23: Link budget for fibre optical repeater and radiating cable

7. Earthling and shielding principles

General grounding principles are described in the high level network plan [1]. The repeater equipment specific grounding requirements are described in the user manuals. For more details than described below see the user manuals.

7.1 RF-Repeater MR341-R

Grounding must be carried out. An earth bonding cable must be connected to the grounding bolt provided at the outside of the cabinet on the left-hand side. Do not use the grounding screw for connecting external devices. The complete grounding kit is part of the delivery schedule.

7.2 Fibre Optical Repeater(FOR) / Remote Unit MOR300BP

As for MR341-R

7.3 Master Unit MOR3xxB

In case of DC supply systems, grounding must be carried out before connecting the two-wire DC cable. For grounding the unit connect a suitable PE cable (with a minimum cross-sectional area of 4 mm²) between the local ground and the ground bar of the unit. It is accessible by opening the back door of the 19" rack. If the backdoor can not be accessed, it can be reached from the front by removing "blindplates", or from the side by removing the side walls of the cabinet.

8. Reference List

#	Doc number	Document name	Comment
[1]	GSM-00-A-20001	Network Design - High Level Network Plan.doc	Overall network description with reference to chapter 9.2.5.2 in Exhibit F
[2]	GSM-00-A-20127	Vendor Specific Documentation Overview	Lists the vendor specific documentation