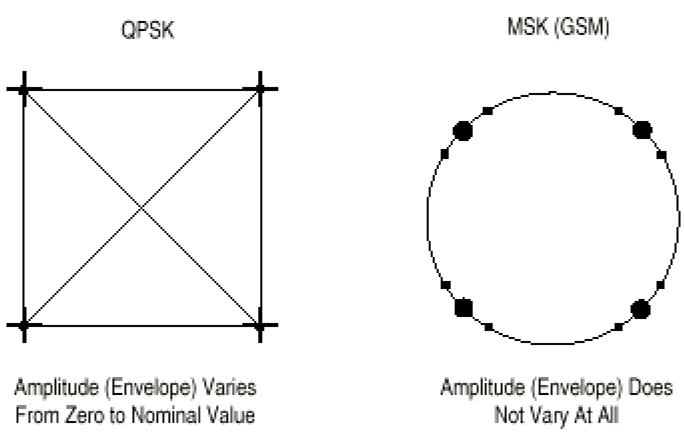
S-72.260

Laboratory works in Radio Communications

Lab #1

GSM Transceiver Measurements



Version 1.53

Previous versions

Date	Version	Changes
14.3.2000	1.4	First English version
9.9.2000	1.5	Text revised, exercises changed slightly.
2.9.2001	1.51	Some problems clarified.
18.9.2001	1.52	Some preliminary problems polished.
2.11.2001	1.53	Laboratory exercises clarified.

Student laboratory is in the room SE306.

Check the links in the course home page. You might (or might not) find some extra information.

Grading: Accepted/not accepted.

This material in this document does not cover GSM basics. It is assumed that students have acquired prerequisites from previous courses, or books etc.

Some prerequisite courses for this laboratory work (not all required!):

S-72.610 Mobile Communication Systems and Services
S-72.232 Radio Communication Systems
S-26.105 Radiojärjestelmän osat (in Finnish)
S-72.244 Modulation and Coding Methods

Literature:

Mouly M., Pautet M., "The GSM System for Mobile Communications", published by the authors, 1992

Redl, Siegmund M., Weber, Matthias K., Oliphant, Malcolm W., "An introduction to GSM" Artech House, 1995

Mansikkaviita, J., Talvo, M.,"Johdatus solukkopuhelintekniikkaan" (in Finnish), Opetushallitus, Helsinki 1998

Carg, V.J., Wilkes, J.E., Principles and applications of GSM, Prentice-Hall Inc., Upper Saddle River 1999

Lab #1: GSM Transceiver Measurements

1 Introduction

In this laboratory work properties of GSM Mobile Stations (MS) are investigated. The goal is to learn the basics of a GSM transceiver and to investigate its error performance by measurements. A Rohde&Schwarz CTS-55 GSM tester used in the laboratory work is able to measure:

- Transmitted power of the MS
- Receiver sensitivity with different error measures (BER, RBER, FER)
- Frequency and phase error of the modulator
- Power ramp
- Transmitter timing errors

The tester performs measurements by emulating the radio interface of the GSM system, i.e. the MS sees the tester as an ordinary base station (BTS). Measurements can be made in all GSM frequency bands (900MHz, 1800MHz, 1900MHz).

A maintenance program by Nokia Mobile Phones is also used in some laboratory exercises to control Nokia 2110 MS transmitter. Spectrum analyser is used in measuring the power spectrum. Modulation errors are visualised with a vector signal analyser.

In preliminary exercises basic concepts of GSM engineering are reviewed. All preliminary exercises should be solved before coming to the lab shift.

The following sections contain a brief overview of GSM mobile phone testing. The goal is to give an idea of the matters that are dealt with in the laboratory work. More information can be found from literature, e.g. [Redl95], as well as course material used in the department of electrical and communications engineering. RF measurements are discussed in courses offered by Radio Laboratory (S-26). Also check out the course home page for latest information.

2 Receiver Measurements

Testing of a GSM transceiver, or any other digital mobile phone, may be divided in two parts: receiver measurements and transmitter measurements. The most important receiver measurements are the testing of sensitivity in various radio propagation conditions, and testing of interference sensitivity of the receiver. Transmitter tests include measurements on modulation errors, transmitter power accuracy and power ramp[1]. This section discusses receiver measurements.

2.1 Sensitivity of a GSM receiver

Receiver sensitivity means error performance as a function of received power. There are many error performance measures defined in the GSM specifications [GSM0505]. In this laboratory exercise mainly the error measures related to speech traffic channels are investigated. See section 2.1.3.

[1] Only physical layer parts are measured in this laboratory work; SW testing is an entirely different ballpark. Notice, however, that a large part of the receiver/transmitter is actually implemented in programmable DSPs.

2.1.1 The Principle of BER Sensitivity Measurement

The phone is connected to the GSM tester via external RF connector used for car mounting the MS. A special SIM card must be used so that the loop back of the received bits (Figure 1) can be activated.

In testing state the MS loops back all received information i.e. the phone demodulates and detects the pseudo-random bits sent in the downlink by the GSM tester, and then transmits the bits in the uplink direction back to the measuring equipment. The measuring equipment demodulates the signal and calculates the bit error ratio by comparing the received bits with the transmitted ones.

The transmission power of the GSM tester can be controlled. Thus, the virtual radio path attenuation, L_{path}, can be changed. By decreasing downlink TX power and simultaneously reading the applicable error measures error sensitivity performance of the MS can be determined.

It should be noticed that with the used measurement method the uplink direction can be assumed error-free, since the measurement cable attenuation is typically only about 0.5 dB.

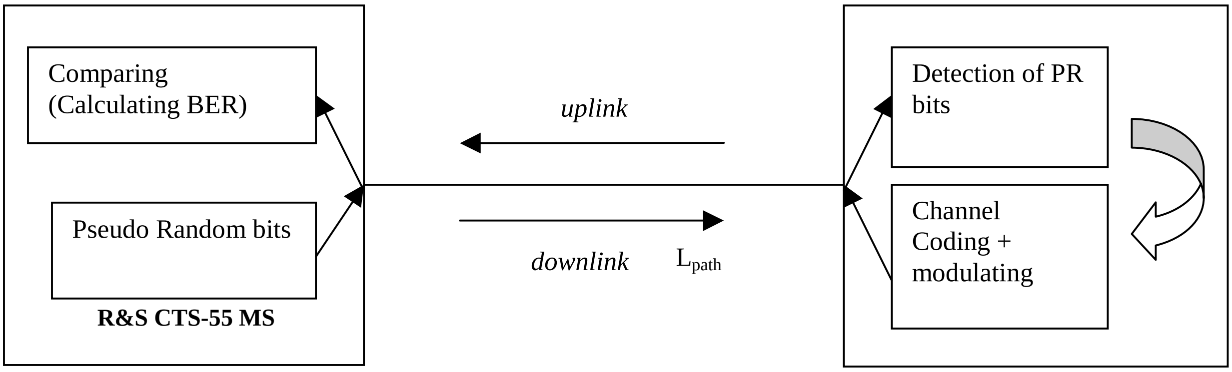


Figure 1. The principle of BER measurement.

2.1.2 Requirements for Sensitivity

Specifications [GSM0505] define required sensitivity levels in different radio propagation conditions (see appendix). For example, in GSM1800 band, TU50 propagation environment (Typical Urban, 50 km/h), half speed FACCH without Frequency Hopping (FH) the sensitivity is the average received power level in which FER has dropped to 7.2%. This power level should be below the *reference* sensitivity of the transceiver type.

The required sensitivity level for different types of GSM transceivers has been defined in [GSM0505], see also appendix. For handheld GSM900 and GSM1800 MS the reference sensitivity level is –104dBm [2]. Car mounted MS have reference sensitivity of –104dBm. Naturally there are many exceptions.

2.1.3 Error measures: FER, RBERxx, BER→RXQUAL

The definitions of different error ratios go hand in hand with channel coding and burst formatting which is different for each logical channel. For example, speech frames are encoded differently from signalling frames.

[2] See appendix for exceptions.

Convolution coding, along with interleaving, is used extensively in GSM. The 50 first bits of speech frame (Figure 2) are considered especially important for the speech quality and no errors are allowed in these bits.

50 bits class Ia	**132 bits class Ib**	**78 bits class II**

Figure 2. A GSM speech frame before channel coding. Full rate speech channel, TCH/FS.

Error ratios used in conjunction with GSM speech channels:

- Frame Erasure Rate, FER, is defined as the amount of swept speech frames (260 bits each) divided by the amount of transmitted speech frames. The speech frame is swept if even one of its most important 50 bits is observed not to be correct. The three parity bits following the 50 class Ia bits are used for error detection.
- Bit Error Rate, BER, is the ratio of erroneously received bits to all received bits. It is important to notice that BER is evaluated *before* channel decoding, i.e. after equaliser. BER is used for defining the RXQUAL value according to Table 1.
- Residual Bit Error Rate, RBER, is the ratio of erroneous bits to all bits *after* frame erasure. It is estimated separately for class Ib and class II bits. Example: After frame erasures, a thousand frames have been passed to the speech decoder, with a total of 5000 bit errors in class II bits. Thus, the estimated RBERII is 5000/78000≈6.4%.

According to some research the most important error measure in speech applications is FER even though RXQUAL value is used as a handover criterion [Haa97]. RXQUAL does not take into account channel coding; even if RXQUAL is bad the speech quality may still be satisfactory due to channel coding and the fact that speech is not very sensitive to errors in bits other than class Ia.

Table 1. Definition of RXQUAL and its reliability [GSM0508].

Quality Band	**Range of actual BER**	**Probability that the correct RXQUAL band is reported by MS shall exceed**		
		Full rate Channel	**Half rate Channel**	**DTX Mode**
RXQUAL_0	Less than 0,1%	90%	90%	65%
RXQUAL_1	0,26% to 0,30%	75%	60%	35%
RXQUAL_2	0,51% to 0,64%	85%	70%	45%
RXQUAL_3	1,0 % to 1,3%	90%	85%	45%
RXQUAL_4	1,9% to 2,7%	90%	85%	60%
RXQUAL_5	3,8% to 5,4%	95%	95%	70%
RXQUAL_6	7,6% to 11,0%	95%	95%	80%
RXQUAL_7	Greater than 15,0%	95%	95%	85%
NOTE1: For the full rate channel RXQUAL_FULL is based on 104 TDMA frames. NOTE2: For the half rate channel RXQUAL_FULL is based on 52 TDMA frames. NOTE3: For the DTX mode RXQUAL_SUB is based on 12 TDMA frames.				

2.1.4 Accuracy of Received Power Level (RXLEV) Measurement

A GSM receiver constantly measures the power of the received signal, and reports the measurement results to the base station as an RXLEV value. RXLEV gets values between 0-63 so that 0 corresponds to level under –110dBm and 63 to level over –48dBm with one dB steps in between. The BSC can use the reported downlink RXLEV for power control and handover decisions.

The accuracy of the received power measurement can be accomplished by tuning the downlink transmission power to a suitable value, and reading the measurement reports sent by the mobile station from the display of the GSM tester.

Accurate measurement of absolute RF power is complicated especially for burst signals. The error can easily be in the order of decibel. This is worth considering when interpreting any results related to RXLEV measurement of an MS. However, the measuring of relative power (the change in power) can be performed more accurately. The required absolute accuracy for RXLEV measurement at received power levels -110dBm…-70dBm is ±4 dBm [GSM0508].

3 Transmitter Measurements

3.1 Phase and frequency error

Phase and frequency errors measure the accuracy of the modulator.

Frequency and phase are connected to one another by the formula

$$d\varpi = \frac{d\phi}{dt}. \quad (1)$$

The GMSK modulator is not ideal and phase error is produced in the process. This error is defined as difference of the measured signal and ideal reference signal [Redl95]. Ideal reference signal is generated at the measurement equipment, usually a vector signal analyzer (VSA). See also [Ttd00] for an excellent review on modulation error measurements.

3.2 The Power Spectrum of Modulated Signal

Means of modulation in GSM is GMSK i.e. Gaussian MSK. Gaussian refers to the filter used to reduce bandwidth of the MSK power spectrum. Narrowing in frequency domain corresponds to widening in time domain, so the result is a compromise to avoid excessive ISI. One way is to implement GMSK-modulator is shown in Figure 2.

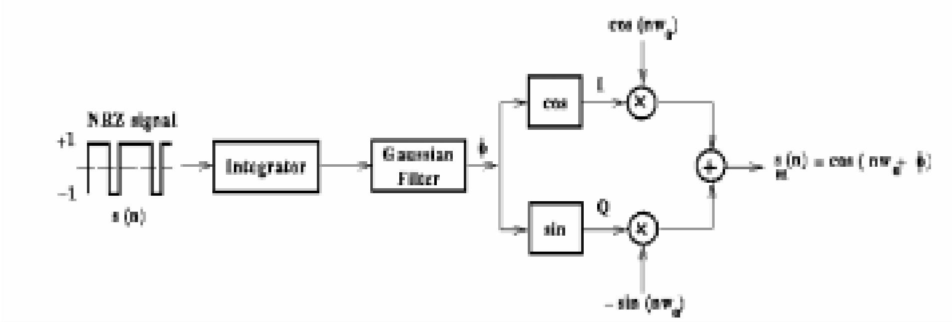


Figure 3 . GMSK-modulator [Tur96]

The constantly changing angle $\phi(t)$ is converted into sine- and cosine-components whose resultant draws a circle with constant amplitude on the IQ plane. The modulator is usually implemented with DSP [Man98]. After DA conversion the signal is fed to the mixer.

It may be said that GMSK is a purely European choice since elsewhere in the world – primarily in the US and Japan – another method, the π/4 DQPSK-modulation, has been chosen. The advantage of this modulation method is larger spectrum efficiency compared to GMSK, since π/4 DQPSK is a four-level modulation method. This means that two bits are transferred each symbol period. The disadvantage of this method is susceptibility to the effects of non-linearities in the transmitter that partly consumes the benefits from higher spectrum efficiency. According to the results of simulating the methods are quite equal when it comes to error performance in Rice- and Rayleigh-channels when also considering the non-linearity of power amplifier [Sor94].

3.3 Power mask

The bursts sent by the phone have to stay within certain limits that have been defined in specifications GSM 05.05 (Appendix 3). The power ramp of the MS transmitter can be measured with the GSM tester. Timing error of the burst can also be measured. Measuring of the timing error is important because the burst sent to the base station by a MS must fit the time mask so that it won't collide with bursts sent by other MS using the same transceiver (TRX).

3.4 Accuracy of the MS Transmission Power

In the GSM system all mobile stations are capable of transmission power control. The BSC directs the transmission power of the MS and the BTS. Power transmission accuracy requirements are defined in appendix 5.

The accuracy of the MS transmission power may be measured by sending a power command to the MS under test and observing the actual transmitted power using the CTS-55.

Appendices

1) About Reference Sensitivity Requirements, excerpt from [GSM0505]
2) Reference Sensitivity and Interference Sensitivity Performance Requirements [GSM0505]
3) Time Mask for a Normal Burst [GSM0505]
4) Frequency Mask of the Modulation Spectrum [GSM0505]
5) Accuracy Requirements of MS Transmission Power [GSM0505]

References

[Tur96] Turletti, Thierry, "GMSK in a Nutshell", http://www.sds.lcs.mit.edu/~turletti/gmsk/

[GSM0505] GSM 05.05, "Radio transmission and reception", version 6.1.0 (phase 2+), ETSI, April 1998

[GSM0508] GSM 05.08, "Radio Subsystem link control", version 6.1.1 (phase 2+), ETSI, April 1998

[Haa97] Haataja Jussi, “Taajuushyppelyn vaikutus DCS1800/1900- järjestelmän yhteyden laatuun”, diplomityö, sähkö- ja tietoliikennetekniikan osasto, TKK 1997

[Redl95] Redl, Siegmund M., Weber, Matthias K., Oliphant, Malcolm W., “An Introduction to GSM”, Artech House, 1995

[Sor94] Sorbara, D., Visintin, M., “Performance Comparison of GMSK- and π/4 –DQPSK Modulations in a Mobile Radio Environment”, Lecture notes in computer science, Springer-Verlag 1994

[Man98] Mansikkaviita, J., Talvo, M., “Johdatus solukkopuhelintekniikkaan”, Opetushallitus, Helsinki 1998

[Ttd00] "Testing and Troubleshooting Digital RF Communications Transmitter Designs", Agilent Technologies application note 1313, literature number 5968-3578E.

Appendix 1: About Reference Sensitivity Requirements, excerpt from [GSM0505]

…

6.2 Reference sensitivity level

The reference sensitivity performance in terms of frame erasure, bit error, or residual bit error rates (whichever appropriate) is specified in table 1, according to the type of channel and the propagation condition. The actual sensitivity level is defined as the input level for which this performance is met. The actual sensitivity level shall be less than a specified limit, called the reference sensitivity level. The reference sensitivity level shall be:

-	for DCS 1 800 class 1 or class 2 MS	:	-100 / -102 dBm *
-	for DCS 1 800 class 3 MS	:	-102 dBm
-	for GSM 900 small MS	:	-102 dBm
-	for other GSM 900 MS and normal BTS	:	-104 dBm
-	for GSM 900 micro BTS M1	:	-97 dBm
-	for GSM 900 micro BTS M2	:	-92 dBm
-	for GSM 900 micro BTS M3	:	-87 dBm
-	for DCS 1 800 micro BTS M1	:	-102 dBm
-	for DCS 1 800 micro BTS M2	:	-97 dBm
-	for DCS 1 800 micro BTS M3	:	-92 dBm

The above specifications for BTS shall be met when the two adjacent timeslots to the wanted are detecting valid GSM signals at 50 dB above the power on the wanted timeslot. For MS the above specifications shall be met with the two adjacent timeslots 20 dB above the own timeslot and the static channel.

* For all DCS 1800 class 1 and class 2 MS to be type approved after 1st December 1999, the -102 dBm level shall apply for the reference sensitivity performance as specified in table 1 for the normal conditions defined in Annex D and -100 dBm level shall be used to determine all other MS performances.

Appendix 2: Reference Sensitivity and Interference Sensitivity Performance Requirements [GSM0505]

Table 1: Reference sensitivity performance

GSM 900					
Type of Channel	Propagation conditions				
	static	TU50 (no FH)	TU50 (ideal FH)	RA250 (no FH)	HT100 (no FH)
FACCH/H (FER)	0,1 %	6,9 %	6,9 %	5,7 %	10,0 %
FACCH/F (FER)	0,1 %	8,0 %	3,8 %	3,4 %	6,3 %
SDCCH (FER)	0,1 %	13 %	8 %	8 %	12 %
RACH (FER)	0,5 %	13 %	13 %	12 %	13 %
SCH (FER)	1 %	16 %	16 %	15 %	16 %
TCH/F14,4 (BER)	10^{-5}	2,5 %	2 %	2 %	5 %
TCH/F9,6 & H4,8 (BER)	10^{-5}	0,5 %	0,4 %	0,1 %	0,7 %
TCH/F4,8 (BER)	-	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/F2,4 (BER)	-	$2\ 10^{-4}$	10^{-5}	10^{-5}	10^{-5}
TCH/H2,4 (BER)	-	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/FS (FER)	0,1α %	6α %	3α %	2α %	7α %
class Ib (RBER)	0,4/α %	0,4/α %	0,3/α %	0,2/α %	0,5/α %
class II (RBER)	2 %	8 %	8 %	7 %	9 %
TCH/EFS (FER)	< 0,1 %	8 %	3 %	3 %	7 %
(RBER Ib)	< 0,1 %	0,21 %	0,11 %	0,10 %	0,20 %
(RBER II)	2,0 %	7 %	8 %	7 %	9 %
TCH/HS (FER)	0,025 %	4,1 %	4,1 %	4,1 %	4,5 %
class Ib (RBER, BFI=0)	0,001 %	0,36 %	0,36 %	0,28 %	0,56 %
class II (RBER, BFI=0)	0,72 %	6,9 %	6,9 %	6,8 %	7,6 %
(UFR)	0,048 %	5,6 %	5,6 %	5,0 %	7,5 %
class Ib (RBER,(BFI or UFI)=0)	0,001 %	0,24 %	0,24 %	0,21 %	0,32 %
(EVSIDR)	0,06 %	6,8 %	6,8 %	6,0 %	9,2 %
(RBER, SID=2 and (BFI or UFI)=0)	0,001 %	0,01 %	0,01 %	0,01 %	0,02 %
(ESIDR)	0,01 %	3,0 %	3,0 %	3,2 %	3,4 %
(RBER, SID=1 or SID=2)	0,003 %	0,3 %	0,3 %	0,21 %	0,42 %
DCS 1 800					
Type of channel	Propagation conditions				
	static	TU50 (no FH)	TU50 (ideal FH)	RA130 (no FH)	HT100 (no FH)
FACCH/H (FER)	0,1 %	7,2 %	7,2 %	5,7 %	10,4 %
FACCH/F (FER)	0,1 %	3,9 %	3,9 %	3,4 %	7,4 %
SDCCH (FER)	0,1 %	9 %	9 %	8 %	13 %
RACH (FER)	0,5 %	13 %	13 %	12 %	13 %
SCH (FER)	1 %	19 %	19 %	15 %	25 %
TCH/F14,4 (BER)	10^{-5}	2,1 %	2 %	2 %	6,5 %
TCH/F9,6 & H4,8 (BER)	10^{-5}	0,4 %	0,4 %	0,1 %	0,7 %
TCH/F4,8 (BER)	-	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/F2,4 (BER)	-	10^{-5}	10^{-5}	10^{-5}	10^{-5}
TCH/H2,4 (BER)	-	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/FS (FER)	0,1α %	3α %	3α %	2α %	7α %
class Ib (RBER)	0,4/α %	0,3/α %	0,3/α %	0,2/α %	0,5/α %
class II (RBER)	2 %	8 %	8 %	7 %	9 %
TCH/EFS (FER)	< 0,1 %	4 %	4 %	3 %	7 %
(RBER Ib)	< 0,1 %	0,12 %	0,12 %	0,10 %	0,24 %
(RBER II)	2,0 %	8 %	8 %	7 %	9 %

(continued)

Appendix 2: Reference Sensitivity and Interference Sensitivity Performance Requirements [GSM0505]

Table 1 (concluded): Reference sensitivity performance

DCS 1 800					
TCH/HS (FER)	0,025 %	4,2 %	4,2 %	4,1 %	5,0 %
class Ib (RBER, BFI=0)	0,001 %	0,38 %	0,38 %	0,28 %	0,63 %
class II (RBER, BFI=0)	0,72 %	6,9 %	6,9 %	6,8 %	7,8 %
(UFR)	0,048 %	5,7 %	5,7 %	5,0 %	8,1 %
class Ib (RBER, (BFI or UFI)=0)	0,001 %	0,26 %	0,26 %	0,21 %	0,35 %
(EVSIDR)	0,06 %	7,0 %	7,0 %	6,0 %	9,9 %
(RBER, SID=2 and (BFI or UFI)=0)	0,001 %	0,01 %	0,01 %	0,01 %	0,02 %
(ESIDR)	0,01 %	3,0 %	3,0 %	3,2 %	3,9 %
(RBER, SID=1 or SID=2)	0,003 %	0,33 %	0,33 %	0,21 %	0,45 %

NOTE 1: The specification for SDCCH applies also for BCCH, AGCH, PCH, SACCH. The actual performance of SACCH, should be better.

NOTE 2: Definitions:
FER: Frame erasure rate (frames marked with BFI=1)
UFR: Unreliable frame rate (frames marked with (BFI or UFI)=1)
EVSIDR: Erased Valid SID frame rate (frames marked with (SID=0) or (SID=1) or ((BFI or UFI)=1) if a valid SID frame was transmitted)
ESIDR: Erased SID frame rate (frames marked with SID=0 if a valid SID frame was transmitted)
BER: Bit error rate
RBER, BFI=0: Residual bit error rate (defined as the ratio of the number of errors detected over the frames defined as "good" to the number of transmitted bits in the "good" frames). RBER, (BFI or UFI)=0: Residual bit error rate (defined as the ratio of the number of errors detected over the frames defined as "reliable" to the number of transmitted bits in the "reliable" frames).
RBER, SID=2 and (BFI or UFI)=0: Residual bit error rate of those bits in class I which do not belong to the SID codeword (defined as the ratio of the number of errors detected over the frames that are defined as "valid SID frames" to the number of transmitted bits in these frames, under the condition that a valid SID frame was sent).
RBER, SID=1 or SID=2: Residual bit error rate of those bits in class I which do not belong to the SID codeword (defined as the ratio of the number of errors detected over the frames that are defined as "valid SID frames" or as "invalid SID frames" to the number of transmitted bits in these frames, under the condition that a valid SID frame was sent).

NOTE 3: $1 \leq \alpha \leq 1.6$. The value of α can be different for each channel condition but must remain the same for FER and class Ib RBER measurements for the same channel condition.

NOTE 4: FER for CCHs takes into account frames which are signalled as being erroneous (by the FIRE code, parity bits, or other means) or where the stealing flags are wrongly interpreted.

NOTE 5: Ideal FH case assumes perfect decorrelation between bursts. This case may only be tested if such a decorrelation is ensured in the test. For TU50 (ideal FH), sufficient decorrelation may be achieved with 4 frequencies spaced over 5 MHz.

Appendix 2: Reference Sensitivity and Interference Sensitivity Performance Requirements [GSM0505]

Table 2: Reference <u>interference</u> performance

GSM 900						
Type of channel		Propagation conditions				
		TU3 (no FH)	TU3 (ideal FH)	TU50 (no FH)	TU50 (ideal FH)	RA250 (no FH)
FACCH/H	(FER)	22 %	6,7 %	6,7 %	6,7 %	5,7 %
FACCH/F	(FER)	22 %	3,4 %	9,5 %	3,4 %	3,5 %
SDCCH	(FER)	22 %	9 %	13 %	9 %	8 %
RACH	(FER)	15 %	15 %	16 %	16 %	13 %
SCH	(FER)	17 %	17 %	17 %	17 %	18 %
TCH/F14,4	(BER)	10 %	3 %	4,5 %	3 %	3 %
TCH/F9,6 & H4,8	(BER)	8 %	0,3 %	0,8 %	0,3 %	0,2 %
TCH/F4,8	(BER)	3 %	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/F2,4	(BER)	3 %	10^{-5}	10^{-4}	10^{-5}	10^{-5}
TCH/H2,4	(BER)	4 %	10^{-4}	$2\ 10^{-4}$	10^{-4}	10^{-4}
TCH/FS	(FER)	21α %	3α %	6α %	3α %	3α %
	class Ib (RBER)	2/α %	0,2/α %	0,4/α %	0,2/α %	0,2/α %
	class II (RBER)	4 %	8 %	8 %	8 %	8 %
TCH/EFS	(FER)	23 %	3 %	9 %	3 %	4 %
	(RBER Ib)	0,20 %	0,10 %	0,20 %	0,10 %	0,13 %
	(RBER II)	3 %	8 %	7 %	8 %	8 %
TCH/HS	(FER)	19,1 %	5,0 %	5,0 %	5,0 %	4,7 %
	class Ib (RBER, BFI=0)	0,52 %	0,27 %	0,29 %	0,29 %	0,21 %
	class II (RBER, BFI=0)	2,8 %	7,1 %	7,1 %	7,1 %	7,0 %
	(UFR)	20,7 %	6,2 %	6,1 %	6,1 %	5,6 %
	class Ib (RBER,(BFI or UFI)=0)	0,29 %	0,20 %	0,21 %	0,21 %	0,17 %
	(EVSIDR)	21,9 %	7,1 %	7,0 %	7,0 %	6,3 %
	(RBER, SID=2 and (BFI or UFI)=0)	0,02 %	0,01 %	0,01 %	0,01 %	0,01 %
	(ESIDR)	17,1 %	3,6 %	3,6 %	3,6 %	3,4 %
	(RBER, SID=1 or SID=2)	0,5 %	0,27 %	0,26 %	0,26 %	0,20 %
DCS 1 800						
Type of channel		Propagation conditions				
		TU1,5 (no FH)	TU1,5 (ideal FH)	TU50 (no FH)	TU50 ideal FH)	RA130 (no FH)
FACCH/H	(FER)	22 %	6,7 %	6,9 %	6,9 %	5,7 %
FACCH/F	(FER)	22 %	3,4 %	3,4 %	3,4 %	3,5 %
SDCCH	(FER)	22 %	9 %	9 %	9 %	8 %
RACH	(FER)	15 %	15 %	16 %	16 %	13 %
SCH	(FER)	17 %	17 %	19 %	19 %	18 %
TCH/F14,4	(BER)	10 %	3 %	4 %	3,1 %	3 %
TCH/F9,6 & H4,8	(BER)	8 %	0,3 %	0,8 %	0,3 %	0,2 %
TCH/F4,8	(BER)	3 %	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/F2,4	(BER)	3 %	10^{-5}	10^{-5}	10^{-5}	10^{-5}
TCH/H2,4	(BER)	4 %	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/FS	(FER)	21α %	3α %	3α %	3α %	3α %
	class Ib (RBER)	2/α %	0,2/α %	0,25/α %	0,25/α %	0,2/α %
	class II (RBER)	4 %	8 %	8,1 %	8,1 %	8 %
TCH/EFS	(FER)	23 %	3 %	3 %	3 %	4 %
	(RBER Ib)	0,20 %	0,10 %	0,10 %	0,10 %	0,13 %
	(RBER II)	3 %	8 %	8 %	8 %	8 %

(continued)

Appendix 2: Reference Sensitivity and Interference Sensitivity Performance Requirements [GSM0505]

Table 2 (concluded): Reference interference performance

DCS 1 800					
TCH/HS (FER)	19,1 %	5,0 %	5,0 %	5,0 %	4,7 %
class Ib (RBER, BFI=0)	0,52 %	0,27 %	0,29 %	0,29 %	0,21 %
class II (RBER, BFI=0)	2,8 %	7,1 %	7,2 %	7,2 %	7,0 %
(UFR)	20,7 %	6,2 %	6,1 %	6,1 %	5,6 %
class Ib (RBER, (BFI or UFI)=0)	0,29 %	0,20 %	0,21 %	0,21 %	0,17 %
(EVSIDR)	21,9 %	7,1 %	7,0 %	7,0 %	6,3 %
(RBER, SID=2 and (BFI or UFI)=0)	0,02 %	0,01 %	0,01 %	0,01 %	0,01 %
(ESIDR)	17,1 %	3,6 %	3,6 %	3,6 %	3,4 %
(RBER, SID=1 or SID=2)	0,5 %	0,27 %	0,26 %	0,26 %	0,20 %

NOTE 1: The specification for SDCCH applies also for BCCH, AGCH, PCH, SACCH. The actual performance of SACCH, particularly for the C/I TU3 (no FH) and TU 1.5 (no FH) cases should be better.

NOTE 2: Definitions:
FER: Frame erasure rate (frames marked with BFI=1)
UFR: Unreliable frame rate (frames marked with (BFI or UFI)=1)
EVSIDR: Erased Valid SID frame rate (frames marked with (SID=0) or (SID=1) or ((BFI or UFI)=1) if a valid SID frame was transmitted)
ESIDR: Erased SID frame rate (frames marked with SID=0 if a valid SID frame was transmitted)
BER: Bit error rate
RBER, BFI=0: Residual bit error rate (defined as the ratio of the number of errors detected over the frames defined as "good" to the number of transmitted bits in the "good" frames).
RBER, (BFI or UFI)=0: Residual bit error rate (defined as the ratio of the number of errors detected over the frames defined as "reliable" to the number of transmitted bits in the "reliable" frames).
RBER, SID=2 and (BFI or UFI)=0: Residual bit error rate of those bits in class I which do not belong to the SID codeword (defined as the ratio of the number of errors detected over the frames that are defined as "valid SID frames" to the number of transmitted bits in these frames, under the condition that a valid SID frame was sent).
RBER, SID=1 or SID=2: Residual bit error rate of those bits in class I which do not belong to the SID codeword (defined as the ratio of the number of errors detected over the frames that are defined as "valid SID frames" or as "invalid SID frames" to the number of transmitted bits in these frames, under the condition that a valid SID frame was sent).

NOTE 3: $1 \leq \alpha \leq 1.6$. The value of α can be different for each channel condition but must remain the same for FER and class Ib RBER measurements for the same channel condition.

NOTE 4: FER for CCHs takes into account frames which are signalled as being erroneous (by the FIRE code, parity bits, or other means) or where the stealing flags are wrongly interpreted.

NOTE 5: Ideal FH case assumes perfect decorrelation between bursts. This case may only be tested if such a decorrelation is ensured in the test. For TU50 (ideal FH), sufficient decorrelation may be achieved with 4 frequencies spaced over 5 MHz. The TU3 (ideal FH) and TU1.5 (ideal FH), sufficient decorrelation cannot easily be achieved. These performance requirements are given for information purposes and need not be tested.

Appendix 2: Reference Sensitivity and Interference Sensitivity Performance Requirements [GSM0505]

The reference interference performance (for cochannel, C/Ic, or adjacent channel, C/Ia) in terms of frame erasure, bit error or residual bit error rates (whichever appropriate) is specified in table 2, according to the type of channel and the propagation condition. The actual interference ratio is defined as the interference ratio for which this performance is met. The actual interference ratio shall be less than a specified limit, called the reference interference ratio. The reference interference ratio shall be, for BTS and all types of MS:

-	for cochannel interference	:	C/Ic	=	9 dB
-	for adjacent (200 kHz) interference	:	C/Ia1	=	-9 dB
-	for adjacent (400 kHz) interference	:	C/Ia2	=	-41 dB
-	for adjacent (600 kHz) interference	:	C/Ia3	=	-49 dB

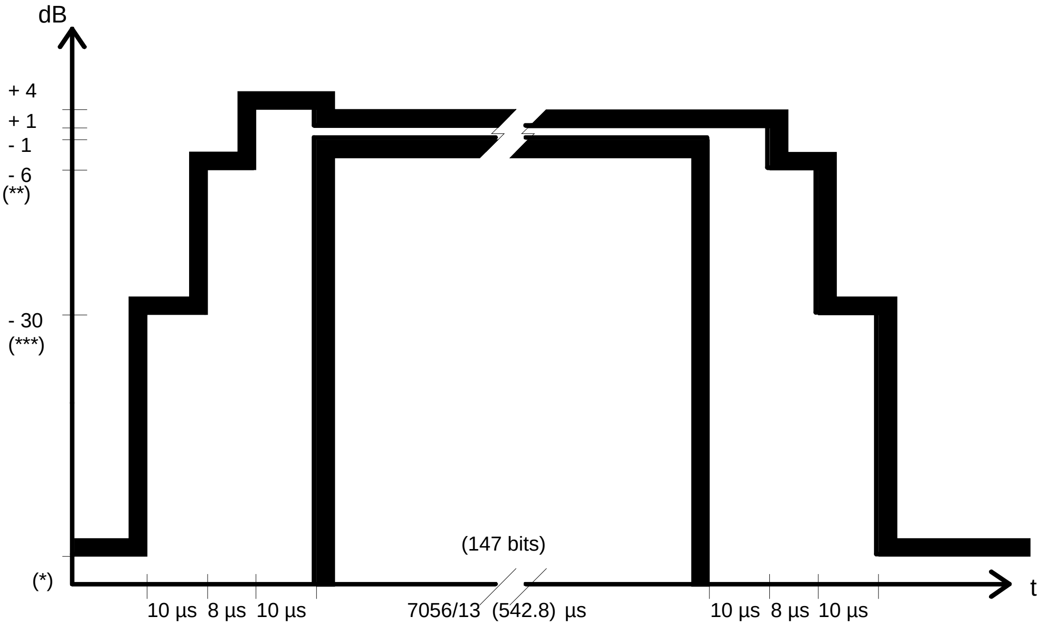
For packet switched channels, the minimum interference ratio for which the reference performance for cochannel interference (C/Ic) shall be met is specified in table 2a, according to the type of channel and the propagation condition. The reference performance is the same as defined in subclause 6.2. The corresponding interference ratio for adjacent channel interference shall be:

-	for adjacent (200 kHz) interference	:	C/Ia1	=	C/Ic - 18 dB
-	for adjacent (400 kHz) interference	:	C/Ia2	=	C/Ic - 50 dB
-	for adjacent (600 kHz) interference	:	C/Ia3	=	C/Ic - 58 dB

NOTE: The C/Ia3 figure is given for information purposes and will not require testing. It was calculated for the case of an equipment with an antenna connector, operating at output power levels of +33 dBm and below. Rejection of signals at 600 kHz is specified in subclause 5.1.

These specifications apply for a wanted signal input level of 20 dB above the reference sensitivity level, and for a random, continuous, GSM-modulated interfering signal. In case of frequency hopping, the interference and the wanted signals shall have the same frequency hopping sequence. In any case the wanted and interfering signals shall be subject to the same propagation profiles (see annex C), independent on the two channels.

Appendix 3: Time Mask for a Normal Burst [GSM0505]



Time mask for normal duration bursts (NB, FB, dB and SB)

(*)	For GSM 900 MS	:	see 4.5.2.
	For DCS 1 800 MS	:	-48 dBc or -48 dBm, whichever is the higher.
	For GSM 900 BTS and DCS 1 800 BTS	:	no requirement below -30 dBc (see 4.5.1).
(**)	For GSM 900 MS	:	-4 dBc for power control level 16; -2 dBc for power level 17; -1 dBc for power level controls levels 18 and 19.
	For DCS 1 800 MS		-4dBc for power control level 11, -2dBc for power level 12, -1dBc for power control levels 13,14 and 15
(***)	For GSM 900 MS	:	-30 dBc or -17 dBm, whichever is the higher.
	For DCS 1 800 MS		-30dBc or -20dBm, whichever is the higher.

Appendix 4: Frequency Mask of the Modulation Spectrum [GSM0505]

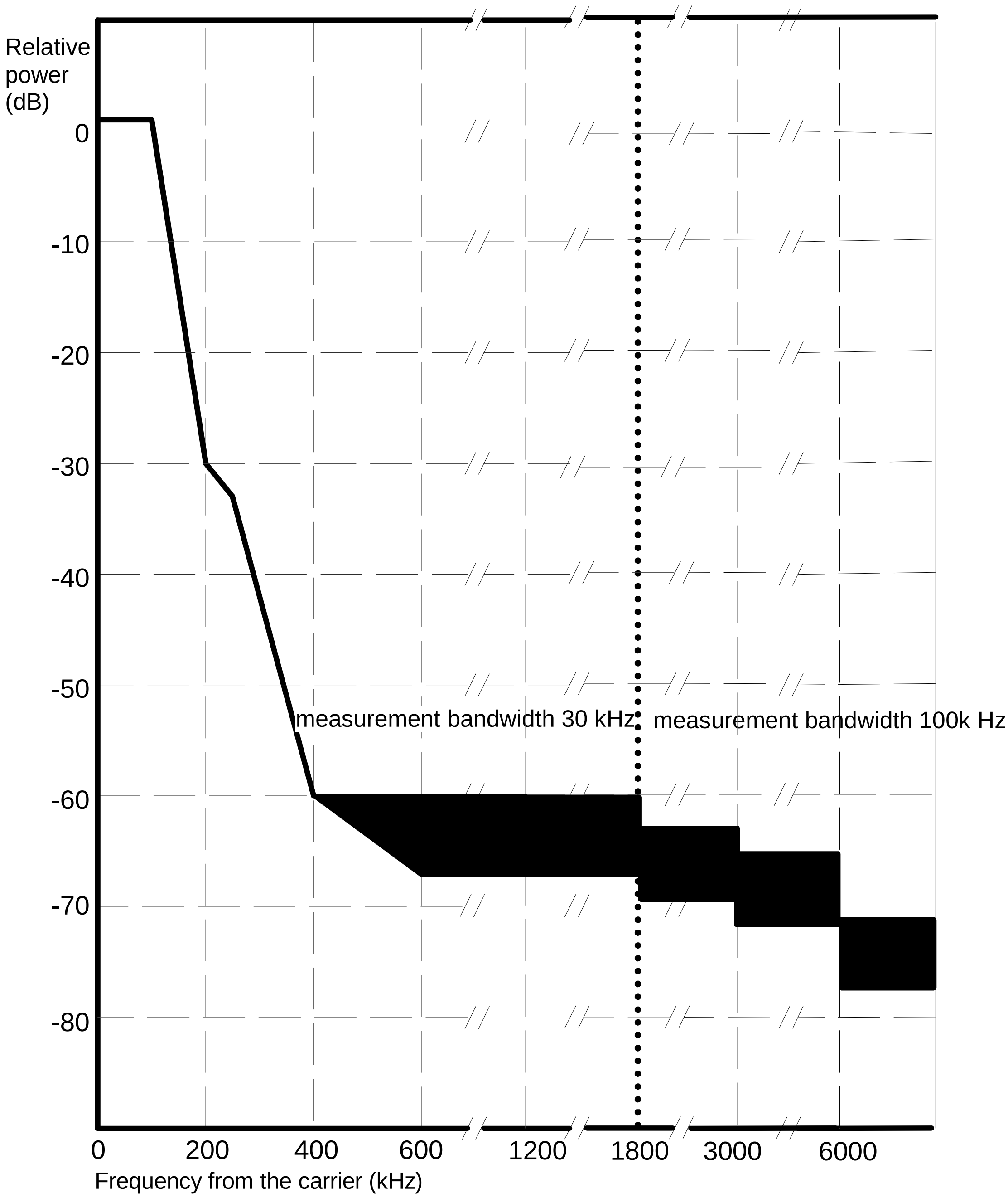


Figure A.1: GSM 900 MS spectrum due to modulation

Appendix 5: Accuracy Requirements of MS Transmission Power [GSM0505].

GSM 900

Power control level	Nominal Output power (dBm)	Tolerance (dB) for conditions	
		normal	extreme
0-2	39	±2	±2.5
3	37	±3	±4
4	35	±3	±4
5	33	±3	±4
6	31	±3	±4
7	29	±3	±4
8	27	±3	±4
9	25	±3	±4
10	23	±3	±4
11	21	±3	±4
12	19	±3	±4
13	17	±3	±4
14	15	±3	±4
15	13	±3	±4
16	11	±5	±6
17	9	±5	±6
18	7	±5	±6
19-31	5	±5	±6

DCS 1 800

Power control level	Nominal Output power (dBm)	Tolerance (dB) for conditions	
		Normal	extreme
29	36	±2	±2.5
30	34	±3	±4
31	32	±3	±4
0	30	±3	±4
1	28	±3	±4
2	26	±3	±4
3	24	±3	±4
4	22	±3	±4
5	20	±3	±4
6	18	±3	±4
7	16	±3	±4
8	14	±3	±4
9	12	±4	±5
10	10	±4	±5
11	8	±4	±5
12	6	±4	±5
13	4	±4	±5
14	2	±5	±6
15-28	0	±5	±6

PRELIMINARY EXERCISES

P1

About: Physical channel structure, which is a very basic thing. Fundamentally related to error measures in P2.

Calculate the exact time duration (i.e. fraction) of the following structural units. Use the length of the traffic multiframe (26 frames) as the starting point. Notice that by remembering the length of the traffic multiframe, exactly 120ms, the length of all other structural units may be derived easily. Show your calculations on paper.

a) normal burst
b) a bit
c) a frame (not the same as a burst!)
d) signalling multiframe (51 frames)
e) guard period
f) superframe
g) hyperframe

P2

About: Different error measures of the GSM system. Necessary knowledge in order to understand L5.

A GSM mobile station is receiving bits on the full rate speech channel. A total of 100 bit errors are detected after the equalizer during 24 bursts. After channel decoding, class I_a has 1 error bit and class I_b has 6 error bits. The frame erasure is performed next. Recall that each burst contains 114 encoded data bits.

a) How many information (=speech) bits were sent during the 24 bursts? "Information bits" means the bits before channel coding.
b) What is RXQUAL?
c) What is $RBER_{II}$?
d) What is $RBER_{Ib}$?
e) What is FER?

Bit class	**Errors after channel decoding, before frame erasure**	**Errors after frame erasure**
I_a	1	-
I_b	6	4
II	12	11

P3

About: Training sequence has a small but essential role in the GSM system…

a) What is the purpose of a training sequence?
b) Why is it useful to place in the middle of the burst?
c) What is the drawback of including a training sequence within a burst?
d) Why is it necessary to have 8 different training sequences?

P4

About: Comparison of π/4 –DQPSK modulation to GMSK. These are the two dominant modulation methods in contemporary mobile communication systems. It is necessary to do this exercise before L8 can be completed.

a) Draw the constellation diagram of π/4 –DQPSK.
b) GMSK is a modulation method with constant envelope but π/4 –DQPSK is not. Compare these two methods from this point of view (what are the advantages and disadvantages?).
c) Derive π/4 –DQPSK power spectrum S(f) after root raised cosine filtering and transmission. Root raised cosine with α=0,35 (D-AMPS) is used. Notice that the power spectrum at the input of the baseband filter $H(f)$ is white, since the autocorrelation function of the random impulse train is a delta function.

Root raised cosine (normalized) transfer function H(f) is

$$H(f) = \begin{cases} 1, & |f| \le 2W_0 - W \\ \cos\left[\frac{\pi}{4}\left(\frac{|f| + W - 2W_0}{W - W_0}\right)\right], & 2W_0 - W \le |f| \le W \\ 0, & |f| \ge W \end{cases}$$

and (R_s is the symbol rate)

$$W = (1+\alpha)W_0 = (1+\alpha)\frac{R_s}{2}.$$

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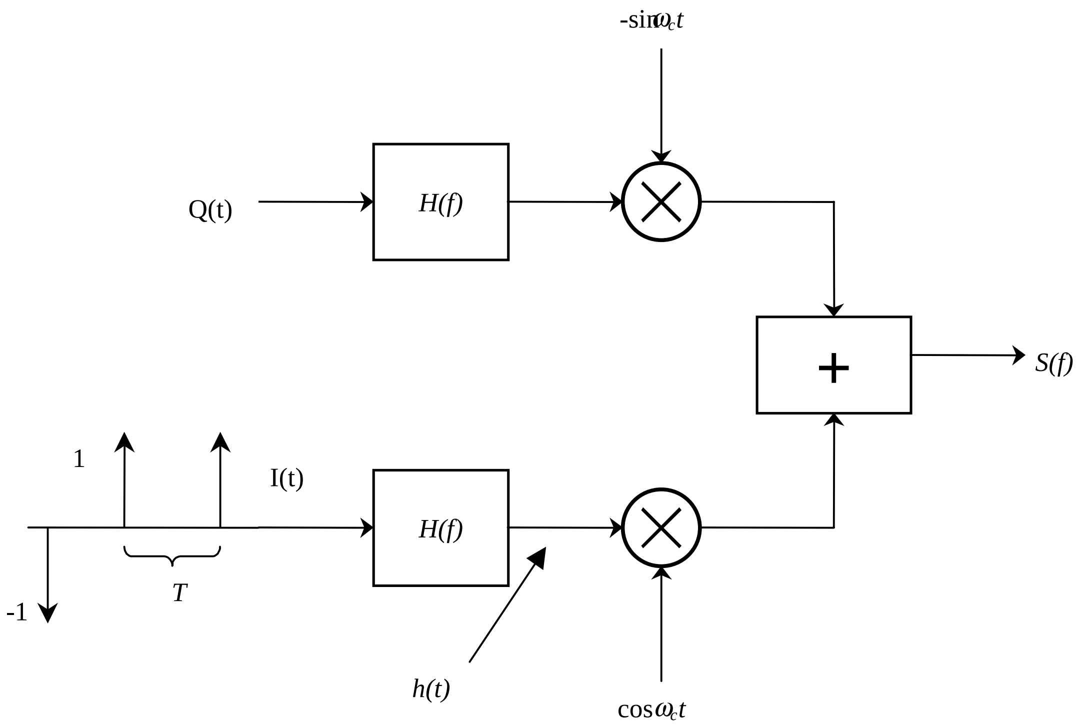

d) 271 kbit/s is transferred with π/4 –DQPSK modulation. How large is the –10dB RF bandwidth?

P5

About: 0.3GMSK modulation. This problem should be completed fully in order to understand L6.

GMSK modulation where the Gaussian filter BT=0.3 is used in GSM. Here B equals the -3dB bandwidth of the filter and T is the symbol duration.

a) What is the –3 dB bandwidth of the Gaussian filter in GSM?
b) The bandwidth of the Gaussian filter is not the same as the bandwidth of the GMSK modulation. Explain why.
c) What are the disadvantages of Gaussian filtering?
d) Calculate the frequency offset of frequency correction burst compared to the carrier frequency f_c. The f-burst is a stream of 148 zero bits.
e) What is the bandwidth efficiency in GSM (assume the bandwidth to be equal to channel spacing)?
f) Sketch transitions in phase (phase trellis) in a function of time when the modulator is fed the following line of bits: 110110010.
g) Sketch how the signal trajectory behaves in the IQ plane when modulator is fed with bit sequence 11011.
h) Draw the ideal constellation diagram and transitions for the GMSK modulation.

P6

About: IQ diagram and modulation errors. This problem should be completed to understand L6.

Data is being received using the standard QPSK modulation, where the constellation points lie on a circle in angles of $\pm 45^\circ, \pm 135^\circ$. Assume that the circle has unit radius.

a) A sample of the received complex baseband signal has value $0.6 + j0.7$. What is the phase error? What is amplitude error? Assume that SNR is very high, and that symbol timing and carrier synchronization are perfect.
b) Suppose we know that for the same signal both phase and amplitude error are zero. Calculate DC offset.

Hint: For information on modulation errors, see the application note “Digital Modulation in Communication Systems - An Introduction”, available through the lab home page.

P7

About: The effect of modulator imperfections to modulated signal. Formulas derived in this problem are needed in L7.

The most common non-idealities of an IQ modulator are that the LO signals are not completely orthogonal, the LO signals have different amplitude, or that there is DC offset in the modulating I and Q signals.

a) Suppose that the input signals in the I and Q branches are $I(t) = \sin(\omega_m t)$ and $Q(t) = \cos(\omega_m t)$, and the phase error in the LO signal of the Q branch is θ and the difference in the LO signal amplitudes is ΔA. Derive an expression for the IQ modulator output signal and show that the amplitude ratio of the spurious output α to the desired output β equals

$$\frac{\alpha}{\beta} = \sqrt{\frac{\left[1-(1+\Delta A)\cos(\theta)\right]^2 + \left[(1+\Delta A)\sin(\theta)\right]^2}{\left[1+(1+\Delta A)\cos(\theta)\right]^2 + \left[(1+\Delta A)\sin(\theta)\right]^2}}\,.$$

Sketch the spectrum of the IQ modulator output.

b) Calculate the output time signal of IQ modulator when the modulating signals are $I(t) = A + \cos(\omega_m t)$ and $Q(t) = B + \sin(\omega_m t)$ i.e. the branches have DC offsets A and B. Otherwise, assume the modulator to be ideal. Draw the spectrum of the output. Indicate the ideal output signal and the spurious output signal caused by DC offset.

c) How many dB lower is the spurious sideband level compared to the wanted sideband when the phase error in LO signals is 5° and the amplitude ratio of the quadrature branch LO signal to the in-phase LO signal is $\Delta A = 0.5\text{dB}$? Use the formula you derived in part a.
d) How many dB lower is the carrier frequency compared to the wanted side band if the DC offset in both modulating signals is $A = B = 0.5$. Use the formula you derived in part b.

P8

About: Phase and frequency error.

The phase error of modulator in a GSM1800 MS changed linearly from –1 degrees to +3 degrees during one burst.

a) What was the frequency error during the burst?
b) Specifications allow a frequency error of 0.1 ppm (parts per million). Is the calculated frequency error acceptable?

P9

About: To save time during lab shift.

Examine the laboratory exercises. At the minimum clear up the following questions:

a) How is the sensitivity of a GSM MS defined?
b) How are CCI and ACI defined? You'll find information in appendices.
c) Sketch the RF connections for measurement of L9. You'll have a power splitter/combiner, interference generator (base station), GSM tester and necessary cables and connectors.
d) What information is needed concerning the base station signal in order to calculate CCI and ACI?
e) How can you calculate CCI and ACI in the laboratory?

P10

About: Spectrum analyzer basics. Important to know in L6-L9.

Unless you are familiar with superheterodyne spectrum analyzers, you should find out the following:

a) How does a superheterodyne spectrum analyzer work?
b) What does resolution bandwidth mean? How does it relate to sweep time and frequency span?
c) What is the dynamic range of a typical spectrum analyzer?

LABORATORY EXERCISES

You can write the answers on this sheet, or use a separate sheet if necessary. The deadline for returning these exercises can be seen on the course web page. If you run into problems, please consult the assistant well before the deadline.

NOTE 1: Sources of measurement errors should be considered in (almost) all the measurements even if this is not specifically required in the exercise. In some cases the schematic of the measurement set-up should be presented. The key point is that the laboratory report should contain enough information so that whoever reads it *should be able to repeat* the measurement (and get the same result).

NOTE 2: RF cables and connectors used in the measurements are very susceptible to any rough or careless treatment. More than that, they are extremely expensive! Treat them with care and avoid unnecessary cable switching.

L1

Measure Erkki GSM900 with Auto Test mode of the GSM tester. Print the test reports. Are the mobiles OK? What kind of errors did you find?

Settings: coupler *on*, mode *continuous,* MS type *default.*

L2

Use Manual Test mode and measure the receiver sensitivity of a GSM1800 MS. Use the automated BER sensitivity test (Manual → BER → BER Sens.). Perform the measurements on channels 512, 700, 885. During the sensitivity search observe the accuracy of the RXLEV measurement done by the MS.

Settings: coupler *on*, MS type *default*, MS transmission power (ctrl level) *30 dBm*.

a) What is the sensitivity of the phone on different channels? Are there differences between frequency channels?

Avoid unnecessary cable switching!

b) Comment on the accuracy of the RXLEV measurement? What are the disadvantages of inaccuracy of the RXLEV measurement?

c) What kind of propagation environment does the measurement situation correspond to? Can the sensitivity measurement results be compared with the sensitivity requirements given in the specifications?

L3

Power ramp: Use Manual Test mode (Manual → Ramp) and measure if the power ramp fits the power mask defined in the specifications?

Settings: channel *516*, MS transmission power *30 dBm*.

a) What is the power-rise-speed in the beginning of the ramp (dBm/s)? Careful with the units! Show calculations.

b) What is the timing error of the phone (in bits)? What is the first bit sent on full power at the beginning of the burst?

c) Observe the middle section of the burst. Is the amplitude constant? Comment. GMSK should have constant envelope (≈amplitude).

d) Why should the power ramp not be too gently sloping? Why shouldn't it be too steep?

e) Measure the accuracy of the MS transmission power on the lowest (0 dBm) and highest (30 dBm) transmission power of the MS. You can do this by giving power commands to the MS, and observing the actual transmitted power measured by the tester. Repeat for channels 512, 700, and 885. Comment on differences. Information about the required accuracy of the MS transmission power is given Appendix 5.

L4

Phase and frequency error: Use Manual Test mode (Manual → PhaseFreq) and measure the phase and frequency error of the GSM1800 MS on channel 700.

Settings: coupler *on*, MS transmission power *30 dBm*.

a) What are the rms errors and peak errors?

b) Observe the behavior of the phase error during the burst. How does the frequency error change? Does the phase error change linearly during the burst as in P8? Comment on the difference of the measurement and the preliminary exercise.

L5

BER curve exercise: Using Manual Test mode, measure and draw FER, $RBER_{Ib}$, $RBER_{II}$ of the MS as a function of received power at the MS input. (Manual → BER → BER Cont.). Start from MS receiving power level at –100dBm, and then drop downlink transmission power gradually. Notice that you will have to use an attenuator between MS and the GSM tester to be able to measure levels lower than –110dBm which is the lowest transmission power of the tester. The attenuation of the measurement cable is about 0.5dB. You can use the program *cts_ber2.exe* to read the BER values from the GSM tester.

Settings: coupler *on* (0.5 dB), channel *520*, MS transmission power *30 dBm*, averaging window *499 frames* (10 sec, BER Cont. → Config), measurement mode *RBER* (BER Cont. → Config).

Hints: You may first decrease the tx power in steps of 1 dB. When the error rates begin to rise faster, use a smaller step, like 0.5 dB, or less. You should aim for a smooth FER curve. You must wait 10 sec after each power drop because of the averaging window. If the FER value is stable you can read the measurement result from the screen of the GSM tester. If FER fluctuates a lot you can use the *cts_ber2.exe* program to read several values to a file and average the results.

Present all three curves in the same graph (eg. Excel).

a) Comment on the behavior of the $RBER_{Ib}$, $RBER_{II}$ and FER. Why does FER suddenly rocket up?

b) Explain how you can estimate coding improvement and coding gain from the measured curves? Estimate coding improvement and coding gain for some suitable point in the curve. Comment on the accuracy of the results and the estimation method.

c) What is the downlink transmission power when the connection is lost?

L6

Examine the constellation diagram and vector transition diagram in the IQ plane using the vector signal analyzer. Erkki phone, without SIM card, is used in this experiment. You can tune the modulator parameters using the WinTesla program. You can put the right settings by choosing Testing → Quick Testing (RF).

Settings for WinTesla: active unit *tx*, tx power level *15*, tx data type *random.*

In order to locate the modulator signal in the spectrum analyzer, use the frequency span 1 MHz centered at the carrier frequency (902 MHz), 1 kHz resolution bandwidth and reference level 10 dBm. Now you should be able to see the signal in the constellation and vector transition diagrams.

a) How does the DC error show in the constellation diagram (Mode → Vector Analyzer → Meas Result → Meas Signal → Polar [IQ] Constell)? Is there any DC error visible in the constellation diagram? How does the phase error show in the constellation diagram? Is there any phase error visible in the constellation diagram? Is the phase error systematic or random?

b) Examine the vector transition diagram (Mode → Vector Analyzer → Meas Result → Meas Signal → Polar [IQ] Vector). Does the signal have constant envelope? What anomalies are there in the vector transition diagram? What is the cause of these anomalies?

L7

Modulation errors.

a) Feed the modulator with a continuous line of zero bits. Measure the output spectrum using 200 kHz frequency span centered at the carrier frequency, and 1 kHz resolution bandwidth. The reference level can be set to 20 dBm. Calculate phase error from the spectrum. Assume that there is no amplitude error. What is the DC offset that the output spectrum corresponds to? Show calculations. You will need formulas you derived in P7.

Use delta markers!

b) Check the measured phase error and DC offset with the vector analyzer, display Symbol Table/Errors (Mode → Vector Analyzer → Meas Result → Symb Table/Errors). Do the results correspond to values of the previous part?

c) Tune the IQ modulator with the WinTesla program by choosing Tuning → Tx I/Q. You can observe how the phase error and DC offset change while at the same time. Try to eliminate the modulation errors completely. What settings did you use?

d) Pedagogical demo: Now that you have almost completely eliminated modulation errors, go back to the spectrum analyzer. Increase phase error to the maximum allowed, and *at the same time* observe what happens to the output spectrum. After that, increase the DC offset of either branch to the maximum, and *at the same time* observe what happens to the output spectrum. Does this comply with the formulas you derived in P7?

L8

Measure the power spectrum of GSM modulation by using the output signal of one of the base stations in the student laboratory. Set the resolution bandwidth to 30 kHz.

a) Does the power spectrum correspond to GMSK modulation value of BT=0.3? Compare with the graphs given in the literature. Compare the power spectrum also with the frequency mask given in the specifications (appendix).

b) Compare the -10 dB bandwidth of the measured GMSK spectrum with the bandwidth you calculated for π/4 -DQPSK in P4.

L9

See Appendix 2

Measure CCI and ACI_{1st} by using interfering GSM signal, power splitter and the GSM tester. Sketch a schematic of the measurement set-up. Indicate the power levels and attenuations in the schematic.

You should examine the interfering signal with the spectrum analyzer before measurement. During the measurement keep the interfering signal power level constant, and decrease the carrier signal level by using the GSM tester. During both CCI and ACI measurements find the C/I ratio when the RBERII exceeds 2.6%, and the C/I ratio when the connection is lost. Use the maximum MS transmission power (30 dBm).

a) CCI. C/I ratio when RBERII goes above 2.6%? C/I ratio when synchronization is lost? Comment on how the measured values correspond to the requirements in the specifications.

b) ACI 1st adjacent channel. C/I ratio when RBERII goes above 2.6%? C/I ratio when synchronization is lost? Comment on how the measured values correspond to the requirements in the specifications.

c) Comment the reliability of the measurement, and usability of the measurement results in a real situation.