UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL ATOMIC ENERGY AGENCY
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

HANDOUT-1

ICTP - URSI - ITU/BDT WORKSHOP ON THE USE OF RADIO FOR DIGITAL COMMUNICATIONS IN DEVELOPING COUNTRIES

(17 - 28 February, 1997)

"Performance of Digital Communications Laboratory"

M.P. Fitton
University of Bristol
Bristol
UNITED KINGDOM

MAIN BUILDING STRADA COSTIERA, 11 TEL. 2240111 TELEFAX 224163 TELEX 460392 ADRIATICO GUEST HOUSE VIA GRIGNANO, 9 TEL. 224241 TELEFAX 224531 TELEX 460449
MICROPROCESSOR LAB. VIA BEIRUT, 31 TEL. 2249911 TELEFAX 224463 TELEX 460392 GALILEO GUEST HOUSE VIA BEIRUT, 7 TEL. 22401 TELEFAX 224559 TELEX 460392

"Performance of Digital Communications Laboratory"

M.P.Fitton, University of Bristol, UK
email: mike.fitton@bristol.ac.uk

Overview:
In this laboratory, you will make use of the '*HP I-Q Tutor*' software package in-order to gain a further insight into the performance aspects of modern digital communication systems. The tools allow you to investigate the *bit error rate* performance in terms of received *signal-to-noise ratio*, for a variety of digital modulation methods. Furthermore software demonstrates the impact of channel filtering, multipath channel impairements, and non-ideal RF power amplification. You will investigate constellation plots (I-Q vectors) and eye-diagrams for a variety of channel conditions and modulation schemes.

The Laboratory
It is recommended that you follow the experimental procedure outlined in the HP IQ Tutor *Digital Microwave Communications Guide*. However, if time permits, please consider an evaluation of the other modulation schemes also supported by the software.

To run the software, change directory to '*iqtutor*' and issue the DOS command '*iqtutorc*'.

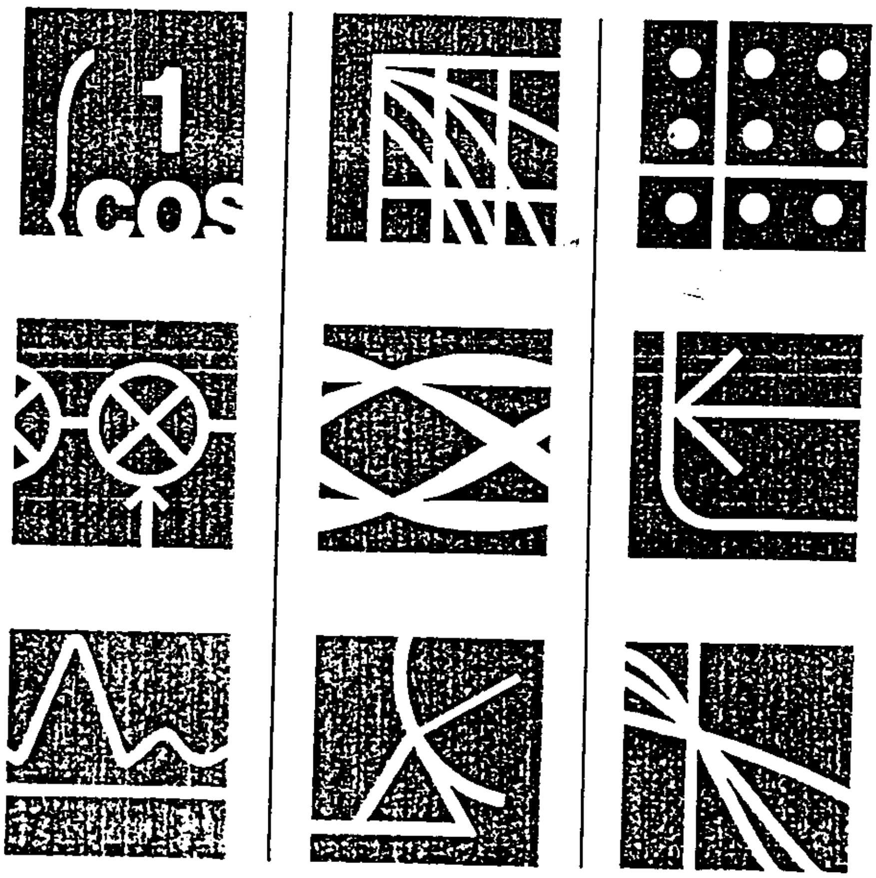
It is suggested that delegates don not cover the material on *M-curves* (pages 5-16 to 5-19), as this is not covered in the lecture material. M-curves useful in analysing microwave links, but do not have widespread use.

Hints
Move about the program using the arrow keys. To enter the EDIT mode, type '*E*', and to exit the EDIT mode press <Enter>.

The IQ Vector diagram can be rotated using the 'PgDn' and 'End' keys.

It is recommended that the multipath simulator is switched-off during the evaluation of the non-linear amplifier impairments.

M.P.Fitton
14/02/97



I-Q TUTOR

HP Digital Microwave Communications Guide

This section walks you through several experiments and activities designed to give you additional insight into practical digital communications system operation. In some cases you will be able to anticipate the results. In others, the results will be more subtle and obscure. You should find them all interesting.

P(e) Versus SNR

Refer back to the Benchtop Overview screen. By now you have probably noticed that on the top left of most displays is the message "Ideal P(e) <= *xx*." The number *xx* is an approximation of the ideal probability of error based on the signal-to-noise ratio (SNR) and the modulation type. P(e) is a measure of the rate at which received symbols are misinterpreted. Errors can be caused by system noise, clocking errors, or any of a number of problems associated with signal degradation. A probability of error of .01 means that on the average there will be one misinterpreted symbol in every 100 symbols received.

The most common cause of errors in symbol detection is that noise in the system causes a symbol to cross a decision boundary and to be detected improperly. One might conclude from this that for a given modulation scheme and signal-to-noise ratio, an estimate of P(e) might be derived. Signal-to-noise ratio in a digital communications systems is indeed a valuable indicator of system performance. Theoretical curves have been generated for most modulation types that provide estimates of P(e) vs. SNR. The I-Q Tutor program uses these theoretical curves to derive the P(e) number displayed on the screen.

Actual error measurements of a system are time-consuming, especially in modern, low-error systems. It would be advantageous if we could predict errors based on the signal-to-noise ratio, which can be measured much more quickly. This experiment compares the actual errors experienced in the I·Q Tutor system to those predicted by the theoretical curves.

Another more common measure of communications efficiency and quality is Bit Error Rate (BER). BER is a measure of the average number of bits in error divided by the total number of bits received. If the P(e) is known, the BER can be calculated, but it will be a function of design parameters including the number of states in the modulation type, whether or not Grey codes are used, the types of error-correcting schemes employed, etc. Because of this, we will limit our measurements to P(e) in spite of the fact that most real system measurements will measure BER.

Procedure:

1. First power up the system. Use the EDIT mode to set I·Q Tutor to BPSK, Filter Alpha = .1, and SNR = +6 dB. Also make sure that neither the "HPA Impairment On" or "Multipath Fade On" messages are displayed. If these impairments are on, turn them off by using the "D" key to get to the advanced design page and select 15 dB HPA backoff and 0 dB fade depth.

2. Once the system has been initialized (the WORKING!!! message disappears), move the cursor to the output of the bit detector and down to the display of the bit detector outputs and their spectrum (the second set of signals from the right). You will examine these signals to determine how many errors are actually being experienced in the system.

3. Then, while looking at the time display of the bit detector output, you will notice errors by looking for dashed lines. Both the detected and transmitted signals are plotted. If an error occurs, the dashed lines indicating the transmitted signal will be visible. The number of errors is tabulated in the display label. Sometimes when using more complex modulation types, the displayed number of errors will be higher than the number of errors that you can see. This is because the error may also occur in the Q channel and you only see the I channel displayed. Since BPSK is transmitted entirely on one channel, you should be able to observe all of the errors. To calculate the P(e), you will divide the number of displayed errors by the number of transmitted symbols which is 100.

4. Write the P(e) you have calculated in the table below and plot the P(e) on the P(e) vs. SNR graph provided. Now re-edit the parameters reducing the SNR by 2 dB and repeat the procedure. Do this until you have plotted the P(e)s for SNR's down to -2 dB.

BPSK

SNR	Errors	Errors/100 = P(e)
6dB		
4dB		
2dB		
0dB		
−2dB		

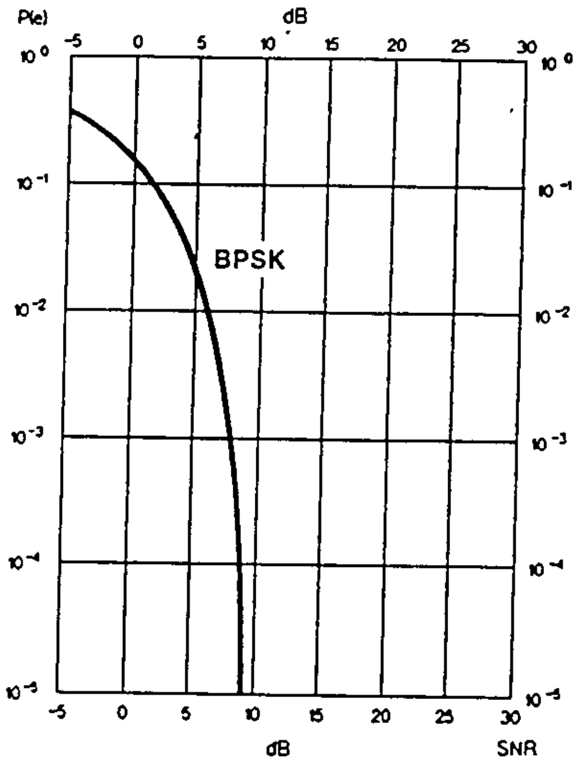


Figure 5-1. P(e) vs. SNR for BPSK

5. There is probably some discrepancy between your findings and the theoretical curves. This is due to two things. First, you are measuring a random process which by its nature is unpredictable. Second, you are using very small samples to determine your results. At any rate, the results you obtain should resemble the theoretical results enough to persuade you to at least believe in the overall picture they paint. The most important lesson to learn from all of this is that small increases in SNR can be catastrophic to the quality of transmission in digital communications systems.

6. If you wish to verify P(e) vs SNR for other modulation types, the theoretical curves are given below. The procedure is basically the same. You will need to use a different range of SNRs when collecting your data so that there are a reasonable number of errors to observe. Use the values shown in the tables of Figure 5-2a.

QPSK

SNR	Errors	Errors/100 = P(e)
8dB		
6dB		
4dB		
2dB		
0dB		

Figure 5-2a. QPSK Table of Errors

16QAM

SNR	Errors	Errors/100 = P(e)
16dB		
14dB		
12dB		
10dB		
8dB		

Figure 5-2b. 16QAM Table of Errors

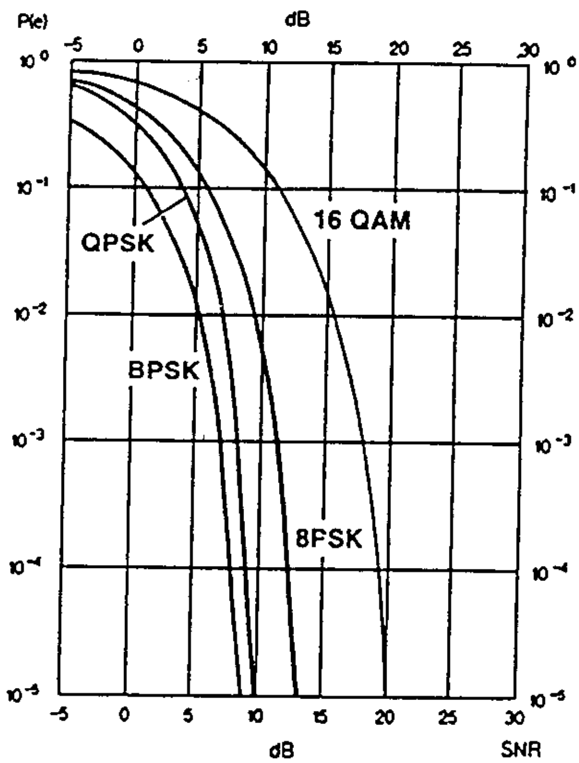


Figure 5-2c. Theoretical P(e) Curves

P(e) Versus Filter Bandwidth

You may recall that there are two reasons for filtering the data in a digital communications system. The first is to limit bandwidth. It should be clear from looking at the baseband I and Q signals that we indeed limit bandwidth quite a bit. The second reason is to reduce the noise introduced in transmission. This experiment is directed at determining whether or not the filter makes any difference in the actual system's tolerance to noise. The measure we will use to determine overall transmission quality is P(e), the rate at which misinterpreted symbols or states are received. A P(e) of .025 means that in 1000 symbols received, on the average 25 would be in error.

Procedure:

1. Use the EDIT function to set up the I-Q Tutor system to BPSK, Filter Alpha =.9, and SNR = 2.

2. Move the cursor to the output of the bit detector and down to examine the time display of the output. From here it is easy to see actual errors in the detected signal since they appear as deviations from the dashed line representing the transmitted data.

3. Using the displayed error count (since you can't see the errors in the Q channel), divide by 100 to obtain P(e) for the system setup given above. Record your results in the table below. It's important that you calculate the P(e) from the error count and not just read P(e) in the upper left part of the screen. The "Ideal P(e)" represents an average value and won't show you the P(e)'s dependence on the filter alpha.

4. Now change the filter alpha to 0.1 and find the new resulting P(e). Switch the filter alpha back to 0.9 and take another P(e) measurement. Continue doing this until you have taken five separate measurements for both filter alphas. The reason for switching the filter alpha back and forth is to obtain a large enough statistical sample to obtain meaningful results.

5. After you have filled the table, take the average of each set of data and write the average value of P(e) for each filter alpha in the bottom of the table. There should be a difference between the two numbers indicating that the narrower alpha = .1 filter

reduces the number of errors seen at the receiver.

What is happening here? As the filter alpha is reduced, the total system bandwidth is also reduced, but the amount of information is kept constant. The only real change is that with higher alphas, more redundant information is transmitted and more noise is allowed to enter the system. This results in slightly higher P(e)s for the same SNR's.

FILTER	Alpha = .1	Alpha = .9
Errors		
AVERAGE		

Figure 5-3. Table of Measured Symbol Error Values

Noise, Errors and the I-Q Vector Diagram

Perhaps you noticed that there seems to be a difference in the number of errors that different modulation types experience with the same SNRs. For any given SNR, the modulation scheme will directly influence the probability of error. Why can't we send 16QAM just as easily as BPSK? In other words, why do we have to use more power to obtain the same P(e) with 16QAM than BPSK? The reason becomes clear when we examine the two signals in the I-Q Vector display using the constellation plot.

Procedure:

1. Set up the I-Q Tutor system using the EDIT function to BPSK, SNR=40 dB and Filter Alpha = .5. Be sure the path impairments are turned off.

2. Move the cursor to the output of the I-Q demodulator and down so that you can see the time domain display of the baseband I-Q signals.

3. Now enter the I-Q Vector display by pressing the "ENTER" key.

4. To look at the data at the clock sampling instant press the "/" key.

5. You should see a practically noise-free diagram of a BPSK signal states. Notice that the states are very small points and that they are very clearly separated from each other.

6. Return to the time domain display and spectrum by pressing the "ENTER" key again.

7. Introduce some noise to the system. Press the "EDIT" key again to re-enter the edit mode and change the SNR to 8 dB.

8. When the WORKING!!! message disappears, re-enter the I-Q Vector display, select the constellation display, and notice that though the states are still clearly separate, there is some visible noise on the signals. The noise increases the ambiguity of the signal by spreading out the states.

9. Return to the time domain display and re-EDIT the parameters, changing the modulation type to 16QAM while leaving the rest of the parameters unchanged.

10. Press the "ENTER" key to see the effect of the same amount of noise on a 16QAM signal. As you can see, the visible noise has not increased. However, the states were closer together to start with so the same noise causes greater ambiguity in the signal. This translates into a higher P(e).

Multipath and "M" Curves

In this lab you will explore what multipath distortion is all about in more depth. With a little patience, the experiments in this section will give you an intuitive feel for what multipath distortion looks like in the frequency, time, and vector domains. In addition, you will learn how to characterize multipath with what are known as "M" curves.

Multipath distortion is probably one of the most troublesome problems for both designers and users of digital radios. As modulation formats get more complex, even slight amounts of multipath will crash a system without sophisticated compensation techniques.

A simple model for multipath distortion assumes that the signal travels over two different paths to the receiver - a direct path, and one that is delayed by a small amount due to reflection or refraction. This delay causes notches in the frequency response of the received signal. If the delay is T microseconds, the notches occur every 1/T MHz. The depth of the notch is determined by the relative amplitude of the main and delayed signals. For example, if the amplitude of the delayed signal is 90% of the amplitude of the main signal, the notch will be approximately 20 dB deep. If the amplitude of the delayed signal is 99% of the main signal, the notch will be 40 dB deep. If the two signals are of equal magnitude, the notch will be infinitely deep.

Let's investigate this characteristic - first in the frequency domain.

Procedure:

1. Position the probe pointer to look at the output of the I/Q demodulator, and then look at the time display of the output. Use the Edit function to set up I-Q Tutor for QPSK, SNR=40dB and Filter Alpha=.3. DO NOT HIT THE ENTER KEY YET!

2. Now enter the advanced design screen by pressing the "D" key. Press the up arrow to change the delay to 16.6ns. You are now changing the delay between the main and the delayed signals. Note that this corresponds to creating notches every 1/16.6ns Hz, or every 60 MHz.

3. Press the right arrow twice to edit the notch depth. Press the up

arrow key repeatedly to change the depth to 40 dB. Note that you are changing the relative magnitudes of the main and delayed signals. Observe the notch as you change the depth.

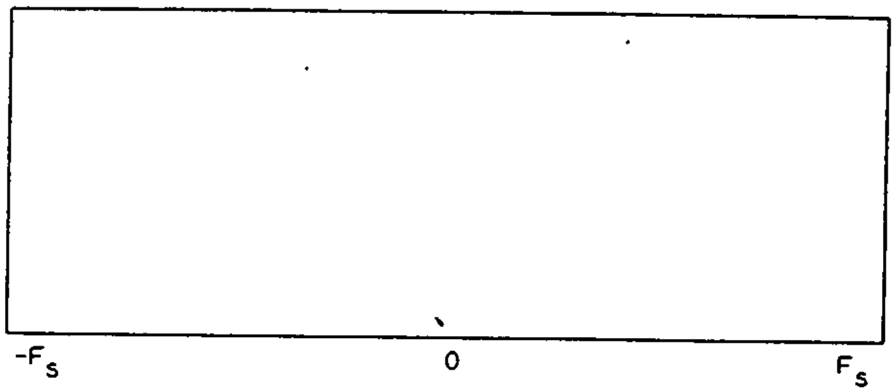
4. Press the left arrow once again to edit the notch position. Press the up arrow key repeatedly to change the position to +100%. You are changing the phase of the delayed signal to move the notch.

5. Draw the frequency response curve of the delay in the box below. The I-Q Tutor is set up to simulate digital transmission at a symbol rate (baud rate) of 30 MHz. Therefore, Fs and -Fs are at +30MHz and -30MHz respectively, and the notches actually fall at 60 MHz intervals.

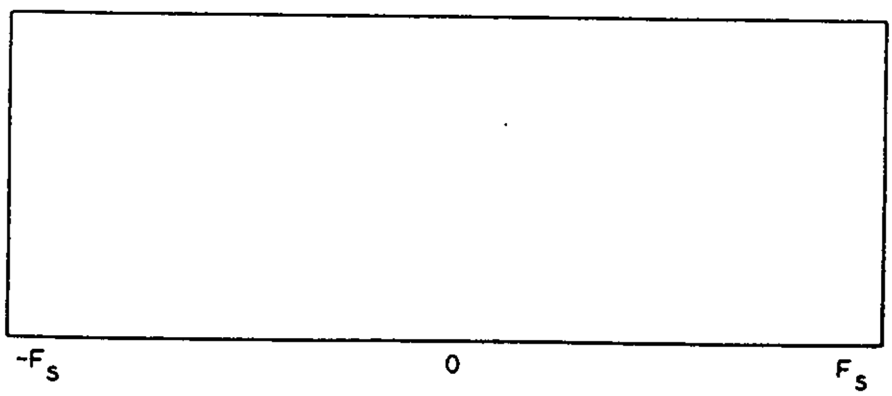
$-F_s$ 0 F_s

Changing the Delay Time

6. Now, press one left arrow to modify the multipath delay again. Hold the up arrow key down until you reach 35ns delay. Draw the frequency response curve below. Note that your notches are now occurring every 1/35ns or 29 MHz.



7. Change the delay back to 6.3ns. This is a very commonly used delay for multipath simulation and is derived from empirical field testing of actual multipath fades. Draw the frequency response curve below.



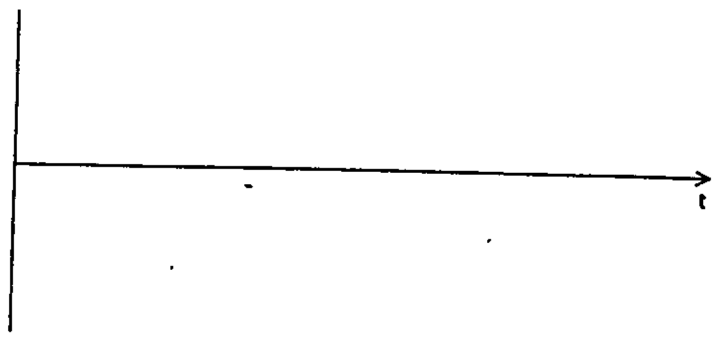
Multipath Distortion in the Time and Vector Domains

8. Change the notch depth to 10 dB. Now make sure that you have the following multipath settings:
   Delay: 6.3 ns
   Depth: 10 dB
   Position: +100%

   Press the ENTER key to exit the advanced design mode and get back to the edit mode. Make sure that the edit parameters are as follows:
   Modulation Type: QPSK
   SNR: 40dB
   Filter Alpha: .3

   Now press the ENTER key again to exit the edit mode and recompute the system waveforms. When the "WORKING!" message goes away, you should be looking at the time waveform of the signal after the I/Q demodulator.

   Press the ENTER key to look at the Vector Diagram. Note that the vector diagram is rotated due to the multipath distortion. Using the knob on the computer, rotate the diagram about 45 degrees clockwise, until the sides of the QPSK pattern are as parallel as possible to the sides of the computer screen. Now, use the left arrow (18 times) to rotate the diagram to the left until you see an eye diagram. Draw the eye diagram below. Notice that the multipath distortion introduces some ISI (inter symbol interference) in the eye diagram. Real radios automatically correct for the phase rotation, but the ISI can't be fixed without equalization. This is what causes system degradation and poor BER performance.



"M" Curves

The effect of multipath distortion on system performance is usually characterized in what is called an "m" curve. A fixed multipath delay is chosen (say 6.3 ns) and the BER is measured as a function of notch depth and notch position. To make the measurements more rapidly, a fixed BER is chosen at a relatively high level (say 10^{-3}) and the notch depth required to reach that fixed BER is plotted as a function of notch position. A theoretical example of such a measurement appears in Figure 5-4. Note that over the notch position span of -Fs to +Fs, the notch depth required to reach a 10^{-3} BER level follows an "m" shaped curve - hence the name of this measurement.

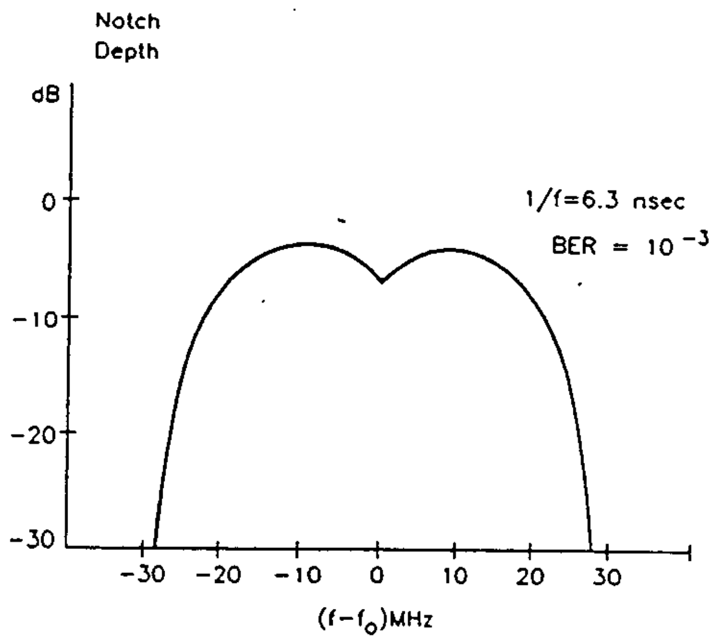
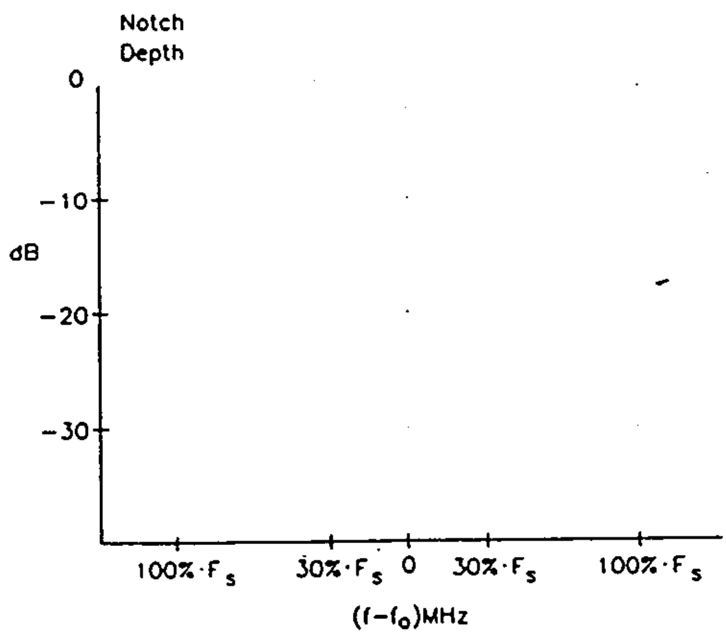


Figure 5-4. M Curve for QPSK for 6.3 nsec delay

Let's try to crudely recreate an "m" curve. Although BER measurements do not work in I-Q Tutor when multipath distortion is used, we can look at the shape of the eye diagram to guess at the signal degradation. Our job will be to change system parameters so that the signal degradation will always look approximately the same (approximating constant BER).

9. Change the notch position to 0%. (Remember, to get back to the advanced design screen you need to press the Enter key to get back to the time display; the Edit or "E" key to get the edit mode; and the "D" key to get the advanced design screen). After you have changed the notch position, press the Enter key twice - once to display mode and calculate new waveforms. After the "WORKING!" message disappears, press Enter to see the eye diagram and press 18 right arrows to rotate back to a vector

diagram. Notice that a 10dB deep notch centered in the data spectrum significantly reduces the signal amplitude. Press 15 ">" (greater than) keys to increase the signal amplitude. Note also that when the notch is centered, the pattern is no longer rotated with respect to the I and Q axes. Use the knob to rotate the pattern back to 0 degrees orientation. Press the left arrow key 18 times until you see the eye diagram again. Press the "S" key to store this eye diagram. Note that the eye diagram is significantly more degraded (higher BER) when the notch is centered in the data spectrum. We will call this picture our "Reference BER". Plot a point on the graph below at zero offset and notch depth of 10dB. This means that it takes a 10 dB notch depth at zero offset to create our "Reference BER" picture.



10. Now go back to the advanced design screen (refer to the beginning of step 9) and change the notch position to 30% and the notch depth to 7dB. Exit the advanced design screen and

edit mode. Press enter to get an eye diagram and press the "<" (less than) key 4 times to adjust the system gain. Rotate your eye diagram back to a vector diagram. Use the knob to rotate the vector diagram until the sides of the QPSK pattern are as parallel as possible to the sides of the computer's CRT screen (approximately 25 degrees clockwise). Now rotate back to an eye diagram. Note that this eye diagram is roughly the same as our "Reference BER" picture. To prove this, recall the "Reference BER" picture by pressing the "R" key. You can see the new eye pattern again by pressing any other key. Note that the system is most sensitive to multipath distortion when the notch is about 30% of Fs - it requires a smaller notch depth of 7dB to get the same amount of degradation. Plot a point on your graph at 30% offset and 7dB notch depth.

11. Go back to the advanced design screen one final time and change the notch position to 100% and the notch depth to 30 dB. Exit the advanced design screen and edit mode. Press Enter to get an eye diagram and press the "<" (less than) key 5 times to adjust the system gain. Rotate your eye diagram back to a vector diagram so that you can align the QPSK pattern so its sides are parallel to the computer screen (approximately 50 degrees clockwise). Now rotate back to an eye diagram. Compare it to the "Reference BER" picture by pressing the "R" key. Does it look roughly the same? When the notch is positioned outside the data spectrum, the system is much more tolerant of multipath distortion. It requires a much greater notch depth to create the same amount of degradation. Finish this exercise by plotting a point on your graph at 100% offset and 30dB notch depth. Congratulations! - you have just plotted a rough "m" curve!

Distortion Caused by High Power Amplifier Nonlinearities

Output power is a precious commodity in digital microwave systems. In order to get best Signal to Noise ratio, system designers often run their High Power Amplifiers (HPA's) near their maximum rated output (the compression range). In this lab, you will investigate the tradeoffs that occur when HPA's are operated in compression. Specifically, you will see what an HPA's characteristics are in the compression range and you will see what effect these characteristics have on digital microwave signals.

Procedure:

1. Move the probe pointer to the output of the demodulator and then press the down arrow to look at the time domain display of the demodulated I and Q signals.

2. Enter the Edit mode by pressing the Edit or "E" key and change the modulation type to 16QAM. (Make sure that the SNR=40 and filter alpha=.3). Press the Enter key to exit the Edit mode and recalculate the waveforms.

3. Once the "Working!!!" message disappears press the enter key again to look at the Vector Display of the 16QAM modulation. Press 5 ">" (greater than) arrows to adjust the gain, then press the "/" key to look at a Constellation diagram. You are now looking at the constellation diagram of an undistorted 16QAM signal.

4. Store this constellation diagram by pressing the "S" key. We will be comparing the distorted constellations to this diagram later.

5. Press the Enter key to get back to the waveform time display. Then press the Edit or "E" key to get to the edit mode. Press the "D" key to enter the Advanced design screen to change the HPA parameters.

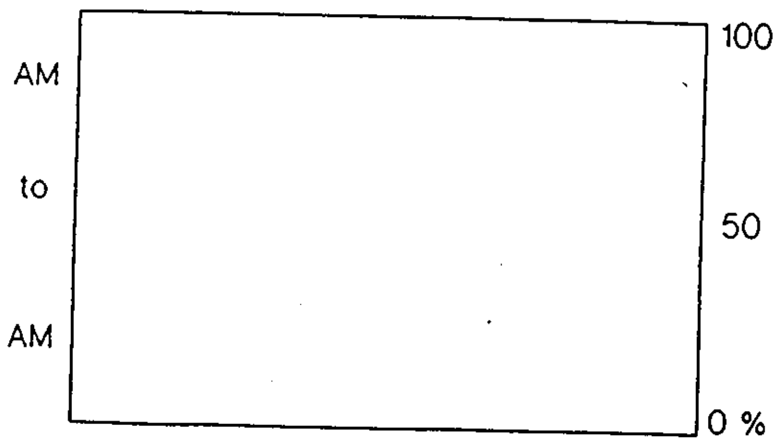
6. The large box on the right hand side of the screen describes the HPA characteristics. In the large box you see two displays. The upper one shows the amplitude at the output of the HPA vs. the amplitude at the input to the HPA. Ideally this should be a straight line with slope equal to the gain of the HPA. In the

bottom box you see the phase of the signal at the output of the HPA plotted against the input level. We arbitrarily call the phase of the output signal, measured at low levels, 0 degrees phase. Ideally, this phase should not change with input amplitude.

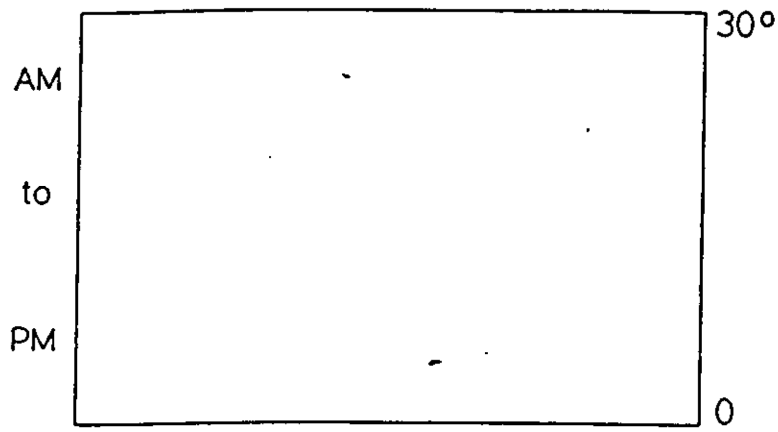
7. At the top of the large box, you will see the amount of HPA backoff - the amount the input signal is reduced or "backed off" from the HPA's maximum output. This number should be -15dB, the maximum backoff in this exercise. Note that at this backoff, we are operating in a very linear region of the amplifier, and the graphs of output phase vs. input amplitude (AM to PM) are ideal.

8. Press a left arrow to edit the HPA backoff and then press up arrows to change the backoff to -10dB. Notice what happens to the output phase vs. input amplitude graph. The amplifier is gradually moving into its nonlinear region which causes some unwanted (or incidental) phase deviation.

9. Now press up arrows to change the backoff to -3dB. Notice the actual amplitude compression in the upper graph of output amplitude vs. input amplitude. Draw the curve in the box provided below.



10. Look at the lower graph of phase shift vs. input amplitude. Notice that there are almost 30 degrees of phase shift at maximum input level. Draw the curve in the box provided below.



11. Now, let's observe the effect that a 3dB backoff has in the Vector Domain. Press the Enter key once to exit the advanced design screen and return to Edit mode. Press the Enter key again to exit the Edit mode and recalculate the waveforms.

12. Wait until the "Working!!!" message disappears (about 50 seconds). You should now be looking at the time display at the demodulator output. Press the Enter key to look at the Vector Display. Press 2 ">" (greater than) arrows to adjust the gain and press "/" to see a Constellation diagram. Compare this diagram to the undistorted diagram by pressing the "R" key to recall the undistorted diagram.

13. You should observe several distortions. First, you will see that the outermost 4 states have collapsed slightly to the center of the vector diagram. Why those states? Look at the first graph you drew above of output amplitude vs. input amplitude. Notice that at higher input amplitudes, the output amplitude no longer increases linearly with the input. Instead, the output amplitude stops increasing as the amplifier goes into compression. This is

what causes the outermost states to look squashed compared to the inner ones.

14. Second, look at the phase rotation of the inner 4 states vs. the outer 12 states. Note that the inner states are rotated counter-clockwise with respect to the outer states. Why does this happen? Again, refer to the second graph you drew above showing output phase vs. input amplitude. Note that the states with larger amplitudes are rotated more than the smaller amplitude states. Some of you may ask why the outer states are not rotated by 30 degrees as the graph shows. The reason is that the program automatically normalizes, or rotates, the diagram so that the outermost 4 states are always parallel to the sides of the display screen. This simulates the corrective effects of some types of carrier recovery schemes.

15. Finally, press the "/" key to return to Vector Diagram mode and press 18 left arrows to look at the eye diagram. Notice that the HPA nonlinearity also adds to the Inter-Symbol Interference as can be seen by the partial eye closure of the diagram.

These distortions also show up in the frequency domain. An unwanted side-effect of HPA distortion is that the frequency spectrum is broadened with unwanted distortion sidebands - possibly spilling over into adjacent channels, causing interference there as well.

16. We will now look at these distortion sidebands. Press the Enter key to return to the time domain waveform of the IQ demodulator output. Press one up arrow to get to the system overview picture. Now press two left arrows to move the probe pointer to the microwave portion of the system. Press a down arrow to look at the frequency domain waveforms of the transmitted and received spectrums. Compare the transmitted spectrum (obtained from signals just before the transmitter's High Power Amplifier) to the received spectrum below. Note that the spectra of the received signals are all a little wider at their bases due to the distortion in the waveform. You can try even less backoff (such as 0 dB) to see an even larger effect on the frequency spectrum.

You have now seen that although getting as much output power from your system as possible is important, it must be traded off with waveform distortions due to HPA nonlinearities as the amplifier operates in its compression range. The distortions due to HPA nonlinearities include compression of the outer states of the signal, rotation of inner states with respect to the outer states, and ISI - all of which combine to cause the system to be more error prone.

Conclusions:

As we have seen, there are large differences among the various modulation types in terms of their tolerances to noise. In general, the more complex the modulation type or the greater number of states, the less tolerant that signal will be to noise. This has been formally stated in what is known as the Shannon Limit Theorem. Having seen the noise on different signals, it should be fairly straight-forward to understand why this is true. As modulation complexity increases, the actual signal level difference between states decreases. As this difference decreases, it becomes more and more likely that the noise level will exceed this difference. This ability to choose tolerance to noise at the expense of information carrying capacity makes digital communications attractive for many long haul applications.

MSc in Communication Systems and Signal Processing

Laboratory Activity in Support of Lecture Course Module 'Performance of Communication Systems'

Overview:

In this laboratory session you will make use of the '*HP I-Q Tutor*' software package in-order to gain a further insight to the performance aspects of modern digital communication systems. The tools will allow you to investigate the *bit error rate* performance in terms of received *signal to noise ratio* for a variety digital modulation methods, impact of channel filtering, multipath channel impairments, non-ideal RF power amplification, and also an investigation of constellation (I-Q vector plots) and eye diagrams for a variety of channel conditions.

Procedure:

It is recommended that you follow the experimental procedure outlined in the HP I-Q Tutor *Digital Microwave Communications Guide*. However, if time permits, please consider an evaluation of the other modulation schemes also supported by the software.

Please record all observations in your laboratory note books and NOT on the I-Q Tutor guide sheets.

In order to run the software on the PCs in room 0.16, change directory to '*iqtutor*' and issue the DOS command '*iqtutorc*'

This laboratory will run on Monday 13th January 1997 (Wk11) starting at 2pm in room 0.16.

Hints:

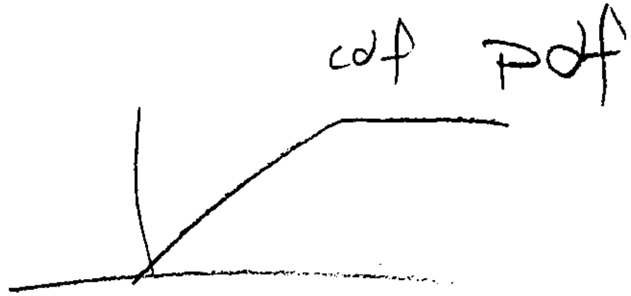
The I-Q Vector diagrams can be rotated using the '*PgDn*' and '*End*' keys.

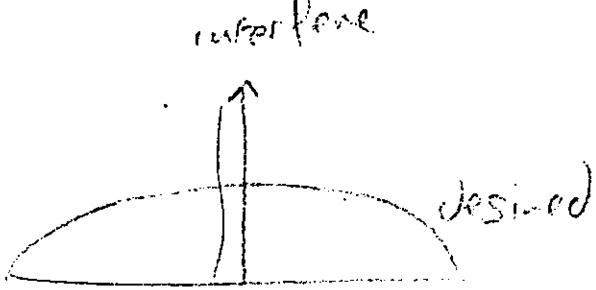
It is recommended that the multipath fading is switched-off during the evaluation of the non-linear amplifier impairments.

Suggestions for your Report:

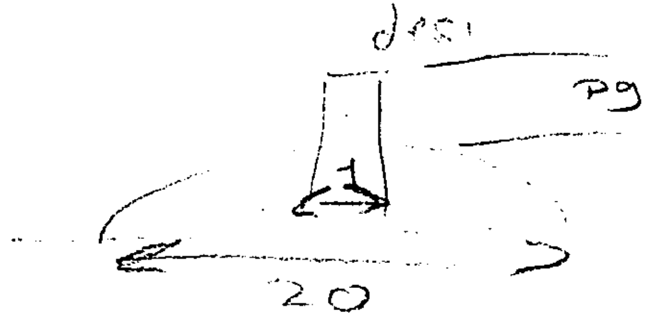
You are required to submit a report in the form of a technical note on this laboratory activity by 5pm on Friday 31st January 1997. Where possible include relevant theory taken from lectures, or other sources, in your observations and conclusions sections. Credit will be given for carefully presented results and a full discussion of observations.

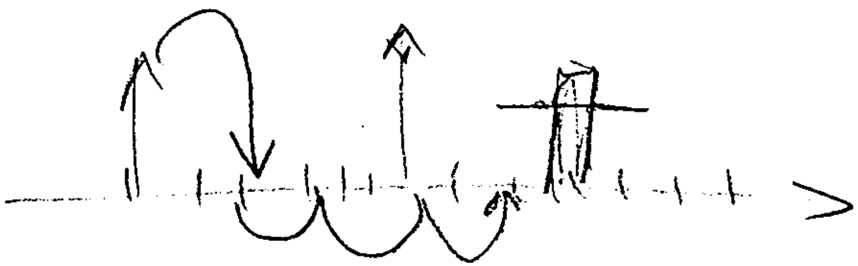
Finally, please return the HP I-Q Tutor Guide when you submit your report.





spread bw = $20 \times f_s$





$$\left(\frac{C}{I}\right)_{overall} = \frac{1}{10\ hops} \sum \left(\frac{C}{I}\right)_{hop}$$

interference diversity

UNIVERSITY OF BRISTOL

MSc in Communication Systems and Signal Processing

Laboratory Activity in Support of Lecture Course Module 'Mobile Radio Techniques (Term 2)'

Objectives:

This laboratory activity provides you with an opportunity to obtain some *hands-on* experience with 'Ray-Tracing' propagation prediction tools. The laboratory session will consist of a mixture of demonstrations and exercises, and as a precursor to using the tools we will give a brief overview of ray tracing methodology as applied to small cell systems.

Initially we will demonstrate the use of the EDX MCS (Microcellular Communications Simulator) 2D PC based ray tracing tool in an outdoor microcellular environment, illustrating how this tool can be used to extract both narrowband and wideband propagation information. You will then be given the opportunity to use this tool in order to extract the propagation characteristics from a predefined indoor environment. We will then offer you a demonstration of our in-house 3D tool called X-Ray. Finally, you will be able to try out X-Ray and examine some of its unique features such as real-time ray tracing and fully 'onward' propagating rays.

This laboratory also complements the RadioWave Propagation module, as well as supporting the assessed MRT laboratory which will be held next term. No formal assessment of this laboratory session is required, however it is suggested that you record all observations in your laboratory note book.

1.0: Suggested Procedures relating to EDX MCS PC Tool:

1.1: Launching MCS:

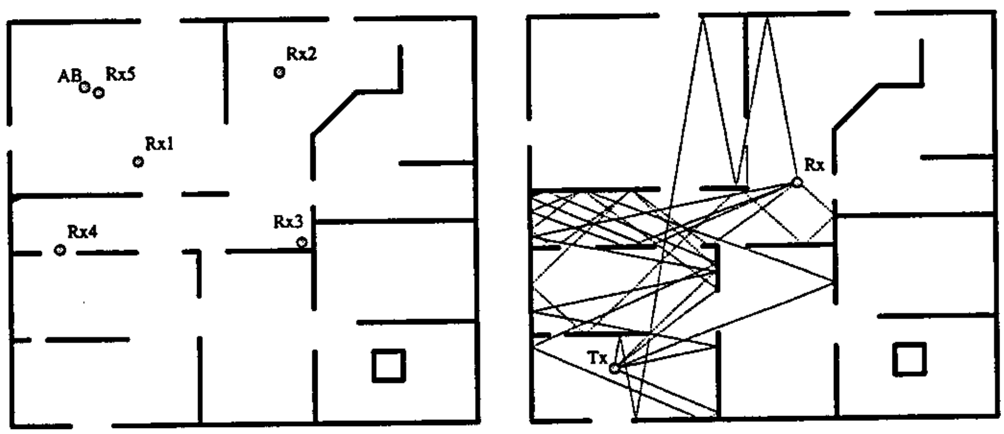
From DOS, issue the command 'mcs' from the directory d:\mcs. This should load and run the 'mcs' software. Note that key definitions are normally given at the foot of the screen, to select an option press the letter or character highlighted in green. The MCS program has been pre-configured with a typical indoor scenario, the following instructions will guide you through the features of this software.

1.2: Basic Ray Trace or Point Mode:

Once the main menu is displayed, select option 5 (by pressing '5') to bring up the main graphical interface. This should automatically load an indoor environment called 'laura3.ang' and also select a transmission centre frequency of 5.2GHz. This particular environment is an example of that in which high bit rate (23 Mbps) radio LAN products conforming to the ETSI HIPERLAN standard are expected to operate.

MCS operates in one of three modes, Point, Route and Grid. The point mode allows the propagation path between a fixed transmitter and receiver to be analysed in detail. Press 'P' to enter *point mode*, and use the 'I', 'O' and 'A' keys to adjust your view of the indoor environment to fit the screen (zoom In, zoom Out, pAn). You can move the receiver location with the mouse by pressing and holding the left mouse button.

Drag the *red receiver* so that it is in the same room as the transmitter labelled 'AB' (location Rx1 in figure 1). Now build the ray trace by pressing 'R'. The bottom portion of the screen will now display an empty power delay profile. Pressing the 'space bar' will single step through the calculated ray paths. If the active ray is purple, then this path is due to a direct line of sight or a reflected ray. A cyan ray represents a path which has undergone a single wall transmission. Note: transmitted rays do NOT undergo any further reflection or transmission, for non-line-of-sight scenarios this limitation can seriously affect the accuracy of the model.



(i) Example Receiver Positions

(ii) Typical Point Mode Ray-Trace

Figure 1: Example Output from MCS

For each path, observe the time delay and power as the impulse response is build-up (press ESC to view ALL the remaining rays or 'D' to display the power delay profile without having to single step through the individual rays). If required, clicking on Tm_scale↑ ↓ will adjust the resolution of the display window, a time window of 500ns should be suitable.

It is suggested that you record the number of rays and the rms delay spread for this environment (line of sight with heavy multipath). Sketch the shape of the power delay profile for these line-of-sight locations. What relationship, if any, exists between the received amplitudes and time delays in the displayed power delay profile?. Can you suggest a simple mathematical model to represent the indoor portable channel?.

Now move the receiver to some of the other rooms and examine the number of rays, the power delay profile and the rms delay spread (for example, locations Rx2 and Rx3 in figure 1). Compare the envelope of the power delay profile in non-line-of-sight locations with the previous line-of-sight cases.

Finally, place the receiver in the corridor below the transmitter (for example, try the left doorway leading into the bottom left hand room, Rx4 in figure 1). Repeat the above. Which type of locations exhibit the largest delay spread, why is this?

1.3: Spatial Fade:

Place the receiver in the same room as the transmitter. Press 'F' to obtain the received spatial envelope of the receiver when moving back and forth ±5 wavelengths (west to east motion). The blue line shows the mean power in dBmW, and the green line shows the instantaneous power variations (mainly fast fading). Also note the Rician K-factor is given for this location in the top left of the graphical output window. Examine the variations in the spatial fades and the Rician K-factor when the receiver is in close proximity to the walls. Observe how the K-factor varies as the receiver is moved towards the transmitter (i.e. Rx5).

Repeat the above for a non-line of sight position in the corridor.

1.4: Received Spectrum:

Place the receiver in one of the corridors or doorways (try locations with both high, >100ns, and low, <50ns, rms delay spreads) and observe the received power spectrum by pressing 'S'. Now, by pressing 'F9', the dynamic received power spectrum can be observed as the receiver moves over a distance of ±5 wavelengths. You will see that certain frequencies suffer selective fading (i.e. nulls will appear in the received spectrum). Is there any relationship between the degree of frequency selective fading and the magnitude of the rms delay spread?

Repeat this exercise for a line of sight position.

1.5: Received Signal Timing Variations:

Place the receiver in the corridor area for a location where the rms delay spread is >100ns, press "D" to determine the rms delay spread. Click on the Tm_scale↑ ↓ control to set the time resolution to 2500ns. Once the resolution has been set, press G. You will now see the received data pulse shape after transmission through the channel. Pressing "F9" shows an animation of the received waveform as the user moves over a 10 wavelength window. For large delay spreads, significant pulse distortion can be seen, the timing point is no longer always optimal at the yellow timing points. Press "G" again to switch back to the standard power delay profile view.

Move the receiver to a position with a low delay spread (<50ns). Press U and you will see the time varying pulses overlaid on the same plot. Note that for large delay spreads you can observe significant distortion and variation in the waveform shape. Press "U" once again to return to the standard power delay profile mode. Note: it is not the actual value of delay spread that is important but the ratio of this parameter to the system bit period.

Press ESC to exit point mode.

1.6: Route Mode:

The route mode allows the user to specify a path along which the receiver will move. Press 'R' to enter the route mode and adjust the display and pan as necessary. A test route will automatically be displayed. Launch the route parameter calculation routines for the predefined route by pressing 'P' (the required results should have been pre-computed and thus the results should be displayed quickly on the screen). The initial display will show a log distance scale, this can be changed back to linear by pressing 'L' ('G' returns to log mode).

Using the mouse, place the receiver on the start of the route and press the left mouse button (top right hand corner). A white marker line should now be displayed in the bottom graphics window to indicate your current route position. Follow the route and note how the power peaks around the location of transmitter "AB". NOTE: during this study only transmitter AB should be active.

Repeat the above for rms delay spread by pressing "D", note how the rms delay is at a minimum in the vicinity of transmitter AB.

It is possible to consider the impact of multiple transmitters by turning on more than one transmitter. Press ESC to go back to the "Point, Route and Grid" mode selector, then Press ESC again to go back to the main text menu. Press "2" to edit the transmit station parameters. You will see three transmitter lines, at the beginning of each line is a letter "Y" or "N". Using either the mouse or keyboard, click on each "N" and then press "F3" to turn on the transmitter ("Y" should now be displayed). Do this for both Tx AA and Tx AC. To confirm this action, press "F2" and then press ESC to go back to the main menu. Press "5" to re-enter the graphics screen and "R" to re-enter the route mode (you will now see three transmitters displayed on the screen).

Repeat the plots of power and delay spread. Note that each transmitter is assumed to operate on the same frequency and the optimum basestation is automatically selected (based on power) for each point in the study. Also, by pressing 'M' the most likely basestation server can be found. Finally, the carrier-to-interference ratio (C/I) can be found along the route by pressing 'R'. In a heavily loaded system the performance of the network is often interference limited rather that power limited, a C/I ratio > 10-12 dB is required by a system such as DECT.

1.7: Further Examples:

Try defining a route of your choice for either the indoor or outdoor environments. If you wish to consider the outdoor location you will need to edit the wall database file from "laura3.ang" to "city1.ang". In addition the location of the various basestations may well have to be edited (please see the demonstrator).

To define a new route, press S to begin, with the mouse place the red receiver at the start location and press F5, with the mouse or cursor keys move to the next point on the route and press F5 again, continue until you have reached the end of your desired route, then press ESC to view the route. To compute the route, press P (you may have to wait several minutes!)

1.8 Grid mode:

To exit the route mode press ESC. The final mode of operation is the GRID mode, as the name implies, this involves generating a grid of points and analysing the received signal properties at each point. This mode allows area wide statistics to be calculated and is interesting since it allows the cumulative distribution of both received power and rms delay spread to be calculated. In most system designs, coverage is planned for a certain percentage of the area. For an indoor environment, coverage may be desired for 90% of locations. Using the grid mode it is possible to calculate the percentage of coverage for each value of signal level and delay spread. The main drawback with a grid mode is the time required to compute the data. For a 25 by 25 point grid, 625 point calculations are required which at 1 second per point requires just over 10 minutes to compute. For a 100 by 100 grid the calculation time would be approximately 2 hours 45 minutes. As the complexity of the environment is increased the time per point will also increase. To be a useful design tool, the speed of such programs clearly have to be improved.

Before entering the grid mode, please turn off transmitters AA and AC using the method outlined in section 1.6 (i.e. press ESC, ESC, 2, .etc). To enter the grid mode press G from the main 'Point, Route, Grid' menu. It is now possible to display a map of either received power, rms delay spread or co-channel interference. To display the power grid press P, note only transmitter AB should now be active, if this is not the case please see a demonstrator. To display the rms delay spread grid press D. Different colours are used to display various parameter ranges, it is also possible to change these levels by pressing E. The cumulative distribution of both power and rms delay spread can be displayed by pressing L (ESC to quit). As for the route mode it is possible to select which transmitters are active. For each transmitter in turn, make a note of the rms delay spread and the power level that 90% of locations experience.

To display the grid of co-channel interference press C, remember more than one transmitter should be active for sensible results!.

2. Introduction to X-ray

X-ray is a UNIX based ray-tracing program being developed in-house at the University of Bristol. This software is currently being developed and is still far from finished. However, the program represents the state-of-the-art as far as site-specific propagation modelling is concerned. One of the main motivations behind X-ray is processing speed. The software has been optimised for the UNIX environment and is capable of analysing extremely complex environments.

In this lab two databases are available for study, the first is an indoor location similar to that analysed with the MCS software. The second is a simplified version of a Bristol microcell (College Green & Park Street) and goes some way to illustrating how such site specific models may be used in the future for microcellular planning. This data file was extracted from the Ordinance Survey 'landline' database for the centre of Bristol.

2.1 Launching X-ray

Although X-ray runs on UNIX workstations it is possible to display the results on a PC running X-windows emulation. To run the X-ray software click of the Xray icon in the X-ray program group. Enter your login name and password, then click on OK to initialise the program (this may take several seconds).

2.2 Loading a database

The X-ray program operates via a windows based user interface. The various options are displayed in the menu bar. To load a database go to the FILE menu and click on OPEN. A file selector box will appear containing a number of different directories. Type in the filter box (top of dialogue box) the following path: /users/tutor/bin/*.map, then click on the filter button. Three possible maps will now be displayed in the Files window. Click on either HAGENUK.MAP for the indoor case or BRISTOL.MAP for the outdoor simplified environment. After clicking on OK, the appropriate database should be displayed on the screen.

2.3 Performing "Real-Time" Ray Tracing

Before a ray trace can be performed several parameters need to be confirmed. From the TX menu select PLACE TX. With the mouse you can now place a transmitter at any location within the map, press the left mouse button to select the final location. Select the RAY CONFIG option from the CONFIG menu. A dialogue box will now be displayed allowing the number of reflections and transmissions to be altered to ANY desired value. For the outdoor environment, 7 reflections and 1 transmission is recommended, for the indoor model, 4 reflections and 2 transmissions is suggested, however you may wish to experiment with these values (for example, 20 reflections and 0 transmissions!).

To begin the ray tracing process click on the RAY TRACING button on the left-hand side of the screen. There will be a small delay will the software builds some internal data tables (known as image maps). You can now click anywhere on the map and the ray trace for that location will be displayed almost instantly (the actual time will depend on the object and configuration complexity and the network loading). By holding down the left mouse button and dragging the receiver around the test location it is possible to display a "real-time" ray trace. Experiment moving around various rooms and/or streets and watch how various rays arrive at the receiver.

For the indoor environment, experiment with the number of transmissions allowed and the location of the transmitter. With MCS only one transmission was permitted and no onward propagating rays were traced. With X-ray, even with one transmission it is possible for further reflections to take place. In many locations no rays will be traced unless sufficient transmission is allowed.

UNIVERSITY OF BRISTOL

MSc in Communication Systems and Signal Processing

Laboratory Activity in Support of Lecture Course Module 'Mobile Radio Techniques'

Objectives:

This laboratory activity will develop the link between propagation information and system performance. The laboratory session will consist of a mixture of exercises using mainly the EDX MCS package. An indoor operating environment is assumed in this study, however by loading the 'city1.ang' database it is possible to re-run the analysis in an outdoor microcell.

In the previous MRT laboratory (MRTLab1) the EDX MCS (Microcellular Communications Simulator) ray tracing tool was used to investigate the propagation conditions for a microcellular environment. In this session, the performance of a digital communications system will be investigated as a function of the channel characteristics encountered. For a number of modulation schemes you will study the Bit Error Rate (BER) performance in particular environments as a function of signal level, vehicle speed, operating frequency and data rate. The concept of an irreducible 'error floor' will be introduced and the factors affecting its magnitude investigated. The MCS software will also be used to evaluate the impact of directional antennas in a microcellular environment.

Using MATLAB, the idea of coherence bandwidth will be explored and typical frequency domain characteristics generated for various values of rms delay spread and operating bandwidth. From these plots, the benefits of wideband systems such as CDMA and COFDM can be visualised.

Finally, *if time permits*, a DOS program is available to illustrate the performance of a number of different modulation and equaliser configurations in an indoor environment, this software was used in the design of the ETSI HIPERLAN standard.

Remember, you will be required to submit a report relating to this laboratory and it is therefore suggested that you record all your observations in a laboratory note book.

1.0: Suggested Procedures relating to EDX MCS PC Tool:

1.1: Launching MCS:

From DOS, issue the command 'mcs' from the directory d:\mcs. This should load and run the 'mcs' software. Note that key definitions are normally given at the foot of the screen, to select an option press the letter or character highlighted in green. The MCS program has been pre-configured with a typical indoor scenario, the following instructions will guide you through the features of this software.

1.2: Basic Ray Trace or Point Mode:

Once the main menu is displayed, select option 5 (by pressing '5') to bring up the main graphical interface. This should automatically load an indoor environment called 'laura3.ang' and also select a transmission centre frequency of 5.2GHz. This particular environment was used in the design of the HIPERLAN standard.

MCS operates in one of three modes, Point, Route and Grid. The point mode allows the propagation path between a fixed transmitter and receiver to be analysed in detail. Press 'P' to enter *point mode*, and use the 'I', 'O' and 'A' keys to adjust your view of the indoor environment to fit the screen (zoom In, zoom Out, pAn). You can move the receiver location with the mouse by pressing and holding the left mouse button.

1.2.1: Errors Due to Additive White Gaussian Noise:

The system is currently operating using differential QPSK 'QPSK-D' at a bit rate of 100 kb/s, in this configuration bit errors will occur whenever the received signal level falls below -90dBm. Move the receiver to various line-of-sight and non-line-of-sight locations throughout the building. At each location, press 'F' to display the spatial envelope variation. The purple line shows the instantaneous bit error rate arising from AWGN distortion (the effects of dispersion and Doppler are ignored in this mode). For LOS locations near to the transmitter ('AB') no error will be seen since the signal level is high, however for non LOS locations, significant error can occur. When Rayleigh and Rician fading is present, the average BER increases for a given average signal level and the resulting bit errors occur in bursts.

Press 'Y' to access the system information screen, increase the bit rate to 1Mb/s (press ESC to return to the graphics screen).

- *What impact does this increased data rate have on BER?*

Explain the relationship between S/N and Eb/No. Press 'Y' and return the data rate to 100 kb/s, now change the modulation from 'QPSK-D' to '16-QAM-C' (highlight modulation and press 'F3' to alter values).

- *Does 16-QAM have a bigger or smaller bit error rate?*

Explain why this result occurs using constellation diagrams for both 16-QAM and QPSK. Press 'Y' and re-select 'QPSK-D', under the 'OTHER' menu, alter the error rate analysis to 'RMS DELAY SPREAD' (use 'F3' to cycle through the entries).

1.2.2: Irreducible Errors Due to Delay Spread

Position the receiver at a point in the building (non line-of-sight) with an rms delay spread of approximately 100ns (press 'D' to calculate the delay spread at the *red receiver* location). The rooms to the right and below the transmitter should offer suitable locations. After pressing 'D' you will see the power delay profile displayed in the bottom half of the screen. If required, click on Tm_scale↑ ↓ to adjust the resolution of the display window, a time window of 500ns should be suitable.

It is suggested that you sketch the profile shape, record the number of rays and note the rms delay spread for your chosen point. Now press 'F' to display a plot of the narrowband fading envelope over a 10 wavelength window (ideally you should see several deep fades). For a wideband transmission (i.e. a bandwidth greater than the coherence bandwidth of the channel), would you expect the envelope fading to be constant across the frequency band?

The current MCS system settings assume differential QPSK operating at a bit rate of 100 kb/s. The purple line in the bottom 'SPATIAL RESPONSE' window shows the instantaneous bit error rate arising from the effects of time dispersion (the impact of Doppler shifts and AWGN noise are ignored in this mode). At the current test point, the rms delay spread should be 100ns and the bit period 10000ns (i.e. $T_{rms}/T_b = 0.01$). Record whether any bit errors occur. Now press 'Y' to access the system information screen and increase the bit rate from 100kb/s to 1Mb/s (press ESC to return to the analysis mode). The bit period is now 1000ns, hence $T_{rms}/T_b = 0.1$.

- *For what value of T_{rms}/T_b would you expect significant errors to occur?*

Note, irreducible errors now occur in bursts, make a note of the instantaneous bit error rate that occurs in a typical burst. Estimate the average bit error rate for the current location, how does this compare with the burst bit error rate? Are the error bursts correlated with the narrowband signal envelope and if so can you explain the cause of this relationship.

Increase the data rate to 5 Mb/s, sketch the error pattern that occurs. Do errors still occur in bursts? Experiment with different locations and data rates. Compare the system performance in a line-of-sight location with a non line-of-sight location (if possible keep the rms delay spread constant). For a given delay spread, why do you think performance is better in line-of-sight locations?

1.2.3: Irreducible Errors Due to Doppler

Press 'Y' and alter the error rate analysis to 'Doppler'. Make sure that differential QPSK (QPSK-D) is selected, edit the data rate to 10 kb/s and ensure that the vehicle speed is set to zero. Select a position within the building that results in significant envelope fading (press 'F' to display the fading envelope). Press 'Y' and enter a vehicle speed of 5 km/h. The purple graph shows the irreducible error rate due to Doppler (Note: errors due to dispersion and AWGN noise are ignored in this mode). Note that errors occur in bursts, are the error bursts correlated with fade depth and if so explain why this relationship exists (see MRT notes).

Edit the mobile speed to 50 km/h and note what happens to the bit error rate. Edit the bit rate to 100 kb/s, what happens to the irreducible bit error rate? Repeat the above tests with a carrier frequency of 900MHz.

- *Explain the significance of normalised Doppler*

How can the concept of normalised Doppler explain the trends in your results?

1.3: Received Spectrum:

The following exercise was part of the previous laboratory, however now that you have covered most of the course you may find it useful to repeat the process. Place the receiver in one of the corridors or doorways (try locations with both high, >100ns, and low, <50ns, rms delay spreads) and observe the received power spectrum by pressing 'S'. Now, by pressing 'F9', the dynamic received power spectrum can be observed as the receiver moves over a distance of ±5 wavelengths. You will see that certain frequencies suffer selective fading (i.e. nulls will appear in the received spectrum). Is there any relationship between the degree of frequency selective fading and the magnitude of the rms delay spread? Repeat this exercise for a line of sight position.

1.5: Received Signal Timing Variations:

The following exercise was part of the previous laboratory, however you may find it useful to repeat the process. Place the receiver in the corridor area for a location where the rms delay spread is >100ns, press 'D' to determine the rms delay spread. Click on the Tm_scale↑ ↓ control to set the time resolution to 2500ns. Once the resolution has been set, press 'G'. You will now see the received data pulse shape after transmission through the channel. Pressing 'F9' shows an animation of the received waveform as the user moves over a 10 wavelength window. For large delay spreads, significant pulse distortion (intersymbol interference) can be seen to occur, the timing point is no longer always optimal at the yellow timing points. Press 'G' again to switch back to the standard power delay profile view.

Move the receiver to a position with a lower delay spread (<50ns). Press 'U' and you will see the time varying pulses overlaid on the same plot. Note that for large delay spreads you can observe significant distortion and variation in the waveform shape. Press 'U' once again to return to the standard power delay profile mode. Note: it is not the actual value of delay spread that is important but the ratio of this parameter to the system bit period. Press ESC to exit point mode.

Explain why the 'instantaneous' timing point varies in a time dispersive channel, what is the impact of these variations in a fast and slow varying fading channel.

1.6: Route Mode:

Press 'Y' and ensure the following settings, frequency: 900MHz, modulation: 'QPSK-D', data rate: 1000kb/s, vehicle speed: 0km/h, Error rate analysis: 'Signal-to-Noise'. The route mode allows the user to specify a path along which the receiver will move. Press 'R' to enter the route mode and adjust the display and pan as necessary. A test route will automatically be displayed. Launch the route parameter calculation routines for the predefined route by pressing 'P' (the required results should have been pre-computed and thus the results should be displayed quickly on the screen). The initial display uses a log distance scale 'G', this can be changed to linear by pressing 'L'.

Using the mouse, place the receiver on the start of the route and press the left mouse button (top right hand corner). A white marker line should now be displayed in the bottom graphics window to indicate your current route position. Follow the route and note how the power peaks around the location of transmitter "AB". NOTE: during this study only transmitter AB should be active. The purple line shows the average bit error rate occurring due to AWGN distortion. Note: the average BER is not only affected by the average signal to noise ratio but also the received Rician K-factor. Press 'Y' and alter the carrier frequency to 5.2 GHz, how is the resulting BER affected?.

Press 'Y' and edit the error rate analysis to 'rms delay spread'. Press 'D' to display a plot of the rms delay spread (green) and resulting bit error rate (purple) along the route. Edit the data rate to 5 Mb/s and note the change in delay spread. If the maximum bit error rate is 1 in 1000, what is the maximum bit rate that can be achieved along the route? Increase the transmit power by 20 dB (press 'Y' and edit the noise power to 0 dB). Does this increase in transmitter power result in a change in the irreducible bit error rate?

Press 'Y' and set the following parameters, frequency 5.2 GHz, modulation: QPSK-D, data rate: 10 kb/s, vehicle speed: 5 km/h, error rate analysis: 'Doppler'. Press 'P' to display the received power against the irreducible error rate due to Doppler. Note how the error floor is NOT correlated with the received signal power. Increase the mobile speed to 50 km/h, note the new irreducible error floor. Decrease the transmit power to its original value (press 'Y' and edit the noise power back to 20dB). Does this lowering of transmitter power result in a change in irreducible bit error rate?

1.7: Combined analysis:

Press 'Y' and select error rate analysis 'combination'. The resulting bit error rate will now be generated as a combination of the irreducible errors due to Doppler and time dispersion and the errors resulting from AWGN. Try editing the data rate, vehicle speed and receiver sensitivity (to de-sensitise the receiver increase the noise power density) and note the resulting performance. Practical systems are often known as noise limited, dispersion limited or Doppler limited.

1.8: Applicable of Intelligent or Adaptive Antennas for Wireless Networks:

By employing adaptive or directional antennas at basestation sites within a wireless communication network, the impact of multipath upon system performance can be considerably reduced.

Configure mcs to use the environment database 'city1.ang' and a transmission frequency of 1800MHz. Check that transmitter AA is active and that both the mobile and basestation are using the antenna called 'omni.pat'. Place the basestation in the northern sector of the city above the Plaza. Using Grid mode calculate both the rms delay spread and BER distribution assuming a QPSK modem operating at 1Mbit/s. In terms of acceptable QoS, a minimum threshold for BER of 10^{-3} should be assumed.

For this system configuration, where is service available?

Now exchange the basestation antenna system for a directional antenna, *dir_15.pat*, and manually steer the antenna south towards the Plaza (180 degrees). Recalculate the rms delay spread distribution and service availability.

Comment upon these results
How could the antenna be automatically steered?

2.1 MATLAB Software

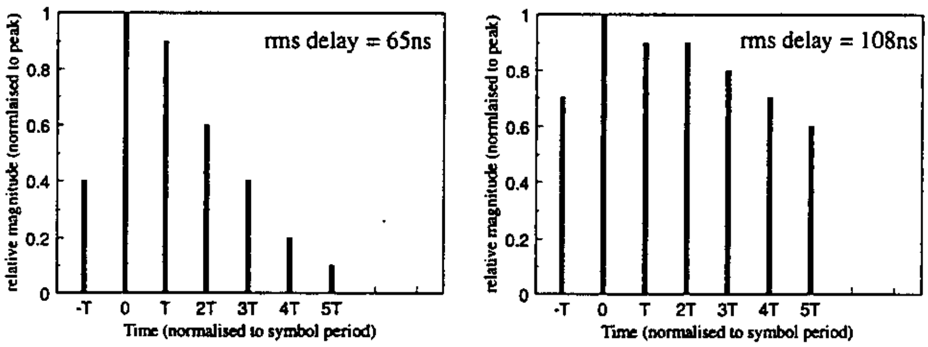
Load MATLAB and ask the demonstrator for a copy of the file ani_freq.m. From the MATLAB command window type cd <directory> where <directory> is the location of the ani_freq.m file. Type ani_freq to run the frequency domain analysis software. Enter the rms delay spread you wish to consider, for an indoor location try 100ns, for an outdoor location try 2000ns. Assume 20 time bins. For an indoor system, a bandwidth of 1-50MHz is appropriate. For an outdoor location, a bandwidth of 0.05 to 1MHz should be selected. Assume 100 frequency bins and 32 frames of animation. The calculation of the 32 frames will take several minutes. The yellow line shows the received envelope as a function of frequency, the purple line shows the mean power over the displayed bandwidth. If there is significant frequency selective fading over the band, the magnitude of the purple line remains fairly constant. However, for narrowband transmissions, the purple line can suffer from significant fading. The animation shows how the magnitude and position of the frequency notches move as the user moves. Explain how systems such as COFDM and frequency hopping can exploit this frequency diversity.

2.2 DOS 'HIPERLAN' software

If time remains, ask for a copy of the indoor 'HIPERLAN' software. Copy all the files from the RES10 directory onto the PC. To run the software go to the RES10 directory and type res10. The main menu will then appear (after pressing a key) and various modulation and equalisation parameters may be altered by selecting the appropriate choice. To ease the use of this software a number of pre-set configurations have been defined and these can be accessed by pressing "L".

Once "L" has been pressed a list of pre-sets will occur, selecting "1" loads the initial configuration which is $\pi/4$ QPSK. The first four configurations compare the performance of equalised $\pi/4$ QPSK, OQPSK, 2CPFSK and 4CPFSK in a channel without dispersion, noise or fading. These set-ups use an LMS update algorithm, 600 training iterations and a DFE(6,5) equaliser configuration. Once the configuration has been selected, the main menu re-appears and the simulation will begin once "R" is pressed. For $\pi/4$ QPSK, the error rate is reduced to below 1e-5 after 200 iterations (perfect performance is achieved since the channel is assumed ideal and the modulation exhibits no non-linear ISI). In addition to showing the mean squared error as a function of iteration number, the constellation diagram both before and after equalisation is displayed. In these diagrams, two colours have been used to represent the odd and even constellation points in $\pi/4$ QPSK. Once the constellations have been displayed, pressing any key will display the filter co-efficients, the symbol error rate and the residual mean squared error. Pressing the keyboard a further two times will return the user to the main menu. To determine the impact of using the RLS algorithm, press "2" followed by "R" (this will replaced the LMS with the RLS algorithm). Running this configuration, the average error on each symbol is reduced below 1e-4 after just 13 iterations. This highlights the main advantage of the RLS algorithm, namely rapid convergence. In this simulation a data rate of 30Mb/s is assumed for $\pi/4$ QPSK and 15Mb/s for OQPSK.

Constant envelope modulation is highly advantageous for systems such as Hiperlan which operate using large bandwidths, configuration '4' investigates the performance of GMSK. A Gaussian filter with a BT product of 0.5 has been assumed and, since the scheme is effectively OQPSK, a data rate of 15Mb/s is assumed. Running this configuration, the resulting constellation diagram can be seen to be relatively clean at the receiver. More importantly, running the simulation with the RLS algorithm shows that the scheme remains stable and converges well within 48 iterations. Performance can be improved by editing the value of lambda (the RLS forgetting factor, press "D" and enter "0.9") - re-running the simulation now results in a more stable operation).



(i) Channel 2 (ii) Channel 3

Figure 1: Channel delay Profiles

Set-up '5' investigates the performance of GMSK at 15Mb/s with a DFE[6,5] and the LMS algorithm (the profile shown in figure 1(ii) was assumed with an rms delay spread of 108ns). Running this simulation reveals the viability of the above proposal with four distinct constellation points being seen after equalisation. However, using the LMS algorithm more than 400 iterations were required to achieve a reasonable degree of convergence.

The use of a simple LTE structure is investigated in set-up '6'. Using an LTE[6] with three delayed taps and 2 future taps (optimal for the profile shape assumed), performance is disappointing and is expected to degrade rapidly in noise. A DFE[6,5] effectively spans 11 symbols and this partly accounts for its superior performance relative to the 6 symbol span proposed with the LTE structure. Pre-set '7' looks at GMSK using the RLS algorithm and a DFE[6,5].

Summarise the performance of the LMS and RLS algorithms in terms of convergence speed. How does a DFE achieve its better performance in a noisy environment?

3.0 Full Report:

You are required to submit a full report on this laboratory activity, and also the relevant sections from MRTlab1 by 5pm on Friday 22nd March to either Dr Nix or Dr Beach. It is suggested that you include relevant propagation theory taken from lectures or appropriate references thus supporting the analysis undertaken, and particular attention should be made to the impact of noise and propagation upon the QoS of mobile wireless networks, as well as performance enhancement techniques such as adaptive antennas and equalisers.