Wireless Mobile and Personal Broadband Communications: From Myth to Reality!

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Introduction

Today's telecommunication networks are experiencing a rapid evolution as a result of the increasing advances in enabling technologies. Multimedia and computer communications are playing an increasing role in today's society, creating new challenges to those working in the development of telecommunication systems. Besides that, the telecommunications industry means to establish more and more wireless links between terminals. Thus the pressure for non-wired systems to cope with increasing data rates is enormous, and Wireless Broadband Systems (WBS's), those with data rates higher than 2 Mb/s, are emerging rapidly, even if at this moment applications for very high transmission rates do not exist[1].

Several WBS's are being foreseen for different users with different needs: they may accommodate data rates ranging between 2 Mb/s and 155 Mb/s (for the time being!?); terminals can be mobile or portable and moving speeds can be as fast as that of a fast train; users may or may not be allowed to use more than one channel if their application requires not be fixed, or dynamically allocated according to the user's needs; communication between terminals may be done directly or go through a base station; Asynchronous Transfer Mode (ATM) technology may possibly be used; and so on . Many other cases can be listed as making the difference between various perspectives of a WBS, but two major approaches are emerging: Wireless Local Area networks (WLAN) directed to communications between computers, of which High-Performance Radio LAN (HIPERLAN) and IEEE 802.11 are examples, and Mobile Broadband System (MBS), intended as a cellular system providing full mobility to Broandband Integrated Services Digital network (B-ISDN) users [2].

The MBS was a project within the RACE (Research and development of Advanced Communication in Europe) framework to develop a third-generation digital micro-cellular service to make the B-ISDN's available to mobile users. Relevant research activities are also running in Canada, Japan and Australia(Table1). Two 1 GHz bands have provisionally been allocated at 62 and 65 GHz, for the down and up links, respectively(MBS). By operating within the oxygen absorption bands, the micro-cells will have coverage typically of about 100m, although the use of directional antennas along highways, for example, could extend this range. With data rates of up to 155 Mb/s, MBS is being developed to provide full multimedia services of data, voice and video to the mobile user. The system is designed to have application in a wide variety of areas, for example in the emergency services, for mobile local area networks (LANs) and for television outside broadcasts such as electronic news gathering.

Applications in the emergency services could, for example, provide live audio and video information from the scene of an accident to doctors at the hospital, who could then give advice to medical staff in attendance at the accident. Fire services could employ small helmet-mounted cameras to transmit video to temporary control centres to enable guidance to be given to fire fighters. Although wireless LANs are currently employed in the exchange of data, applications being considered for the future include the need for video, for example in the use of robots in hazardous locations, where the robot may be operated by remote control using high-definition video from a robot-mounted camera [4]. In outside broadcasts of television, a number of different television cameras at different locations in a sports arena, for example, could be connected to a local control centre using MBS links. This would provide a high level of flexibility and, further, enable the system to be installed very quickly. Other applications envisaged for MBS include such diverse areas as traffic advice, pictorial data for travel, access to banking services for mobile

Invented Region	***Europe (MBS)***	***Canada***	***Japan***	***Australia***
Operator	public, private	private	private	private
Data Rate	155 Mbit/s	155 Mbit/s	155 Mbit/s	100 Mbit/s
ATM support	yes	yes		yes
Mobility	up to 100 km/h	portable	portable	2m/s
Applications	in-/outdoor	indoor	indoor	indoor
	all business sectors	office	office	office
Frequency bands	62-65 GHz	20-60 GHz	59-64 GHz	60/40-65 GHz
Modulation	16OQAM/4OQAM	BPSK	BPSK	
Access Method	TDMA	TDMA	TDMA	TDMA
Duplex Method	FDD	TDD		
Number of Channels	34			
Channel Allocation	dynamically	fixed		dynamically
Handover	yes			

Table1. Relevant research activities

users, interconnection of mobile LAN, surveillance and military applications. The Mobile Broadband System will depend critically on the development of low-cost millimetre-wavecomponents and systems, but it is seen as having enormous potential as next generation multimedia communication service for a very wide range of user applications in a whole host of fields [4].

At millimetre waves the maximum power density for continuous exposure for the general public is 1 mw/cm^2. Assume that this is set at 6 cm of an antenna with 9dBi directivity of its radiation pattern, the transmitted power is limited to about 50 mW at the remote stations. Limiting transmitter power levels to some tens of mW is not only a safety requirement, but it is also a measure to limit the coverage range in order to improve the *frequency reuse* capabilities, with the final goal again to increase network capacity[5].

With respect to indoor applications, high traffic density can be achieved by using frequency bands above approximately 40 GHz due to the possibility of frequency reuse between neighbouring rooms because of the severe attenuation of electromagnetic waves at these frequencies by most inner walls. With respect to frequency reuse in outdoor cells, the band around 60 GHz is especially advantageous because of the specific attenuation characteristic due to atmospheric oxygen of about 15 dB/km.

At millimetre waves, modelling of wave propagation is usually done on the basis of Geometrical Optics, by using ray-theory (either the image or the ray-launching approach). Modelling at such high frequency bands poses the problem of accurately describing the propagation scenario at the wavelength scale (wavelength is less than 5mm at frequencies above 60 GHz).

1.0 Channel Sounding Techniques

Because of the importance of the multipath structure in determine the small–scale effects(delay spread, coherence bandwidth, Doppler shift) in the wireless mobile communication channel a number of wideband channel sounding techniques have been developed. Channel Sounders are often categorised in four main classes: Periodic pulse, pulse compressing, convolution matched filter and frequency sweep sounders. In a pulse channel sounder, a short-RF pulse is transmitted, and the received signal envelope is detected in the receiver. Only information about the received signal amplitude is obtained, it is thus not possible to get any information about Doppler spectra.

The basis for all pulse compression systems is based on the principal that if white noise is applied to the input of a linear system, and if the output is cross-correlated with a delayed replica of the input then the resulting cross-correlation coefficient function is proportional to the impulse response of the system. In practice, it is unrealistic to generate white noise, and, as a result, experimental systems must employ deterministic waveforms, which have a noise like character. The mostly known examples of such waveforms are the maximal length Pseudo Random Binary Sequence (PRBS). One way of affecting pulse compression is to design a system where a PRBS is used to Bi-Phase modulate a carrier prior to transmission. At the receiver the signal processing is based on correlating the Inphase I and Quadrature Q components with an identical PRBS to that used at the transmitter, but clocked at a slightly slower rate. This process is known as swept time-delay cross correlation (STDCC) method .

The frequency sweep technique had been used widely in radar theory. A Vector Network Analyser (VNA) controls a synthesised frequency sweeper. The sweeper scans a particular frequency band (centred on the carrier) by stepping through discrete frequencies. This complex frequency response is then converted to the time domain by taking the inverse Fourier transform, giving a band limited impulse response. A second method based on the frequency sweep technique is the chirp using a digital signal processor (DSP) to perform correlation in the receiver. The frequency swept method offers high resolution, has a constant transmitted power that allows larger areas to be measured, and reduces the effects of non-linearities.

1.1 Design and Implementation of a Frequency Swept Wideband Channel Sounder

1.1.1 Transmitter

“Fig.1” shows the block diagram of this system. At the transmitter the VNA’s (HP8714C) synthesised output is step-swept between 1-2 GHz, and then up-converted (mixed) to a 62.4GHz carrier prior to transmission. This PLO can be either synthesised from a 100 MHz internal oven controlled crystal or an external reference one. The output of the 100 MHz internal crystal is coupled at the output and initially was used as reference for both PLO’s at the transmitter and the receiver. However it was found that the receiver PLO frequency was not exactly as that of the PLO at the transmitter. This is because the frequency of this crystal is about 99.98 MHz and not 100 MHz. So an external 100 MHz oven controlled crystal was used as a reference for both 62.4 GHz PLO’s. The up-converter has an IF bandwidth from DC-6 GHz and can also be used as a modulator. The output of the up-converter is two sidebands at a level approximately 6-7 dB below the swept IF signal level.

1.1.2 Mobile Receiver

At the mobile receiver a 62.4GHz phase locked oscillator is synthesised from the same 100 MHz oven controlled crystal by connecting a 50m Sucoflex flexible coaxial cable (very low loss, 0.23-0.73 dB/m) from the transmitter to receiver. The 1-2 GHz signal is coherently detected, amplified by a low noise amplifier (LNA) with bandwidth 900-2000 MHz and 32 dB gain and then is fed-back through a second 50m Sucoflex flexible coaxial cable to the receive port of the VNA to measure the channel transfer function. The main parameters of the channel sounder are given in Table 2.

The time resolution $\tau_{res,}$ that can be achieved with a 1 GHz bandwidth is1ns and is inversely proportional to the sweep bandwidth BW_{meas}, and is given by:

$$\tau_{res} \approx \frac{1}{BW_{meas}} \tag{1}$$

The value of the time resolution of this sounder is mainly limited by the bandwidth of the LNA at the receiver. The resolution can be increased to 0.5ns by sweeping the VNA over the bandwidth of 1-3 GHz and replacing the LNA with one that can accommodate this bandwidth.

The frequency resolution depends on the number of steps used to sweep over the 1 GHz bandwidth. For 1600 frequency steps $\Delta f_{meas,}$ (1601 points), the frequency resolution is 625 KHz, and is given by:

$$F_{res} \approx \frac{BW_{meas}}{\Delta f_{meas}} \tag{2}$$

The unambiguous time range $\tau_{unamb,}$ is 1600ns and is given by:

$$\tau_{unamb} = \frac{\Delta f_{meas}}{BW_{meas}} = \frac{1}{F_{res}} \tag{3}$$

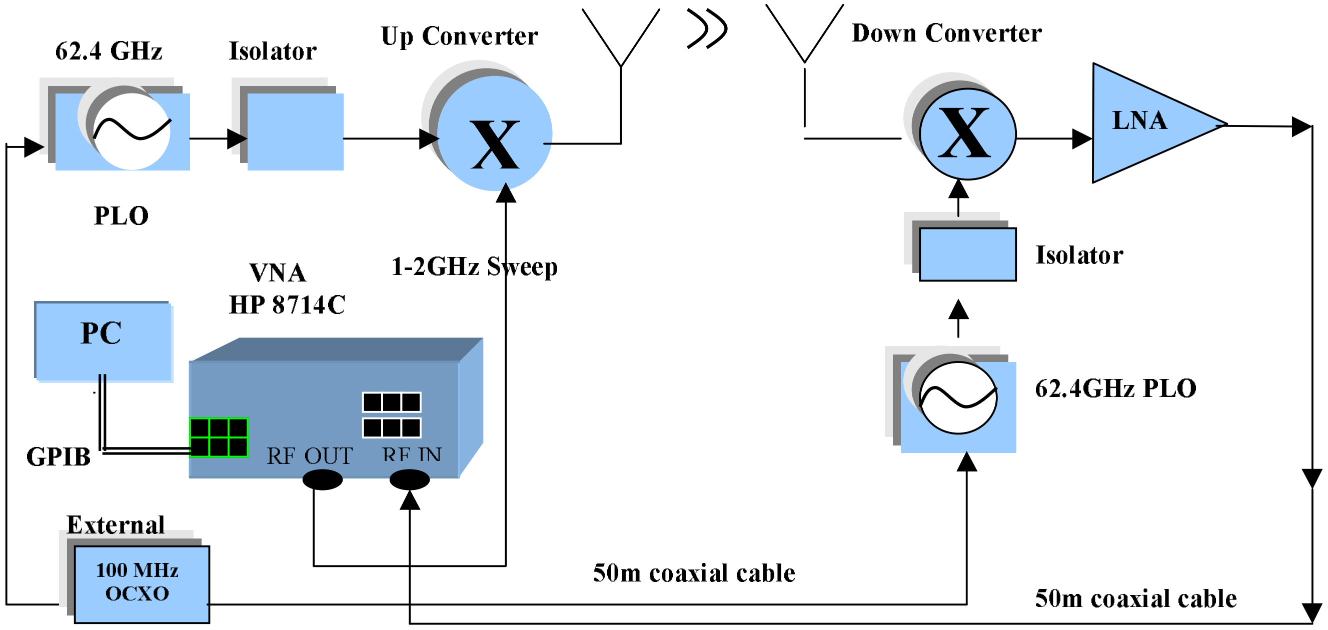


Fig.1 The 62.4GHz Frequency Domain Channel Sounder.

1.1.3 Data Acquisition

The VNA settings are automated using the instrumentation package LabView and GPIB interface. A personal computer (PC), -Pentium II, 333 MHz, 128 Mb/s- was used for data acquisition. This package offers the features of transferring, displaying, storing and analysing the data at the same time. The instrumentation software was developed to operate in two modes:

- In continuous mode (no averaging) in order to enable examination of the channel statistics with time (i.e. presence of people).
- In discrete mode (averaging) to enable examination of the channel statistics with respect of the position of the terminals (i.e. antennas separation, height) and for noise reduction.

Parameter	**Value/Range**
Carrier Frequency	62.4 GHz
Sweep Bandwidth	1-2 GHz
Output power prior to antenna	2 dBm
Dynamic Range (Noise floor -110dBm)	>70 dB
Time resolution	1 ns (Rectangle window)
Spatial resolution	0.3m
Range	50m

Table .2 Channel Sounder Specifications

1.2 Channel Sounder Testing

1.2.1 Calibration

Calibration of the channel sounder is necessary to remove tracking error of the source and more importantly, any frequency dependant effects of the measurement system, e.g. connectors and cables. If these effects were not removed by calibration, they would appear as "spikes" in the power delay profile, which could be mistaken for multipath components. Thus, the accuracy of the calibration process effectively sets the dynamic range of the measurement system.

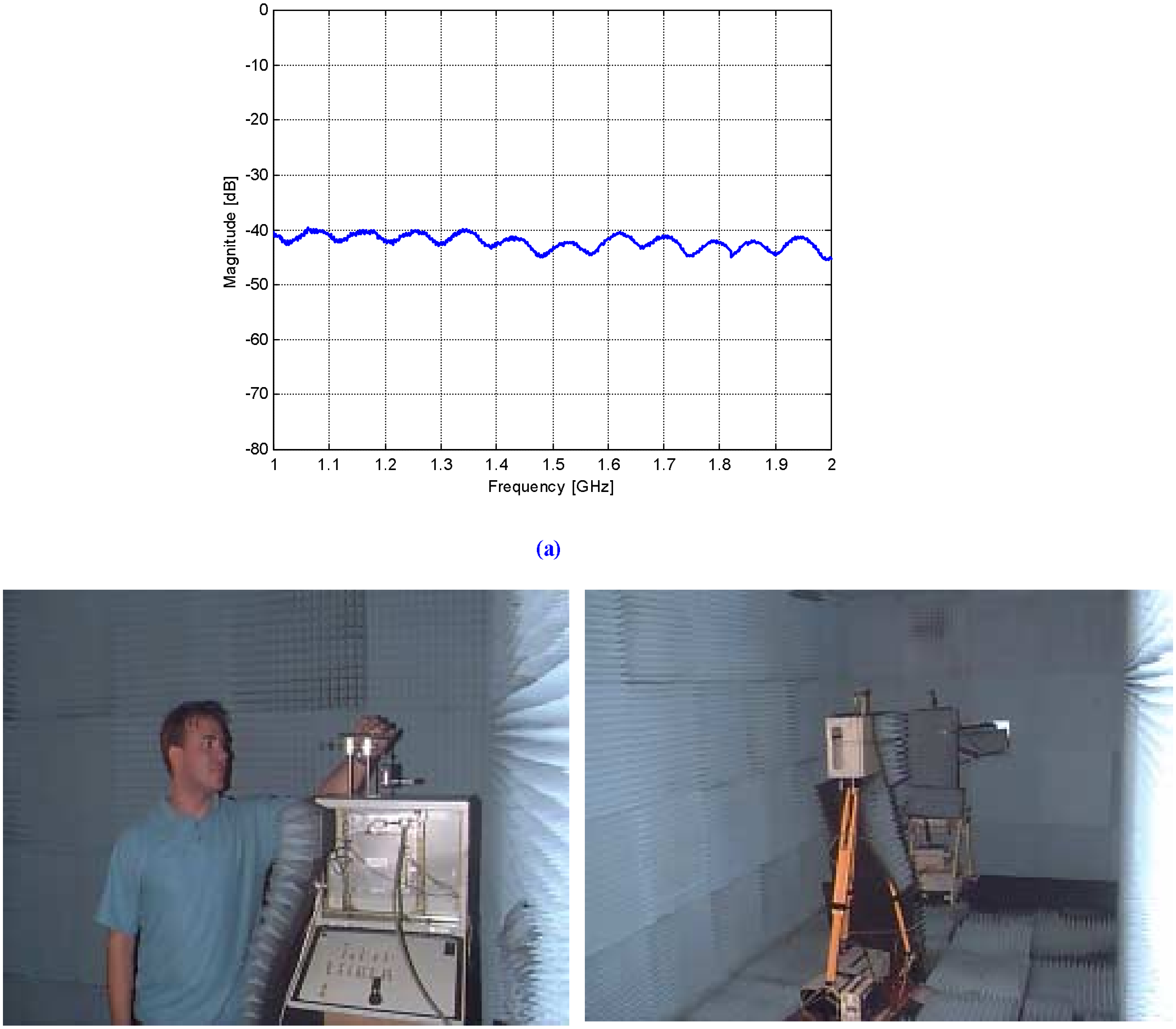
The rigorous approach to calibration is to measure the transfer function of the complete system, S_{21cal} , in an anechoic chamber,Fig.[2(a),(b),(c)] ,with the transmit and receive antennas 1.5m apart and 1.70m high, so the antennas radiation patterns are taken in account. The system was calibrated using to identical 10dBi antennas with 69^{o} and 55^{o} E and H-plane 3-dB beamwidths, respectively. The VNA's receiver bandwidth is 3.7KHz (IF filter) which results in a noise floor of approximately -100dBm. For noise reduction purposes, 8 sweeps had been averaged, which reduces the noise floor to -110dBm. With the terminals 1.5m apart the received signal is approximately -40dBm thus a signal to noise ratio of about 70dB is obtained. The calibrated data file is then stored and used to normalise the experimental results. At this distance the theoretical received signal level is given by:

$$P_{RX} = P_{SW} - UpC_L + G_{Tx} - FSL + G_{Rx} - DoC_L + G_{LNA} - Cable_{Loss} \qquad (4)$$

where: P_{RX}, Received power
P_{SW}, IF sweep level
UpC_L, Up-Converter Loss
G_{Tx}, Gain of transmit antenna
FSL, Free Space Loss
G_{Rx}, Gain of receive antenna
DoC_L Down-Converter Loss
G_{LNA}, Low Noise Amplifier gain
Cable loss: 50m cable loss between LNA-RF in, port of the VNA

$$P_{RX} = 9 - 7 + 10 - 71.8 + 10 - 7 + 31 - 8 = -33.8 \text{ dBm}$$

This level is about 6dB lower than the measured inside the chamber and is due to connectors and cable losses that are not considered.



(a)

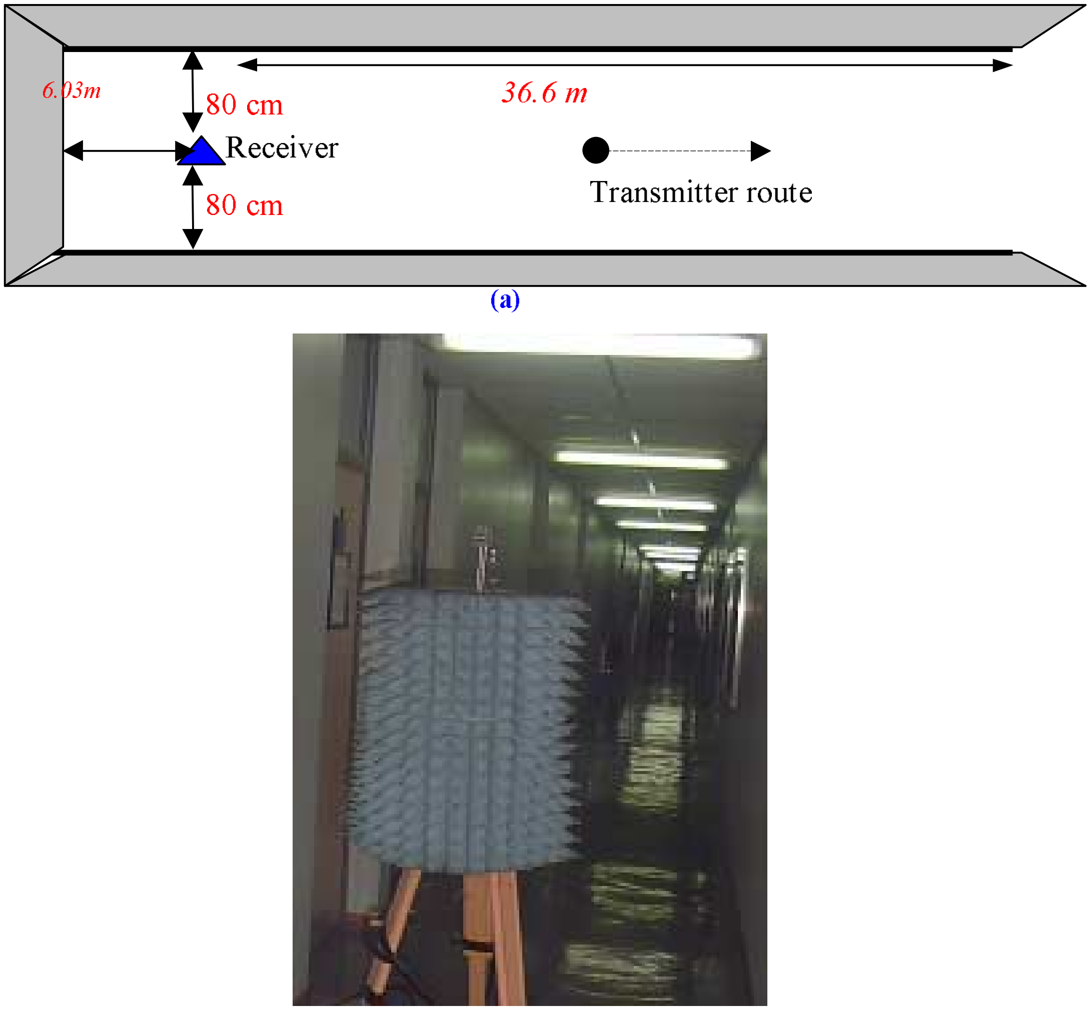
(b) (c)

Fig.2 (a),(b),(c). The calibration signal (S_{21CAL}) measured inside the anechoic chamber using 10dBi transmit and receive antennas.

1.2.2 Initial Experiment and Results

An initial line-of-sight experiment has been carried out in a long narrow corridor on the top floor in the School of Electronics building at the University of Glamorgan with 41 impulse responses recorded Fig.[3(a),(b)]. The corridor is 42.63m long, 1.60m wide and 2.70 m high. The corridor has no windows with a number of wooden doors leading off and plasterboard sidewalls covered with a thin metal sheet. The floor is covered with plastic tiles.

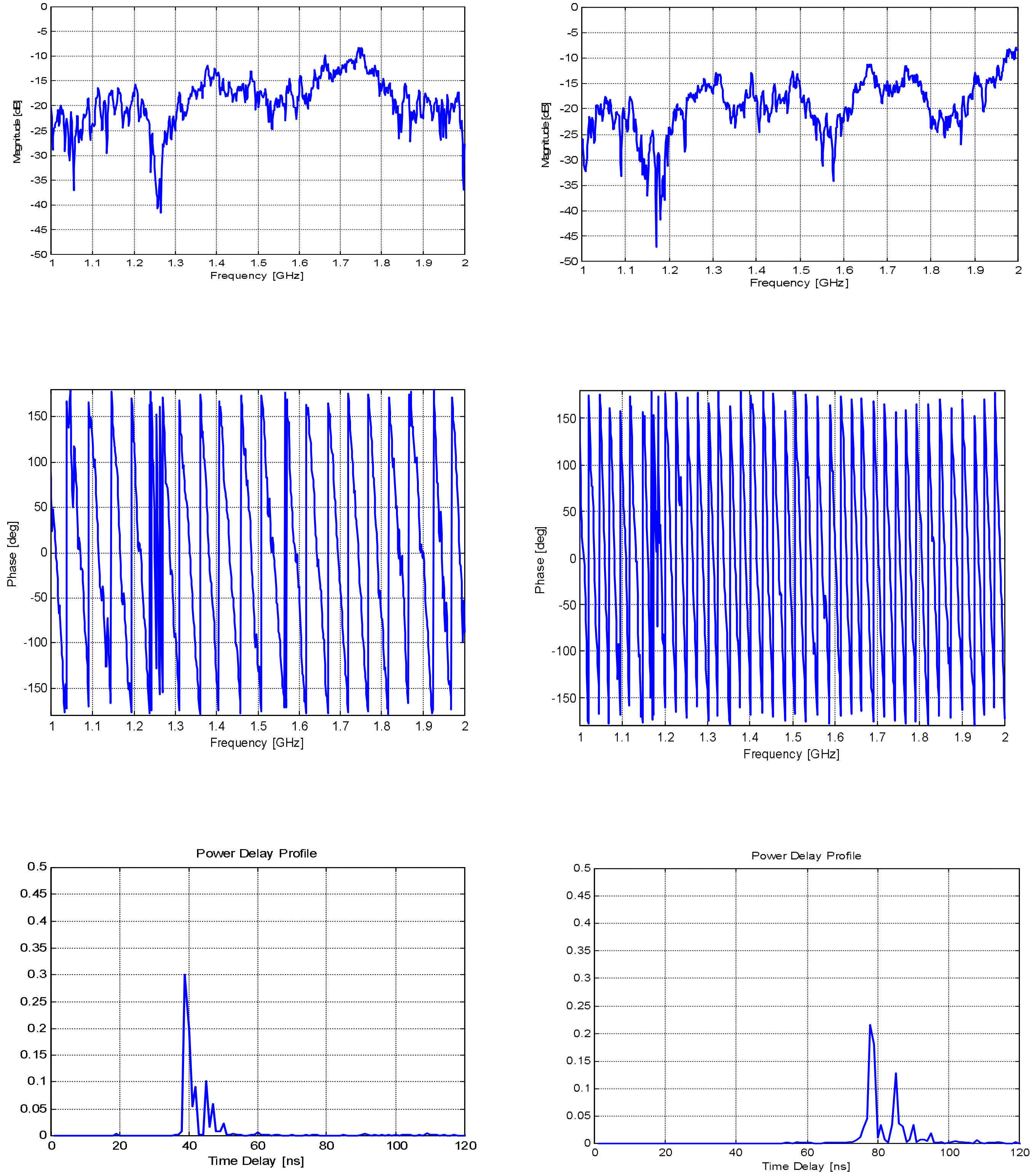
The transmitter was mounted on a box and left stationary at one end of the corridor. The receiver was also housed in a box and fixed on a mobile trolley. The receiver was moved to different locations along the centre line of the corridor. The measured frequency responses using 10dBi horn antennas, after normalisation to the calibrated signal, with the terminals 12.95 and 23.75 metres apart are given in "Fig.4", together with their power delay profiles. The power delay profiles are normalised to so that the total power is unity. The frequency selective nature of the channel is seen to result in deep fades at certain frequencies. The power delay profiles exhibit a number peaks which correspond to reflections of sidewalls, floor and ceiling. The most significant peak represent the line-of-sight path. It is intended to identify those peaks that represents reflections and those that are due to noise, and then calculate the RMS delay spread and its statistics.



(a)

(b)

Fig.3 (a),(b) Plans of the initial experiment carried out in a long narrow corridor at the School of Electronics, University of Glamorgan.



(a) **(b)**

Fig.4 Measured transfer functions and power delay profiles at (a) 12.95m (b) 23.75m

An important parameter for the evaluation of digital systems is the coherence bandwidth[6]. The coherence bandwidth is the statistical average bandwidth, over which signal propagation characteristics are correlated. This parameter has been obtained by computing the normalised auto-correlation of the measured complex frequency function."Fig.5"shows the normalised coherence function measured at distances of 1.55, 12.95 and 23.75m. The 0.5, 0.7, 0.9 coherence bandwidths obtained from these results are given in Table 3. The commutative distribution function $B_{0.9}$ measured at all receiver locations are shown in Fig.6. It can be clearly seen that the coherence bandwidth values varies with the distance from the base station (Fig.7). For 90% of the receiver locations the $B_{0.9}$ is below 57.90 MHz.

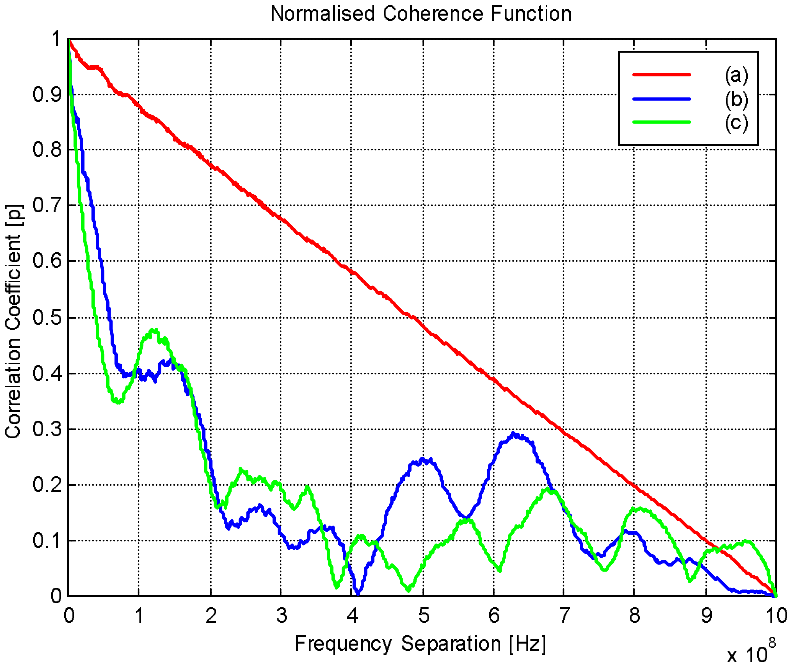


Fig.5 Frequency Correlation functions measured at:
(a) 1.55m, (b) 12.95m, (c) 23.75m TX- RX separation.

TX-RX Separation (metres)	Coherence Bandwidth, MHz		
	$B_{0.5}$	$B_{0.7}$	$B_{0.9}$
1.55	484.40	275.46	73.48
12.95	58.09	33.72	4.11
23.75	83.48	52.19	13.67

Table.3 Measured Coherence Bandwidth values.

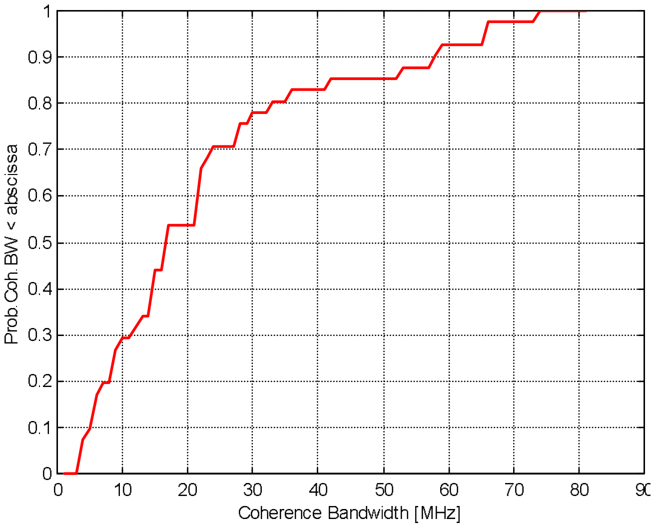


Fig.6 Commutative Distribution function of the Coherence Bandwidth at $B_{0.9}$ correlation level.

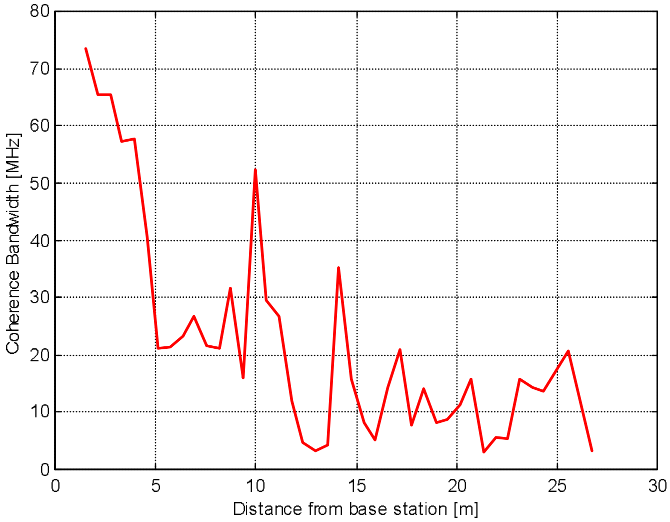


Fig.7 Coherence bandwidth for 0.9 correlation level as a function of the receiver position.

1.2.2.3 Conclusions

Three significant conclusions are being observed after this experiment:

- *The coherence bandwidth is highly variable with the location of the mobile receiver with respect to the base station [7].*

- *A computer controlled motor driven positioning system and experimental set-up that allows precise and automated positioning and data acquisition of the channel sounder is a necessity (4.8mm wavelength). This high-precision positioning system must be capable to capture the fast fading variations, delay spread and coherence bandwidth, and to enable varying system parameters (antenna pattern, height etc.)*

- ***" It's too dangerous to put limits in wireless!!!"***

References

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