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EXCESS PHASE EFFECTS AND MODULATION TRANSFER FUNCTION DEGRADATION IN RELATION TO LOUDSPEAKERS AND ROOMS INTENDED FOR THE QUALITY CONTROL MONITORING OF MUSIC

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1 INTRODUCTION

Previous papers [1, 2] have discussed the effects of loudspeaker alignment and resonances on the accuracy of reproduction of low frequency audio signals, and a system of modulation transfer function (MTF) measurement was developed which incorporated both the time and frequency domain information into a single measure of response accuracy. The aim of this paper is to extend the previous work into the listening rooms and to assess the degree of information loss which may be incurred as the sound travels across rooms with different modal characteristics.

2. THE MODULATION TRANSFER FUNCTION

The modulation transfer function is a measure of the ability of a system to preserves the depth of modulation of an input signal, and is the basis upon which established speech intelligibility measurement systems such as the STI (speech transmission index) and the simpler RASTI (room acoustics STI or rapid STI) are based. Each of a range of band-limited random noise signals are amplitude modulated over each of a range of modulation frequencies. These signals are used as inputs to the system under test, and the resultant outputs are inspected for loss of modulation depth. Alternatively, if it can be assumed that the system under test is linear, time-invariant and free from external noise, the MTF can be calculated directly from the measured system impulse response, thus:

$$m(F) \approx \frac{\sum_0^N h_f^2(n)\, e^{-j2\pi Fn/F_s}}{\sum_0^N h_f^2(n)} \;, \qquad (1)$$

where F is the modulation frequency and $h_f(n)$ is the discrete (digital) measured system impulse response of length N and sampling frequency F_S, band-pass filtered with centre frequency f. As described in a previous paper [2], a simulated noise floor (equivalent to the threshold of hearing) is included in the calculation. All of the MTF results presented in this paper were calculated using Equation (1) with system impulse responses estimated from long-term averaged two-channel FFT analysis using pink noise signals, and a simulated reproduce level of 85 dB SPL.

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3 MTFs OF DIFFERENT LOUDSPEAKERS UNDER DIFFERENT ACOUSTIC CONDITIONS

An initial study was made with a high quality, wide range monitor loudspeaker system in a very highly damped studio control room. Measurements were made at 1m and 4m from the loudspeaker. Figures 1 show the MTFs for the two measurement positions and Table 1 shows the frequency-averaged values (unity weighting). It can be seen from Figures 1 and Table 1 that the difference in the MTF for the two positions is minimal, suggesting that this room has little effect on the communication of low-frequency information from the loudspeaker to the listener.

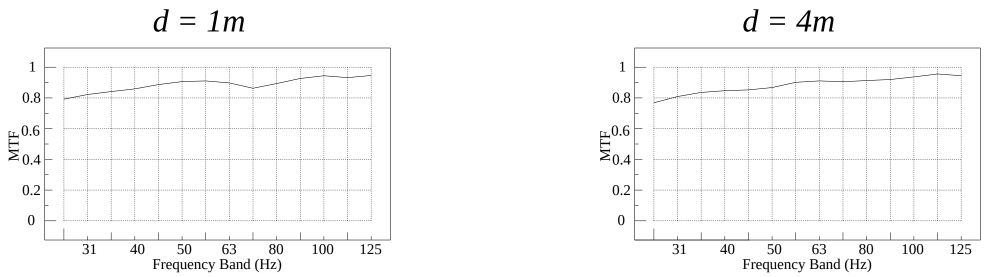

Figure 1 MTFs of a Wide Range Monitor System in a Very Highly Damped Studio Control Room at Different Distances d from the Loudspeaker

	d = 1m	*d* = 4m	change
Average MTF	0·88	0·88	0%

Table 1 Frequency-Averaged MTF Values Corresponding to Figures 1

Measurements were then made at distances of 1m and 4m in a fairly well controlled studio room that has less acoustic damping and hence more reflexions than the control room of Figures 1. Three different types of loudspeakers were measured: two studio monitor loudspeakers of similar physical size but different design philosophies, and a low-cost domestic loudspeaker. The paired results at 1m and 4m are shown in Figures 2 and Table 2. In all cases it can clearly be seen how the MTF, and hence low-frequency signal quality, degrades with increasing distance from the loudspeakers.

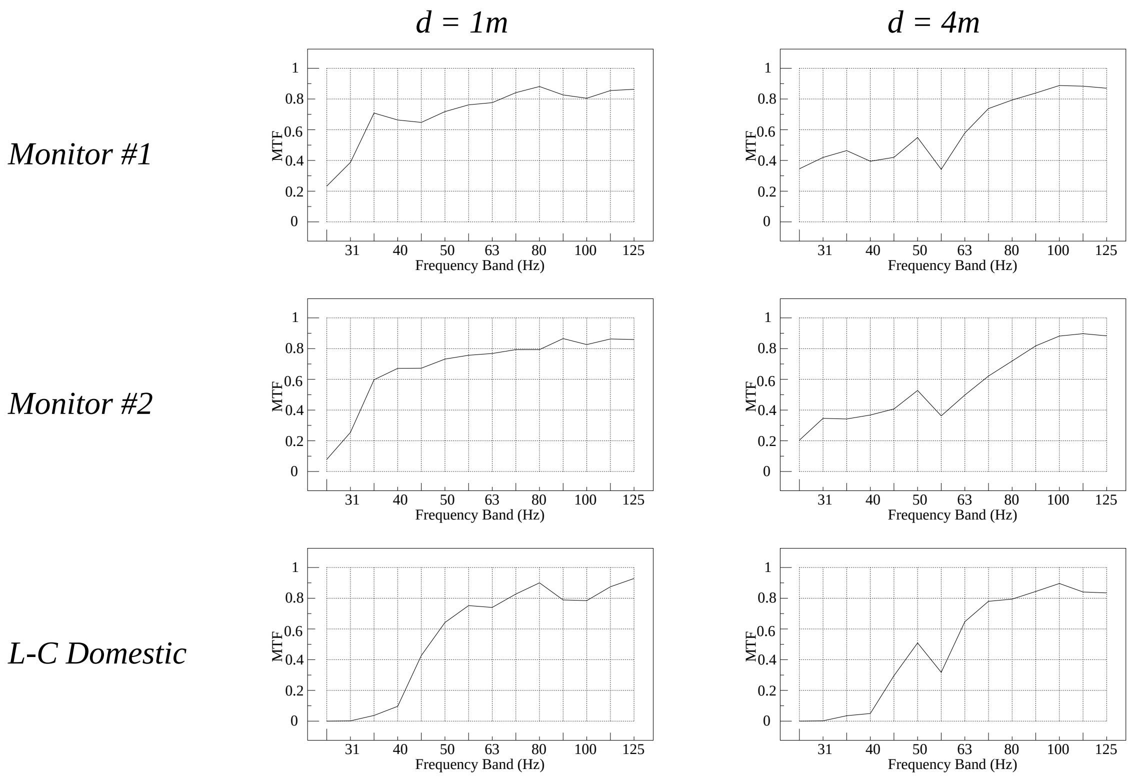

Figure 2 MTFs of 3 Loudspeakers in a Reasonably Well Damped Studio Recording Room at Different Distances d from the Loudspeakers

	d = 1m	*d* = 4m	change
Monitor #1	0·71	0·60	15·5%
Monitor #2	0·68	0·56	17·6%
L-C Domestic	0·55	0·49	10·9%

Table 2 Frequency-Averaged MTF Values Corresponding to Figures 2

A further set of measurements were then made in a very reverberant 'live room' with rigid, irregular granite walls. The results of these measurements, again for distances of 1m and 4m, are shown paired in Figures 3 and Table 3. The MTF values for these measurements are all lower than those for the corresponding studio room measurements and the losses with distance are significantly less, suggesting that the stone room has a significant effect on the MTF even at a distance of only 1m from the loudspeaker. This is clear evidence that, even in the low-frequency range from 30Hz to 120Hz, signal information can be significantly corrupted by reflective / resonant rooms, even at close listening distances.

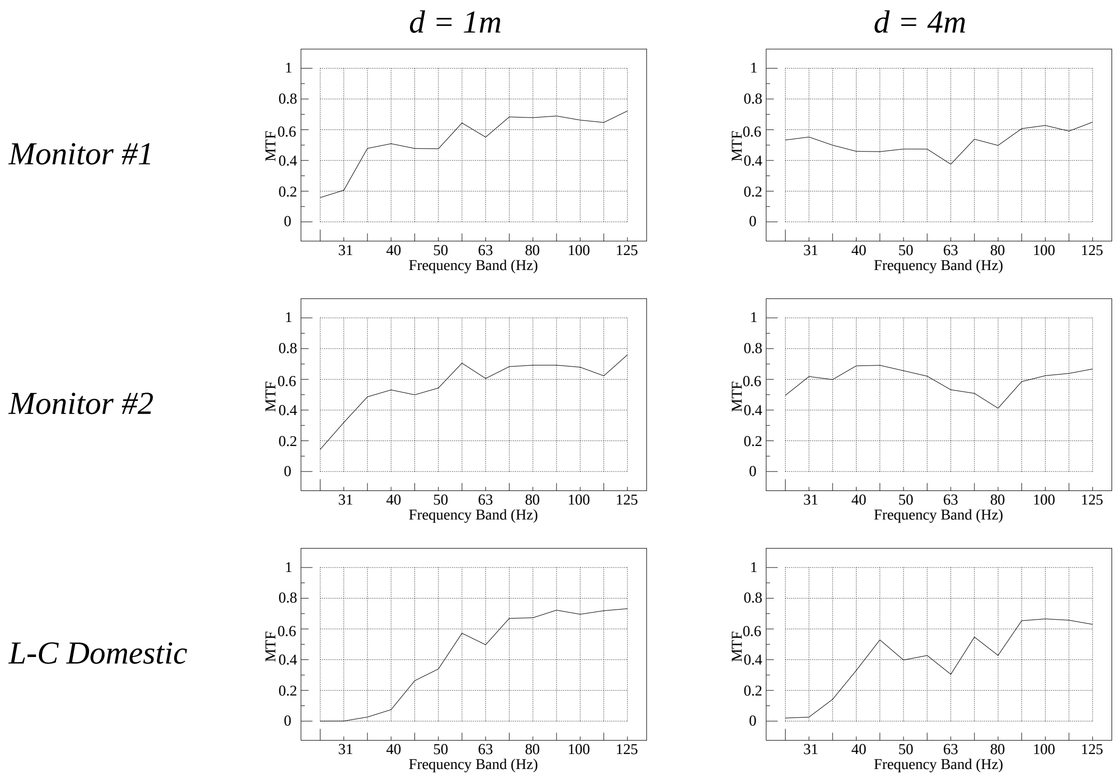

Figure 3 MTFs of 3 Loudspeakers in a Very Reverberant Live Room at Different Distances d from the Loudspeakers

	d = 1m	*d* = 4m	change
Monitor #1	0·54	0·52	3·7%
Monitor #2	0·56	0·59	−5·4%
L-C Domestic	0·42	0·41	2·4%

Table 3 Frequency-Averaged MTF Values Corresponding to Figures 3

It is interesting to note that in some frequency bands, moving further from the loudspeaker in the stone room yields an increase in the MTF rather than the more usual decrease. This may be because the resonances of the room amplify the reproduced levels of these frequencies away from the noise floor. It may be reasonable to assume, therefore, that the careful use of room equalising filters may reduce, or even negate, the effect of the room on the information loss. To investigate this, the following section describes a simulation of the application of 'perfect' equalisation filters (within the bounds of causality) to the loudspeaker / room combinations described above.

4 APPLICATION OF ROOM EQUALISATION

In general, the phase response of a loudspeaker / room system can be separated into minimum- and excess-phase components. Application of a real-time filter to equalise the amplitude response will automatically equalise the minimum-phase component of the phase response, but not the excess-phase part. It is possible to separate a frequency response function into the two components: a minimum-phase response which has the amplitude response of the original response and minimum phase, and an all-pass response which has unit amplitude and the excess phase; the original response is then the product of the two component responses

$$H(\omega) = |H(\omega)| \; exp\{j\phi_m\} \, exp\{j\phi_e\} \quad , \qquad (2)$$

where ϕ_m and ϕ_e are the minimum and excess phases respectively. The calculation of the minimum phase reponse is detailed in a previous paper [1]. The excess-phase response, $exp\{j\phi_e\}$, represents the response of the system after equalisation by a 'perfect' real-time filter. As the excess-phase response extends 'flat' down to 0Hz, any practical equalisation filter will include a high-pass filter to protect the loudspeaker from excessive input at very low frequencies. A 2nd-order filter having a turn-over frequency of 20Hz was therefore chosen as representing the response of an ideal loudspeaker / room system.

Figures 4 show the MTFs for the wide range monitor / highly damped room system after simulated perfect real-time equalisation. There is little difference between the results in Figures 4 and those in Figures 1 for the case with no equalisation.

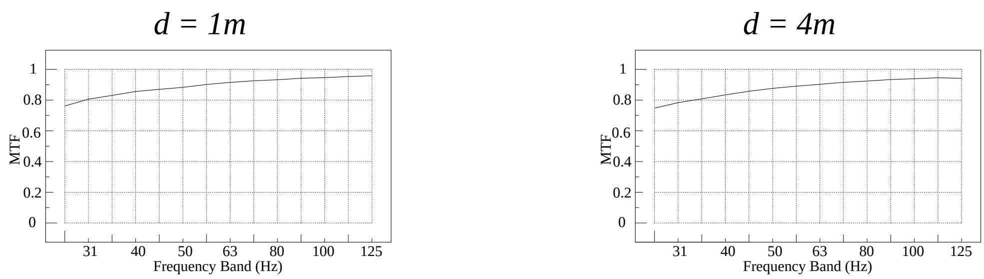

Figure 4 MTFs of a Wide Range Monitor System in a Very Highly Damped Studio Control Room at Different Distances d from the Loudspeaker after Equalisation

Figures 5 and Table 5 are as Figures 2 and Table 2 but with equalisation applied to the loudspeaker / room system in each case. Clearly, the equalisation has reduced the information loss considerably at a distance of 1m, but has made no significant improvement at a distance of 4m. This result suggests that room equalisation can improve performance for close listening, but cannot correct for room problems at larger listening distances.

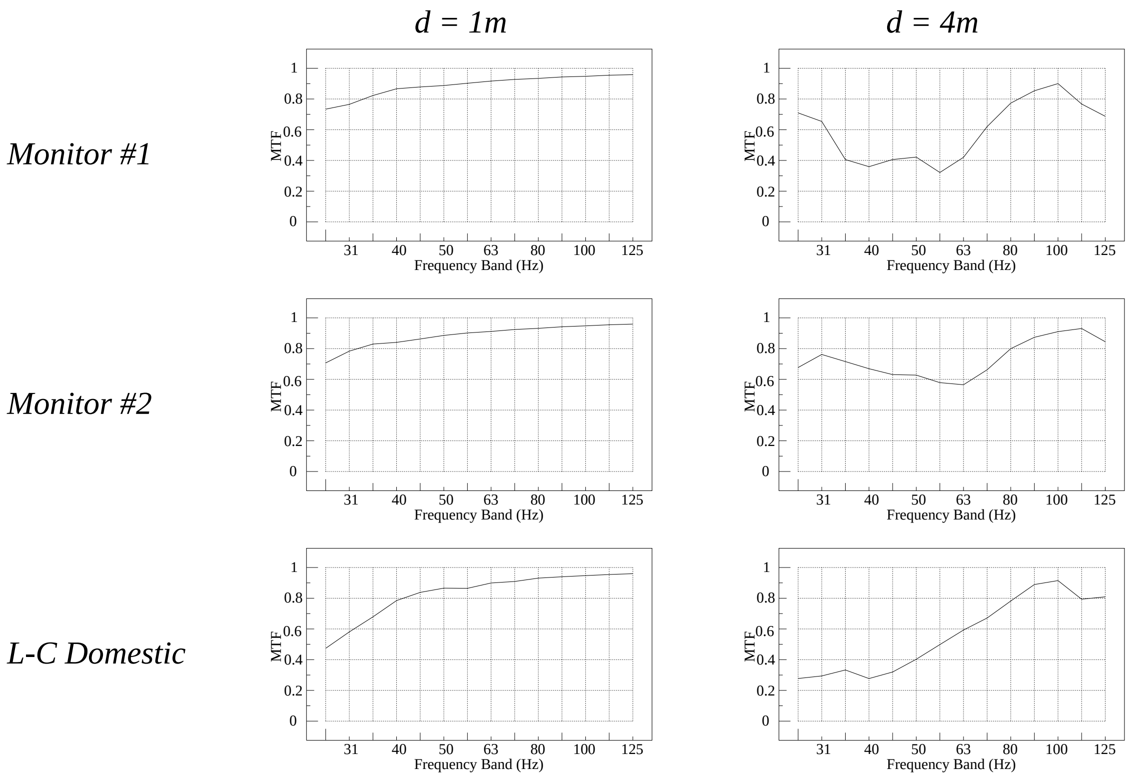

Figure 5 MTFs of 3 Loudspeakers in a Reasonably Well Damped Studio Recording Room at Different Distances d from the Loudspeakers after Equalisation

	d = 1m	*d* = 4m	change
Monitor #1	0·88	0·59	32·9%
Monitor #2	0·88	0·73	17·0%
L-C Domestic	0·83	0·56	32·5%

Table 5 Frequency-Averaged MTF Values Corresponding to Figures 5

Figures 6 and Table 6 are the results for the stone room after equalisation and can be compared with those in Figures 3 and Table 3. As for the studio room results, the application of equalisation has reduced the low-frequency information loss for the 1m distance but there is only marginal improvement at 4m distance.

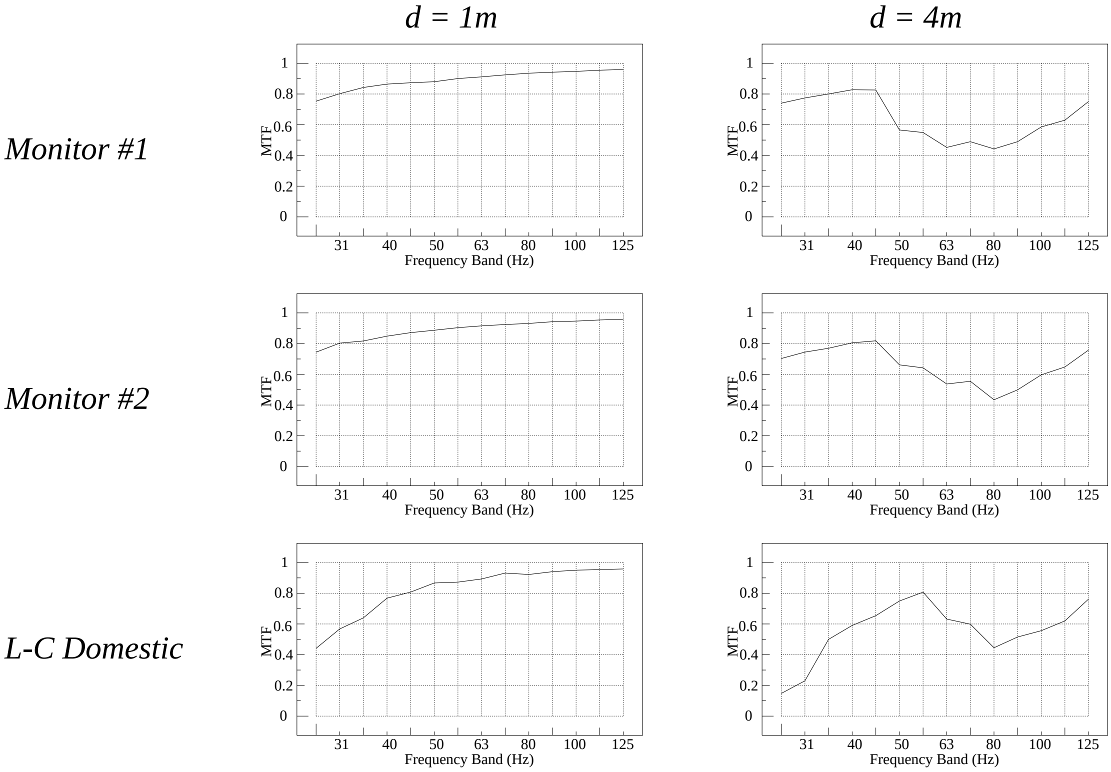

Figure 6 MTFs of 3 Loudspeakers in a Very Reverberant Live Room at Different Distances d from the Loudspeakers after Equalisation

	d = 1m	*d* = 4m	change
Monitor #1	0·89	0·63	29·2%
Monitor #2	0·88	0·65	26·1%
L-C Domestic	0·80	0·55	31·3%

Table 6 Frequency-Averaged MTF Values Corresponding to Figures 6

Comparing the four sets of results for the three different loudspeakers it can be concluded that the low-cost domestic loudspeaker is always out-performed by the two studio monitor designs, but that the choice between the monitors depends upon the particular combination of room, listening position and equalisation. The wide range monitor / highly damped room system does not suffer significant information loss, even at a 4m listening distance, and does not benefit from equalisation.

5 CONCLUSIONS

A number of conclusions may be drawn from the above results.

- All rooms, unless very well damped, affect the transmission of low-frequency information from a loudspeaker to a listener, and this effect increases with increasing distance from the loudspeaker.
- Measurement of the low-frequency MTF of a loudspeaker / room system can yield useful information concerning the loss of low-frequency signal information.
- Carefully applied room equalisation can reduce the loss of low-frequency signal information for close listening distances.
- Room equalisation does not, in general, reduce the loss of low-frequency signal information for farther listening distances.
- The lower quality loudspeaker was consistently out-performed by the two higher quality loudspeakers under all acoustic / equalisation conditions.
- The highly damped room does not have a significant effect on the low-frequency information radiated from the wide range monitor loudspeaker.

6 REFERENCES

1. Keith Holland, Philip Newell & Peter Mapp, “Steady State and Transient Loudspeaker Frequency Responses”, Proceedings of the Institute of Acoustics, **25**(8), Reproduced Sound 19, Oxford, 2003.

2. Keith Holland, Philip Newell & Peter Mapp, “Modulation Depth as a Measure of Loudspeaker Low-Frequency Performance”, Proceedings of the Institute of Acoustics, **26**(8), Reproduced Sound 20, Oxford, 2004.