Proceedings of the Institute of Acoustics

MEASURING THE FUTURE

A REVIEW OF THE STATE OF THE ART ELECTROACOUSTIC MEASUREMENT TECHNIQUES

P MAPP Peter Mapp Associates Colchester UK

1. INTRODUCTION

Over the past twenty five years, electroacoustic measurement techniques have developed considerably both in terms of accuracy and sophistication. The paper shows that range of electroacoustic measurement techniques currently available is vast - with over sixty basic forms being listed. The advent of personal computers and their inherent computing power has enabled completely new classes measurement to be undertaken. Furthermore, they also enable the data to be post processed and displayed in ways that enable either a completely different view of the measurement to be taken often leading to new insights and understanding of the subject. The paper describes some of these developments and introduces three new measurements / measurement techniques that enable further new insights to be brought to the still rapidly developing field of electroacoustics.

2 TYPES OF MEASUREMENT

Although electroacoustic measurements may be categorised and divided into a number of different areas, there are essentially two fundamental forms of measurement technique, Steady State and Transient or Impulse response. Traditionally and up to just a few years ago, steady state measurements were the most widely used with transient response data being of very much secondary importance. This was primarily due to the difficulties in capturing and analysing impulsive data. However, digital technology and the fast personal computer have radically changed this. The development of new measurement forms such as Time Delayed Spectrometry (TDS) and Maximum Length Sequences (MLS) coupled with Cross Correlation techniques and the Fast Fourier Transform have opened up a whole new raft of measurement possibilities. These have also been further enhanced by th discovery that traditional steady state responses can be obtained form the impulse response. The traditional steady state measurement however has not been completely overshadowed, as there are many areas where this approach can not be simulated, harmonic distortion being a typical example.

By its very definition, electroacoustics spreads across the boundaries of electronics and acoustics and so to do the measurement techniques. When dealing with electroacoustic systems, required measurements can extend right across the audio electronic spectrum and even into RF (eg emc and radio microphones) as well as infringing into auditorium acoustics adopting techniques such as STI and Rasti as well as Reverberation Time and Direct to Reverberant Ratios. The measures may relate to either the physical performance of the device or have a psych-acoustic aspect in order to determine how a device or system may sound. The following table summaries some of the main measures in use.

Measuring the Future - Peter Mapp

ELECTRONIC	ELECTROACOUSTIC / ACOUSTIC	
Frequency Response	Frequency Response	
	Polar Response / Directional Response	
Amplitude & Linearity	Amplitude & Linearity	[V, I, P, v]
Phase	Phase	[Nyquist, Bode, Heyser]
	Polar Phase	
Group Delay / Delay	Group Delay / Echo	
Distortion	Distortion	[THD, Harmonic, Intermodulation, TID]
	Polar Distortion	
Power Output / Bandwidth	Power Handling / BW	
	Sound Power	
	Intensity	
Sensitivity	Sensitivity	
Inherent Self Noise &	Inherent Self Noise &	
Signal to Noise Ratio	Signal to Noise Ratio	[CCIR, Lin, A wt, Spectral]
Stability / RFI / EMC	Stability / RFI / EMC	
Jitter / Wow & Flutter	- -	
	Rub & Buzz	
	Directivity Q	
Transient Response	Transient / Response	[Impulse, ETC, Polar ETC Log Squared, Doublet]
Correlation	Auto / Cross Correlation	IACC
	Polar Correlation	
	PSD	
	Rasti / STI	
	Complex Modulation TF	
	Direct / Reverberant / C50/C7	
	EDT / RT	
	HRTF	
	Wavelet	
Psychoacoustic	Loudness	
	Sound Quality	[Roughness / Fluctuation Strength]
	STI	
	AI	
	Subjective Intelligibility	
	Masking / Error Masking	
	Error Surface	

There are of course many more !

3 MEASUREMENT & DATA DISPLAY

An important aspect of the above measurements is the associated resultant measurement and data display format. From the above listings, it can be seen that the electronic measures are generally one dimensional and can usually be displayed either as a single value or on an X-Y format. Occasionally however, the need arises to display two variables simultaneously. In contrast, many of the corresponding electroacoustic measurements require two or three axes (and often ideally four) to display the data originating from a 3 dimensional object or system.

Display formats currently in use include conventional X-Y plots or X-t plots. Where the data has a directional aspect, Polar Diagrams of course may be employed. Traditionally, this tends to be restricted to single frequency or a band of frequencies. In practice however, it is often desirable to simultaneously see how an object radiates over a wide range of frequencies. This can be effected either by multiple plotting on a single graph or more recently by animating the polar display. This new technique enables each frequency of interest to be rapidly stepped through and viewed as a whole. Where the radiation pattern varies rapidly with frequency, this novel technique can provide a very useful and intuitive insight into the radiation characteristics, previously unavailable without the computing, data manipulation and display capabilities of the modern PC. The ability to see the radiation in more than one plane is also very useful, particularly when trying to predict the likely effects of sound radiating into a space for example. By taking multiple polar measurements and combining them into a composite display, a 3 dimensional radiation Polar or Polar Balloon can be created - again providing a very much more powerful insight into the way sound is radiated. The 3D polar can of course also be animated to show frequency dependent information.

Another method of displaying 3 parameters simultaneously is by employing the use of colour graphing. This technique is typically used in colour spectrographs, where the two fixed axes represent Frequency and Time and a Colour display is employed to indicate amplitude. Typical examples include speech spectrograms and displaying the transient behaviour of rooms of delay / reverberation enhancement systems and loudspeakers. The technique has also been adapted by the author to form interference spectrograms and spatial cross correlations. The idea can also be extended to post process multiple polar response files and to create a new form or polar or sound radiation display. Again colour is employed to denote amplitude whilst the fixed axes become frequency and polar angle.

By displaying multiple spectral response files, or slices through an impulse response , with each file or slice sequentially delayed by a preset offset, Waterfall plots can be created and are particularly useful in viewing transient phenomena including room and loudspeaker response decays.

The ability of most computer based instrumentation to post process display information, has also brought about a minor revolution in how we are able to view and interpret data. The ability to smooth, re-scale or zoom in to areas of interest, whilst providing greater potential information, also poses the problem of interpretation and data integrity - particularly for the non specialist. For example in seconds, a strongly varying response graph with serious response anomalies can be transformed into a smooth curve, showing no such aberrations.

The newer, computer based measurement techniques have also significantly affected the way in which measurements are made and data collected.

4 MEASUREMENTS AND DATA MANIPULATION

It is only in the past 10 years or so that computer based instrumentation has really become a reality. Before this time, a number of conventional instruments were equipped with computer control and some with storage capabilities. However, these were basically analogue instruments under cumbersome computer control. Whereas when used for repetitive measurement making eg production control, they could work well, they were still essentially dedicated, task specific instruments. The problems of achieving reliable operation were legion as were the problems of high frequency and RF noise from the computer itself contaminating the measurement being carried out. In the mid eighties, three separate approaches to computerised electroacoustic measurements heralded the beginning of the computer instrumentation age. They were, the Techron TEF 10 analyser, The Audio Precision System One and MLSSA from DRA Laboratories.

The TEF, as it became known, was very much an electroacoustic analyser, enabling for the first time, outside the research laboratory, time windowed, continuous frequency response and frequency selective reflection and impulse response measurements to be made. The instrument quickly caught on in the USA and became the De-facto standard electroacoustic analyser. Being software driven, its range of measurement capabilities grew continuously, some of which have still not been surpassed even today. The audio Precision was aimed very much more at the electronics side of audio, though some limited acoustic measurement applications have been released. It has however, become the world wide standard for electronic measurements within the audio industry. Again the form was an integrated software measurement platform. At around the same time, DRA introduced the MLSSA system, based on an MLS algorithm. Mlssa was unlike either the TEF or AP in that the hardware was minimal (an A to D converter and programmable filter on one, full size computer plug in card). The system literally fitted into the host computer and the rest was software. Again Like TEF, the software applications grew rapidly but tended towards the acoustic domain. Elements of these three analysers can now be found in numerous other instruments, but each continues in its own right. Each has also contributed to a number of major breakthroughs in electroacoustics. Interestingly, it has taken to the late 1990s (well over a decade since the introduction of the TEF and AP) for a similar radical rethink and breakthrough in instrumentation to occur. The newest generation of instrumentation takes the concept of computer based measurement devices on a further stage and employs no dedicated hardware at all, but instead uses a modern PCs own internal sound card to act as the A/D and the rest is implemented purely in software. (Though not without some loss of accuracy in most implementations).

It is worth briefly noting here the types of signal commonly used for electroacoustic measurement purposes. These include :

- Sine Wave
- Multi Sine signal
- Square Wave
- Sine Sweep
- Stepped Sine Sweep
- Warbled Sine Sweep / Step
- Pink Noise
- White Noise
- MLS
- Step Response
- Rectangular Pulse
- Shaped Pulse (eg cosine tapered)
- Programme Material (music)

The MLS approach has literally revolutionised acoustic measurement technology, as a single measurement can be post processed in numerous different ways to yield a range of parameters. Like TEF it has enjoys superior noise immunity but does depend upon a linear system in order to produce meaningful results. In the majority of cases this automatically occurs, but many electroacoustic systems are potentially non linear and may produce corrupted but apparently correct data.

TDS and MLS techniques have radically altered the way in which electroacoustic measurements may be made. For example the time windowing capabilities of each approach enable 'anechoic' measurements to be made without resource to an anechoic chamber, indeed they can even be made in highly reverberant spaces, provided that the reflecting surfaces are sufficiently separated from the object under test. The process however does not obviate the need for anechoic chambers or traditional anechoic measurements, but can lead to reduction for this need.

The ability to normalise and difference response measurements also leads to new ways of carrying out such tests, obviating the need for example for reference equipment with ruler flat response curves or complex feedback loop compressor circuitry. The ability to average and spatially average results also provides a powerful technique for looking at resultant sound fields and sound power measurements.

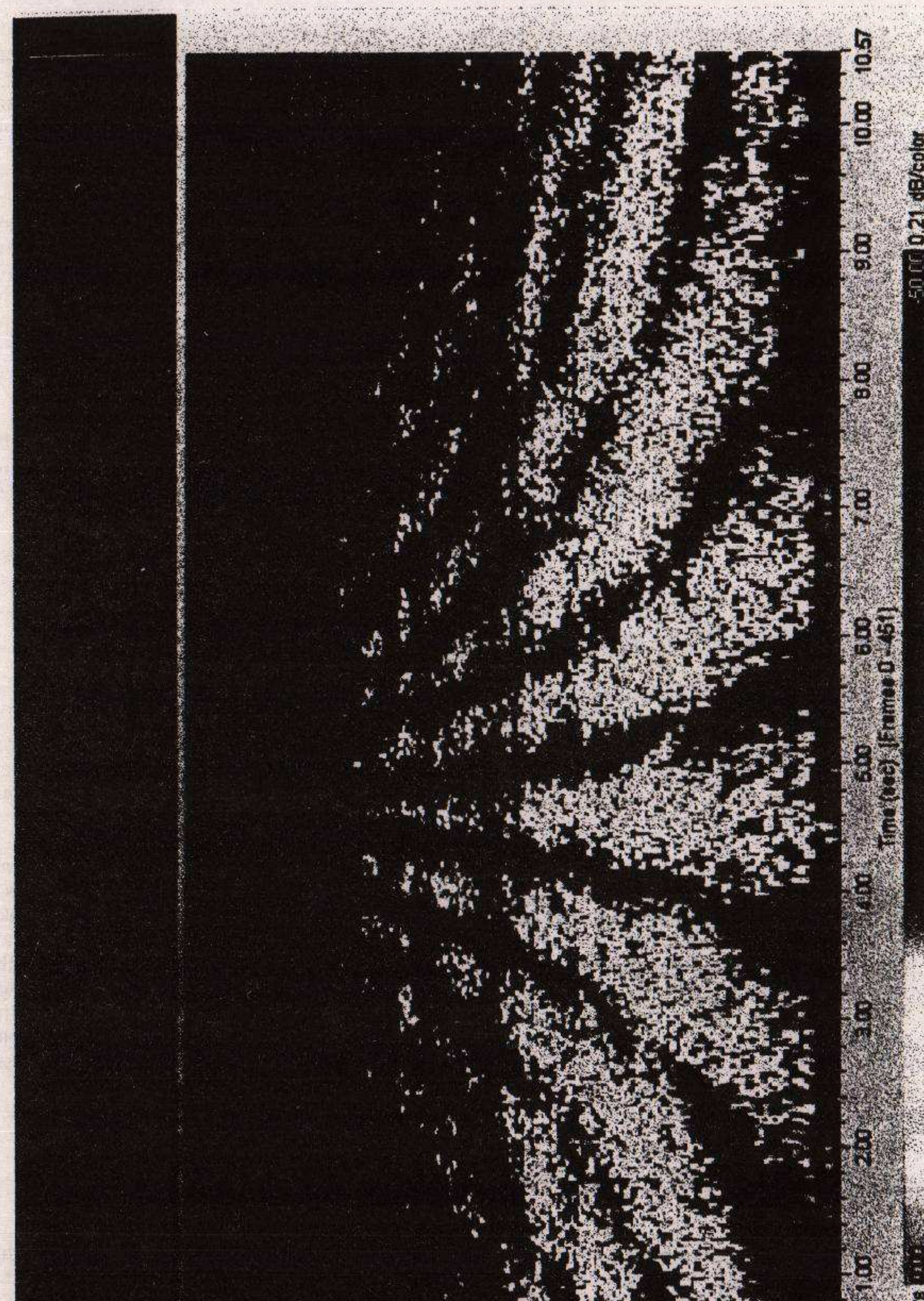
5 NEW MEASUREMENT TECHNIQUES

The ability to store and post process raw data and export data files to other utilities such as excel, matlab and mathcad for example, enables new measurements and data manipulations to be performed. Three new measurement techniques will be illustrated within the lecture, these are Polar Animations, Polar Coherence / Correlation and a Spatial Interference Spectrograph. (Spatial Cross Correlation).

Whilst it is well appreciated that loudspeakers radiate sound in 3 dimensions, measurements are frequently restricted to a single 'on axis' position. By looking at the problem on a polar basis in at least 2 dimensions, the author has found a number of interesting insights into loudspeaker radiation behaviour. Correlation measurements show that the off axis response of many loudspeakers varies significantly with those found on axis. Similarly phase and distortion measurements show similar trends. The interference spectrograph shown in figure 1 is not only a measure of such correlations but also is a good example of a new measurement technique that not only immediately gives an intuitive indication as to what is happening in a very complex situation but also one which could not have been made without a modern computer based analyser.

6 IMPLICATIONS FOR THE FUTURE

Whilst the newer measurement techniques undoubtedly help to provide a better understanding of electroacoustic objects, they are not without their pitfalls, It is very easy to fall into a number of traps that can affect the accuracy of the results. Equally, it is also time for a number of standards relating to electroacoustic measurements to be brought up to date to take account of new measurement techniques and procedures. As to the future, it is clear that measurement techniques will continue to increase in sophistication. The next major influences are likely to be the introduction of Psychoacoustic parameters and Psychoacoustic modification to existing measures so that we will be able to better predict just how an item may audition or perform.


0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
10.57
Time (sec) [Frames 0 - 451]
236 colors
0.21 dB/color
Frequency (Hz)
500
1k