IN-SITU ACOUSTICAL INVESTIGATION OF AGRICULTURAL LAND

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1. INTRODUCTION

Predictions of outdoor sound propagation have improved with advancements in the understanding of micro structural effects on acoustic signals. Progress of propagation prediction has been due in part to realistic ground surface impedance models [5]. These are based on acoustical properties of rigid framed granular materials rather than fibrous materials with near unity porosity. Impedance tube measurements of ground impedance are protracted and destructive. Technological improvements in data acquisition and analysis coupled with spherical wave reflection theory have enabled relatively simple and more importantly portable measuring techniques. Such techniques may be used to remedy the general shortage of impedance data concerned with outdoor ground surfaces.

The method described here, measures excess attenuation above the surface; that is the attenuation of an acoustic signal due to the interference between the direct and ground reflected sound. The amplitude and phase of the reflected sounds are governed by the acoustic impedance of the ground; as the impedance is frequency dependent, so too is the excess attenuation. The developed excess attenuation measurement technique uses impulses rather than a broad band continuous wave or a swept sine signal as a source. Use of impulses circumvents problems arising from extraneous reflections from external surfaces.

Combining accurate ground impedance models with spherical wave reflection theory results in predictions of the ground effect for a given source/receiver geometry. Fitting the prediction to measured data enables deduction of parameters for the ground impedance models which best characterise the ground surface. This information, when using physically accurate impedance models is useful not only for accurate propagation modelling but also where the constitution of the ground is of interest, for example in soil science.

This paper presents preliminary results from in-situ excess attenuation measurements over soils and grassland..

2. THEORY

It has been shown that the first minima (ground effect dip) in excess attenuation spectra is most sensitive to the physical properties of ground surfaces, especially when it is located at higher frequencies [1]. The exact position in frequency depends on the relative locations of the source, receiver and ground ; for example a decrease in source and receiver height will cause an upward frequency shift in excess attenuation with an accompanying increase in spectra amplitude (Figure 2).

Consider a point source above an impedance boundary (figure 1)

$$p_t = \frac{e^{ik_0R_1}}{k_0R_1} + p_r$$

A useful approximation for the total sound field due to an incident spherical wave is commonly referred to as the Weyl van der Pol solution. Weyl van der Pol provides an adequate approximation if (a) the surface is locally reacting (sound on entering the material is refracted towards the normal, so there is no lateral wave propagation), (b) the incident sound wave is spherical, (c) the range is greater than a wavelength and (d) the angle of incidence is near grazing.

The Weyl van der Pol formula for the pressure at a receiver due to a point source is given by

$$p_t = \frac{e^{ik_0R_1}}{k_0R_1} + Q\frac{e^{ik_0R_2}}{k_0R_2}$$

Where the spherical wave reflection coefficient is given in terms of the plane wave reflection coefficient, which itself is given in terms of the surface admittance (β) and the angle of incidence (φ).

$$Q = R(\varphi) + (1 - R(\varphi))F(\omega)$$

$$R(\varphi) = \frac{\cos\varphi - \beta}{\cos\varphi + \beta}$$

F(ω), the boundary loss factor is given in terms of ω, often called the numerical distance

$$F(\omega) = 1 + i\sqrt{\pi}\omega e^{-\omega^2}[erfc(-i\omega)]$$

$$\omega^2 = 0.5(ik_0R_2)(\cos\varphi + \beta)^2$$

The calculation of the complimentary error function used in the expressions for spherical wave reflection coefficient follows published method from Abramowitz [6] or Pirinchieva [7].

Excess attenuation is then defined by $EA = 20\log\frac{p_t}{p_d}$

where p_d is the direct field sound pressure

For impedance fitting techniques, that is fitting ground impedance models to excess attenuation data using Weyl van der Pol (or a similar solution), only two parameters may be deduced uniquely since there are effectively only two parameters governing the data (real and imaginary components of impedance).

A preferred model is the Attenborough variable porosity 2 parameter model [5], which offers much greater flexibility compared to semi-empirical models.

$$Z = \sqrt{\frac{\sigma_e/f}{4\pi\gamma\rho_0}}[1+i] + \frac{ic}{8\pi\gamma}\frac{\alpha_e}{f}$$

α_e is the effective value of the rate of exponential change of porosity with depth.
σ_e is the effective flow resistivity given in terms of a pore shape factor ratio, the surface porosity and the surface flow resistivity.

γ is the ratio of specific heats in air
c is the speed of sound in air
f is frequency.

3. EXPERIMENTAL WORK

In-situ measurement of excess attenuation has been made considerably easier by developments in techniques of data analysis. Maximum length sequence signal analysis (MLSSA) enables input and output signals to be related in time. This is a major benefit for outdoor acoustic measurements where background noise (wind, traffic, aircraft, generator) may reduce the signal to noise ratio. The measurement of excess attenuation requires two measurements, a 'free field' or direct wave measurement and the total field measurement (direct and reflected). Difficulties arise in the measurement of the direct wave. Previously this measurement would have required anechoic conditions to ensure that no reflected wave component was also measured; not very practical for in-situ experiments. However use of a PC based maximum length sequence system analyser (MLSSA) allows the separation of relevant time domain data providing there is a sufficient time lag between the direct pulse and the reflected pulse. It is preferable for the time lag between direct and reflected pulses to be as wide as possible to achieve a better frequency resolution in the frequency domain.
The free-field measurement can be achieved by moving the source and receiver above the ground sufficiently high for the direct and reflected pulses to be individually discernible. The source/receiver separation for the free field reference measurement should be kept constant for further measurements.

The spectrum level at the microphone was measured above several different ground conditions including cultivated soils and grassland. Whilst keeping the same measurement geometry, the soil was artificially roughened through 5 grades. After processing and FFT, each spectrum level was divided by the direct field measured earlier. All of the processing was performed solely by the MLSSA software, the final output being excess attenuation. The only experimental difficulty involved in measuring the excess attenuation is in producing a sound stimulus which acts as a point source. The addition of a heavy brass tube with a small (2 cm) constant cross sectional area to the loudspeaker driver unit is a possible practical method for producing spherical sound waves.

4. EXPERIMENTAL RESULTS

Data obtained from excess attenuation measurements over soil are presented in figures 3 and 4. Figure 3 shows the difference in excess attenuation when the surface texture is changed, figure 4 shows results over two different grass covered grounds.

The measurement geometry was sited in a flat, open field. The equipment was powered by a generator which was 100 m away. The wind was relatively still. The first set of measurements were conducted over a patch of weather smoothed earth which contained no surface vegetation. For each additional measurement the earth between source and receiver was slightly modified. The first modification consisted of raking straight shallow ruts normal to the propagation path. The separation of the ruts was approximately 4cm.

The second surface change was over the whole area, the surface earth was lightly turned over to produce rough ground with an average aggregate diameter of 3cm. The next surface modification involved turning over the earth to a depth of approximately 15cm, this created a much coarser surface which had an average aggregate diameter of 10cm. The final measured surface condition was compact ground with the same area stamped flat to form a smooth surface.
For all of these measurements the set-up geometry was untouched.

For measurements concerned with vegetation, the set-up was moved to nearby grass covered areas. The first vegetation site was covered with a moss-like short grass. The second site contained a much longer grass.

The addition of roughness to an impedance plane without altering the base material properties has the acoustical effect of modifying the surface impedance [8]. However cultivation of soil has two effects on its surface impedance. The extra roughness alone causes a change in frequency at the first dip. The process of creating the roughness also changes physical parameters such as porosity and flow resistivity. Examination of the data suggests that changes in excess attenuation spectra by surface modification are due to the change in surface properties rather than the addition of roughness.

It has been shown [3] that increasing surface impedance moves the location of the first minima up in frequency for a fixed source-receiver geometry. The act of turning the soil increases porosity thereby reducing the ground impedance, which would explain the relative positions in frequency of the ground effect dip for the five surface conditions (Fig 3).

There is a possibility that the variations shown in figure 3 are due to the modifications of surface texture, effectively moving the surface nearer the source and receiver. However figure 2 shows the ground effect dip location to be moved up in frequency with decreasing source and receiver heights indicating that any effects due to changes in the geometry are slight.

The data presented in figure 4 is unexpected, as all the measurements were performed in close proximity to one another and grass is effectively transparent to sound waves the difference in excess attenuation spectra would be expected to be small. The differences are possibly due to a number of factors, the effect of the respective root systems increasing the near surface ground porosity, changes in the source-receiver geometry between measurements or time domain windowing errors.

There were experimental difficulties with open end reflections from the brass pipe attached to the loud speaker driver unit. The signal from the open end of the pipe reflected back again from the speaker face and overlapped in time with the direct signal. A close or overlapping unwanted reflection needs to be removed from the measured data as it would otherwise introduce additional dips in the excess attenuation spectra. However simply windowing out the unwanted reflection produces two main problems (a) loses in signal energy from the tail end of the time window and (b) a worsening in frequency resolution (due to the reduced time data). Further experimental work needs to be conducted to ensure that the noise source behaves like a point source.

5. CONCLUSIONS

The data shows that simple modifications to outdoor ground surfaces can have significant effects on a propagated signal. Such changes could be used deliberately for passive noise control.

The method described is a relatively simple and convenient method to assess the affect a surface will have on a sound field.

6. REFERENCES

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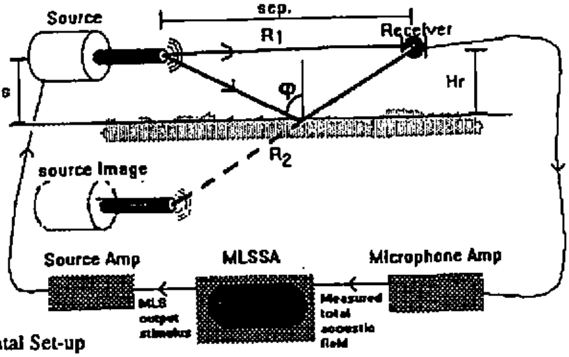

Figure 1 Experimental Set-up

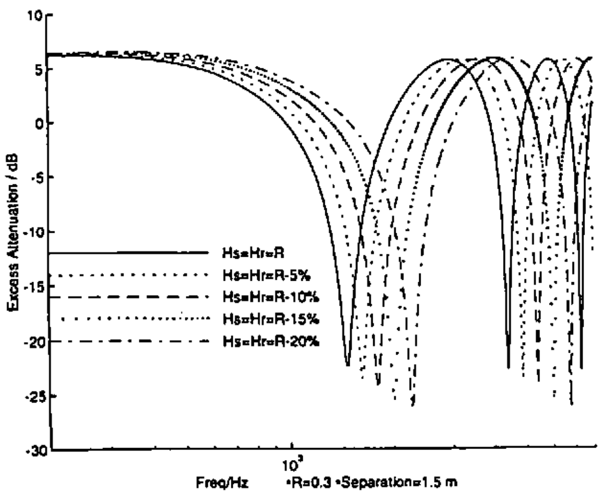

Figure 2. Modelled Excess Attenuation : Effect of lowering Source and Receiver

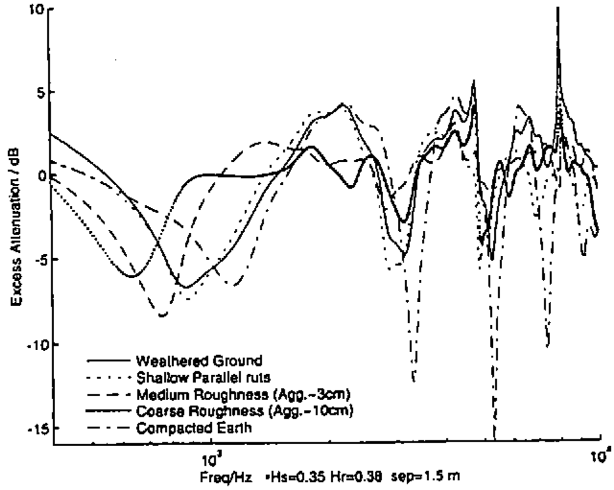

Figure 3. Excess Attenuation Measurements : Over 5 modified Ground Surface

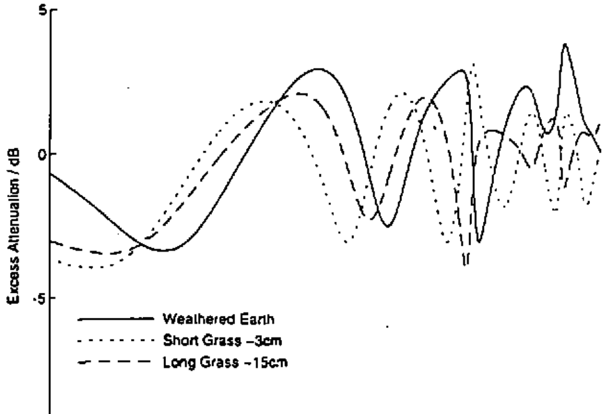

Figure 4. Excess Attenuation Measurements : Over Vegetation