ACOUSTIC SCATTERING: MEASUREMENTS ON MODEL TREES AND THEIR EXTENSION TO NATURAL FORESTS

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1. INTRODUCTION

Acoustic scattering in natural woodlands has been studied in the past by a variety of investigators [1,2,3] with the principal focus being on the attenuation of sound along a line between a source and a receiver. In this approach the scattering effect is accompanied by normal geometrical spreading and attenuation effects due to absorption. Also, ground effects can play an important role [4,5]. To minimize these influences direct subtraction of propagation path and spreading effects has been used [6] and they have been included in composite analytical models [3,1]. Our approach is to investigate scattering by focusing on back scattering where the direct sound waves are not present and the scattering mechanism is dominant [7]. In this paper we present scattering data from a model tree, construct an artificial "grove of trees" and compare the scattering data from this configuration with measurements of scattering from natural woodlands.

2. SCATTERING BY CYLINDERS

Both electromagnetic and acoustic scattering from cylinders has been studied since the analytical problem is reasonably tractable [8]. Acoustic models incorporating the surface impedance of the cylinders have also been produced [9] and measurements have been compared with this theory [1]. Perhaps the most reasonable shape to consider for modeling trees and individual parts of trees is the cylinder. (We focus our efforts in the lower frequency region of the spectrum where leaves and needles have little influence). Back scatter measurements have been conducted on cylinders in an anechoic chamber [7]. These compared well with predictions based upon the "physical optics" approximation where the scattering cylinder is treated as an equivalent source after calculating its illumination, A(r), by the sound source, A, of interest using $A(r)=A/r*\exp(-ikr)$, where r is the distance from the source and k is the wave number. Figure 1 compares theoretical, solid line, and measured points, *,

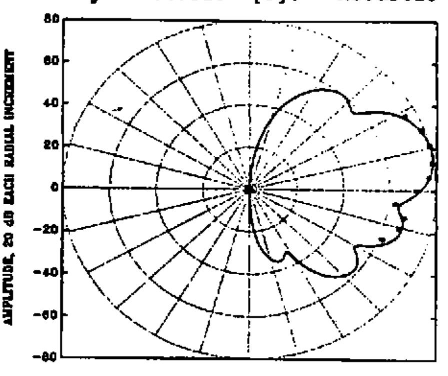

Figure 1. Backscattering from a wooden cylinder.

for a 0.025 m diameter wooden cylinder of length 0.1 m. In this case the source was located 15 degrees below a line normal to the mid point of the cylinder axis.

3. MODEL TREE MEASUREMENTS IN AN ANECHOIC CHAMBER

In order to utilize a simple construction technique and to facilitate theoretical analysis by using the cylinder as a basic building element a model "tree" was constructed from wooden cylinders having three different sizes. The trunk (1.0 m long, 0.05 m dia.) supported six limbs (0.40 m long, 0.025 m dia.) and each limb supported four branches (0.20 m long, 0.0125 m dia.). The limbs were nonuniformly distributed around the azimuth of the trunk and were spaced at irregular intervals along the length of the trunk. The branches were similarly placed on the limbs. This construction presents different tree silhouettes when it is viewed from a distant point at the same elevation as the middle of the trunk but from different azimuth angles. In this manner 24 different views could be obtained by fixing the tree in 24 different rotational positions at 15 degree azimuth angle intervals.

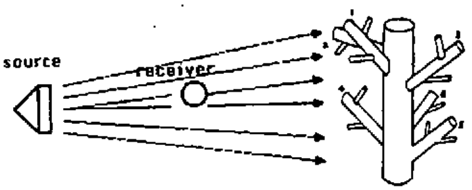

Figure 2. Arrangements for model tree, source-receiver = 0.87 m and receiver-tree = 1.05 m.

The backscattering measurements were performed with a 0.03 m diameter speaker driven by a pulse gating system through an amplifier. The physical arrangement of the source and the microphone is shown in Figure 2 along with a sketch of the model tree. Figure 3 shows the direct pulse and its spectrum while Figure 4 shows an expanded view of the pulse scattered from the tree after band limiting it and subtracting repetitive background noise. Sixteen repetitions of the measurement were averaged to reduce the effects of random noise. The useful bandwidth of the direct pulse was approximately 1 kHz to 12 kHz.

The tree was elevated 0.9 m on a stand which was padded to reduce its effect on the measurements. Measurements made with the stand in place but no tree were used in order to produce an estimate of the repetitive background.

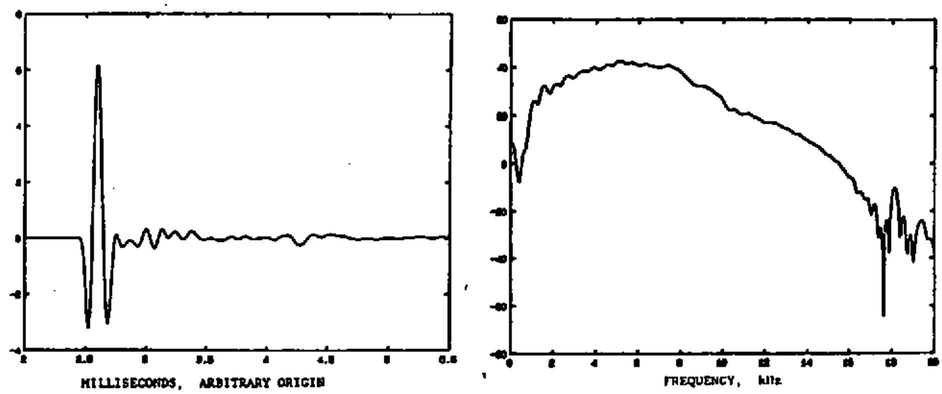

Figure 3. The direct pulse at the microphone (volts) and its spectrum (dB)

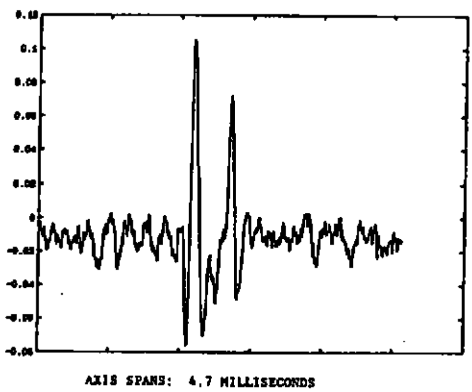

Figure 4. The backscattered signal (volts) from the tree in one orientation

4. AN ARTIFICIAL GROVE OF TREES

In order to approximate the backscattering from a small grove of trees an irregular separation was postulated as shown in Figure 5. Each of the nine trees in the grove was represented by a different azimuth view of the model tree and an artificial time history was generated for the nine tree grove by appropriate time delaying and amplitude scaling of each of the separate backscatter records. We assume no interaction between the scattering of each tree in the grove. Thus the individual records are simply added together. Figure 6 shows the time record produced for the nine tree grove while Figure 7 shows the backscatter spectrum of a single tree which has irregularities compared to the spectrum of the direct pulse; a direct result of multiple scattering from different parts of the single tree. Figure 8 shows the backscatter spectrum from all nine trees and compares it with the spectrum of the direct pulse.

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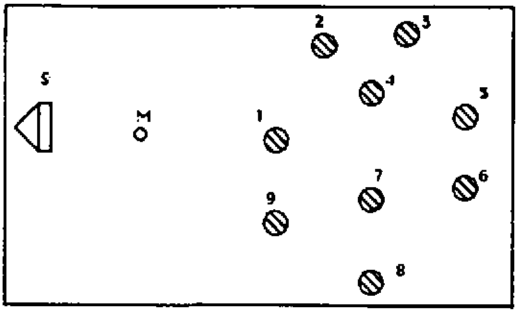

Figure 5. Conceptual arrangement of nine trees in "grove". Average separation distance is about one meter.

The general shape of the backscatter spectrum from the grove is the same as that of the excitation pulse. The major difference is the high variability of the the spectrum with frequency. This is characteristic of multiple returning pulses from different trees and from different parts of individual trees.

5. BACKSCATTERING MEASUREMENTS IN NATURAL WOODLANDS

An initial measurement of backscattering from a wood has been made by occupying an adjoining grassy field. A freon air horn source and sound level meter were located 60 and 40 m from the edge of the wood, along a line normal to the edge of the woods. Each was elevated 1.2 m. Short blasts of the horn and the backscattered sound were recorded on a high

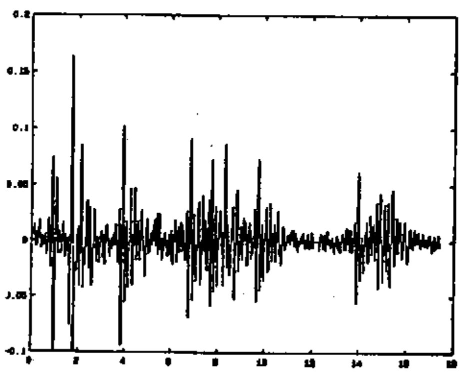

Figure 6. Synthetic scattering for nine tree grove.

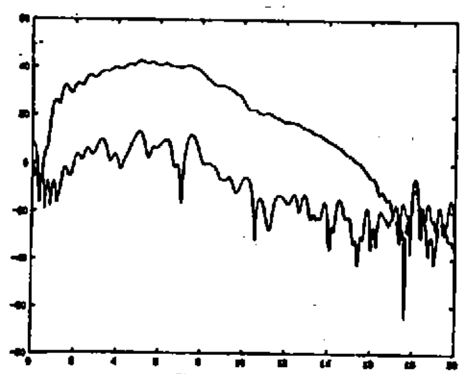

Figure 7. The spectrum of a single tree and direct spectrum

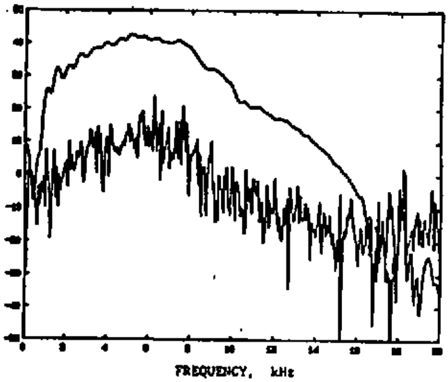

Figure 8. Spectrum (dB) for the nine tree grove and direct signal spectrum.

fidelity analog tape recorder. Analysis of those records produced the spectrum shown in Figure 9. No special provisions were made to account for ground effects in these preliminary measurements; however, at higher frequencies and for distances greater than 30 m, ground reflection interference effects have been observed to be absent in the forward

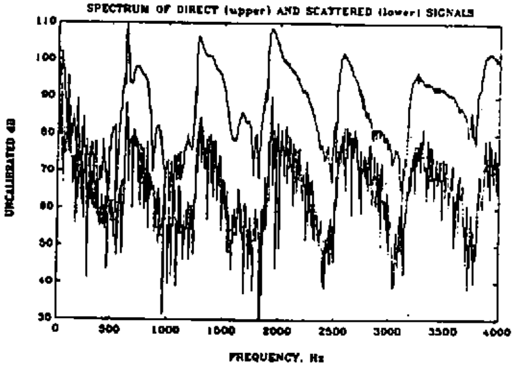

Figure 9. Scattered spectrum (dB) and direct signal spectrum, woodlands.

propagation case[1]. As is seen from the figure, the amplitude spectrum of the returned signal is similar in shape to the direct pulse spectrum which is shown by the upper solid line. Although the air horn has a somewhat peculiar spectrum it is reasonably broad band and provides a good signal to noise ratio. The useful bandwidth is approximately 0.5 to 5.0 kHz.

6. CONCLUSIONS

A comparison of the natural woodlands results, Figure 9, with those of the artificial grove, Figure 8, shows that many of the same basic features are seen. In each case the scattered signal spectrum closely matches the spectrum of the direct signal although there is considerable variability in the amplitude of the scattered signal spectrum. If one investigates the phase characteristics these are found to have a large linear component (due to the large time delay for the scattered signals) and to appear as a totally random signal. This is the behavior one would expect from the given physical situation. The spectral amplitude of the scattered signal, in the region of 1300 Hz, is approximately 30 dB below that of the direct signal for the woodland. If one assumes geometrical spreading, while ignoring ground effects, and uses the edge of the woods to approximate the spreading effect of the scattered signal, one would predict 14 dB reduction for the signal of a perfect back scatterer. Thus, figure 9 shows the measured result to be approximately 16 dB below the simple spreading model which is indicative of the effectiveness of the woodland in scattering the signal. One can thus estimate the scattering crossection of the woods in this case to be about 0.16. Similar calculations can be made for the model grove of trees, however, in this case the ground effect does not exist due to the nature of the anechoic chamber data. In this case the scattered signal is approximately 30 dB below the direct signal. Again, simple geometrical spreading (we chose to use the center of the grove as the location of an equivalent scatterer) predicts 15 dB attenuation. The 15dB difference equates to a scattering crossection for the grove of about 0.18.

It appears that there might be some frequency effects in the data of Figure 9. In particular, the region from 2500 to 3000 Hz displays less apparent attenuation than the regions between 1300 Hz to 1800 Hz and 3300 Hz to 3600 Hz. The measurements were performed in the fall of the year and there was full foliage with autumn colors. Price and Attenborough [1] modeled ground effect, scattering loss, and attenuation for sound propagating through trees. They used scattering exclusively to model propagation above 2 kHz while below this the principal influences were ground effect and scattering. We recognize the complexity of the combined influences in this frequency region but have not yet attempted to sort out the principal effects seen in our data. Also, no attempt has been made to perform a complete analysis of the total scattered signal over all the relevant parts of the trees. This is a complex calculation involving many assumptions; we are investigating models appropriate to a more complete analysis.

7. REFERENCES

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