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SCATTERING MEASUREMENTS ON NATURAL AND MODEL TREES

James C. Rogers and Sung M. Lee
Michigan Technological University

SUMMARY

The acoustical back scattering from a simple scale model of a tree has been experimentally measured. The model consisted of a trunk and six limbs, each with 4 branches; no foliage or twigs were included. The data from the anechoic chamber measurements were then mathematically combined to construct the effective back scattering from groups of trees. Also, initial measurements have been conducted out-of-doors on a single tree in an open field in order to characterize its acoustic scattering as a function of azimuth angle. These measurements were performed in the spring, prior to leaf development. The data support a statistical model of forest scattering; the scattered signal spectrum is highly irregular but with a remarkable general resemblance to the incident signal spectrum. Also, the scattered signal's spectra showed little dependence upon scattering angle.

INTRODUCTION

Acoustic scattering in forests has often been studied in the context of sound which propagates through forests and thereby suffers attenuation. This attenuation is attractive to those who might consider the acoustic screening effects of forested areas. Thus, sound propagation in forested areas has been considered by many researchers (ref. 1, 2, 3). At least five factors contribute to the attenuation of sound propagating in forests: spherical spreading, atmospheric absorption, foliage absorption, ground loss, and scattering. It appears that scattering is a significant factor in sound attenuation at the middle frequency range (ref. 4, 5). The approach toward studying scattering that we use here is to focus on scattering alone and to particularly include back scattering. In this way only the scattered signal is measured whereas in traditional measurements of attenuation through forests both scattered signals and direct signals are present. In this case it is quite difficult to separate the scattered component from the considerably stronger direct signal component. Since forests are made up of many single trees, back scattering from forests can be considered using single tree scattering processes and extending this to the aggregate effects of many trees.

MODEL TREE BACK SCATTERING MEASUREMENTS IN AN ANECHOIC CHAMBER

Purpose of Measurements

There are several advantages to making back scattering measurements on a simple model tree in an anechoic chamber. If an asymmetrical tree is used the scattered signal will be different for different azimuth angles and synthetic "forest scattering" data can be generated by using an ensemble of these model scattering measurements. Also, it is possible to observe scattering as a function of increasing scattering angle: zero degrees for back scattering and one hundred eighty degrees for forward scattering. The results reported here do not use this capability however. If the tree is elevated on a pedestal the effects of ground reflections are removed, something that is not possible with a natural tree. Finally, the measurements are quite repeatable with no effects from meteorological influences.

Description of Model "Tree"

A tree silhouette was selected that approximately simulates that of a tree in a northern hardwood forest. The basic structure is a trunk, several limbs and a large number of branches as described earlier in Rogers et. al. (ref. 6). In order to utilize a simple construction technique and to facilitate theoretical analysis (something not yet completed), the cylinder shape was used as a basic structure element in our model. Hard wooden cylinders of three diameters were used for fabricating the three basic elements: the trunk, the limbs, and the branches. A single wooden cylinder that is several wavelengths long provides an effective back scattering element with a structured scattering pattern (ref. 7). Figure 1 shows a sketch (not to scale) of the tree and lists the dimensions and numbers of the components. The limbs were randomly distributed around the perimeter of the trunk and were spaced at irregular intervals along its length. The branches were similarly placed on the limbs. The effects of leaves and twigs were ignored. We believe that these will not give significant back scattering contributions in the low and mid frequency range studied.

Back Scattering Measurements and Results

The basic arrangement of the speaker source and receiving microphone in relation to the tree are shown in Figure 1. A single pulse was applied to the speaker through an amplifier, received by the microphone as a "direct" wave, and again received by the microphone as a back scattered signal.

Our small speaker (with a hemispherical cone approximately 0.02m in diameter) did not radiate a great deal of energy and several techniques were used to ensure an adequate signal to noise ratio. The tree was removed from its stand and a "constant background" measurement was made by coherently time averaging several pulse events; this gave a reliable estimate of the signal which regularly existed in the portion of a time record occupied by the desired scattered signal. This signal was subtracted from all scattering records. Also, coherent time averaging was used in all scattering measurements to reduce the effects of random noise. Using the known geometry it is possible to construct a time window in which the scattered events will appear; such a window was used to exclude all signal outside of the desired scattering events. Finally, the useful spectral content of the source was judged to be from approximately 1 kHz to over 10 kHz. A filter was applied to the scattered signal to permit only those frequencies in the analyzed data.

Figure 2 compares the signal back scattered from the trunk alone, after it has been processed as described above and amplified by a factor of approximately 30, with the "direct" signal. There is a high degree of similarity between the signals as would be expected for back scattering from a single cylinder. The scattered signal is considerably more complex after the limbs and branches are added to the trunk.

After the tree was assembled, twenty four separate back scattering measurements were made. For each the tree was rotated 15 degrees about its vertical axis. The non symmetrical nature of the silhouette produced 24 unique scattering records which were then treated as the back scattering from 24 separate trees.

SYNTHESIS OF BACK SCATTERING FROM A GROUP OF MODEL TREES

Eighteen of the unique back scattering records were used to synthesize the scattering one would measure from a grove of 18 trees. Figure 3 shows a plan view of the grove, to scale, where the distance between the source, the microphone, and the first tree in the grove is indicated. Each original time domain measured back scattered signal was amplitude scaled by a (1/distance) factor to account for the round trip distance from the source to the tree and back to the microphone. Also, each original signal was time delayed by an amount proportional to the round trip distance. Finally all eighteen time domain records were added to simulate the signal back scattered from a grove of trees. Figure 4a shows the composite time domain signal. Two features are apparent: several individual tree scattering events are seen and as time increases in the figure the signal amplitude diminishes in accordance with the (1/distance) spreading factor. Figure 4b presents the spectrum of the composite scattered signal and compares it with the spectrum of a single direct pulse.

Over the useful bandwidth of the signal shown in the figure, approximately 1 kHz to 14 kHz, there is a close resemblance between the average spectrum of the scattered signal and that of the direct signal. There is approximately a 30 dB level difference between the two spectra and a very irregular character to the scattered signal spectrum as would be expected for a random combination of similar signals. This random spectral appearance is observed even though the model tree did not have a broad distribution of sizes in its structure (in fact, only three different cylinder diameters and lengths were used). We conclude, by comparing the spectrum of the scattered signal from the synthetic grove with that which is produced by an actual forest (not shown here) that a high degree of realism has been achieved with a relatively small number of "trees" in the grove. One further comment about the synthetic scattering record should be made: since we combined individual records of sound scattered from individual trees, we have not allowed multiple scattering between trees. However, each individual tree record naturally incorporates multiple scattering among elements of the tree such as the trunk, limbs and branches. This scattering is probably considerably more important than that between individual trees.

SCATTERING MEASUREMENTS ON A SINGLE TREE IN A FIELD

Purpose and Measurement Arrangement

Scattering within a forest is a complex process; the presence of a large number of individual scattering trees with a wide spatial distribution precludes the study of the process at the level of the individual tree. We have therefore selected an isolated tree located in a uniformly flat grassy field for a series of scattering measurements. Both back scattering and scattering at angles up to 165 degrees from back scattering have been measured. This arrangement permits use of an impulsive source which is desired for separating the scattered signal from the signal which travels directly from the source to the microphone. The source was a simple mechanical device with a barrel and firing pin. It was machined to accept shot shell primers, Winchester part # 209, which are detonated by striking the firing pin.

Figure 5 is a plan view of the measurement arrangement. The source was located at a fixed point 30 meters from the center of the tree and the measurement microphone was located a distance of 15 meters from the tree at a series of points separated by 15 degrees of azimuth. A reference microphone was situated along a line between the source and the tree and 5 meters from the source. The source and measurement microphones were at fixed heights of 1.15 and 1.10 meters respectively. Bruel and Kjaer microphones, type 4155, were used on type 2330 sound level meters for both the reference and measurement microphones. Typical peak direct wave sound levels measured by the reference and measurement sound level meters were 137 dB and 120 dB respectively. At each location three separate shots were fired and the data recorded on a 4 channel digital audio tape recorder with a uniform frequency response from 0 to 10 kHz and a dynamic range of 84 dB.

Ground Impedance Measurements

It is not possible to directly remove the effects of ground reflections from the measurements since the source-ground-tree geometry is quite variable over all of the tree components such as the trunk, limbs, and branches. A level difference measurement was made between two microphones; one was placed at the ground level and the second was elevated 1.15 meters directly over the first. The shot source was located 5 meters away from the pair at an elevation of 1.15 meters. The ratio of the elevated microphone power spectrum to the ground level microphone power spectrum produced a differential spectrum or "transfer function" magnitude characteristic of the interference process between the direct and the reflected wave as described in ref. 4. Using the experimental data found in Donato (ref. 8) and the fact that the real and imaginary parts of the ground impedance are observed to vary approximately as the inverse square root of the frequency, a good fit was found for our experimentally determined differential spectrum with a theoretically predicted differential spectrum. The fit was better at frequencies below 1000 Hz but quite acceptable above that frequency too. We thus have a good estimate of the ground impedance for the field surrounding the tree. A representative value for the magnitude of the ground reflection coefficient at 300 Hz is about 0.8.

The initial scattering investigation sought to minimize the variability of all effects except the azimuth angle which was varied in 15 degree increments as shown earlier. Thus, although the precise effect of the ground reflections on the "insonification function" for the tree is not known, the source-tree geometry was fixed for all of the measurements. Also, the measurement microphone was always maintained at a fixed distance of 15 meters from the tree. The impulsive source proved to be quite repeatable but to reduce the effects of random noise and source variability somewhat, each scattering measurement reported here is the average of three power spectra from three separate measurements. The temperature was approximately 78 degrees F at 1 meter elevation and the wind varied in strength from 0.5 to about 1.5 meters per second.

Results of Scattering Measurements

Figure 6 shows the back scattered (0 degree azimuth angle) signal spectrum. The general shape is characteristic of the source alone in an anechoic environment (without any ground effect present). The spectrum, which is the average of three power spectra, is highly irregular in the same manner as that previously observed in Figure 4b for the synthetic grove of trees. The maple tree used for the outdoor experiment had multiple trunks with dozens of limbs and branches. Since the measurement was made early in the spring there were no leaves on the tree. One can estimate the signal to noise level by examining the background noise spectrum (the average of three noise power spectra) which is also shown on the figure. There is good signal to noise (about 15 dB to 25 dB) over an approximate frequency range from 0.5 kHz to 9.5 kHz.

The scattered signal spectra at azimuth angles of 45, 90, and 150 degrees are shown in Figures 7, 8, and 9 respectively. Also, the scattered signal at 0 degrees, from Figure 6, is shown in these figures. A principal feature of these plots is that the scattered signal spectrum level varies only a small amount with azimuth angle for the frequency range of the measurements.

DISCUSSION AND CONCLUSIONS

Close examination of Figures 7, 8, and 9 shows that the scattered signal is remarkably similar over all angles of scattering. The insonification of the tree was the same in all cases since the source-tree geometry remained constant so comparison between figures examines only the effects of varying the scattering angle. Only at 150 degrees (Figure 7) does there appear to be a significant variation from the scattered signal at 0 degrees. This deviation is seen in frequencies from approximately 700 Hz to 1200 Hz. The rather narrow frequency range of this feature is perplexing. The scattering record for 165 degrees has been examined in this frequency range. It too shows reduced signal levels over approximately the same frequency range. However, the scattering record at 135 degrees does not display this feature.

The measurements presented here are part of a continuing investigation of scattering by forests. Foliage effects are to be included and additional low frequency data are required. Also, scattering models for trees and forests are required. These should adequately treat azimuth angle, frequency effects and address the problem of ground effects. Finally, the influence of tree variety should be considered on forest scattering.

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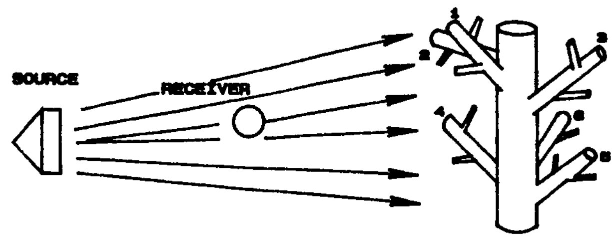
AN ARTIFICIAL TREE



TREE SPECIFICATIONS:

1 -	TRUNK,	1.0m x 0.050m Dia.
6 -	LIMBS,	0.4m x 0.025m Dia.
24 -	BRANCHES	0.2m x 0.012m Dia.

ASYMMETRICAL ARRANGEMENT

GEOMETRY:

Source - Receiver = 1.05 m
Receiver - Tree = 0.87 m

Figure 1. Sketch of model tree (not to scale) with element dimensions and physical arrangement for back scattering measurements in an anechoic chamber.

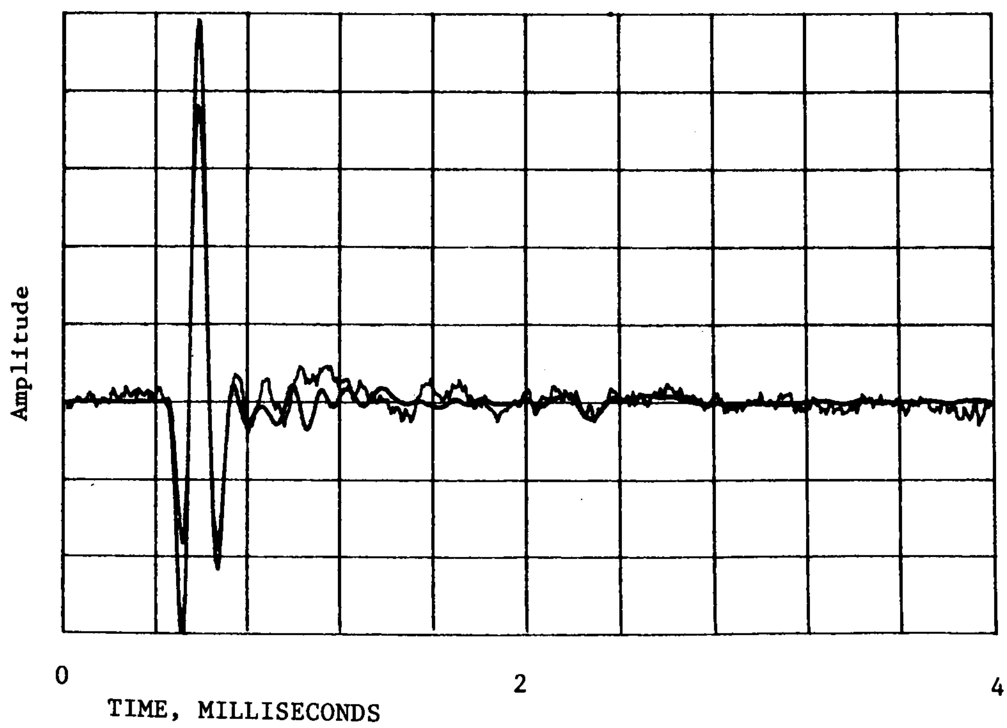


Figure 2. The direct signal (smooth) and the back scattered signal from the trunk alone (noisy and irregular) after amplification by a factor of 30.

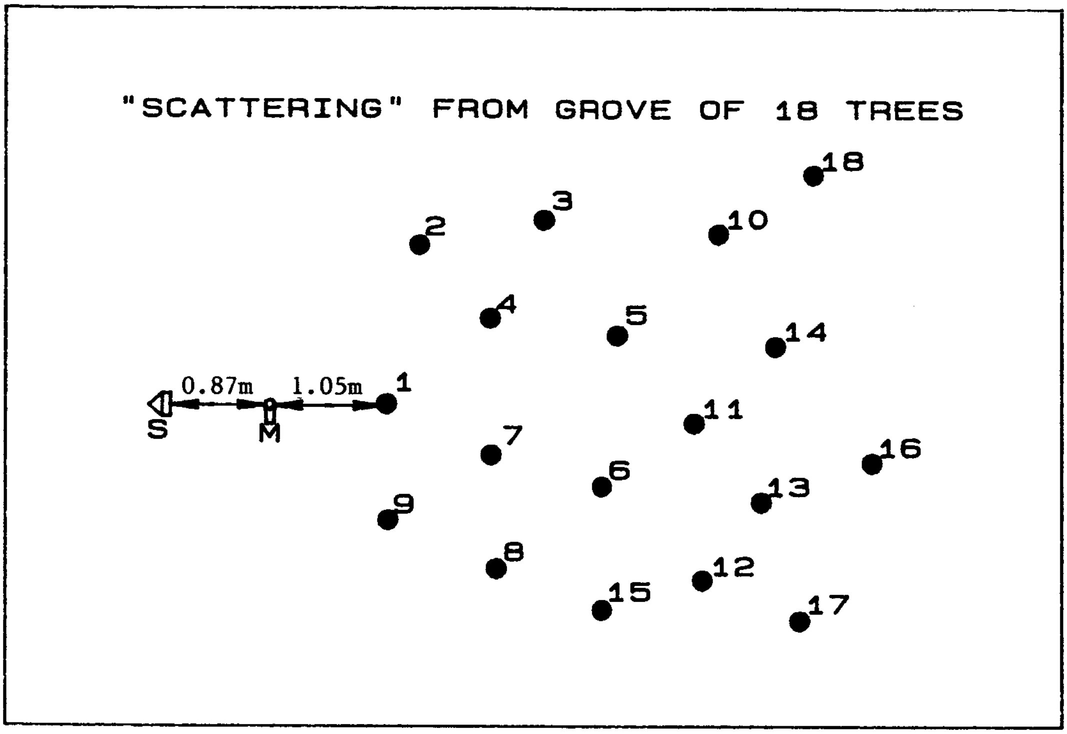


Figure 3. Arrangement of individual trees in synthetic grove of trees (to scale). The source and microphone positions are also to scale. Each tree position contributes an individual time domain scattering event to the synthetic back scattering record as described in the test.

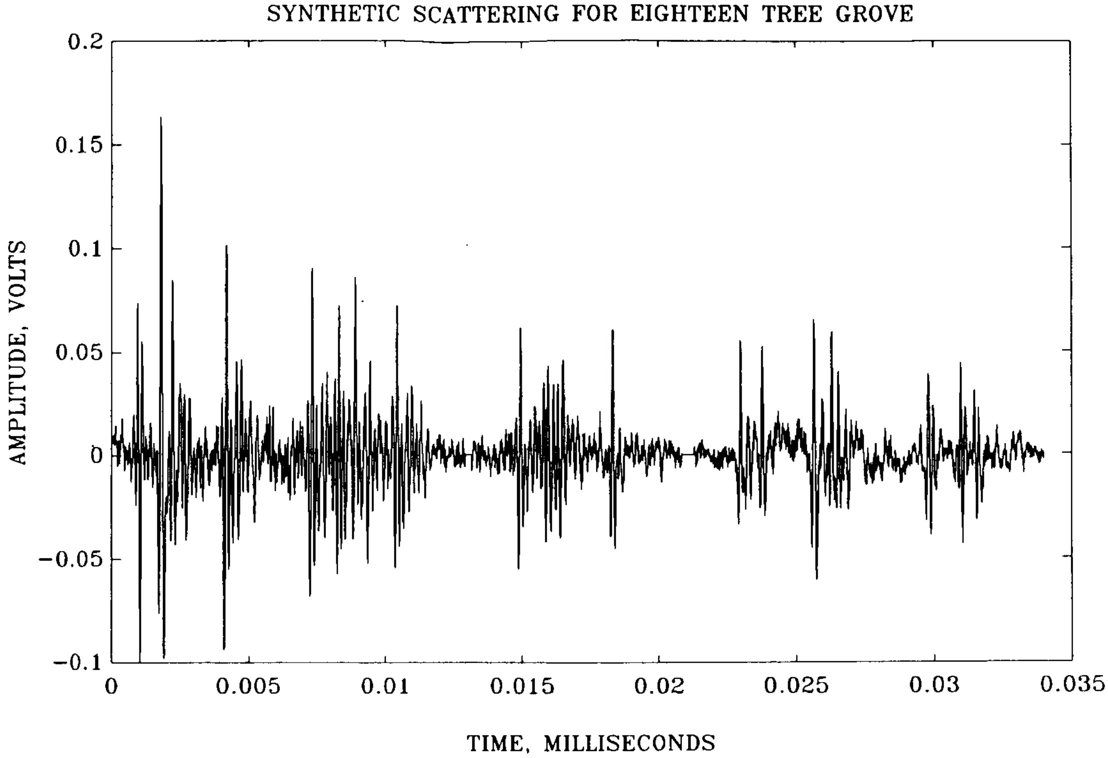
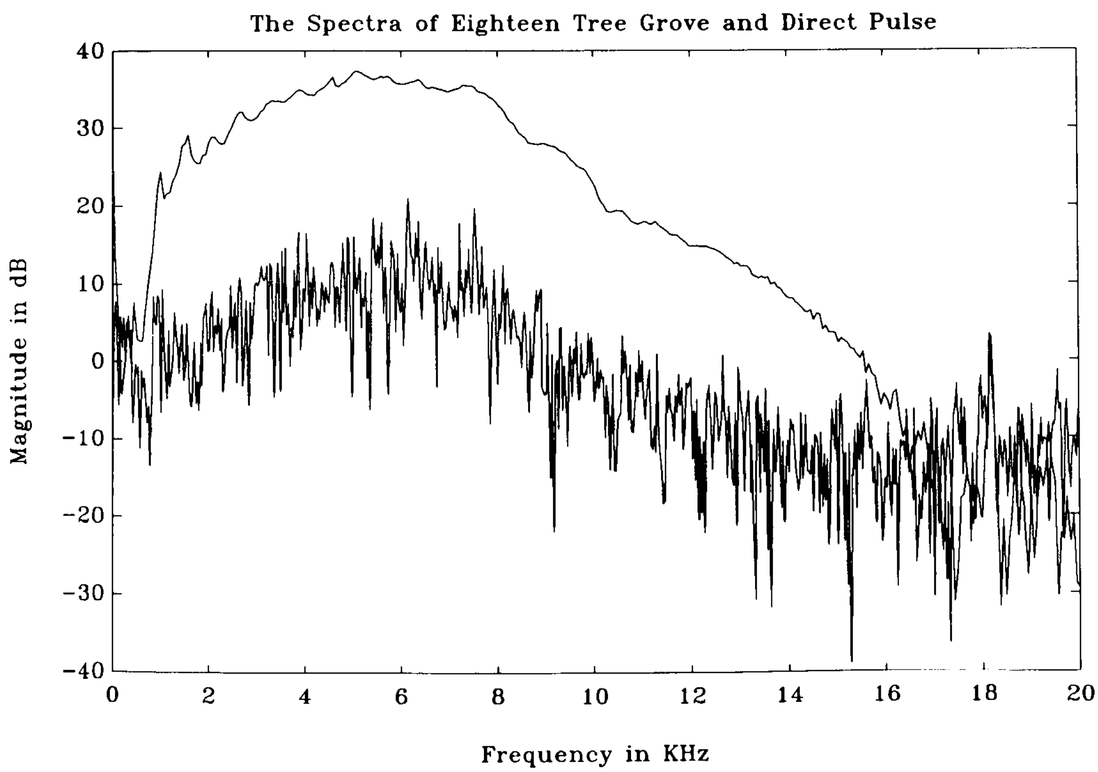


Figure 4. a). Synthetic time domain record constructed for grove of 18 trees shown in Figure 3.



b). Comparison of the direct signal spectrum with that from the synthetic scattering data in a).

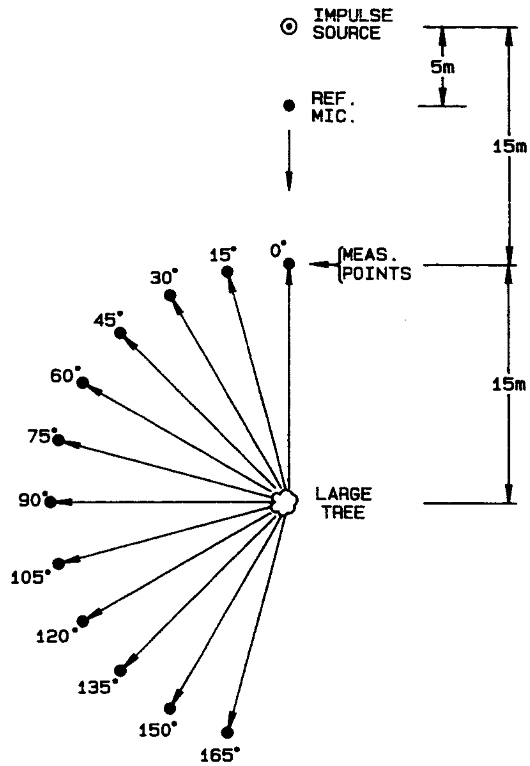


Figure 5. Plan view of scattering measurements made on a single tree in a grassy field.

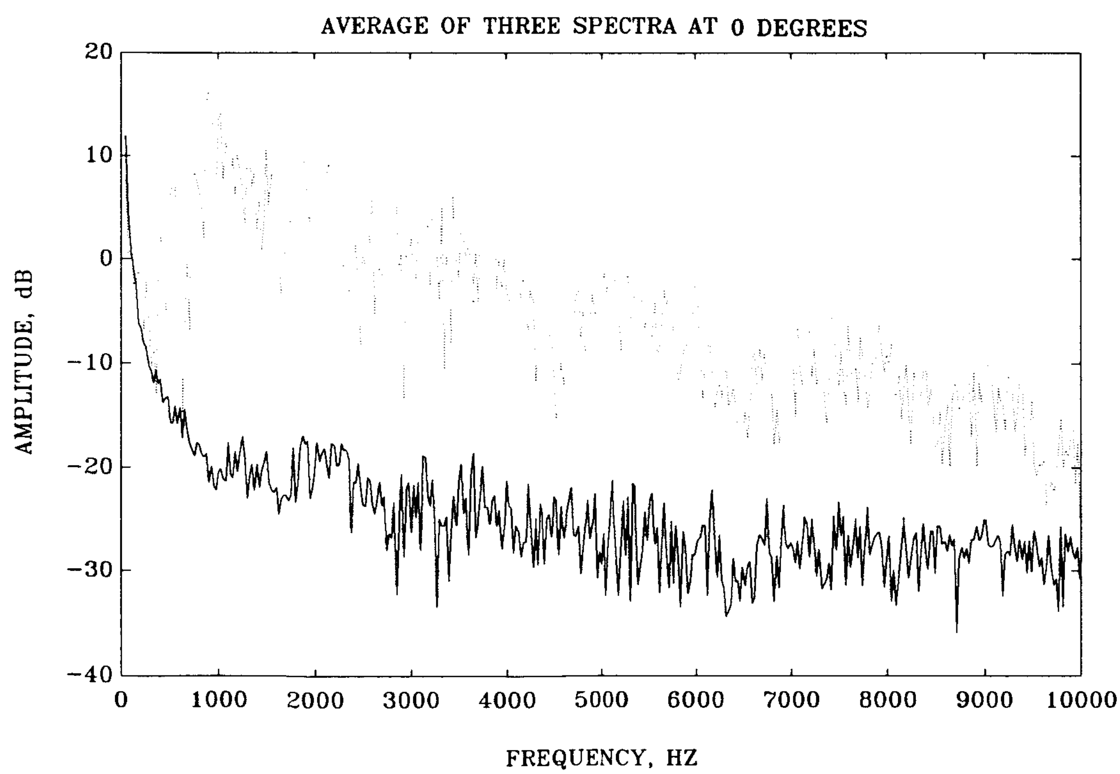


Figure 6. Single tree scattering at 0 degrees (back scattering), dashed line, and background noise spectrum, solid line.

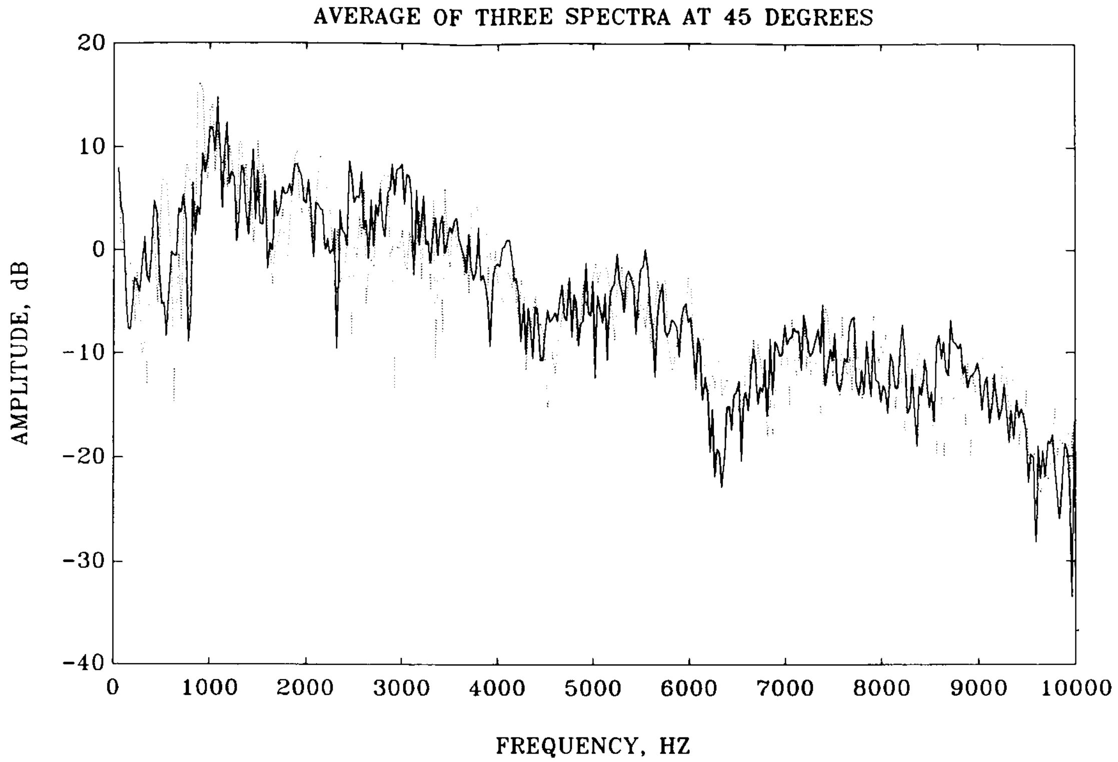


Figure 7. Single tree scattering at 45 degrees, solid line, compared with back scattered spectrum, dashed line.

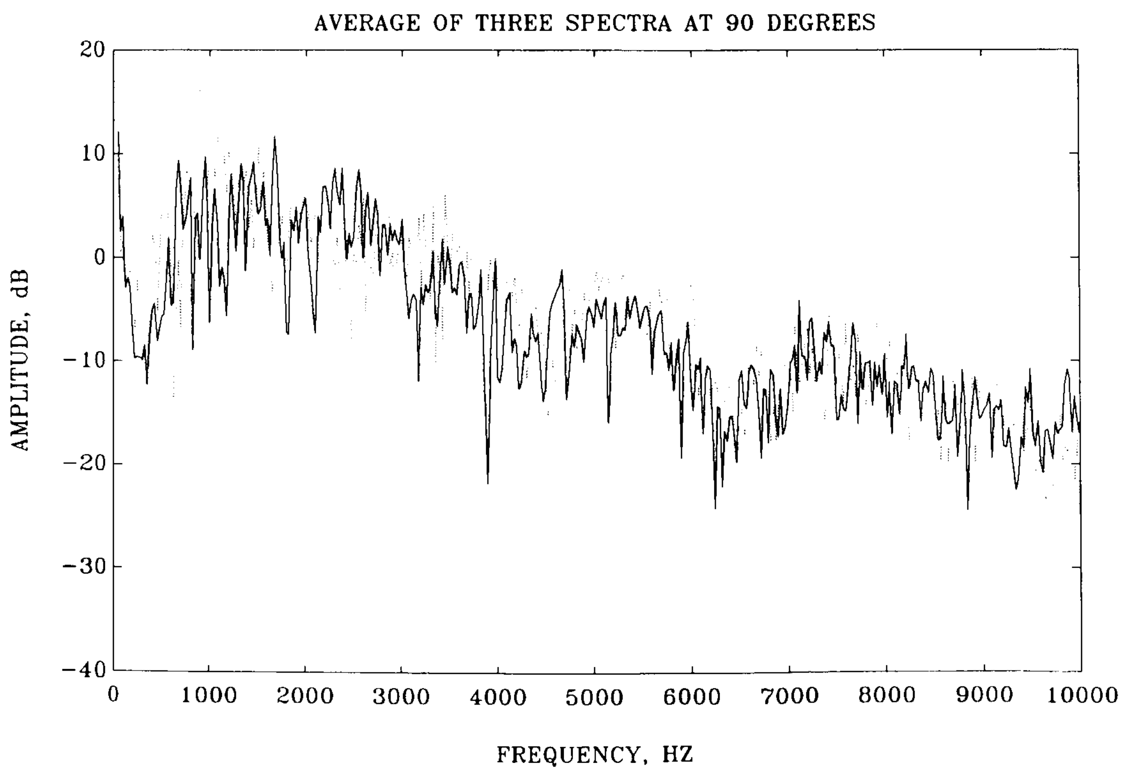


Figure 8. Single tree scattering at 90 degrees, solid line, compared with the back scattered spectrum, dashed line.

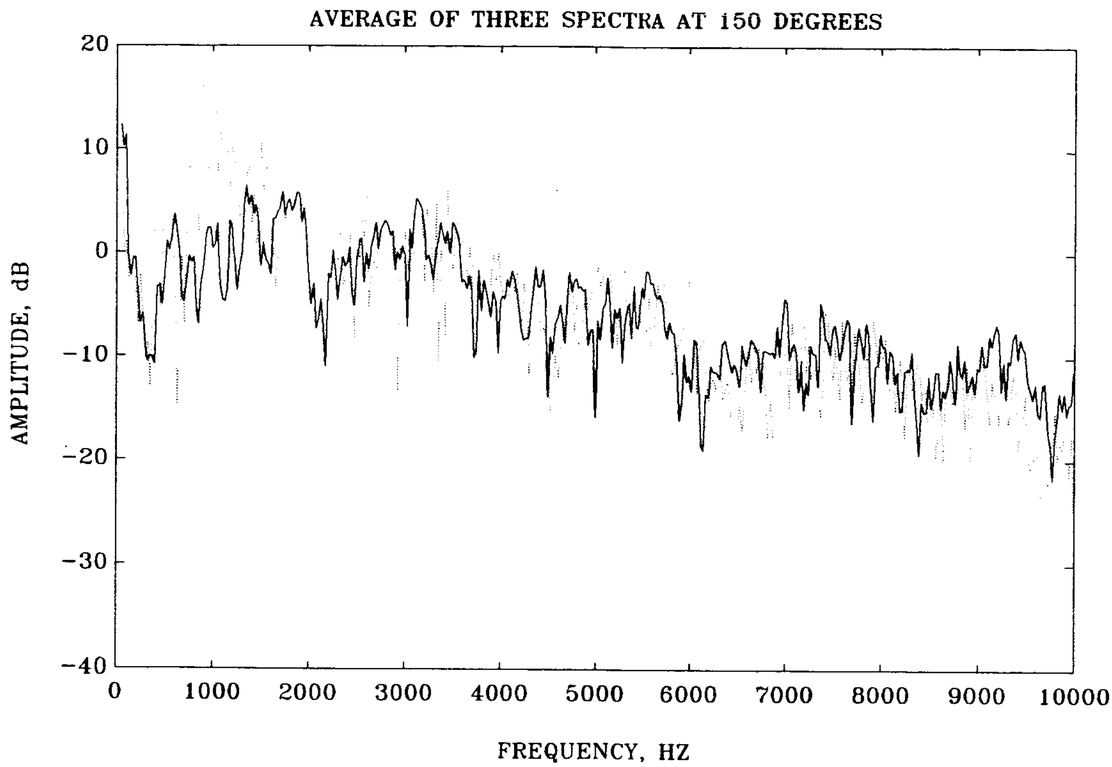


Figure 9. Single tree scattering at 150 degrees, solid line, compared with the back scattered spectrum, dashed line.