Acoustic and electronic modelling of environmental noise and vibration, building acoustics and electro-acoustic equivalent circuits

Cedric Roberts

Retired Acoustical Engineer, Brisbane, Australia

1 INTRODUCTION

The paper deals with airborne and underground acoustic models and electronic modelling developed for real life simulations. It examines the translation of the physical understanding of sound in the air and underground transmission into mathematical models that can simulate acoustical propagation, noise reception and reverberation in the air and underground. Electronic models apply complex numbers and electrical theory to equivalent circuits to determine characteristic impedances and ultimately the voltage gain and frequency response of the equivalent electroacoustic model. These models programed on Excel spreadsheets can be used in a variety of research and operational applications to predict and diagnose the performance of acoustical systems operating in air and underground environments and electronic equivalent circuits. Descriptions of and guidelines for selecting and using available propagation, noise reception, reverberation and electronic models are highlighted. Instructive case studies demonstrate applications in airborne, underground and electronic simulation.

The paper will provide guidance in the selection and application of airborne, underground acoustic and electronic models. Simulation is fast becoming an accurate, efficient and economical alternative to actual field testing and in-situ training.

Real life examples cover explosive sounds (airblast and ground vibration) and re-radiated noise and low frequency ground vibration from underground railway operations. There are further applications for construction noise and vibration, shooting noise, and motor racing noise; space does not permit them to be included here. Modelling for electronic and electro-acoustic applications will be presented, along with examples of electrical characteristics of passive bandpass filters, transfer characteristics of audio transmission lines and impedance matching.

2 EXPLOSIVE SOUNDS FROM QUARRY AIRBLASTS

Airblast levels for a specific site can be calculated from the distance to the blast, the mass of the maximum instantaneous charge per delay and constants C1 and C2 for a specific site.

3 LOW FREQUENCY GROUND-BORNE VIBRATION AND RE-RADIATED SOUND FROM UNDERGROUND RAILWAY OPERATIONS

Trains moving along an underground railway will excite the rail and the underlying track structure.

4 GROUND VIBRATION ATTENUATION

The propagation of waves is influenced by attenuation along the propagation path. The attenuation can be through geometric spreading, energy loss within the material, or reflection and refraction at boundaries.

Modelling predicts an upperbound for the vibration level in a building near a subway during the passage of a train. The analysis neglects all wave types except compressional waves. As a starting point the upperbound tunnel wall octave band acceleration level (dB re. 10^{-6}g) spectrum in bands 4 Hz to 1000 Hz is used. The spectrum is for a train (assumed a line source) speed of 56km/h on jointed rail supported on stiff fasteners. For other speeds it is necessary to correct each octave band level. Other corrections are necessary if resilient rail fasteners are used, rail is welded rather than jointed and if the tunnel is soil based rather than rock based. The re-radiated sound pressure level within the apartment on an upper floor depends on the size and shape of the room, the amount of sound absorption in the room, and the vibration levels of the room surfaces.

5 RAILWAY NOISE

The noise sources on moving trains which have to be considered are the locomotive for low speed operation, particularly with diesel traction, and the rail/wheel interaction for all operations. Predictions are presented for both these individual sources and a single total value derived to represent the passage of each train.

6 TUNNEL ACOUSTICS

There are negative effects of annoying noise escaping from tunnel portals, since the sound generated inside tunnels does not dissipate but rather reverberates within the structure. The total sound energy level at sensitive receptors from a tunnel opening with their directivity patterns is determined as $L_{Aeq,T}$ at $1/3^{rd}$ octave band centre frequencies.

7 SEMICIRCULAR CROSS SECTION TUNNEL

The total power radiated outside through the tunnel mouth is determined from the radius of the mouth, distance from the point source to centre of the mouth, sound power of the point source, absorption parameter of the inside walls and the solid angle subtended from the location of the point source to the crown of the tunnel mouth.

8 RECTANGULAR CROSS SECTION TUNNEL

The total sound power is derived from half the width of the tunnel mouth and the height of the tunnel mouth.

9 ELECTRONIC MODELLING; PASSIVE BAND PASS FILTERS

A band pass filter passes signals within a certain "band" of frequencies without distorting the input signal or introducing extra noise. Bandwidth is commonly defined as the frequency range that exists between two specified frequency cut-off points that are 3dB below the maximum centre peak while attenuating the other frequencies outside of these two points.

It is constructed using RC components that will only allow a range of frequencies to pass above the lower cut-off frequency and below the upper cut-off frequency. Assuming that both the resistors (R) have fixed values, the values of the two capacitors (C) for the high pass and low pass stages can be calculated. The "Centre Frequency" of the band pass filter can be calculated as the "geometric" mean value.

10 TRANSFER CHARACTERISTICS OF AUDIO TRANSMISSION LINES

The distinguishing feature of transmission lines is that they have uniform cross sectional dimensions along their length, giving them a uniform characteristic impedance, to prevent reflections. For frequencies above 1MHz, the characteristic impedance of a coaxial cable line depends on the dielectric constant of the inner insulator, length of the cable and the ratio of the diameter of the inner conductor to the inner diameter of the outer conductor (shield).

11 IMPEDANCE MATCHING NETWORKS; PI-PAD ATTENUATOR

The Pi-pad attenuator is used in radio frequency and microwave transmission lines. The Pi-pad attenuator has a series resistor and two parallel shunt resistors to ground at the input and the output. This type of attenuator can be used to impedance match either equal or unequal transmission lines.

12 PI-PAD ATTENUATOR WITH EQUAL IMPEDANCES

In this case three resistive elements are chosen to ensure that the input impedance and output impedance match the load impedance which forms part of the attenuator network. As the Pi-pad's input and output impedances are designed to perfectly match the load, this value is called the "characteristic impedance" of the symmetrical Pi-pad network.

13 PI-PAD ATTENUATOR WITH UNEQUAL IMPEDANCES

This network can be used for impedance matching of unequal source and load impedances.
The value of the three resistors and impedance factor can be calculated.

14 CONCLUSION

This presentation will demonstrate that the application of acoustical and electronic modelling has the capacity to become a valuable supplement to the existing protocols of actual field measurement and in-situ training. Modelling is becoming an accurate, efficient and economical alternative.