ANALYSIS OF ATTITUDINAL RESPONSE TO AUDIBLE NOISE FROM HIGH VOLTAGE TRANSMISSION LINES AND TRANSFORMER STATION

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ABSTRACT

Procedures for statistical analysis of audible noise from 550 and 735 kV transmission lines and a 735 kV transformer station are discussed. The research also entails psycho-acoustic testing of people to determine attitudinal response to this form of noise as compared to other environmental noises. The evaluation of subjective response to corona noise in a laboratory environment are also discussed. A Participation Program between the Canadian Electrical Association, the American Electric Power Service Corporation and the National Bureau of Standards in Washington is outlined.

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Les procédures pour l'analyse statistique du bruit audible des lignes de transmission électriques de 550 et 735 kV et d'une station de transformateur de 735 kV sont discutées. La recherche fait également intervenir des tests psycho-acoustique faites sur des personnes pour déterminer le comportement et l'attitude de ces gens face à ces sources de bruit par rapport à d'autres sources de bruit environnementales connues. Les évaluations de la réponse subjective au bruit de corona dans un environnement de laboratoire sont également discutées. Un programme de participation entre "Canadian Electrical Association", "American Electrical Power Service Corporation" et le Bureau des Normes à Washington est aussi décrit.

1 Introduction

With the development of EHV and UHV lines in recent years for the transmission of electric power, the field of corona discharge has gained considerable prominence, particularly with reference to the influence of corona discharge on line design and accompanying energy losses and noise generation. Typical noise from the lines occurs when droplets form on the line, and energy from the line is then discharged from the droplets to "ground" (air). This results in large energy loss from long transmission lines. Research [1] tended to indicate that audible noise is of concern in current 550 and 735/765 kV lines and could be the predominant design factor in future high voltage transmission lines, especially where adverse weather conditions such as rain, fog and wet snow pertain.

Audible noise due to transmission line corona discharge has not received the same public recognition that general community, transportation and industrial noise problems has received. This potential noise problem has been of concern in the scientific community primarily because of the anticipated energy demands which will result in the need for higher capacity lines in the future, and the desire of public utilities to ensure that disturbances such as noise from these high voltage lines do not present an adverse environmental impact on community life.

The Sound and Vibration Laboratory of The University of Western Ontario, under a contract from the Canadian Electrical Association, undertook field measurements of, and attitudinal responses to, existing high voltage lines and a high voltage transformer station. The aims of the research were to carry out (1) long-term audible noise measurement of existing high voltage transmission lines and a typical high voltage transformer station, and (2) a subjective evaluation of the annoyance of people caused by the transmission line and transformer station audible noise. It was intended that information from this study, together with information from a study being carried out at the Institut de Recherche de l'Hydro-Quebec (IREQ) on the effect of conductor design on audible noise, would, through extrapolation of results, enable predictions to be made of the effect of noise on people from future lines of higher voltage.

Throughout the planning stages of a procedure to be followed in this project, the Laboratory had been conscious of tests which had been carried out by other agencies, particularly in the U.S.A.; the Laboratory had also taken note of the report prepared by the Task Force of the Radio Noise and Corona Subcommittee of the Transmission and Distribution Committee of IEEE [2], together with the guide for measurement of audible noise from transmission lines prepared by an earlier IEEE Radio Noise Subcommittee [3]. The Laboratory had also benefited from the comprehensive papers which appeared in the Proceedings of the Workshop on Power Line Noise as Related to Psycho-Acoustics, sponsored by the Radio Noise and Corona Subcommittee of the IEEE Transmission and Distribution Committee [1]. Further, valuable upgradings of the techniques of field measurements of corona noise and laboratory attitudinal response testing were obtained from the Symposium on Transmission Line Audible Noise sponsored by the Radio Noise and Corona Subcommittee of IEEE [4].

2 Field Measurements

The field tests were carried out on 550 kV and 735 kV lines, and a 735 kV transformer station, for a period of approximately one year using continuous automatic monitors; the data from the monitors were statistically analyzed in conjunction with the processing facilities of the Laboratory and the Computing Centre at The University of Western Ontario.

Two measurement systems had been developed: (1) a digital recording system which logged corona noise (and, in one case, transformer substation noise) in octave band frequencies centred from 31.5 Hz to 16 kHz, overall sound level, overall background noise, wind direction and velocity, temperature, relative humidity, radio interference, rain and snow precipitation, and (2) a system for recording corona sound from the line (and the transformer substation) on a four-track analog tape recorder of studio quality, controlled by a microprocessor.

Four test sites were established. These were at La Plaine on the 735 kV line of Hydro-Quebec leading into Montreal from Churchill Falls, a 735 kV transformer station at Boucherville, outside Montreal, a 550 kV line at Kleinberg north of Toronto and a 735 kV site at the Ohio Power line near Canton, Ohio.

The operating personnel of the various local divisions of the utilities participated in a collaborative effort in obtaining this data. In addition to the measurement trailers which housed the instrumentation at each site, the mobile facility of the Laboratory was used for on-the-spot instruction with regard to instrumentation, calibration, measurement techniques, and for general troubleshooting. The test trailer at each site was insulated and heated for winter operation and fan-cooled for summer operation.

Protection of the test microphone from the rain was probably the most important consideration for installation of long-term recording stations. A Bruel and Kjaer Model 4921 outdoor microphone system was chosen for the measurements. The unit consisted of: a 1/2 inch quartz-coated back-vented condenser microphone, a windscreen housing a rain cover, and an electrostatic actuator for microphone calibration at the upper end; a stainless tubula stem which enclosed the preamplifier and its heater and connected the microphone to a silica gel dehumidification system at its lower end; a cast aluminum weatherproof case and glass panel for observing the condition of the silica gel; an internal power supply and individual voltage generators for microphone polarization, electrostatic actuator, preamplifier power supply, and heater; a 60 dB amplifier; calibration potentiometer; and sealed cable entries. The overall omnidirectional response of the unit satisfied the requirements of IEC 179 for precision sound level meters; the unit had a frequency response from 20 to 20,000 Hz and, with the sensitive condenser microphone, the system was capable of measuring down to 26 dBA (which was 5 dB above the electronic noise floor of the system).

Digital Acoustics meters were used to log the measurement data and a PDP 11digitizing computer (with magtape storage) was used for the measurements. The specifications were:

1. Sampling rate from 4 to 32 samples per second;
2. Dynamic range of 100 dB (autoranging);
3. Frequency response from 20 Hz to 20 kHz;
4. Measured Data points - corona noise in 10 octave bands, overall corona noise level, background microphone noise, environmental and line conditions;
4. The 20 data ponits (4 second interval between data points) were scanned every 80 seconds;
5. The scanner was controlled from a tape advance mechanism in the digital monitor;
6. Each tape storage capacity was 8 days of data;
7. Digitized data capable of producing various combination of acoustic data for further analysis.

Corona <u>sounds</u> were recorded on a four-track studio-type Otari tape recorder. The recorder used ½ in. professional recording tape, and at a recording speed of 15 in./sec, the frequency response was up to 20 kHz and recording time was approximately 3 hours. A microprocessor had been developed by the Laboratory to control the recorder. The microprocessor had been designed so that it would turn the tape recorder on when preset levels of (1) acoustic signals through a 16 K filter, (2) radio interference, and (3) wind velocity, had been reached. At the same time, a crystal clock and a tone coding system (part of the microprocessor) inserted a calibration and a time signal on the tape at the start of recording (which was eventually identified on playback of the field tape through the microprocessor decoder at the Laboratory). This time of recording, when cross-referenced with the time of the digital data recording system, gave all information regarding sound pressure levels vs frequency, background noise, weather, RI data, etc. The microprocessor also controlled the time interval at which the tape recorder was turned on (for example, 3 to 5 minutes every 20 to 30 minutes) and, through the remote control input to the tape recorder, sensed when the tape was at the end of each track, rewound the tape to the beginning, indexed the recording head to the next track, restarted the tape recorder, and, at the end of Track 4, rewound the tape to the beginning and shut down the unit. The 16 K acoustic signal identified the presence of corona noise (as opposed to most background noise), as did the RI signal. The wind velocity sensing ensured that noise recording took place only when the wind speed was below a predetermined level. With the precision sound level meter; the unit had a frequency response from 20 to 20,000 Hz and, with the sensitive condenser microphone, the system was capable of measuring down to 26 dBA (which was 5 dB above the electronic noise floor of the system).

2.1 Participation Program with the American Electric Power Service Corporation

On behalf of the Canadian Electrical Association, the Laboratory negotiated an "AEP-CEA Participation Program" with the American Electric Power Service Corporation. The Laboratory and AEP worked closely with the High Voltage Section of IREQ and the Environmental Noise Program Team of the National Bureau of Standards. The program provided for undertaking noise measurements and attitudinal response testing on a joint basis, in which instrumentation, measurement procedures and response testing procedures were coordinated and selected in such a way that there was compatibility and interchangeability of data, tapes, etc. associated with measurements and testing being carried out by the various research groups.

The Laboratory carried out all attitudinal response testing. In addition to assessing attitudinal response to contemporary corona noise from high voltage transmission lines, and predicting attitudinal response to higher voltage transmission lines of the future, a major objective of the study between AEP and the Laboratory was to develop a comprehensive cataloguing and library of contemporary noise from high voltage transmission lines and the associated environmental and line conditions [Reference 5, part 2].

3. Development of Subjective Testing

The existing or proposed regulations on audible noise

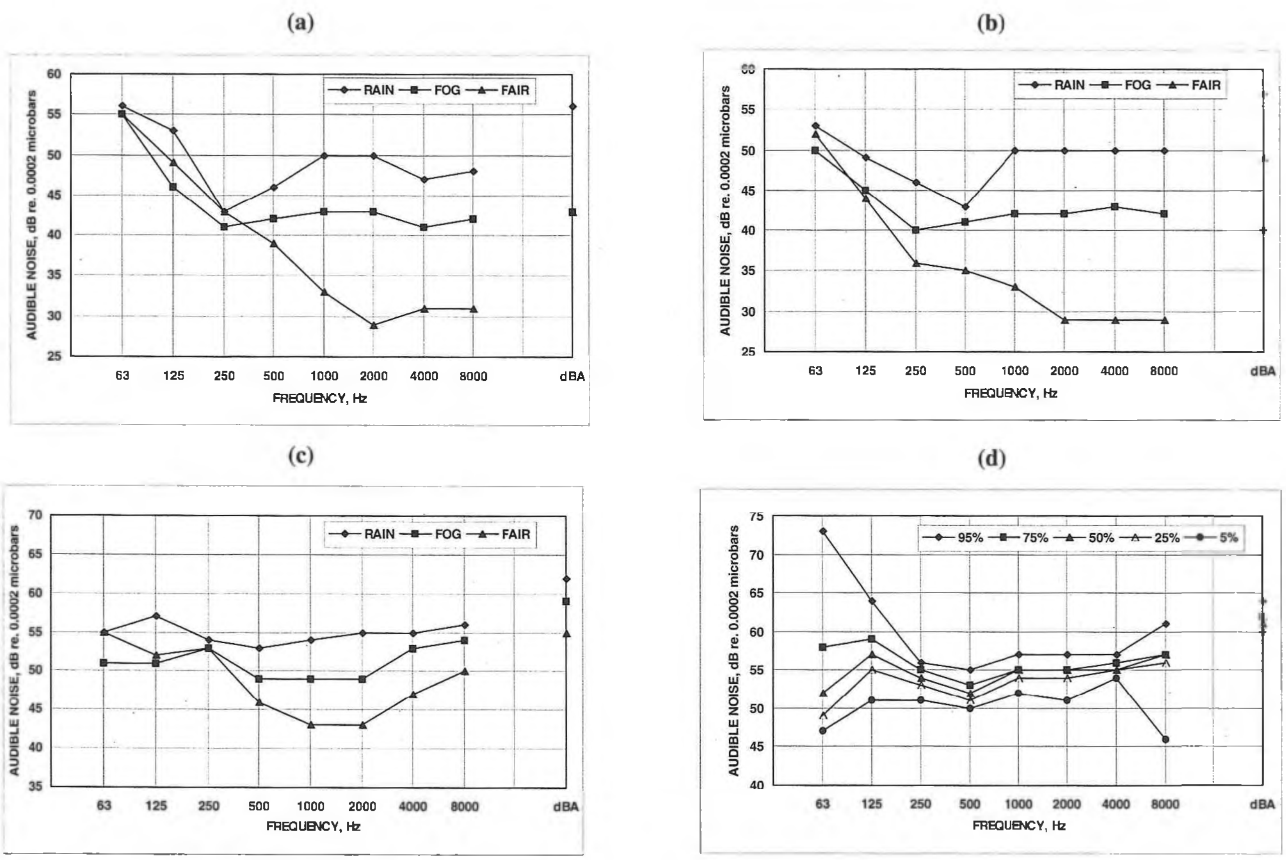

Figure 1. Frequency Spectra of Trasmission Lines - (a), (b) and (c) Three separate 750 KV Transmission Lines. d) Spetra of Percentile Levels of Line (c) during Rain.

have been normally developed with noise sources such as traffic and industry in mind, rather than audible noise from transmission line corona. The noise spectra associated with these types of disturbances normally covered the low to mid-frequency range, while corona noise spectra during rain and fog was relatively broad-band or flat up to and beyond 20 kHz. Typical spectra of corona noise from three different 750 kV lines are shown in Figure 1. In addition, there were sometimes pronounced peaks at the pure tone components which are harmonics of the fundamental 60 Hz frequency, and to these may be added, under special circumstances, a modulation caused by subconductor vibrations of 1 to 4 Hz. These latter vibrations were caused by wind or conductor corona phenomena or both. Consequently, regulations which embody descriptors reflecting a correlation between attitudinal response or annoyance and the traditional forms of environmental noise could not necessarily be expected to apply to the situations of corona noise.

In addition, many noise regulations differentiate between day and night values, while the audible noise from transmission line corona does not depend upon the time of day but rather upon the prevailing weather conditions—and it would appear that, even at comparable precipitation rates, the noise spectra and levels could vary markedly day-by-day or hour-by-hour on the same line, presumably due to local wind condition. Furthermore, it should be recognized that an increased level of corona noise during inclement weather may be tolerated by most people, since, on the average, inhabitants of the rain-affected region would be expected to be indoors at the time with their windows closed, and that the rain beating on roofs and windows, and usually accompanied by winds, would have a tendency to mask the corona noise. No such provision of course was included in any present regulations.

Further, present regulations do not take into account the slow variation with time of audible noise from transmission lines. The literature [1] indicates that noise complaint rating (NCR), which takes into account the time variation of noise, could be used as a descriptor for corona noise. This would appear to be a reasonable approach to the evaluation of annoyance of relatively fast-varying noises, such as traffic noise which fluctuates up and down with the passage of vehicles, perhaps having a mean cycle rate of seconds or minutes. In comparison to this, however, the variation of transmission line noise must be considered slow as it fluctuates only with changes in weather. For a day in which the rain is fairly steady, noise may stay fairly constant for hours at a time. Similarly, during a period of fog, noise levels may remain unchanged for prolonged periods of time. In this connection, it should be noted that steady noises have less of a disturbing effect than do periodic or intermittent noises. [6]

It can be seen then that the question of interpreting attitudinal response or annoyance to transmission line noise, and the development of a suitable descriptor or measure to be used by regulatory bodies, are fraught with all sorts of difficulties. It is therefore extremely important that an accurate and viable means of eliciting attitudinal response to corona noise be developed (in particular, in comparison with the response to other forms of contemporary environmental noises). The Laboratory had evaluated the relative merits of test tapes played back to subjects through a speaker in an isolated test room of the Laboratory, as compared with subjecting subjects to corona and other environmental noises through the use of quality headphones. The Laboratory

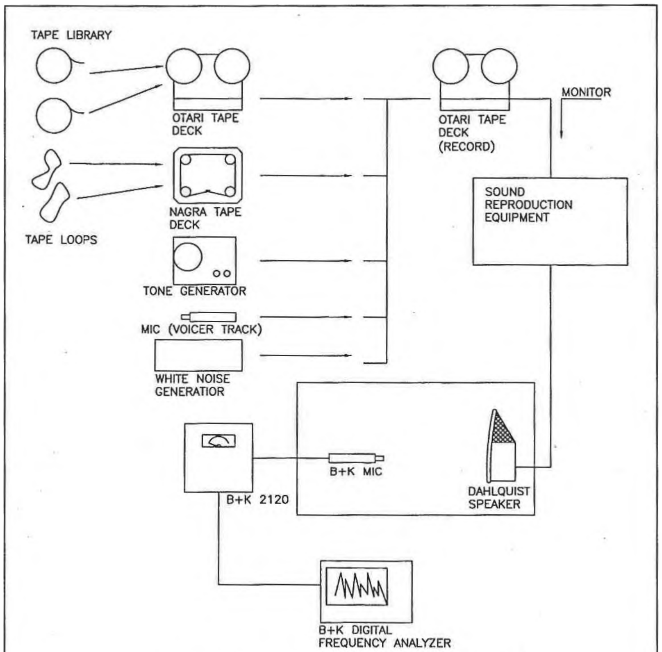

Figure 2. Test Tape Preparation

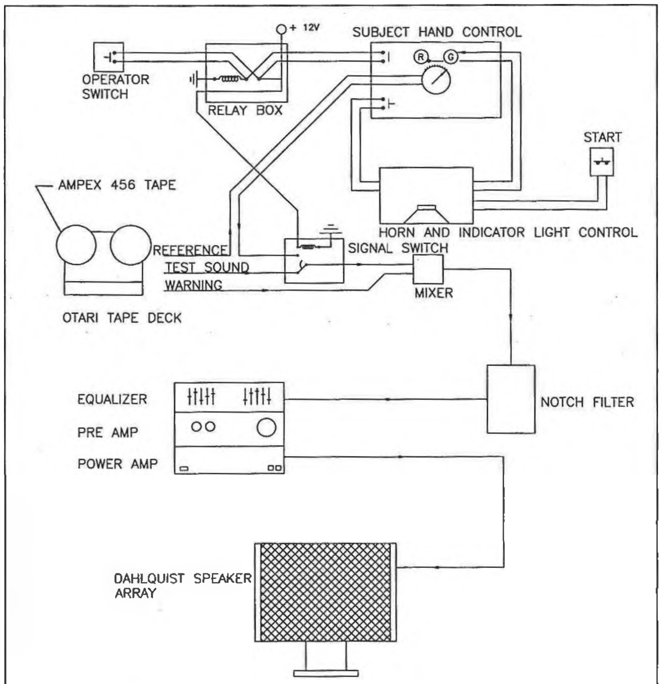

Figure 3. Sound Reproduction System

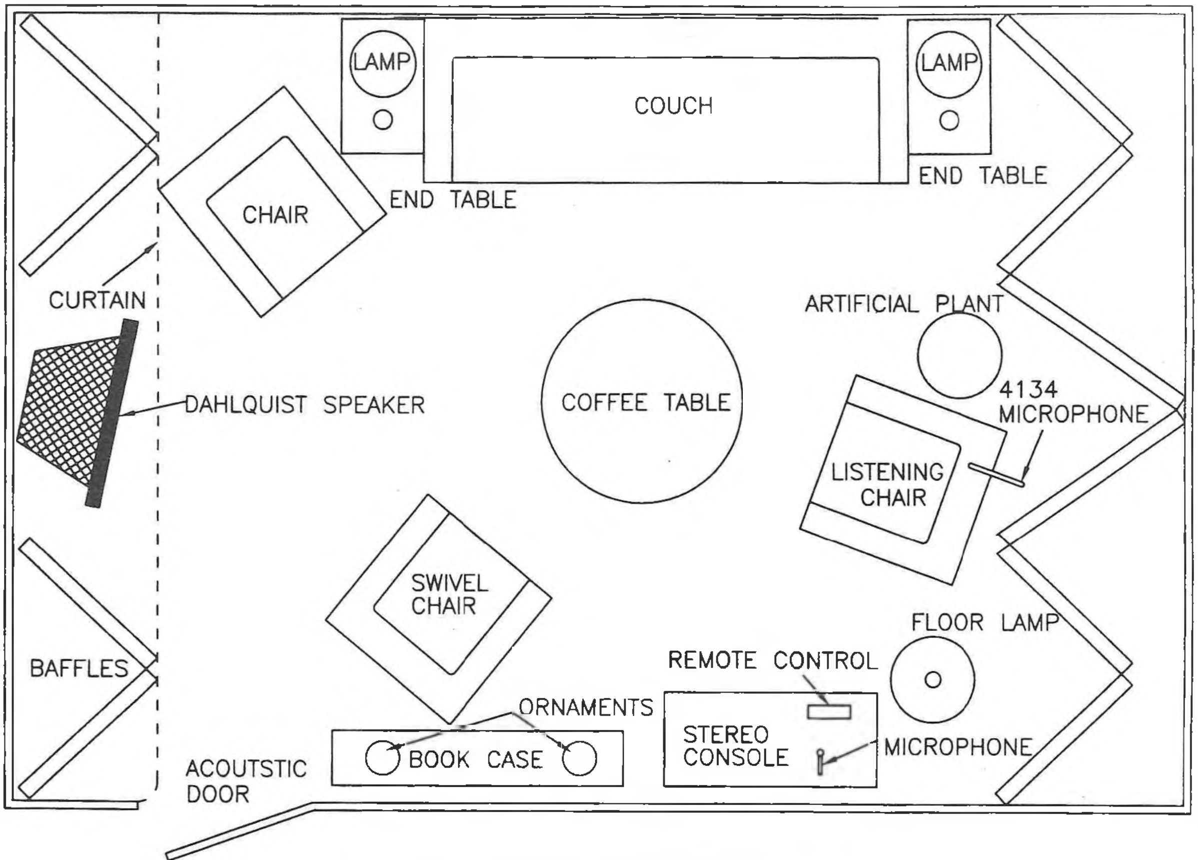

Figure 4. Psychoacoustic Test Room

ruled out the use of headphones, primarily because of the deterioration in frequency response of these units above 12 to 14 kHz, plus the fact that task performances which may be asked of subjects would be carried out in an 'unnatural' setting (i.e. headphones on one's ears) which could prejudice results.

The field tapes of corona line and transformer station noise, including field tapes from 765 kV lines of AEP were edited, catalogued, and subsequently used in the preparation of a 30- minute test tape for subjective response of people to this form of noise (and, as mentioned previously, for comparative purposes, to other forms of environmental noise). A block diagram of preparation of the test tapes is shown in Figure 2 and a diagram of the test tape playback procedure to the test room is shown in Figure 3. The test room was isolated from external airborne sound transmission, and was located on a separate foundation in the Laboratory which effectively isolated the room from building structural vibrations. The room was suitably decorated and furnished (i.e. simulating a family room or study - see Figure 4) and it was acoustically calibrated and equalized apropos of standard procedures which have been developed at the National Bureau of Standards [7, 8, 9].

The acoustic calibration of the test room, in particular at the position where the subjects were seated during attitudinal testing, was carried out by a microphone moved to various positions around the subject's head (Figure 4). It should be noted that audio signals, even though they are well defined in the reproduction system, can become distorted at various points in the room by the room's physical layout, absorption and reflections—with the result that it was necessary to equalize audio distortions at the listener's ear. This was accomplished through the use of spectrum shapers, which consisted of electronic attenuators and amplifiers associated with the frequency bands of interest; this instrumentation is of the type used in high-quality stereo reproduction in studios. [5]. Absorption baffles were also used in this equalization. (Figure 4)

4. Attitudinal Testing

The site at one of the locations had to be abandoned because of malfunctioning and difficulty in servicing the equipment (Capreol). At this point, there were three units functioning in Canada - one at La Plaine (a 735 kV transmission line) in Quebec, one at Boucherville (a 735 kV transformer station) in Quebec, and one at Kleinberg (a 550 kV transmission line in Ontario). The data from these three locations were thoroughly analyzed, and, from the analysis tapes, preferred samples of corona sound were selected (as well as the other environmental sounds) for play back to lis-

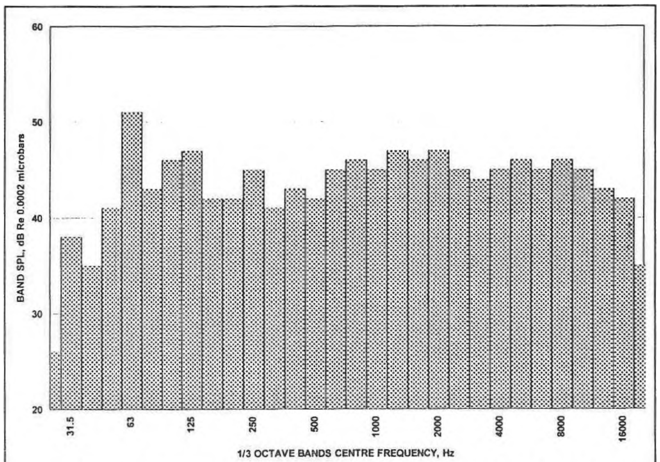

Figure 5. Sample of Corona Noise from 750 KV Line

teners in the listening room. At the same time, categorizing of all samples of corona noise on the tapes [see reference 5] was done, there were 25 samples categorized, and from these four corona test samples were chosen for psychoacoustic testing, along with five other environmental sounds.

A typical corona spectra which was measured from one of the high voltage transmission lines is shown in Figure 5. Note the frequency of the current in the line (63 hz) and its harmonics, and the wide band frequency (up to 16 kHz) associated with the corona discharge.

A behavioural conversion procedure, the "paired comparison", was used to assess human aversiveness to noise. Reproduced samples of corona noise (four separate stimuli), transformation noise, and other environmental noises (jet engine, traffic, lawn mower, air conditioner) were compared with an artificial reference stimulus in the above-mentioned listening room (see Figures 3 and 4). The artificial reference stimulus was an octave band of white noise centred at 1000 Hz. There were 32 participants (16 male, 16 female) evenly divided in the age groups of 30 years and under and 45 years and over. The nine test stimuli were presented to participants in random order. Each participant was involved in two separate test sessions, where the nine test stimuli were presented four times in different order during each session. This resulted in 256 responses per stimulus.

The background noise spectrum was below the preferred noise criteria (PNC 25) recommended for bedrooms and quiet residential areas [10]. The background noise spectrum was at or below that of each noise stimuli. The instrumentation for the reproduction of the sound stimuli in the listening room and the means whereby the listener adjusted the reference sound (comparison to each stimulus for equal aversiveness) is shown in Figure 3. The measuring equipment which was used in monitoring each stimulus and in recording the levels to which the reference sound was adjusted by the listener is shown in Figure 3. The intercom system which was used for verbal communication between the operator (who was outside the listening room) and the listener is also shown in Figure 6.

4.1 Procedure

The listening room tests were conducted in three stages. A pilot study was first conducted in order to familiarize the Laboratory with psychoacoustic testing to obtain some preliminary responses of people as to the annoyance of corona noise, and to assess the efficacy of the test room and the testing procedures as far as how listeners reacted (i.e. were they comfortable with the room and the procedures, were there any improvements for instance which could be made in the furnishings, etc.?). For details of this pilot study, refer to reference 11.

A major aspect of the present study (the second stage) involved an assessment as to how people responded to recorded and reproduced sound versus the original live

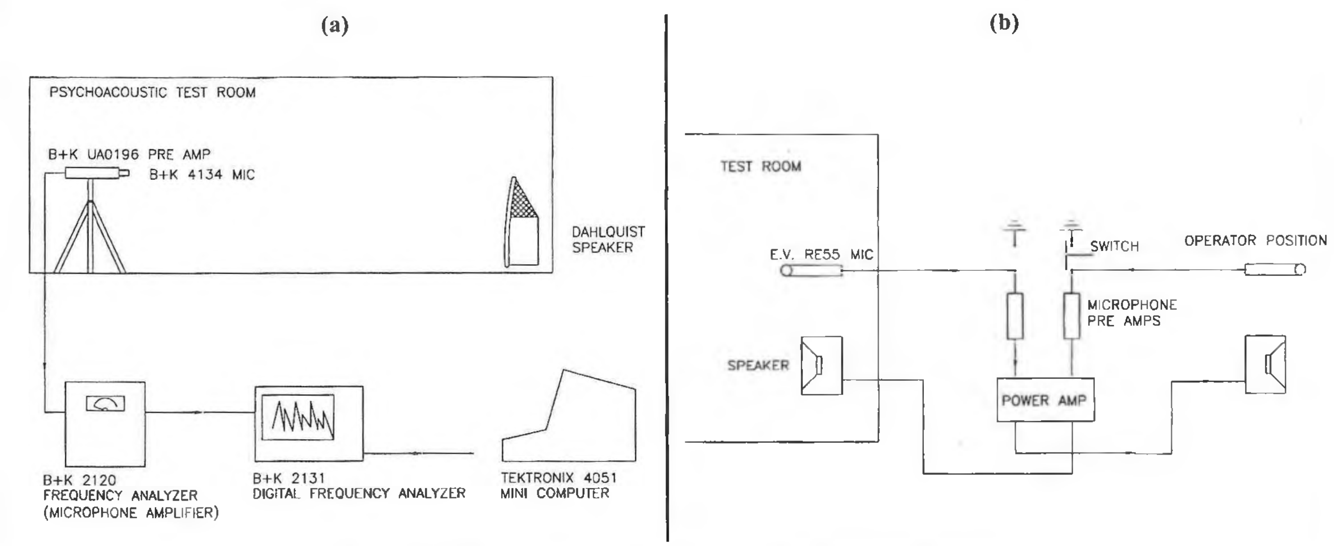

Figure 6. (a) Measureemht Equipmenmt; (b) Intercom System

sound, both presented at the same sound level to the listener [11].

Although it has been realized for some time in the recording industry that limitations in electronic instrumentation produce distortions in recorded and reproduced sound, it has not been known to what extent this might have an effect. The Laboratory carried out a series of tests using the same recording equipment as was used for field recording of the stimuli used in the final testing and tested several different reproduction systems (amplifiers, speakers, etc.). The sound from a spark generator was used as both the live sound and the reproduced sound and both were presented to listeners from behind the drapes (as in Figure 4). Listeners then adjusted the level of the reproduced sound until it was equally aversive to that of the live sound, as judged in a side-by-side comparison test. A statistical analysis of the results showed that respondents judged the recorded and reproduced sounds to be more aversive than the live sounds, when both sounds were presented at the same overall level. This indicated that the electronically recorded and reproduced sounds had been adversely modified (as far as human annoyance was concerned) by electronic distortion in the recording and/or reproduction system. This has, of course, considerable significance in use of listening rooms and reporduced sounds during psychoacoustic testing for attitudinal response of humans to noise aversion.

It was not possible to draw any conclusions regarding the problem of the response to reproduced vs live sound because of the limited nature of the testing which was carried out. In subsequent meetings between the liaison engineers to Project 77-27, and representatives from IREQ, Ontario Hydro, and American Electric Power, and representatives from the Laboratory, it became evident that considerable further testing would have to be carried out involving facilities where people could be exposed to real corona live sound and its reproduced version, in order to arrive at some indication as to the extent of the problem. Measures could then, perhaps, be applied to listening tests as a correction to the results.

The main difficulty in accurately reproducing a recorded sound appears to be in the speaker system. Inasmuch as IREQ [22] and the National Bureau of Standards [8, 9, 12, 13, 14) had carried out listening room tests using a Dahlquist Model No. DQ-10 speaker, it was decided that, in the interest of consistency, the Laboratory would use a similar speaker in its final psychoacoustic testing.

The final stage of psychoacoustic testing involved 32 participants. The selection of the number of participants and age groups, and the testing procedures (outlined below) were arrived at after consultation with Dr. Brian Shelton of the Department of Psychology at the University. A copy of the consultant's report and recommendations is included in Appendix I of reference 5. Each participant was audiometrically screened for hearing acumen (no more than 20 dB deficiency in each of the octave bands from 125 Hz to 8 kHz). An appointment was then made for each participant who successfully passed the hearing test for two separate occasions when he or she would be available to participate in the main test. Each participant was briefed with regard to the testing, and given a set of instructions to read at the beginning of the first test (see Appendix II of reference 5). Each test took approximately one hour (although this depended on the time that it took the listener to adjust the reference sound so that it was equally aversive to the test stimulus). There was a short session at the beginning of each hour to familiarize the participant with the testing procedure which consisted of nine samples of white noise at different levels to be compared with the octave band reference sound. The nine acoustic test stimuli were then presented in 4 blocks randomly distributed within each block (see Appendix III of reference 5 for a description of the tape format). Two warm-up (and "throw-away") test stimuli were presented at the beginning of blocks 1 and 3; there was a 3-minute break between the presentation of blocks 2 and 3. Each stimulus test signal was of 60 seconds duration and the participant had control of the sequential presentation of the test signal and the reference sound through anotated buttons on a console held, usually, on the participant's lap. A volume control knob on the console allowed the participant to adjust the level of the reference sound (white noise in the octave band at 1 kHz); by sequentially calling up the test signal and the reference sound and adjusting the volume of the reference sound, the participant then established a sound pressure level at which he or she judged the reference sound to be equally aversive to that of the test signal. The participant then pressed another button on the console which activated a horn at the operator's position at the outside of the listening room. The level at which the participant had ajusted the reference sound was then measured on the 2131 Analyzer (Figure 4) by the operator, and duly recorded.

TABLE I - Sound Levels of Test Stimuli Presentations (dB)**

		Linear	A-wt	D-wt
Corona	CR-1	57	55	62
	CR-2	60	58	65
	CR-3	55	53	59
	CR-4	60	58	65
Transformer Station	TRN	60	51	57
Traffic	TRF	58	46	52
Jet Engine	JET	60	60	68
Lawnmower	LWN	58	51	57
Air Conditioner	A-C	57	47	53

** All decibel levels quoted in this report are referenced to 20 μPa.

The levels of presentation of the nine test stimuli, as measured by the microphone at the listener's ear (linear setting of measuring system, A-weighted setting and D-weighted setting) are recorded in Table 1. The rationale for the choice of these measurement ratings is discussed in the next section.

The levels (Linear) at which the stimuli were presented to the listeners were chosen such that (1) the stimuli spectra would be above the room background spectrum, and (2) the octave band reference sound, when adjusted for equal aversion to each stimulus, would not exceed a maximum of 80 dB. (80 dB had been stipulated as the permissible upper limit of exposure levels to subjects as required by a University Senate Committee which monitored procedures in the use of human subjects for research.) The corona and air conditioner stimuli were presented at the levels at which they were recorded in the field. The transformer, traffic, jet and lawnmower stimuli were adjusted from the field recorded levels. Althouh the stimuli presentation levels in these tests were somewhat higher than were used by other experimenters in similar tests [6, 15, 16] it should be noted that higher levels of presentation of acoustic stimuli result in smaller standard deviations of listerners' responses [10].

5. Results and Discussion

The procedure which was adopted for the presentation order of the test stimuli resulted in 2 x (9 x 2) = 36 responses per participant per test session. With 32 participants and two test sessions per participant, this resulted in a total of 36 x 32 x 2 = 2304 responses (or 256 responses per stimulus).

The responses were analyzed and statistical comparisons made using the Statistical Package for Social Sciences (SPSS) and a UWO statistical package called BALANOVA (balanced analysis of variance). A summary of statistical tests which were carried out to check for significance of tape order effect, noise stimuli effect, day effect, gender/age effect, block effect, and an assessment of the use of the six participants with slightly impaired hearing in one ear, is given in Appendix IV of reference 5.

It has been noted earlier in this report that the objective in this part of Project 77-27, and the results as noted in this report, were to assess the attitudinal response of people (i.e. their aversiveness) to corona noise from HV transmission lines as compared to other forms of contemporary environmental noise and to also assess which of the most commonly used noise ratings might best fit the requirements for sound measuring equipment to be used in future monitoring and control of corona noise. The study was therefore concerned with the relative annoyance of various noises, and does not assess the annoyance levels of noise in absolute terms. (For a preliminary assessment of corona noise and a limited number of contemporary environmental noises with respect to the standard octave band of white noise at 1 kHz, expressed in terms of word descriptors ranging from "very pleasant" to "very annoying", see reference 21; also see reference 8 for a discussion and comparison of respondents' reactions, again in absolute terms, to various levels of corona noise obtained by (a) measurements in the field and (b) playback or recorded corona sound in a laboratory.)

As was mentioned in the Introduction, the measurement scales which will be assessed in this study are confined to Linear, A-weighting, and D-weighting, these being the most commonly used and most readily available in contemporary instrumentation. The Linear and A-weighted level of each stimulus as presented to listeners was obtained from the Bruel and Kjaer 2131 real-time analyzer (Figure 2); the linear 1/3 octave band spectra for the nine acoustic stimuli were used to arrive at the equivalent D-weighted levels. Equations and procedures for deriving these latter values may be found in Pearsons and Bennet [10]. These various levels are recorded in Table 1.

No attempt was made to account for transmission losses encountered when outdoor noises are heard indoors. The results thus approximate the situation of listeners located in a family room close to a large open window.

Figures 7, 8 and 9 show the ΔdB values (mean, standard

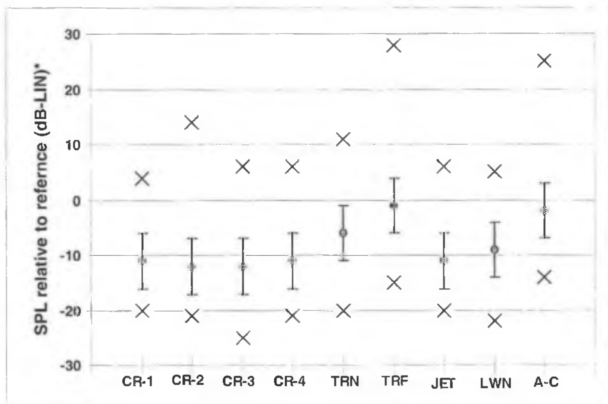

Figure 7. Difference in SPL-LIN between Test Sound and 1 KHz Octave Noise

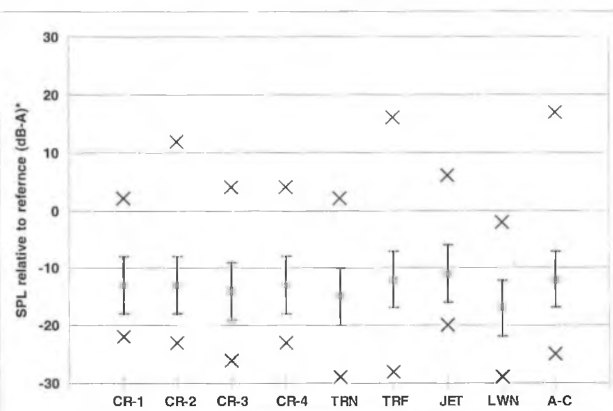

Figure 8. Difference in SPL-A between Test Sound and 1 KHz Octave Noise

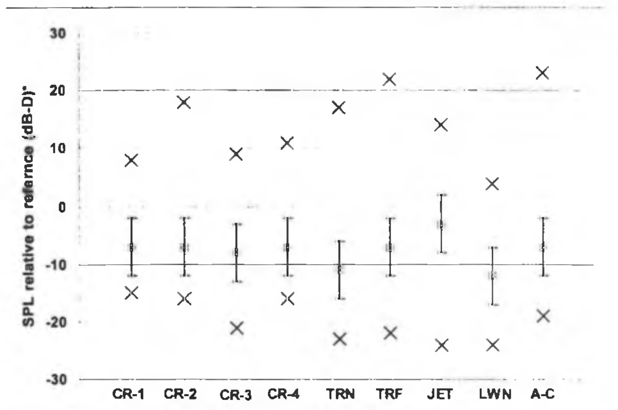

Figure 9. Difference in SPL-D between Test Sound and 1 KHz Octave Noise

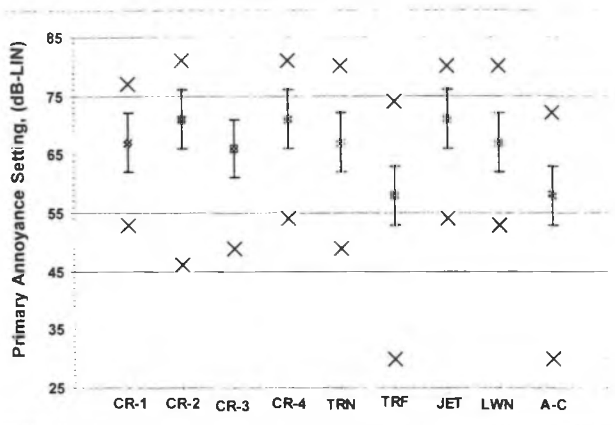

Figure 10. Distribution of P.A.S. in Response to Test Sounds

deviation and range) for each of the test stimuli, plotted for the three noise ratings of Linear, A-weighting, and D-weighting respectively. [x-x is the range, ⊢⊣ is the standard deviation plotted around the mean value] The ΔdB values are the difference between the sound pressure levels at which the stimuli were presented, and the levels to which respondents adjusted the reference (1 kHz octave band of white noise), for equal aversiveness of each. For instance, in Figure 7, for equal aversiveness (or, conversely, for equal preference), the stimulus CR-1 would have to be 11 dB lower than the reference noise, as measured by the linear scale. On the other hand, respondents adjusted the reference sound 0.5 dB lower (mean value) for traffic noise for equal aversiveness.

The values of SPL relative to the reference in Figures 7 to 9 (the ΔdB values) are thus an indication of relative aversiveness expressed by respondents to stimulus based upon actual assessment as measured in the listening room (Lin) and aversiveness as adjusted to the weighting measurement scales (A-weighting and D-weighting). The procedure for transforming the ΔdB Lin values to ΔdBA and ΔdBD is outlined in Appendix V of reference 5.

Referring to Figures 8 and 9, where the ΔdB values are the reference sound plotted using A-weighting and D-weighting respectively as the measurement scale, it can be seen that corona noises are rated basically comparable in aversiveness to traffic noise and more aversive than jet noise.

The primary annoyance settings (PAS) are shown plotted in a different form in Figure 10. (PAS is the level in dB to which respondents adjusted the 1 kHz octave band reference noise in order to achieve equal aversiveness with each stimulus). Mean values, standard deviations and ranges of PAS are shown. It can be seen that the predominately low frequency sounds (traffic and air conditioner) yield a greater variability in responses (larger standard deviations, larger ranges) indicating that people are less positive in defining aversiveness to low frequency content sounds than they are in defining aversiveness to high frequency content sounds. Figure 10 shows the preference of respondents for low frequency content sounds (PAS means of 58 and 57.8 dB, traffic and airconditioner) to higher frequency content sounds, including corona (PAS means from 67.5 to 70.8 dB).

Molino et al found that, with respect to the 11 dB difference for equal preference between corona sounds and the octave band reference sound for linear weighting, A-weighting increased this difference to 13 dB, while D-weighting reduced the difference to 8dB. Referring to Figures 7 and 8, the comparable values obtained in the current research are 12.9 dB and 6.8 dB respectively. There is good agreement.

Pearsons et al [10] concluded that, of the three measurement scales in question, the A-weighting and D-weighting scales were preferable to the Linear scale (there was little to choose between the two), because these scales gave the least standard deviation of listeners' responses. (Molino et al arrived at similar conclusions, but for somewhat different reasons [13]). Again, the results of the present research are in agreement with these conclusions.

This study showed that standard deviations were less than those found by Pearson [10], Molino [12], Merritt [15] and Maruvada [16], found that annoyance to corona noise varied linearly with the stimulus sound pressure level. The present research has also shown that aversiveness to corona noise has a direct relationship to sound pressure level, irrespective of the corona spectra shape. This can be seen in the consistent ΔdB values (sound pressure level relative to reference) of corona in Figures 7 to 9.

Maruvada et al [16] carried out listening tests using DC and AC corona and 1kHz octave band reference sound, and showed through a graph of MAR (Minimum Annoyance Rating) vs SPL (Sound Pressure Level) that annoyance with AC corona sound varied linearly with SPL; they also showed the relative annoyance of AC corona noise with respect to the 1 kHz octave band reference sound. When the results of the present tests (PAS vs SPL) are extrapolated to their MAR vs SPL graph, there is close agreement.

6 Observations

The main observatons to be drawn from this research are:

1. When measured as linear sound levels, the corona noises tested are equally aversive to a 1 kHz octave band of white noise (the reference sound) about 11.5 dB higher in sound pressure level, while the traffic noise is equally aversive to the reference sound which is about 0.5 dB higher in sound pressure level; the inference here is that for equal aversiveness to traffic noise, corona noise would have to be presented at approximately 11.5 dB lower than the traffic noise level;
2. When the measurements of the test signatures and reference sound were A-weighted, the difference between the corona sounds and traffic sound for equal aversiveness to the reference sound was reduced from 11.5 dB to approximately 0.5 dB;
3. When all sounds are measured as A-weighted sound levels, corona noise is about equally aversive to other common environmental sounds (Figure 8). The spread in judged aversiveness is about 5 dBA for all sounds tested, with the corona noise signals being in the middle of this range (e.g. corona noise is judged to be about 2 dBA more aversive than traffic noise, and 3 dBA more aversive than jet engine noise, and about 2 dBA less aversive than transformer station noise). Since the standard deviations are larger than those values, it is suggested that these differences are not statistically significant. (Further analysis could be undertaken to determine this point);
4. When all sounds are measured as D-weighted sound levels, the conclusions are identical to those in 3, except that the spread in judged aversiveness is about 8 dBD;
5. Aversiveness to corona noise appears independent of the corona spectre shape and is directly related to sound pressure level of the noise;
6. A-weighted and D-weighted measurement scales are preferable (with A-weighting slightly better than D-weighting) to the Linear measurement scale since the A and D scales have the lowest standard deviation and therefore are the most consistent predictors of judged aversiveness;
7. Since practically all environmental sound levels and criteria are normally quoted as dBA levels, A-weighted levels as quoted above would appear to be preferable to the D and Linear scales (an exception being that D-weighting might be better for jet noise);
8. The corona noise stimuli which were used in this research utilized noise samples which were selected (from long-term measurements on operating transmission lines) for individual uniqueness of spectre and weather conditions and for frequency of occurence [22], and were thus more representative of corona sounds than were those used in previous psychoacoustic experiments [8, 13, 14, 16, 17, 20, 21];
9. The paired comparison method of testing (with individual adjustment of a reference sound as used in this research appears to be a useful method for investigating aversiveness to environmental sounds such as corona noise from transmission lines;
10. Observations 1 to 6 above are in general agreement with results published by Molino [17]; Observation 6 is in agreement with results published by Pearsons [20] while conclusions 2, 3 and 4 are in contradictions.
11. The result of Pearsons' survey, coupled with observations 2 and 3 above, would suggest that, as a first pass, corona noise can be treated in a manner similar to traffic noise when establishing suitable criteria. Caution must be exercised, however, as there are many assumptions implicit in both studies which may invalidate this conclusion. (For instance, Horonjeff et al (reference 17, vol. 2) in a series of studies on sleep interference showed that the propability of awakening is about ten times as great from steady-state corona noise intrusion (in a bedroom) as compared with traffic noise.

7 Summary of Results

It is felt that the instrumentation and procedures which were utilized in this current project sponsored by CEA resulted in comprehensive, accurate and reliable data regarding long-term statistical analysis of audible noise from high voltage transmission lines and the attitudinal response of people to these noises. The co-ordination of the CEA study with similar studies being conducted by the American Electric Power Service Corporation (in conjunction with the National Bureau of Standards) in the U.S.A., and with allied studies by IREQ in Canada, provided a much broader base for assessment of the environmental implications of contemporary corona noise.

It was found: that the corona noise samples were equally aversive to a 1 kHz octave band of white noise that was about 12 dB higher in sound pressure level (see Figure 7); that the corona noises tested are about equally aversive as jet engine noise, somewhat more aversive than transformer and lawnmower noises, and considerably more aversive than traffic and air conditioning noises; that aversiveness to corona noise appears independent of the corona spectra shape and is directly related to sound pressure level of the noise; that if A-weighting and D-weighting were the measurement scales used in assessing relative aversiveness, these would under-estimate the impact (i.e. the degree of judged aversiveness) of corona noise when compared with certain environmental sounds such as traffic, transformer station, air conditioner and lawn mower noises, and would slightly over-estimate the degree of judged aversiveness of corona noise when compared with jet noise (see Figure 8 for example of A-weighting); and that A-weighted and D-weighted measurement scales are preferable (with A-weighting slightly better than D-weighting) to the Linear measurement scale with respect to consistency (least standard deviation and hence variability) of responses from listeners.

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Bibliography

1. Kolico, Ware, Zagier, Chartier and Dietrich, "The Applegrove 750 kV Project Statistical Analysis of Audible Noise of Conductors at 775 kV", IEEE Trans. - Power and Apparatus Systems, Vol. PAS-93, No.3, pp.831-840, May/June 1974.

2. Perry, D.A., "An Analysis of Transmission Line Audible Noise Levels Based upon Field and Three-Phase Test Line Measurements", IEEE Trans. - Power and Apparatus Systems, Vol. PAS-91, pp.857-864, May/June 1972.

3. Baker, Comber and Ottosen, "Investigation of the Corona Performance of Conductor Bundles for 800 kV Transmission", IEEE Trans. - Power and Apparatus Systems, Vol. PAS-94, No.4, pp.1117-1130, July/August 1975.

4. Juette, G.W. and Zaffanella, L.E., "Radio Noise, Audible Noise and Corona Loss of EHV and UHV Transmission Lines under Rain: Predetermination Based on Cage Tests", IEEE Trans. - Power and Apparatus Systems, Vol. PAS-89, No.6, July/August 1970.

5. IEEE Committee Report, "CIGRE/IEEE Survey on Extra High Voltage Transmission Line Noise", IEEE Trans. - Power Apparatus and Systems, Vol. PAS-92, No.3, pp.1019-1028, May/June 1973.

6. Trinh, N.G. and Maruvada, P.S., "A Method of Predicting the Corona Performance of Conductor Bundles Based on Cage Test Results", IEEE Trans. - Power Apparatus and Systems, Vol. PAS-96, No. 1, pp.312-320, Jan/Feb. 1977.

References

1. Proceedings of the Workshop on Power Line Noise as related to Psychoacoustics, IEEE Power Engineering Society Summer Meeting and Energy Resources Conference, Anaheim, California, July 17, 1974, Special Publication 74CH0967-0-PWR.

2. Report of Task Force of the IEEE Radio Noise and Corona Subcommittee of the Transmission and Distribution Committee, "Audible Noise from Power Lines - Measurement, Legislative Control and Human Response", IEEE Trans.-Power Apparatus and Systems, Vol. PAS-94, No. 6. pp.2042-2048, Nov/Dec. 1975..

3. Report of Task Force of the IEEE Radio Noise and Corona Subcommittee of the Transmission and Distribution Committee, "A Guide for the Measurement of Audible Noise from Transmission Lines", IEEE Trans. - Power Apparatus and Systems, Vol. PAS-91, pp.853-856, May/June 1972.

4. Symposium on Transmission Line Audible Noise, sponsored by the Radio Noise and Corona Subcommittee, Power Engineering Society of IEEE, South Bend, Indiana, Sept.19-21, 1977.

5. J.E.K. Foreman , T.G. Onderwater, and E.M. Placko, "Report to the Canadian Electrical Association on Project 77-27 Assessment of Audible Noise from High Voltage Transmission Lines and on High Voltage Transformer Stations", The University of Western Ontario, March 1986.

6. Bolt, Beranek and Newman, "Initial Studies on the Effects of Transformer and Transmisstion Line Noise on People: Vol. 1 - Annoyance (Pearsons, Bennett and Fidell); Vol. 2 - Sleep Interference (Horonjeff, Bennett and Teffeteller); Vol. 3 - Community Reaction (Fidell, Teffeteller, Pearsons):, Electric Power Research Institute, Project EPRI-EA-1240, December 1979.

7. Molino, J.A. et al, "Preliminary Tests of Psycho-acoustic Facilities and Techniques for Studying the Human

Response to Transmission Line Audible Noise", Division of Electric Energy Systems, National Bureau of Standards, Washington, December 1977.

8. J. Molino, G. Zerdy, M. Lerner and D. Harwood, "Preliminary Test of Psychoacoustic Facilities and Techniques for Studying the Human Response to Transmission Line Audible Noise," Tech Report HCP/T-6010-1EZ, U.S. Department. of Energy, Washington, DC, 1977.

9. J. Molino, G. Zerdy, M. Lerner and D. Harwood, "Initial Pyschoacoustic Experiments on the Human Response to Transmission Line Audible Noise", Tech. Report DOE/ET-6010-1, U.S. Department of Energy, Washington, DC, 1979.

10. K. Pearsons and R. Bennett, "Handbook of Noise Ratings", Rep. CR-2376, National Aeronautics Space Administration, Washington, DC, 1974.

11. J. A. Stobbe (and J.E.K. Foreman), Report to Canadian Electrical Association on "Psychoacoustic Test to Determine Difference in Attitudinal Response of People to Live vs Recorded Sound", Sound and Vibration Laboratory, The University of Western Ontario, March 31, 1982.

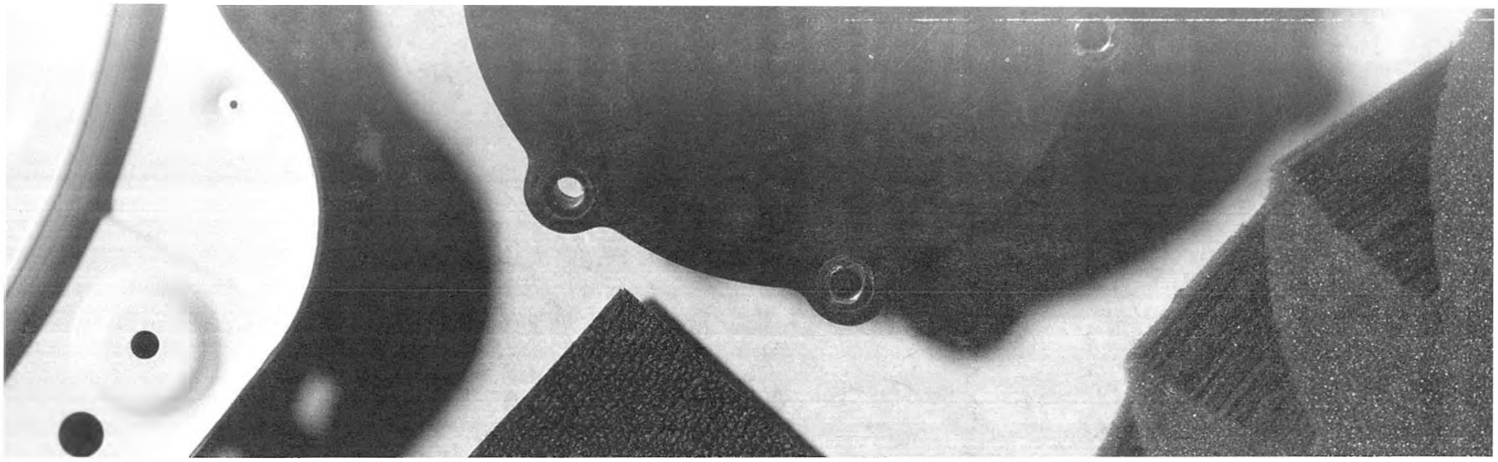
12. J. Molino, G. Zerdy, M. Lerner and D. Harwood, "Use of the 'Acoustic Menu' in Assessing Human Response to Audible (Corona) Noise from Electric Transmission Lines", Journal of Acoustic Society of America, 66(5), 1435-1445, 1979.

13. J. Molino, G. Zerdy and S. Tremaine, "Psycho-acoustic Evaluation of Transmission Line Audible Noise: Building Attenuation Effects, Methodology Comparison, and Field Study Feasibility", Technical Report DOE/RA/29323-1, U.S. Department of Energy, Washington, DC, December 1979.

14. R. Cortina, F. Rosa, W. Serravalli, E. Brosio, and R. Piazza, "Experimental Investigation in the Anechoic Chamber on the Loudness of Acoustic Noise Caused by AC Corona", IEEE Power Engineering Society Winter meeting, 81WM039-7, Atlanta, Georgia, Feb. 1-6, 1981.

15. C. Merritt (and J.E.K. Foreman), Report to Canadian Electrical Association on "A Psychoacoustic Pilot Study to Determine the Response of People to Audible Noise from High Voltage Transmission Lines", Sound and Vibration Laboratory, The University of Western Ontario, London, Ontario, April 16, 1980.

16. Maruvada, Dallaire, Heroux, "Bipolar HVDC Transmission System Study Between + 600 kV and + 1200 kV - Section 6, Psychoacoustic Studies", Electric Power Research Institute, Project EPRI-EL2794, 430-2, December 1982.



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