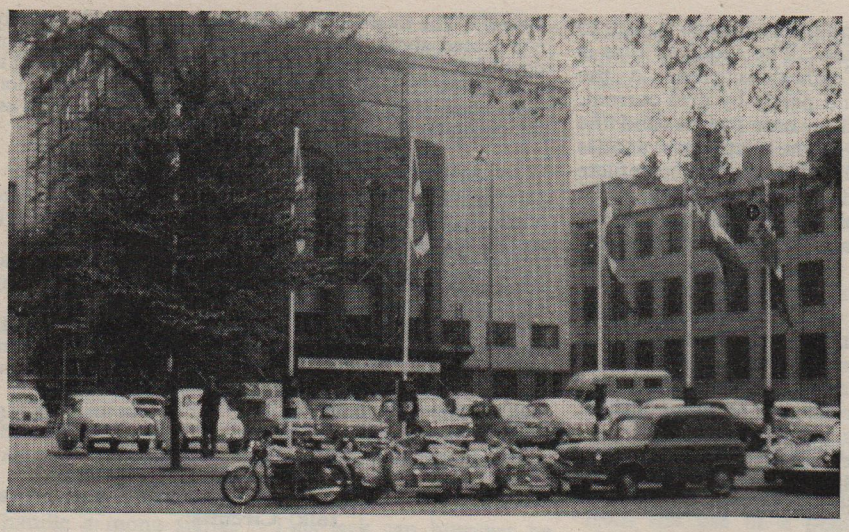


POINTS FROM PAPERS READ IN COPENHAGEN

21st—28th AUGUST 1962

Fourth International Congress on Acoustics

THE field covered by acoustics today is wide and topics discussed at the Congress ranged from the effects of the hundreds of *megawatts* of acoustic power radiated from the launching pads of the latest space rockets to the minute quanta of vibrational energy (phonons) involved in the transfer of energy between ultrasonic waves and electrons in the interstices of crystals. Between these extremes there was, among the 350 papers read and discussed in nine concurrent sessions, something for everybody including those interested in high-quality sound reproduction (possibly even "hi fi fans"!)

Mega-acoustics

According to present estimates, future space vehicle rocket engines, such as NOVA, will produce 500 MW of acoustic energy at lift-off, and to ensure that intolerable or even hazardous noise levels do not reach residential communities, the choice of launching sites is now under active review. According to F. M. Wiener (Bolt, Beranek and Newman, Inc.) sound pressure amplitudes equivalent to $\frac{1}{10}$ atmospheric pressure (160dB) are generated in the field near the launching pad. Reduction of noise by the injection of water streams (to increase density and so reduce the velocity of the exhaust gases) has been suggested but is hardly feasible since the flow requirement at launch would be of the order of half a million gallons per minute. Launching over a static water tank would also be ineffective and there seems no alternative to the wedge shaped deflector system which splits and diverts the stream in opposite directions. Measurements made by J. M. Cole, *et al.* (Aerospace Medical Research Labs. U.S. Air Force) on static tests and the launch of SATURN (10^6 lb thrust) indicate noise levels of the order of 130dB at a distance of one mile during the first half minute.

This energy is capable of causing structural damage not only in the rocket but also in ground installations. J. K. Hilliard *et al.* (L T V Research Centre, U.S.A.) showed photographs of fatigue failure produced in test panels after five minutes exposures at 170dB. The sound source was a battery of electro-pneumatic modulated air stream generators, horn-coupled to a progressive-wave tube of 5ft × 6in cross-section.

Macro-acoustics

Sound is propagated in water to distances of the order of thousands of miles and is now playing an important role in oceanography. L. B. Brekhovskikh and I. E. Mikhaltzev (Acoustics Institute, Academy of Sciences, U.S.S.R.) described investigations of the surface acoustic channel above the upper isothermal layer by means of calibrated TNT charges, and of the use of the wideband characteristics of the pulse to determine (by the deformation of the echo) the nature of the ocean floor.

Underwater signalling at a distance of 60 miles in the middle of a storm was reported by J. L. Stewart and W. B. Allen (U.S. Navy Electronics Lab.) who showed that pseudo-random (PR) signals of large time-bandwidth product in conjunction with a cross-correlation technique can give more information about the perturbation of underwater propagation than impulsive or single-frequency signals.

Returning to dry land, and exchanging our scale of miles for feet we next consider—

Room Acoustics

This was the title given to the section dealing with sound in enclosed spaces and it included many papers covering sound transmission through parti-

tions and many other aspects of what is generally termed architectural acoustics. But it was in the qualities of listening rooms, studios and concert halls that most readers of this journal would have been most interested.

Dr. Ing. R. Boutros-Attia (Alexandria University) described an important method of assessing instantaneously and subjectively the acoustics of a room by means of ultrasonic waves in a model. A recording of a speech or music in an echo-free room is made on tape at a normal (low) speed. This is replayed n-times faster (n being the scale of the model) and reproduced by an ultrasonic "loudspeaker." Microphones in an artificial head inside the model pick up the reverberant sound which is then recorded at high speed and played back at the original low speed in separate headphones. With normal longitudinal tape recording a time lapse between the original sound and the playback from the model is inevitable because of the change of tape speed, but it is proposed to overcome this by using a wide tape running at constant speed in conjunction with three heads rotating at different speeds (modified television tape recorder). The first pair of heads records and monitors the original "dry" sound, the second set revolves at say 10 times the speed of the first, and the third at the original (low) speed. This will pose some difficult mechanical problems because the first and third heads must be given a longitudinal motion equal to 0.9 tape speed if all the traverses of the tape are to be made at the same angle. The longitudinal head motion will be saw-toothed since the heads must return to their original position for the start of each track with correct synchronism.

The quality of diffusion, or the distribution in direction of the received sound, is important in listening rooms and concert halls. G. A. Goldberg (Academy of Sciences, Moscow) described a method of displaying the reflections from a spark source by means of 90° crossed microphones connected to the x and y plates of an oscilloscope. By differentiating the microphone outputs, directional ambiguity was removed and "rose patterns" photographed at various time intervals after the spark showed the build-up of diffusion from the first reflections onwards.

Many papers dealt with the design of recently contructed large concert halls. In continental Europe the seating capacity is usually 1,000-2,000, but in the U.K. and in America the tendency is to larger halls seating 3,000 or more. L. L. Beranek (Bolt, Beranek and Newman Inc.) gave an invited paper on criteria for the design of concert halls and opera houses, based on detailed acoustical analysis of 54 halls in 16 countries and a subjective judgment of these halls by 22 renowned conductors and 23 professional music critics. The results explode the idea that judgment is personal and a matter of individual taste, for he found full agreement between musicians and technicians in their grading of these halls.

Noise. The mounting level of noise in civilized communities is causing our legislature some concern, and they in turn are pressing scientists for criteria by which subjective nuisance can be assessed from objective measurement. As D. W. Robinson (N.P.L.) put it, "We are being asked to say 'yes' or 'no' on matters on which the scientist himself has doubts." Nevertheless, some good progress had been made in correlating the readings of a sound level meter, with the so-called "A" weighting scale to stimulate the characteristics of the ear, with subjective judgment. In Dr. Robinson's view consistency of subjects' response meant measurement, but in relying on this statistical approach for international agreement, care was necessary in translating instructions; emotive adjectives like "loud," "annoying," "disturbing" could be changed in meaning. Much work still remained to be done on time-dependent factors, such as occurred in drop forging or pile driving. Some work on impact noise reported by G. J. Thiessen and K. Subbarao (Nat. Research Council, Ottawa) leads to the conclusion that tolerance of impact noise is increased if the reverberation time of, say, an office is reduced by means of absorbing material. One interesting by-product of work in noise aseessment was that judgments indoors of street noise tended to be harsher than out-of-doors; it seemed that walls were subjectively transparent and that one tended to project oneself outside.

Psychological and Physiological Acoustics

Some properties of the brain which play an important role in the perception of sound were discussed by Prof. E. C. Cherry (Imperial College) who held that the function of two ears was primarily to separate sound images rather than to give directional properties. Although complete fusion takes place between these images and we hear "one world," the mind is able to concentrate on one speaker in the babel of sound at a cocktail party. This is to some extent dependent on our linguistic heritage and the fact that there is an associated (even if suppressed) motor activity in the mouth when listening to speech. He demonstrated that separation of two superimposed voices is easy when the words spoken are coherent but that this facility fails when both speeches are composed of random clichés.

In Dr. Cherry's view binaural fusion is a central correlation process carried out in two stages; first autocorrelation at each ear to establish the envelopes of high-frequency components of the sound in time, and then cross-correlation between these envelopes. Experiment had shown that the fusion process was operative up to time differences of 6 to 7 milliseconds between signals applied separately to each ear. The points of the nervous system where these processes are carried out are not yet known with any certainty, but Dr. Cherry put forward the hypothesis that the properties of the cochlea could provide the mechanism of autocorrelation by the interaction of compressional waves in the fluid with transverse waves in the basilar membrane.

The response of the ear to transients of short duration (5 μsec) has been investigated by D. L. Pimonow (Centre Nat. D'Etudes des Telecomm.). Separate sources of pulses at 1 second intervals were applied together to an amplifier and Ionophone loudspeaker having a pass band of 100 kc/s. The pulse trains were staggered so that an observer heard clicks at 0.5 sec intervals. A variable low-pass filter (10 kc/s upwards) was then introduced into one chain, and subjects were asked to restore any inequality by adjustment of the gain of the preamplifier in the filtered channel. One boy of 15 years could detect a cut-off frequency of 45 kc/s and other observers, irrespective of age, made adjustments at 20 kc/s or higher (more than twice the cut-off frequency of the ear in all cases). These results

may influence the design of high-fidelity equipment and of hearing aids, since the intelligibility of speech is closely associated with the transients of consonants.

Electro-acoustics

Prof. E. Meyer (Göttingen University), in an invited paper, took as his theme the prospects which are opened by a closer examination of possible analogies between acoustical and electromagnetic fields and oscillators. He chose three examples:

(1) An acoustical travelling wave amplifier in which sound is passed, together with a steady air stream (equivalent to an electron beam), through a tube with a periodic wall structure. Amplification of the input sound had been proved experimentally.

(2) Broadband reflection-free surfaces with wedge structure in which phase relationships in waves travelling parallel with and adjacent to the surface had been investigated by observing the motion of particles suspended in the acoustic medium.

(3) Acoustic and electromagnetic absorption by reverberation methods. The reverberation room at the Göttingen Physikalisches Institut had been lined with copper and when empty had been found to have an e.m. "Q" of 2,000,000 at 10kc/s.

Loudspeakers and Headphones. The successful reproduction of stereophonic sound depends on clearly defined arrival times of the components from the two loudspeakers, and to this end F. H. Brittain (G.E.C.) described a modified version of the "Peri-phonic" push-pull system in which the middle and upper frequency units are arranged vertically above the low-frequency push-pull pair. Particular attention has been given to equality of polar response at all frequencies above 500c/s.

High-quality electrostatic headphones which do not require any polarizing voltage have been developed by G. M. Sessler and J. E. West (Bell Telephone Labs.). A laminar (4-layer) Mylar diaphragm (total thickness 0.001in) carries a central (metallized) electrode and is polarized (with 3500V at 120°C for 15 minutes) to form an "electret" (the electrical equivalent of a permanent magnet). The diaphragm is mounted between parallel perforated metal plates to which the push-pull signal is applied. Tests on an artificial ear show a frequency response ±3dB between 30 and 11,000c/s and harmonic distortion less than 0.9% at a sound pressure level of 100dB.

Pickups. Prof. F. V. Hunt gave a paper on the rational design of the stereo disc pickups in which he divided the available groove-wall reaction force (which balances the bearing weight) between requirements of stylus acceleration, low-frequency tracking and tone-arm acceleration. He showed that the allowable value of stylus mass is set by the acceleration due to the second harmonic components of tracing distortion, and that in stereo recording these components are additive in the vertical plane, whether the fundamental groove modulation is lateral or vertical. The non-linear character of the stylus-groove contact means that resonance at this point can contribute to in-band noise through intermodulation. This noise can be suppressed if the first resonant mode is located at or above the translation loss cut-off frequency but this requires an effective stylus mass/bearing weight ratio of 0.14 mgm/gm and this is nearly an order of magnitude lower than is available in present-day pickups. An extended discussion of these points has been submitted for publication in a forthcoming issue of the *Journal of the Audio Engineering Society*.

The high-polymer plastics used in pickups and other transducers to control their mechanical performance may exhibit sharp transitions in rigidity and internal energy loss with temperature, particularly below freezing. P. Lord and E. R. Pithey (Royal College of Advanced Technology, Manchester) described a torsional vibration method of determining these parameters rapidly at audio frequencies and gave some results which indicate that the damping may be controlled by cross-link density between polymer chains without adversely affecting the modulus of rigidity.

Micro-acoustics

As this account started with mega-acoustics it seems logical to finish at the opposite end of the scale.

In our report of the 3rd Congress at Stuttgart in 1959 we recorded the fact that acoustic exploration of solids and liquids at high ultrasonic frequencies was not only shedding new light on crystal and molecular structure but was proving a useful practical tool in chemical analysis by revealing the relaxation times of transitions of atoms in complex molecules.

At Copenhagen E. H. Jacobsen (General Electric Co., Schenectady) described research which is now going on at frequencies up to 10 kMc/s. The ends of a quartz or ruby rod terminate in annular cavity resonators which act as transducers by the interaction of the electric component of the field with the end faces of the rod. The velocity of the stress wave through the quartz is observed from standing-wave peaks in the receiving oscilloscope, due account being taken of the acoustic waveguide mode and of flexural modes in the end faces. The quartz crystal must also be cut in a direction favourable to propagation of the wave. The whole unit is cooled to 12°K or less to eliminate disturbances from thermal "phonons".

Experiment has support the hypothesis of a quantum-mechanical basis for vibration and "sound," the phonon being defined as the elementary quantum of elastic energy associated with change of state of elementary particles in atoms. It has been found, for instance, that paramagnetic atoms react strongly under microwave ultrasonic excitation, which provides energy for electron spin reversal at critical frequencies. The ferrite Fe^{++}· MgO shows this effect well and exhibits marked anomalous dispersion effects near the resonance frequencies. There is a close analogy here with light quanta (photons) in an electromagnetic field. Stimulated emission of phonons from inverted states has been achieved in ruby in the X-band using plump frequencies in the K-band.

Ultrasonic travelling wave amplification in n-type semiconductor crystals was described by D. L. White (Bell Telephone Labs.). When an ultrasonic wave traverses the crystal in a preferred direction it is accompanied by an alternating electromagnetic field and current; the current produces heating and the ultrasonic wave is attenuated. If, however, a direct current with an electron drift velocity exceed-the velocity of sound flows through the crystal, the ultrasonic wave grows in amplitude. The gain can be very high (e.g. 0.35dB per wavelength). In

practice a d.c. pulse is applied to prevent spontaneous oscillation and overheating (at 1000 V) and a gain of 57dB has been observed in a 1.2cm bar of cadminium selenide (Cd Se) using shear waves at 45Mc/s. Applications envisaged (up to 1 kMc/s where continuous operation without overheating is feasible) include low-loss wide-band ultrasonic delay lines and possibly amplification of electrical signals as well as the primary uses as a generator, amplifier and detector of ultrasonic energy. It is particularly useful as a detector, since the d.c. is also amplified.

The organization of the Congress by Prof. Fritz Ingerslev, Chairman of the Acoustical Society of Scandinavia and of the Acoustical Society of Denmark, and his colleagues ran like clockwork—literally. Just before the end of the twenty-minute period allowed for the reading of each paper the sound of a metronome faded unobtrusively in and out of the loudspeaker system in each lecture room as a gentle reminder that time was running short. At the end of the period music gradually swelled and finally drowned the words of the lecturer. On the last day Prof. Ingerslev fell victim, whether by design or accident will never be known, to his own device, which appropriately terminated both his closing speech and the congress.

The next (5th) International Congress on Acoustics will be held in Belgium (Liège) under the chairmanship of Prof. J. Frenkiel.

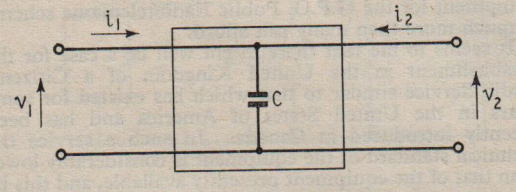
LETTERS TO THE EDITOR

The Editor does not necessarily endorse opinions expressed by his correspondents

The Reciprocity Theorem

MR. THOMAS RODDAM in his article "Ban the Reciprocity Theorem," p. 409, September issue, has described network analysis as a "simple logical closed system." I trust he will forgive me for failing to see the logic by which he concludes that "at any instant the total power supplied (to a black box containing no resistors) must be zero, since once power is supplied it turns into heat and cannot be turned back . . ."

Consider a simple example such as that in the accompanying figure:



In this particular case the voltages v_1 and v_2 at a given instant are equal (to v, say) having a value dependent on the past history of the black box. If we assume further that $v=0$ at time $t=0$, and that subsequently

$i_1 + i_2 = i$ (constant),

the voltage at a subsequent time $t=t_1$ is $v=it_1/C$ and the power is then

$v(i_1 + i_2) = vi = i^2 t_1/C$

which is not zero unless $i = 0$ (since $t_1 \neq 0$ by assumption). Furthermore the power is not turned into heat but into the energy of an electrostatic field, which is recoverable.

Mr. Roddam can still independently *postulate* as an element of the logical system one which will obey the equation

$v_1 i_1 + v_2 i_2 = 0.$

He could also doubtless prove that such an element would contain no resistors, for good measure. He finds an example in the ideal transformer. He may equally well postulate an element which obeys the equation for all values of i_1 and i_2, and find the logical consequences of this behaviour: I think that this is what he has done, although "this is to be true for all values . . ." sounds more like an assertion than a postulate. Having done this the rest follows.

I take it that the Reciprocity Theorem became established during a time when nobody happened to have thought of this device, the gyrator, which presumably cannot be represented as a common branch between meshes. Or can it? I cannot help a sneaking feeling that there might be a sixth element, whose discovery might perhaps invalidate the proof that the five were all-sufficient.

Manchester. R. S. TAUNTON.

The author replies:

If Mr. Taunton will examine my text he will see that I say that "a network . . . made up of meshes . . . inductance, capacitance, resistance, . . . mutual inductance . . . a simple logical closed system." He is quite correct, however, in saying that the total energy supplied to a reactive network need not be zero. I must confess that I had overlooked the fact that it was as long ago as September 1957 that I discussed the gyrator more fully and I was seeking to keep compact the discussion I knew I had given in an earlier article. The right approach is to say that we have energy dissipators (R), energy storers (L and C) and, should we say, energy level converters. Then we say that this last class is defined by the transformer equation, $v_1 i_1 + v_2 i_2 = 0$, which leads on to the gyrator.

This is Tellegen's approach and Mr. Taunton will find the formal treatment he wants in *Philips Res. Reports*