ELECTRONIC MUSIC

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BY electronic music is meant the electrical reproduction of musical tones through loud-speakers, the actuating currents either having a purely electrical origination, or, if arising from a musical source, depending essentially on electronic selection of such machines, without attempting to be exhaustive, because of the rapid developments in this field and the repeated introduction of new types. Those with novelty value do not compete among themselves, like the pianos. There is certain

REPRESENTATIVE ELECTRONIC MUSICAL INSTRUMENTS

Type	Name	Basic principle		Note operation	Special effects	Tone Registration
Novel	Thérémin	Beat oscillator		Hand-adjustment	Glissando, Tremolo, Stop-button	None
	Martenot	Beat oscillator and filters		Hand in ring	Glissando, Tremolo	Stop keys
				Keyboard	Tremolo	
	Trautonium	Neon relaxer with formants		Wire over plate	Glissando, Tremolo	Continuous stop knobs
	Novachord*	Valve oscillators with multivibrator division and filters		Keyboard (72 notes)	Mixed Tremolo, variable attack and decay	Dial stops, foot sustain
Piano	Miessner or Vierling	Hammer on strings	E-s pick-up	Piano keyboard (88 notes)	Swell and filters	Stop keys
	Neo-Bechstein*		E-m pick-up		Swell	None
	Pianotron*		E-s pick-up		Volume control only	None
Organ	Orgatron*	Air-blown reeds, E-s pick-up		Manuals, pedals, swells, tremolos	—	Stop keys, pistons, and couplers
	Coupleux	Valve oscillators and filters			—	
	Hammond*	E-m generators, synthetic			Variable stops	
	Midgley*	E-s generators, synthetic			Variable stops	
	Electrone*	E-s generators, synthetic			Synthetic bells	

Instruments marked * are easily available in Great Britain and have been examined by the author. All instruments, except the Pianotron, have foot-swells; the organs, except the Hammond, have grand-swells also. In the Hammond, one stop only on each of the manuals and pedals can be drawn at a time. Specifications of organs can be varied over a wide range, according to requirements; the Hammond and the Novachord alone are mass-produced, and therefore invariable.
(E-m = electro-magnetic, E-s = electro-static)

means for their control and amplification, thereby leaving the musical designer free to make experiments which are not limited by the necessity of making adequate acoustic power.

The most comprehensive developments have taken place in the United States of America, where Benjamin F. Miessner and Laurens Hammond lead the patent and commercial fields, and Lee de Forest demonstrated an electronic organ, one valve for each note, so far back as 1915. Germany, France, and Great Britain have also made important individual contributions, and the literature of the subject grows apace. This article is a brief review of the important electronic instruments available in Great Britain. The accompanying table gives the characteristics of a representative competition among the organs, since they have all been highly developed to meet a common need. Comparisons are difficult, since one cannot get them in pairs for a proper trial, but probably the time is coming when a scientific assessment of their qualities is due, which would settle many contentions among organists. Technically speaking, no one is quite certain what organists really want.

There are three major aspects of the problem, commercial, scientific and artistic. The commercial drive incites people to want something new or to do something already satisfactory in a cheaper or simpler way, for example, reducing the cost and bulk of pipe-organs, a lighter substitute for bells, or more noise from the feeble harpsichord. The

scientific urge is to do these things in a new way, producing perhaps novel effects which may or may not have an eventual commercial value. The artistic aim in supporting these endeavours is to obtain new methods of expression and to compose for them, since composition in orthodox modes seems to be declining. The usage of an instrument depends on whether it is commercially satisfactory at the price, and on the sales drive to satisfy a manufactured demand.

The instruments mentioned have had some circulation and demonstration. The Electrone has been well received in cinemas and by the British Broadcasting Corporation, while the Hammond* has become best known. In the few years that the latter has been available, about four hundred models have been sold in Great Britain as compared with some six thousand in the United States, the production being fifty to sixty a week. Of the other organs, the Orgatron was used at the last Eisteddfod, and the Midgley* has just been launched. The Pianotron has recently appeared, made both by Everett and Chappell, and meets the modern need of conservation of space combined with concert-grand tone and volume. The latest instrument, the Novachord (a Hammond product), is so entirely novel, except its ordinary keyboard, that it will keep musicians of all grades amused for a long time. It is the sort of machine from which any keyboard enthusiast can get something worth while; it does not demand the discipline of the piano or regular organ.

The Novachord

Of the instruments offering novelty value many have been described, using a great variety of physical effects for generating and synthesizing desired or new musical tones. Valve oscillators, either pre-set or beating, have frequently been employed; also blocked-out wave-forms, either sinusoidal, chopped, or obtained from recordings of high-grade musical instruments, on spinning disks, scanned by light falling into a photo-electric cell, have been used.

The Novachord uses valves entirely, and in a new way. It is the second musical machine put out commercially by Hammond, and we are told there are more to come. It cannot replace any existing instrument, although it can imitate passably many familiar timbres. It has a 6-octave keyboard, above which is a row of stop-lever controls; for the feet there is a swell pedal, a duplicated sustaining pedal, and a bass sustaining pedal. The omission of the pedal clavier is a good selling point for non-organists. The keyboard manuals are not strictly percussive, as in a piano, but by setting the controls for a long build-up time, a very effective percussive touch is obtained, permitting, for example, a legato violin solo with a light harp-like accompaniment, passing through each other, if desired, on the one keyboard. The pedal sustains the weaker notes, without altering their loudness level.

The tones are obtained from twelve oscillators, the frequencies of which correspond to the top chromatic octave, the highest fundamental frequency being $E = 2637{\cdot}0$ ($A = 440$). The remaining fundamentals are derived from these twelve frequencies by division, one half in each of the five stages, each in a multivibrator dividing circuit, rather like those in television scanning circuits. Each fundamental has a control valve in which the output wave-form is adjusted, together with its attack and decay. The 72 notes, therefore, require 144 valves; some channel-amplifiers and power-packs bring the normal total to 159, double-triodes and small pentodes forming the majority. It is claimed that all valves, except the output stages, are lightly loaded and that the valve hazard is greatly diminished. The scheme for frequency-division seems logical, since the top frequencies cannot require much harmonic development; also the tuning operation on the top notes makes for precision over the whole range. Tuning is effected by adjusting the oscillators until one of the divided frequencies beats a known frequency with a known harmonic of the rectified mains.

The basic qualities of the Novachord are in the great range between percussive and singing, and in the adjustable attack. The tone-controls and filters, all adjustable over a wide range, are to some extent what one might expect, leading from a full diapason, reminiscent of a cathedral when fully delayed, to a thin reedy wood-wind of considerable power. Brassy and delicate tones are available, and the string tones are better than have been previously heard on a non-string instrument. A guitar effect is easily obtained, but, what is more interesting, good imitations of clavichord and harpsichord can be found, with, of course, ample volume; such possibilities may help to revive the interest in the older keyboard music, especially in public, which must have waned to some extent because of the lack of acoustic power and the difficulty of the cramped keyboards in authentic models.

A new feature in electronic music is not so much that three degrees of tremolo are here available, but that there are also six different rates, distributed in the twelve oscillators. The result is a delicate shimmer rather than the usual throb or wobble, recalling *tutti* violins; perhaps this is an effect organists are seeking; they never seem

* Descriptions of the Hammond and the Midgley organs appear in a paper recently issued by the Institution of Electrical Engineers, to be printed later in the Institution's *Journal*, entitled "Electronic Musical Instruments and the Development of the Pipeless Organ", by G. T. Winch and A. M. Midgley.

certain whether they require amplitude or frequency modulation, or both.

In construction, the Novachord has novel features. The whole of the valve system, couplers, filters, etc., is built into an enormous chassis, which can be turned over for servicing; electrical connexions to the keyboard are taken through long springs, so that the valve system need not be made dead during adjustments.

Finally, it may be remarked that there is no synthesis of notes on an equi-tempered scale involving borrowed quasi-harmonics, as in some electronic organs. This may please regular organists, because the non-coincident harmonics of the notes of a chord beat against each other in the customary way, and are not resolved into a perfect series of overtones, which is apparently one of the things conservative organists do not like, however pure it may be declared to be. We refrain from attempting to define what a pure tone, in the musician's sense, is supposed to be.

NEW PIANOS

The difficulties of imitating a piano are great, the initial impulse and the dither being awkward from the electronic point of view. A negative time-constant of attack has been achieved in the Novachord and this may lead to a complete electronic piano. The electrical amplification of piano tones is of long standing, but the usage has been slight; the recent arrival of the Pianotron may change this.

It is an easy matter to apply either electromagnetic or electrostatic pick-ups to the strings of the piano, and to control the output currents in volume and tone; the mistake which seems to have been made is to try to get something new out of hitting a stretched string with a felt hammer. It is true that tone amplification permits less tension in lighter strings and the elimination of the sounding board, with consequent lighter frames and extremely long time of decay, due to reduced damping. In the Neo-Bechstein, the middle forty notes alone have double strings, the remainder are single. This results in a steel-string tone, substantially undamped when sustained, with great range of crescendo and diminuendo on the swell pedal. Supposing that one wants real steel-string tone, very great care is necessary to avoid considerable blur. This instrument uses electromagnetic pick-ups, one for each set of four strings, located near the ends of the strings remote from the hammer. In the Vierling Electrochord there are a number of pick-ups along the wire, so that some of the sustained overtones are not lost.

Whereas in the Neo-Bechstein the piano has been simplified, in the latest Pianotron, where only straight amplification with electrostatic pick-ups is attempted, it has been found that it is essential to take the greatest care in the construction of the complete small piano, otherwise defects in the tone production are magnified. The electrostatic pick-ups are merely adjusted screws, ranged on a shaped board, which can be fitted into any ordinary piano: screening to some extent is essential, but the scheme permits concert-grand volume in the smallest space at a very reasonable cost. Many novelties may come and go, but the attractions of the dynamics of the free felt hammer on trichords will remain for those who wish to attain to them.

PIPELESS ORGANS

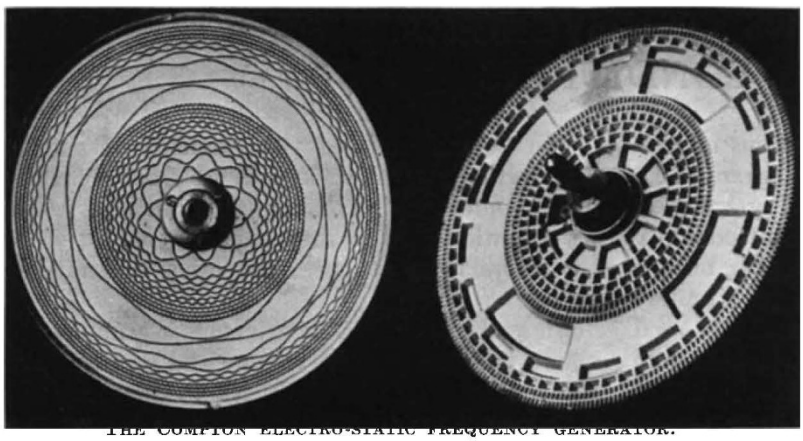
The dictionary definition of an organ must now be curtailed by the omission of any reference to pipes blown by air, for clearly an instrument which is played like an organ and sounds like an organ is certainly an organ, in spite of the purists. The wide variety of wave-forms obtainable from a valve oscillator has induced inventors to synthesize and control tones for organ purposes in diverse ways; the more recent successful instruments, however, do not use valves at all, except for amplification.

The Orgatron is most near a regular organ; indeed, it is a five-rank instrument, entirely pneumatically controlled, with air-blown free reeds, the motions of which are amplified through electrostatic screw pick-ups. The scheme is rather like that of the Pianotron, except that the polarizing voltages are not constant but are applied to the ranks as required by the stop keys. Fundamentally, when a key is depressed, high-pressure air is passed into the tube mechanism and eventually allows low-pressure air to pass through all reeds brought in by the pneumatic action of the stops. The stops also charge the pick-up screws to pre-set potentials through resistance-capacity retarders (to obviate key clicks). The fluctuating potentials on the screws, arising from the motion of the reed and consequent change in capacitance, are applied rank by rank, all the rank screws being in parallel, to the relative amplifier, after which they are mixed by anode-coupling.

Thus there is no synthesis of tones in the electronic sense. The five ranks of reeds, of which there are 289 in all, are voiced and tuned by the usual manipulation of the languids, and fundamentally give celeste, melodia, diapason, viole, and a pedal tone. From these a good selection of registrations is possible, augmented by a synthetic oboe and quintadena. Actual tubular chimes can be operated by second touch on the great, and an echo-radiating unit helps with reverberation in damped surroundings. Tremolo arises from a motor-driven paddle in front of the loud-speakers

In appearance, the Orgatron is similar to most other two-manual organ consoles.

The Hammond organ has previously been described in these pages (NATURE, June 19, 1937, p. 1043), and was shown by Sir James Jeans recently at the Royal Institution. The original model has been brought into conformity with the requirements of the Royal College of Organists for non-secular purposes by curving and adding a few notes to the pedal clavier, by having independent swells for the two manuals, and replacing the manual stop keys by pistons. Readers will remember that tones are synthesized from 96 inductor generators on two shafts driven by a synchronous motor, a number of adjustable stops for experimentation being provided.



THE COMPTON ELECTRO-STATIC FREQUENCY GENERATOR.

Left, one of the stators, showing the electrified tracks between anti-phase sine-wave insulating ridges, the remaining spaces being earthed; right, the rotor, which scans all the tracks and couples the modulated potential to the grid of the amplifier via the ball-bearing contact at the end of the shaft.

Scientifically, the Electrone and the Midgley are very similar. Each uses electrostatic runners, the periodic change in capacitance modulating the potential steadily applied through a resistance. In the Electrone there are twelve generator units, corresponding to the lowest chromatic scale, driven by one continuous belt from a synchronous motor. In the generator unit the scanner is connected, together with the eleven others, to the grid of the first amplifying stage. The radial scanning blocks, one per wave-length, are embossed so as to oppose double sine-wave tracks with earthed separations.

It is evident that all the harmonics of a bass-note can be obtained from one unit, since there is no fundamental difficulty in cutting tracks of an increasing number of wave-lengths. The total number of tracks is, however, markedly reduced by borrowing. For example, on the natural scale the G-wheel has a speed 1·5 times that of the C-wheel, all the units being the same, except for speed. Therefore the 3rd harmonic of C coincides with the 2nd harmonic of G; so why not use the 2nd harmonic track on the G-wheel when the 3rd harmonic of the C-wheel is required, thus dispensing with the 3rd harmonic track on the C-wheel, and so on, yielding a great economy in tracks? The driving wheels, however, are so diametered that the fundamentals and the harmonic tracks are equi-tempered. This makes the G-wheel about 0·1 per cent slow on the C-wheel. The third (borrowed) harmonic of C is therefore a little out of tune, a fact which is easily noticed on a cathode-ray tube, but it is doubtful if any organist can have noticed it by ear. Again, when C and G are sounded together, either on the keys or as a synthetic stop, the third harmonic of C does exactly coincide with the second of G, since it is borrowed, the increased magnitude of the common frequency being provided for in the electrical circuits. This means that the beat which ought, on the equi-tempered scale, to be present between the third harmonic of C and the second harmonic of G, amounting to about 0·1 per cent of the nominal common frequency, is not there. This argument can be greatly extended, the absent beats between some harmonics being more pronounced than that above indicated. The Electrone compromises in that only the third harmonics are borrowed.

There is no doubt that the scheme works and the machine sounds very much like a regular organ, but is it this absence of beats among harmonics which prevents the more precious and conservative of organists from admitting that the Electrone is an adequate substitute, at a third the cost, for a regular pipe-organ? Can any ears be so sensitive in a live room?

The Midgley electronic organ functions in a very similar way, except that in the unit generator the dielectric alone rotates. The sine-wave areas on the stator electrodes oppose the blocks of the scanning dielectric as before. The notes are synthesized as required by the stops in the electrical circuits as before; registering a number of stops builds up the contributions, just as extra ranks of pipes are ordinarily brought into action. Corresponding in function to the draw-bars in the Hammond, sets of dials are provided for players to experiment with in using new stops or doubling existing stops.

It can be fairly claimed that these electronic organs function as intended, but whether one is

superior to the others for a specified musical purpose is an open question and must await a proper series of trials, with adjudication by a representative body of musicians; meanwhile, those who have to pay for organs are deciding for themselves.

Accepting the musical adequacy of electronic organs, their use in churches has several artistic and technical advantages. The disposition of the sound radiators permits a fine unanimity of attack in congregational singing. Acoustical treatment to enable preachers to be heard need not spoil reverberation, which can be increased artificially to any degree desired. Finally, the great enemy of pipe-organs, cold weekdays and a warm Sunday, is rendered innocuous: electronic organs scarcely need tuning.

The craft of the organ tuner, with his mallet and cones, has started to pass; he is being replaced by an electrician, with no more equipment than is required for servicing a radio-set. There is one thing we can be certain of, no electronic organ ought to succeed unless it is finally voiced by a craftsman of tradition. If this is not insisted on, classical organ tone will not be known to the rising generation, brought up on secondhand and harsher music, and may be lost for ever.

APPLICATIONS OF PSYCHOLOGY IN WAR CONDITIONS

A SYMPOSIUM on some applications of psychology in war conditions was arranged by the Industrial Section of the British Psychological Society and held on January 25. The introductory paper was by Dr. May Smith, who gave an outline of the final report of the Health of Munition Workers Committee, published in 1918, and addressed to the Right Hon. Winston S. Churchill, M.P., then Minister of Munitions. The Committee included Sir George Newman, Sir Walter Fletcher, Sir Leonard Hill, representatives of the Home Office, members of Parliament, physiologists and pathologists. It had been appointed in September 1915 "to consider and advise on questions of industrial fatigue, hours of labour, and other matters affecting the personal health and efficiency of workers in munition factories and workshops".

At the beginning, the Committee was confronted with the width and complexity of its inquiry. The central and foremost problem was concerned with fatigue. Having realized that continuous human activity is associated with a gradually diminishing capacity, the Committee decided that the only direct test was that of output.

Views on the more theoretical aspects of fatigue were really immaterial, since it was known that the ordinary restrictions on hours of labour had been very widely relaxed, that Sunday labour previously forbidden for women and young persons and practically unknown for men, except for a few continuous processes, had become common. The employment of men for 70–90 hours a week was common, more than 90 hours was not infrequent, and there were even cases in excess of 100 hours. In short, there was a return to some of the worst conditions of the early nineteenth century.

The Committee used two methods of getting information: (1) it took evidence from people in direct contact with workers, (2) it initiated *ad hoc* investigations. The first method enabled it to get information at once, the other necessitated time.

On reading through the evidence, it is impossible not to be struck by the volume and pertinence of the findings. On the whole, the evidence showed that long hours imposed too severe a strain on the workers, with the result that the rate of production tended to decrease, sickness absence and broken time to increase. Evidence of the almost intolerable strain on the management was given. The full blast of the hours was not felt at first, because the increased pay resulted in better food.

Such evidence, while overwhelming in some cases, was, however, not quantitative, and witnesses differed widely as to what constituted reasonable limits; the Committee had to emphasize the almost complete absence of any scientific data.

The appointment of Dr. H. M. Vernon and others was intended to supply this deficiency. He showed by output figures that the 12-hour day was a costly and useless procedure, that the long hours simply defeated their own end. "The country cannot afford the extravagance of paying for work done during incapacity from fatigue just because so many hours have been spent upon it," reported the Committee.

Apart from hours, environmental conditions were realized as important, and ventilation emerged out of the hands of the engineers and passed to those of the physiologist, and under the ægis of Sir Leonard Hill there entered the kata-thermometer.