Stockhausen's Electronic Studies I and II

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Abstract: *Stravinsky remarked of Boulez and 'the young Stockhausen' that 'these composers have sprung full-grown', taking over the new music scene as if by magic (Igor Stravinsky and Robert Craft,* Conversations with Igor Stravinsky*; London: Faber and Faber, 1959, 127). The Cologne premiere in November 1954 of Stockhausen's* Electronic Studies I *and* II *(1953–54) injected an air of sobriety and purpose to a novelty tape idiom championed by Pierre Schaeffer for France and already at risk of dissipating in trivial sound effects. Complaints from the acousmatic community that Stockhausen's* Gesang der Jünglinge *and* Hymnen *owe a debt of allegiance to* musique concrète *by virtue of incorporating preformed musical objects (a boy's voice, national anthems, etc.), ignore the underlying agenda of such works and their relevance to current information science, voice recognition, and artificial intelligence research. Since the launch of IRCAM, a gradual release of previously classified information relating to Cold War surveillance objectives has brought to light a narrative of shared principles, procedures, research objectives, and personal histories establishing a clear and coherent intellectual context for Stockhausen's electronic studies, not only in relation to the composer's personal legacy, but also to the history of information science.*

Composed in 1953 and 1954, Stockhausen's *Electronic Studies I* and *II* are serial exercises in compound tone synthesis executed in the then novel medium of magnetic tape. The theory underpinning both studies can be traced back a hundred years to a paragraph by Hermann Helmholtz in *On the Sensations of Tone*, commenting on terms of harmonic integration and perception of combination tones originally formulated by Joseph Fourier and elaborated in Georg Ohm's Harmonic Theory.

> 'The theorem of Fourier here adduced shews first that it is mathematically possible to consider a musical tone as a sum of simple [sine] tones, in the meaning we have attached to the words, and mathematicians have indeed always found it convenient to base their acoustic investigations on this mode of analysing vibrations. We have rather to inquire, do these partial constitutents of a musical tone, such as the mathematical theory distinguishes and the ear perceives, really exist [or is Fourier's

> theorem] merely a mathematical fiction . . . for facilitating calculation, but not necessarily having any corresponding actual meaning in things themselves?'
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> (Hermann Helmholtz, *On the Sensations of Tone* (1885). Revised enlarged edition translated and annotated by Alexander J. Ellis.. New York: Dover, 1954, 35)

Stockhausen's two electronic studies are carefully planned, neatly executed, consistent in tone, and pleasant to the ear. What has long remained unclear from a musical viewpoint is their motive for existing, aesthetically or conceptually. There are few clues. On page 190 of his memoir *A la Recherche d'une Musique Concrète* (Paris, Seuil, 1952; English edition, University of California Press, 2012, 180) Pierre Schaeffer reproduces a sample page of the little-known *Etude sur un son* by Pierre Boulez, a tape composition dating from 1952 and based on the sound of an African *sansa* or *mbira*, a thumb piano. Stockhausen's Cologne studies were preceded by a tentative *Konkrete Etüde*, composed in Paris the same year as Boulez's study, its original tape long presumed lost in the composer's archives and retrieved only in 1992. In contrast to the abrupt, stuttering quality of the *Konkrete Etüde*, the elegant lines and finish of the technically sophisticated *Studie I* call to mind a pleasantly jingling 19th-century luxury musical box; and *Studie II* a slightly wheezy paper-roll harmonium. These superficial resemblances have some significance. In years to come, authentic musical boxes and harmoniums are destined to play themselves in Stockhausen's *Tierkreis* (1975) and *Der Jahreslauf* (1977).

The two Cologne electronic studies, Stockhausen's work numbers 3/I and 3/II, appear altogether too sophisticated, too 'through-composed', and acoustically speaking, too different from one another to have 'sprung full-grown' in Stravinsky's phrase, out of the imagination of any one individual, let alone a comparative novice. My own observations to one side, further discussion of their position in Stockhausen's oeuvre, and connection to later works including *Gesang der Jünglinge*, *Kontakte*, and *Hymnen*, has remained off limits during Stockhausen's lifetime and subsequent to the composer's death in 2007.

Here is the immediate timeline. In 1949 Boulez introduces John Cage, a newcomer from the United States, to Messiaen, Schaeffer, and Paris high society, as inventor of the prepared piano, a concert instrument whose strings are muted and distuned by a variety of inserted objects to evoke the sounds of an exotic percussion orchestra. That year, influenced by Cage's prepared piano, Messiaen composes *Mode de valeurs* for piano, a work of carefully stratified tone options in which each individual pitch of a limited collection of three overlapping twelve-tone registers is 'prepared' or assigned a fixed combination of serial coordinates (frequency, attack, dynamic, duration). Then in 1950, with Pierre Henry assisting, Schaeffer produces *Bidule en ut* (‘Thingummy in C’) by a process of multiple acetate disc to disc copying, at varying speed transpositions, of prerecorded figures improvised by Henry directly on the strings of an open piano. In 1952, to a commission by Schaeffer, Boulez creates a serially organized ‘Study on one sound’ in the newly acquired tape medium, a work based on speed transpositions of the twang of an African musical instrument consisting of metal free reeds affixed to a simple frame. The same year, working quietly at his desk in a student lodging, Stockhausen painstakingly assembles serially organized fragments of tape into a burbling *Konkrete Etüde* for tape based on transformed piano sounds, not of a thumb piano, but a prepared piano. Curiously, each and every item involves modifying, limiting, or distorting the struck or plucked sounds of a keyboard instrument.

Fast forward to a decade or so ago when I was invited by Stephen Walsh to give an introductory talk on *Hymnen* at a Cardiff University concert featuring four-channel tape only playbacks of the Stockhausen work and *Bhakti* by Jonathan Harvey. (I do not remember the music of *Bhakti*, but vividly recall the composer bringing his tape to a timely halt by yanking the plug out of its socket by the cord.) In my talk I determined to address the popular misconception that the presence of national anthems in *Hymnen*, and of a boy’s voice in the earlier *Gesang der Jünglinge*, automatically categorized the two works as musique concrète. *Hymnen* employs national anthems as easily recognizable motifs for an exercise in melody disassembly and reformulation. However implausible the interpolation process might appear, logically or aesthetically, the method was manifestly grounded in textbook US information theory and cognitive linguistics of the kind Stockhausen had observed in Meyer-Eppler’s seminars in the 1950s, studies eagerly communicated in his 1971 lectures and published conversations.

Among other sources I consulted a paper by Bell Labs authors Max Mathews and Leonard Rosler, from the proceedings of a 1966 computer music conference. The paper introduced a FORTRAN based computer melody composition programming system called GROOVE, illustrated by flexidisc music examples in which opposing representative melodies ‘The British Grenadiers’ and ‘When Johnny comes marching home’ are taken apart and reintegrated with the aid of Markov decision trees and formulae derived from probability theory. (Max Mathews and Leonard Rosler, ‘Graphical Language for the Scores of Computer-generated Sounds’. In Heinz von Foerster and James Beauchamp eds., *Music* *by Computers*. New York: Wiley, 1969) Musically, the results were laughably bad, and the sound quality dire. Procedurally, though, the similarity to *Hymnen* was startlingly obvious. *Hymnen* had not only pre-empted and parodied, but outclassed the Bell Labs effort in every particular. There could be no doubt Stockhausen had been alerted in advance to Mathews and Rosler's endeavours and was determined to trump their American efforts and prove the superiority of German inventiveness and that of analogue over digital synthesis. I consulted my notes from the composition class in 1965 when Stockhausen outlined a preliminary plan for *Hymnen* as his next big project for instrumentalists and tape. Working at speed, in two years Stockhausen and assistant David Johnson assembled a radiophonic work of art in four-channel surround sound which still impresses today beside the puny efforts of the Americans and their ostentatiously primitive digital equipment. (Maconie, *Other Planets* 277–78)

Digesting the counter-intelligence implications of American voice recognition research led to a search for further clues elsewhere and in earlier works. Could the outwardly religious message of the boy's voice praising the Lord in *Gesang der Jünglinge* disguise a secret purpose already intimated in the syllabic detail of the published form scheme, and the poetic image of a boy's voice condensing out of a chaos of speech particles. A casual reader may be disposed to take literally Stockhausen's programme note that 'whenever the voice becomes comprehensible, it is to praise God', as a religious allusion; but barely concealed under the cloak of religion is a frankly dadaist study in speech disassembly and recombination. The theme of fragmentation and reconstitution of coherent speech is not restricted to music for tape, but a unifying thread connecting a broad range of high profile European avant-garde compositions from the 1950s through to the present era. Examples include Boulez's *Le marteau sans maître*, Berio's *Circles*, and *Omaggio a Joyce*, Ligeti's *Volumina*, *Aventures*, and *Nouvelles Aventures*, and even Stravinsky (the *Introitus* of 1965). Written into its manifesto as a research centre, voice recognition continues to remain a core objective at IRCAM, explicitly in compositions such as Harvey's *Mortuos Plango* (1983) and *Speakings* (2007–8), and implicitly in instrumental works such as Boulez's *Répons* (1981–84) through to *Anthèmes II* (1997) and *Sur Incises* (1998).

It remained to be seen whether, despite their outward appearance of aloof formalism, Stockhausen's electronic studies from 1953–54 belonged in the category of speech-related inventions, and if so, what might be their ulterior significance. Both the musical box sound of *Studie I* and the harmonium-like clusters of *Studie II* are connected over a span of two centuries to a period of mechanical invention extending from the late eighteenth century to the first half of the nineteenth century. Urban Europe in the age of Maelzel’s panharmonicon and Joseph Jacquard’s weaving machine, both programmed by punched cards, was preparing for the imminent arrival, among other marvels, of musical boxes capable of assembling and performing melodies by random selection, and androids capable of speech. Mozart, Beethoven, C. P. E. Bach, and Haydn, among the best minds of the late eighteenth century, were involved or implicated in composing or processing works for mechanical reproduction by pin cylinder, paper roll, or punched cards. Musical boxes, pianolas, and barrel organs to steam-powered fairground calliopes were rapidly becoming a familiar presence in city streets, parks, public houses and chapels.

In 1791 Vienna, to great acclaim Hungarian inventor Wolfgang von Kempelen unveiled a prototype keyboard operated voice synthesizer, the third of its line, designed as a programmable system of plug-in modules capable of reproducing intelligible speech by emulating the physical actions of the vocal tract: the lungs by bellows, vocal cords by free reeds, and consonants with the aid of percussion instuments. Android fever excited a popular market for do it yourself parlour games or kits for composing melodies by the throw of a pair of dice, promoted under the name of ‘country-dances’—a euphemism for peasant or gipsy folk entertainments—or ‘waltzes’ after the German term for a barrel or lucky dip. In England, following the downfall of Napoleon, Kempelen’s speaking machine attracted the attentions of engineers Robert Willis (1800–75), a doctoral student at Trinity College, Cambridge, and Charles Wheatstone (1802–75), the inventive son of a London musical instrument maker and publisher in 1806 of an English edition of a ‘Musical Dice Game’ attributed to Mozart.

In February 1828, at the Royal Institution, London, Michael Faraday presented a paper ‘On the Resonances, or Reciprocated Vibrations of Columns of Air’ on Wheatstone’s behalf. The paper addressed the use of passive air columns as resonators to amplify exotic musical instruments including a Javanese vibraphone or *génder*, and Chinese mouth organ or s*heng*, the latter a bundle of bamboo pipes protruding from a cup-shaped mouthpiece. With the aid of a simple sliding tube resonator, moving in and out in the manner of a Swanee whistle, Wheatstone showed how different partials of the tone of a tuning fork could be selectively amplified, a process analogous to the player of a jew’s harp varying the cavity resonance of the mouth to enhance a desired overtone region or formant.

Only a few months later in April 1828, Robert Willis presented the first of two papers ‘On Vowel Sounds’ to the Cambridge Philosophical Society, examining the potential of Wheatsone's sliding tube resonator for reproducing and studying vowel formants, a simple enough mechanism to be implemented in a keyboard instrument for synthesizing speechlike sounds. In Germany, Willis's paper duly caught the attention of Hermann Helmholtz, who added his endorsement of the combination of free reed and tube resonator as a practical solution for the 'audition' (i.e., synthesis) of vowel sounds. (Helmholtz, 117–18) Wary of causing unease among academic colleagues at Cambridge University, then a hotbed of evangelism, by pursuing research seeming to challenge the Almighty by creating a machine capable of speech, and thus possessed of a soul, Willis tactfully withdrew from speech science to the safer pasture of church acoustics and architecture. At Cambridge meanwhile Wheatstone collaborated with Charles Babbage on the design of intricate switching mechanisms, before going on to invent the button concertina and collaborate with French and German manufacturers in servicing a growing market for free reed wind instruments. A miniaturized version of the original sliding tube mechanism became a key component of the popular *serinette* or mechanical chirping bird. Stravinsky reproduces the exact musical figures of artificial birdsong in flute parts for the 'Dawn Chorus' sequence of *The Rite of Spring*, at rehearsal number [11] of the score.

Long after Helmholtz's lifetime, speech and hearing were presumed to rely on sympathetic vibrations initiated in the vocal cords and excited in the structures of the inner ear. Interest in the articulation and preservation of speech peaked with Thomas Edison and Alexander Graham Bell, and launch of the telephone and phonograph. Seventy-five years after Edison introduced his tinfoil phonograph, a time when Stockhausen was preparing to compose his Electronic Studies, the structures and mechanisms of speech and hearing were still being analogized to a musical box. In *Klangwelt unter der Lupe*, an up to date student textbook in musical acoustics published in 1952, Fritz Winckel wrote 'Helmholtz was the first to ascribe frequency-selective properties to the basilar membrane, visualizing it as a succession of tuned strings resonant at different frequencies', analogous to a harp, piano, or the comb of a musical box. (Fritz Winckel, *Music, Sound and Sensation: A Modern Exposition*. Revised edition tr. Thomas Binkley; New York: Dover, 1967).

When Thomas Edison first presented his tinfoil phonograph for audition by the Editorial Board of *Scientific American* in 1877, his audience readily understood the machine to be actually talking, making sense, saying good day and how do you do, and reciting a familiar nursery rhyme. They heard it not as Edison's voice, but the voice of a machine. Not recognizing the speaker's voice leads one to wonder in retrospect if his distinguished panel appreciated the difference between hearing and listening—hearing the actual sounds the machine was making, as distinct from recognizing the words they were expecting to hear in the circumstances—for example, that they were spoken in English, rather than Polish or French. Hearing the familiar melodic and rhythmic inflections associated with 'Good day!' and 'How do you do?' might well have been sufficient to persuade Edison's listeners that those words were actually spoken. Likewise, the uniquely familiar pattern of 'Mary had a little lamb, its fleece was white as snow' could only mean one thing, despite the actual speech sounding more like a noisy '*Maywe yada redulam. Eth leewith wideth naw. An aebury way damari wen. Dalamwath yodugo*'. And this is the point. Had the material not already been familiar, the editorial board of *Scientific American* would not have understood it. They did not identify the mechanical voice as Edison speaking because it did not sound like his voice, the quality of reproduction was not up to it. In due course the radio and record industries were obliged to confront the issue of poor quality signal transmission. From the outset, poor reproduction dogged the industry. The market responded by reducing the language to a uniform dialect (in Britain, BBC English), and deliberately ring fencing musical entertainment to a familiar diet of easily recognizable formulae.

Quality issues came to a head in the late thirties, the threat of a Second World War triggering a demand for greatly improved signal reproduction. The standard industry five-octave bandwidth assigned to radio and telephone communication, 100–3,500 Hz, while adequate for ordinary speech was not high enough definition to allow operators to identify individual voices or highly technical messages with confidence. At the request of the British Air Ministry, Arthur Haddy at Decca developed *ffrr* extended range full frequency recording to a limit of 15,000 Hz, an unprecedented clarity of reproduction essential to train wireless and telephone operators to detect and identify enemy personnel and aircraft of interest, and track their movements by sea and air. Following the entry of the United States into the Second World War, in early 1942 the vocoder, a Bell Labs telephone device invented by Homer Dudley, was taken over by the US military for evaluation by Claude Shannon and Alan Turing as the basis of the SIGSALY or X-System for encrypted telephone communication between Roosevelt and Churchill, an episode vaguely outlined by James Gleick in his recent title *The Information.* (James Gleick, *The Information: A history, a theory, a flood.* London: Fourth Estate, 2011, 204–8) Surprisingly, vocoder technology was selected for covert telephone communications not because it delivered a signal of high quality, but because the system was infinitely degradable, allowing a speaker's identity and words to be scrambled beyond recognition even if the signal were intercepted by an enemy.

In his survey first published in 1985, Peter Manning teasingly hints at the history of events leading to the foundation of the electronic music studio of Cologne Radio.

> 'During 1948 Dr Werner Meyer-Eppler, at the time director of the Department of Phonetics at Bonn University, was visited by Homer Dudley, a research physicist at Bell Telephone Laboratories, New Jersey, USA. Dudley brought with him a newly developed machine called a Vocoder . . . which could function both as a speech analyser and also as an artificial talker. . . . Although the fidelity of the machine was distinctly limited, its purpose being to process speech rather than music, Meyer-Eppler was considerably impressed'. (Peter Manning, *Electronic and Computer Music.* Oxford: Clarendon Press, 1985, 43)

In his own memoir Manfred Schroeder, a junior colleague and speech specialist at Bell Labs, describes Dudley as the original inventor and developer of the vocoder, which in 1948 was far from being a new invention, having originated in 1928 as a speech compressor, been reinvented as a piece of laboratory equipment for analyzing pre-recorded speech samples, and by 1938 evolved into a real-time visible speech spectrograph, nominally to assist the hearing impaired to receive and conduct telephone calls. (Manfred Schroeder, *Computer Speech: Recognition, Compression, Synthesis* (1994); second revised edition. New York: Springer Verlag, 2004)

The vocoder made its public debut at the 1939 New York World's Fair as part of a robotics exhibit, along with a companion keyboard speech synthesizer called the Voder, the latter in effect a modern interpretation of Kempelen's 1791 invention. The Voder rather than the vocoder was the application singled out for enthusiastic commendation by John Cage in a review article for the May-June 1942 edition of Henry Cowell's periodical *Modern Music*. ('For More New Sounds'; reprinted in Richard Kostelanetz ed., *John Cage*. London: Allen Lane, 1970, 64–66) Contemporary newsreel footage of the Voder in action during the World's Fair is now available for view on YouTube.

In 1946, after the cessation of hostilities, a planned resumption of the Bell Labs Visible Speech programme was abruptly cancelled and the research team of Potter, Kopp, and Kopp disbanded. (Ralph K. Potter, George A. Kopp, and Harriet Green Kopp. *Visible Speech* (1947). New edition. New York: Dover, 1967.) The extended bandwidth essential for progress in automated speech and voice identification operations moving into the Cold War could not be met within the limited frequency range of prewar technology. By 1950, mutual surveillance operations were ramped up in a race to develop automated voice recognition technology accurate enough to track the movements of persons of interest, and trigger alarm at the detection of critical keywords. Phone tapping was the tactic of choice on both sides of the Iron Curtain. Robert T. Beyer recalled, ‘Attempts to identify voices on the telephone by speech spectra techniques became intensive in the 1950s and even earlier. Anyone who has read [Alexander] Solzhenitsyn’s novel *The First Circle* will recall the laboratory described therein in which Stalin was attempting to identify his enemies by such techniques’. (Robert T. Beyer, *Sounds of Our Times: Two Hundred Years of Acoustics.* New York: AIP/Springer Verlag, 1999) During the Joseph McCarthy scare, US secret service operations were themselves targeted by a 1954 MAD magazine spoof of Munro Leaf’s popular ‘Watchbird’ series, in this case warning ‘This is a Tel-tapper-phoner. This is a Watchbug watching a Tel-tapper-phoner.’ (Reprinted in William M. Gaines, *The Brothers Mad*. New York: Random House, 1958, 137)

Synthesizing speech by machine and speech monitoring by machine are reciprocal but different objectives. In achieving the musical objective, knowledge is acquired which can be applied to implementing the surveillance objective. Voice identification and keyword recognition involve very different skills. Recognizing who is speaking is spectrum analysis, while message interception and keyword recognition demand specialized skills in language, grammar, and the dynamics of continuous speech. In simple terms, the first objective requires a sense of harmony, the second an understanding of rhythm and melody. Spectrum analysis is the underlying message of the His Master’s Voice logo; it signifies that the listening dog recognizes the person speaking even though it does not understand words. Keyword identification by comparison relies on the real-time segmentation of continuous speech into meaningful unit phrases, words, and parts of words, a complicated task demanding a matching vocabulary, attention to the dynamics of the speech act, and knowledge of sentence formation.

The involvement of US military and security interests in the promotion of cutting edge modern art, ideas, and music for propaganda purposes from 1950 to 1967 is the compelling subject of Frances Stonor Saunders’ *Who Paid the Piper?* (London: Granta Books, 1999; published in the United States as *The Cultural Cold War: the CIA and the World of Arts and Letters*). It appears altogether possible that Werner Meyer-Eppler and André Moles were knowingly installed in experimental music studios in Cologne and Paris as scientific observers with responsibility to oversee, assist, and steer music programmes toward areas of interest to cognitive science and artificial intelligence in the fields of voice and word recognition. Homer Dudley’s mission in visiting Meyer-Eppler in Germany can be read in the context of a Bell Labs programme to recruit German expertise to assist in enlarging and refining technology with applications in covert surveillance operations. For his part, Meyer-Eppler saw genuine potential in involving and encouraging musical talents in cognitive research activities. In 1951, attending a Physics Colloquium at Göttingen University, Meyer-Eppler departed from his scheduled topic to talk to physics students about Shannon’s Information Theory and the prospect of opportunities to pursue generously funded research at Bell Labs. Among the audience was Manfred Schroeder, an acoustics PhD of Stockhausen’s age who had seen war service as a teenage radar operator and was currently preparing a thesis on concert hall acoustics. In 1954, at his second attempt, Schroeder was recruited to a research post at Bell Labs in the United States. Twenty years later, he would return to Europe as a member of a Bell Labs team under John R. Pierce deputed to assist Pierre Boulez in the acoustical design of IRCAM.

As cofounder of the Cologne Radio electronic studio and founder director of the Cologne-Bonn Institute for Phonetics and Communications Research at Bonn University, Meyer-Eppler was Stockhausen’s principal mentor and teacher. Regarded disdainfully by fellow students as an outsider with little grasp of scientific principles, Stockhausen duly attended Meyer-Eppler’s classes in Bonn for two years, taking in topics in information theory delivered in the holistic terms of pioneer codebreaker John von Neumann, drawing together ideas from the radical arts world of surrealist and dadaist poetry with game theory, Markov chains, decision trees, magic squares, and codebreaking strategies employing probability theory. In 1958, invited to the United States for the first time to lecture on electronic music, Stockhausen’s schedule quickly grew from a tentative few days to a nationwide tour lasting over a month, attracting full houses of white-coated science graduates, eager composers, and bemused musicologists. Among the composer’s audience at McMillin Theatre, Columbia University, on November 3, 1958, was an enthusiastic Percy Grainger. (John Bird, *Percy Grainger*. London: Elek, 1976, 233)

‘One study resembles a musical box, the other a harmonium.’ Historically, plucked and blown vibrations form a complementary set, evoking the flute and harp of ancient Greece, allusions to voice and heart, the mysteries of sympathetic resonance, the emotion of speech and expression of character, even the mechanism of hearing itself. The key element linking instruments of the musical box and harmonium families is the free reed, a tempered metal tongue producing a relatively pure tone. In a musical box, a set of free reeds is formed into a comblike array of tongues, set individually in motion by pins projecting from a revolving cylinder, and allowed to die away in their own time. By comparison the free reeds of the harmonium family are set vibrating by air pressure, either direct from the player's mouth, or by internal bellows responding to hand or foot pressure. The two styles are similar in employing the free reed as a source of relatively pure waveforms, while differing in the manner of exciting tones and chords. Gesture is key. Whereas a musical box is an instrument for the passive reproduction of musical speech, the free reed family of wind instruments involve an interpreter with responsibility for shaping music in a lively, speechlike manner. Both classes of instrument adhere to a convention regarding music as abstract speech, and speech as a continuously evolving complex of sympathetic vibrations selectively excited in a structure of tuned resonators. The unexpected commercial success of an entirely new species of wailing free reed wind instruments is evidence of a growing public taste for sentiment expressed in a music of tangible emotion.

Studie I is described by the composer as 'the first composition with sine tones', in other words the first tape composition assembled exclusively from electronically generated pure waveforms, a caveat secured in order to avoid any taint of association with a pre-existing instrument, electronic organ, trautonium, or synthesizer. Unlike Cage's prepared piano (or Harry Partch's customized harmoniums), Stockhausen insisted from the outset on controlling the synthesis process from first principles. Electronically generated sine tones have no overtones, making them equivalent to the simplest components of any sound in nature. *Studie I* is also the first composition whose tone colours or timbres are wholly derived from serially determined combinations of partial frequencies, in a challenge to Joseph Fourier's classic dictum that any waveform can be expressed as the sum of a set of sine waves corresponding to harmonics of a common fundamental, and Ohm's Acoustic Law, that the internal mechanism of human hearing is structured to perceive such complexes as integrated harmonic spectra. *Studie I* is uniquely able to create complex aggregations thanks to the tape medium allowing overlayering more or less at will without suffering the rapid deterioration of quality associated with repeated disc to disc copying.

Intentionally or otherwise, serialist doctrine in 1953 mirrored a politically radical sensibility defending the rights of all, and the equality of all attributes, in pursuit of a revolutionary goal of 'rebuilding music from the basics, without pre-existing hierarchies'.

Composing by serial permutation of parameters (frequency, loudness, attack, duration, etc.) is even today regarded by many as an arbitrary convention of post-1950s modernism, attributable either to Messiaen (in *Mode de valeurs*, 1949) or Milton Babbitt (in *Three Compositions for piano*, 1947). In practice, the quantification of individual tone qualities—for example, profiling the unique style of a famous performer in terms of a combination of measurable stylistic variables—was recognized in the 1890s, the era of the reproducing piano, beyond which the serialization of timbre by numbers can be dated at least to a commentary on Helmholtz by English author Sedley Taylor, published in 1875. In a chapter on the art of permutating the components of a synthesized complex tone or *clang* Taylor could be speaking for Stockhausen when he writes:

> 'The quality of a clang depends on the number, orders, and relative intensities, of the partial-tones into which it can be resolved. . . . Any two clangs may differ in the number, orders, and relative intensities, of their consituent partial-tones. . . . Thus a clang of four tones will produce 15 sounds of different quality; one of five tones 31; one of six tones 63, by variations of intensity only.' (Sedley Taylor, *Science of Music: Or the Physical Basis of Musical Harmony*. New York: Appleton, 1875, 74–76).

The original six 'sound complexes' of *Studie I* form a succession of linked proportions based on 5 : 4, the ratio of a perfect major third. The undulating sequence unfolds as a descending minor tenth (12 : 5), rising major third (4 : 5); descending minor sixth (8 : 5); rising minor tenth (5 : 12); and descending major third (5 : 4), yielding a row of six frequencies (1920, 800, 1000, 625, 1500, 1200 Hz) from which all remaining tone mixtures are generated by serial transposition. (Maconie, *Other Planets*, 131) A sequence of intervals related to the major third is a controversial alternative to the normal practice of tempering by fifths (3 : 2), since despite each successive interval being mathematically pure, a scale based on major thirds rapidly slides out of tune. Stockhausen's method of building interval sequences into serial aggregations also invites comparison with Boulez's technique of 'proliferation by multiplication' transforming a melody or succession of intervals into denser harmonic aggregations, as outlined in *Penser la musique aujourd'hui*. (English edition *Boulez on Music today*, London: Faber and Faber, 1971, 35–38.)

The naïve expectation of additive synthesis is that superimposed pure tones will spontaneously fuse together to form distinctive tone colours. In practice other refinements come into play, which the professional equipment available to Stockhausen was neither equipped nor sufficiently refined to ensure. The musical box-like chiming chords which result are nonetheless interesting and a significant achievement. Thirty years after *Studie I*, the goal of synthesizing integrated tone colours from sine tones is revisited digitally in the computer-generated cadenzas of Boulez's *Répons*, yet again with only limited success, yielding a narrow spectrum of muted metallic sonorities calling to mind the chiming clocks of Ravel's *L'Heure Espagnole*, or the glittering percussion cadenzas of Boulez's own *Improvisations sur Mallarmé I* and *II* of 1957.

In *Studie II* Stockhausen changes tactic, injecting descending arpeggio strings of five sine tones at a time into an echo chamber at high speed and recording the reverberation, in an apparent attempt to make the partial tones combine in advance. (The arpeggios descend in pitch perhaps because lower frequencies take longer to reverberate.) The two-stage process of excitation followed by reverberation appears to be modelled after the voice emitting pulse trains from the larynx and being shaped by the vocal cavity. The difference between the two processes is analogous to the difference between a musical box and a mouth organ, even evoking the dramatic change from crisp chords to tinkling arpeggios executed by the solo celesta in the 'Dance of the Sugar-Plum Fairy' from Tchaikovsky's *Nutcracker Suite* (music to a storyline of mechanical dolls and a corps of dancing androids). For Stockhausen as for Tchaikovsky, the transition from exact chords to rolling arpeggios introduces a movement dynamic while unavoidably corrupting the purity of individual tones subsumed in collective reverberation. The point at issue is whether tonal purity is more significant in conveying meaning, or the associated physical gesture.

In *Studie II* Stockhausen is composing with block formations rather than individual tones. The new materials vary in density and bandwidth from semitonal clusters to choric aggregations of thirds and fourths. The composition mainly occupies a mezzo-soprano or violin notated treble range, the same bandwidth as a normal vocoder voiceprint, with very occasional high frequency accents. Uniformity of material creates a sense of overall consistency in variation, allowing serial permutations of texture, duration, dynamics, and layering to be easily identified with a range of contrasting associations, fast and slow, instrumental and choric, percussive and consonantal, or voicelike vowel combinations. Each element of every segment is dynamically shaped in the simplest of ways: rising, unchanging, or falling in amplitude in formations of onset, steady state, and decay after the phonemes of speech science, not to mention the neumata of medieval plainchant. So disciplined a process is admirable in itself, and allows for any special effect encountered along the way to be precisely accounted for and reproduced.

Perhaps by chance, Stockhausen’s choice of aggregate sonorities tempered to powers of 1/25 root of 5 amounts to a near approximation to the Golden Section (Red and Blue series of proportions) adopted by the architect Le Corbusier. For the architect also, a standardized scheme of interval ratios ensures harmonic consistency between large and small dimensions, or ‘thick’ and ‘thin’ quantities. Stockhausen’s programme note to the first concert performance of both Studies in November 1954 puzzlingly alludes to a method of deriving the block tone materials for *Studie II* from white noise by filters, when it is clear from the score that a completely different process is employed. As I read his original German text, the composer is saying ‘In *Studie II*, rather than adding together sine vibrations in static combinations, an alternative method of electronic tone generation was undertaken, of extracting the required tone materials from white noise with the aid of filters, which has the added benefit of producing sounds of a lively quality. Not having suitable filters, other means were employed to obtain the desired effect’. (Karl H. Wörner, *Karlheinz Stockhausen: Werk + Wollen 1950–1962.* Rodenkirchen: P. J. Tonger Verlag, 1963, 10–11)

In retrospect, the above admission is fascinating, suggesting that an alternative method to *Studie I* was adopted to avoid the sounds appearing static, or ‘dead’ in the sense of Karel Goeyvaerts’s electronic *Composition No. 5* ‘for dead sounds’ composed in 1953, the same year as *Studie I*. Reviewing the question in his first and only contribution to *Die Reihe*, Meyer-Eppler criticizes the tremulants of mainstream commercial electronic organs as convenient cover for discreetly insinuating that a subaudio ‘aleatoric’ derived from filtered white noise would be a desirable way for producing sounds of a naturally lively inner character. (‘Statistic and psychologic problems of sound’; *Die Reihe I*, English edition. Bryn Mawr PA and London: Theodore Presser /Universal Edition, 1958, 55–61) In identifying his *Studie II* with a compositional process he did not actually employ, Stockhausen is either relying on outdated work notes, or is perhaps anxious to stress the two works as a complementary pair, and *Studie II* as an alternative synthesis strategy to *Studie I*. Analogous tone synthesis options duly emerge in 1955 with the RCA Mark I and II Synthesizers designed by Harry Olson and Herbert Belar, offering a set of tuning forks as pure tone generators on the one hand, along with a white noise generator and filter bank, advertised as a means of synthesizing percussion. As a matter of interest, after taking ownership of the Mark II Synthesizer, Milton Babbitt refused point blank to use filtered white noise as compositional material, perhaps not realizing its intended application for synthesizing speech consonants.

Despite a less than ideal method of production, Stockhausen’s tone families in *Studie II* are attractively nuanced, undeniably coherent and musically persuasive. I hear the opening measures as similar to the opening parallel woodwind harmonies of Debussy’s *Le Martyre de Saint Sébastien*. As the pace of change picks up, the spectrum of textures and combinations broadens in interesting ways. Echoes of *Studie II* emerge in late Stravinsky, from the block tone sequences of the lively ‘Building of the Ark’ movement from *The Flood* (1962), to the solemn low flutes and timpani refrain of the ‘Interlude’ from *Requiem Canticles* (1966). We still have a lot to learn from *Studie II*, not least about the superior, computationally simpler, and more natural timbres to be created by aleatoric processes and external shaping of electronic noise.

With Stockhausen’s *Zyklus* for solo percussionist (1959) in mind, Stravinsky envisioned a score that ‘didn’t have to be *translated* into sound but were a kind of hand-drawn photo-electric sound (after a spectrum)’. (Stravinsky and Craft, 118) Perhaps he already knew of a method of hand drawing and reproducing speech on transparency in a simplified graphic language based on vocoder imaging, released to the public in 1953, and destined to influence not only the graphic design of *Studie II* and *Zyklus* but also the formal structures of *Refrain* (1959), *Kontakte* (1958–60), and *Momente* (1964–72). Devised by Franklin S. Cooper in the late 1940s, and developed by Haskins Laboratories, the Pattern Playback project was an optical commercial speech synthesizer based on Dudley’s vocoder, allowing speech sounds to be drawn by hand on transparencies in simplified shapes, and immediately reproduced as recognizable speech, albeit in a strangled monotone. A gross and one-dimensional, but all the same fascinatingly effective simplification of visible speech, Pattern Playback is demonstrated in a vintage Haskins video clip from 1953, available on multiple YouTube sites, and on the Haskins site. As an added bonus, at the end of the demonstration the video presenters transform a selection of black and white pictures into sound by the same process, establishing beyond any doubt the existence of a viable, practical and commercial medium for musical works of graphic fantasy in a genre freely associated with Percy Grainger, John Cage (*Fontana Mix*) Earle Brown (*December 1952*), or any number of hanger-on Darmstadt graffiti artists. Said Beyer, ‘This machine reversed the procedure of spectral analysis of speech, in which spectrograms of speech sound gave information about formants. The playback patterns (synthetic spectrograms) of formants *for different speech sounds* were painted on the Pattern Playback and the corresponding sounds were emitted. To quote a later review, “the experimenter could see at a glance the whole acoustic pattern, could repeatedly hear how it sounded, and could easily modify it”.’ (Beyer, 353–56)

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