

If one were to implement Xenakis's screens, one would want to modify the theory to allow Δt to be less than the grain duration. This measure would allow grain attacks and decays to overlap, thereby smoothing over the perception of the frame rate. Similar problems of frame rate and overlap are well known in windowed analysis-resynthesis techniques such as the *short-time Fourier transform* (STFT). Frame-based representations are fragile, since any transformation of the frames that perturbs the perfect summation criteria at the boundaries of each frame leads to audible distortions (see chapter 6).

We face the necessity for a synchronous frame rate in any real-time implementation of granular synthesis. Ideally, however, this frame rate should operate at a speed as close as possible to the audio sampling rate.

Analog Impulse Generators

The most important sound particle of the 1950s, apart from those identified in Xenakis's experiments, was the analog impulse. An impulse is a discrete amplitude-time fluctuation, producing a sound that we hear as a click. Although the impulse is ideally a narrow rectangular shape, in practice it may be band-limited or have a ramped attack and decay. An *impulse generator* emits a succession of impulses at a specified frequency. Impulse generators serve many functions in a laboratory, such as providing a source for testing the *impulse response* (IR) of a circuit or system. The IR is an important system measurement (see chapter 5).

The common analog circuit for impulse and square wave generation is the *multivibrator* (figure 2.3). Multivibrators can be built using many electronic technologies: vacuum tubes, transistors, operational amplifiers, or logic gates. Although sometimes referred to as an oscillator, a multivibrator is actually an automatic switch that moves rapidly from one condition to another, producing a voltage impulse which can be positive, negative, or a combination of the two. The multivibrator circuit has the advantage that it is easily tuned to a specific frequency and duty cycle by adjusting a few circuit elements—either resistance or capacitance values (Douglas 1957).

The multivibrator was used in electronic music instruments as early as 1928, in René Bertrand's Dynaphone (Rhea 1972). Musicians appropriated laboratory impulse generators in the electronic music studios of the 1950s. Karlheinz Stockhausen and Gottfried Michael Koenig worked extensively with impulse generators at the Cologne studio. As Koenig observed:

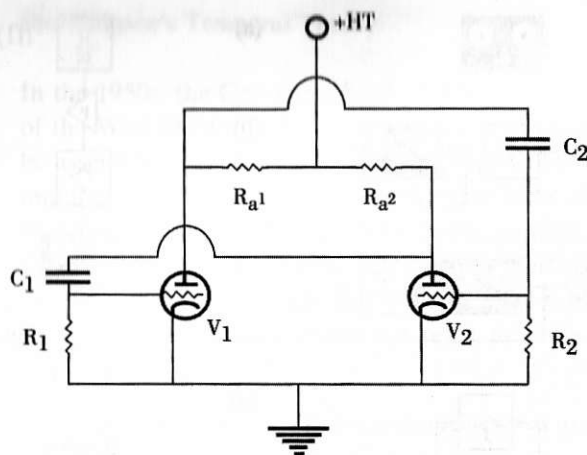


Figure 2.3 A multivibrator circuit, after Douglas (1957). Suppose that when switching on, a small positive voltage appears at V1. This increases the anode current of V1, and in so doing increases the anode potential of V1, which is communicated to the grid of V2. As the voltage of V2 falls, so will the anode current of V2, causing a rise in the anode potential of V1, making it more positive. The process continues until it reaches the cutoff voltage of the vacuum tube. The circuit stays in this condition while the grid of V2 leaks away at a rate depending on the time constant of C1 and R1. As soon as the anode potential of V2 reaches a point where anode current can flow again, the anode potential of V2 will fall again since the current is increasing, which drives the grid of V1 negative. The whole process is continued in the opposite direction until V1 is cut off, and so on continuously. If $C1 = C2$ and $R1 = R2$ the waveform is symmetrical (square) and has only odd harmonics.

[The pure impulse] has no duration, like sinus and noise, but represents a brief energy impetus, comparable to a leaping spark. Consequently it has neither pitch nor timbre. But it encounters an object and sets it vibrating; as pitch, noise, or timbre of the object which has been impelled. (Koenig 1959)

Stockhausen's great 1960 composition *Kontakte*, realized with assistance from Koenig (Supper 1997), is based entirely on filtered impulses. Figure 2.4 shows the patch interconnections used in its realization, all of which begin with impulse generation. The technique of *recirculating tape feedback loops*, seen in many of the patches, was developed in 1951 by Werner Meyer-Eppler, Stockhausen's teacher (Ungeheuer 1992, p. 121).

Kaegi (1967) describes applications of impulse generators in electronic music. Chapter 4 presents applications of impulse generators (trainlets and pulsars) in digital synthesis.

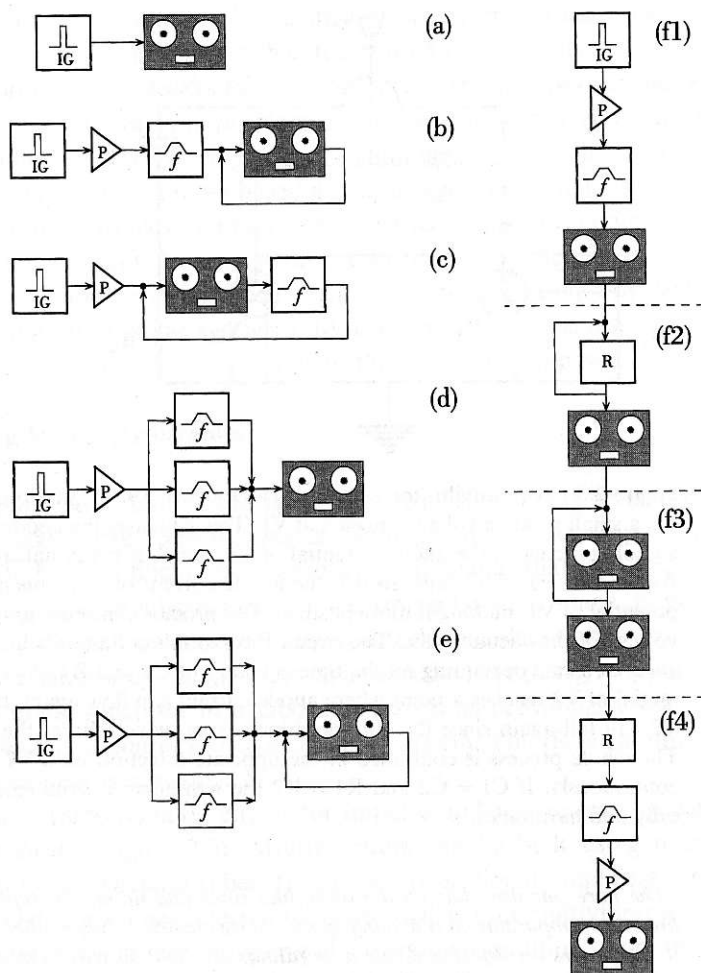


Figure 2.4 Synthesis patches used in the creation of *Kontakte* by Stockhausen. The components include impulse generators (IG), preamplifiers (P), analog tape recorders, bandpass filters (f), and plate reverberators (R). Feedback loops appear as arrows pointing backwards. (a) Simple impulse generation and recording. (b) Impulse generation with preamplification, filtering, and tape feedback. (c) Impulse generation with preamplification and filtered feedback. (d) Impulse generation with preamplification, multiband filtering, and tape feedback. (e) Impulse generation with preamplification, multiband filtering, and tape feedback. (f) A four-stage process involving (f1) Impulse generation, preamplification, filtering, and recording. (f2) Reverberation with feedback and recording. (f3) Tape feedback and recording. (f4) Reverberation, filtering, preamplification, and recording.