A synthesizer of bell and chime sounds - ISABEL

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III. MUSIC ACOUSTICS

A. A SYNTHESIZER OF BELL AND CHIME SOUNDS — ISABEL*

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Abstract

A bell and chime synthesizer, ISABEL, has been built for theatres and research. It is a stand-alone, portable device which connects to the theatre's sound equipment. The synthesis is additive, based on analog hardware. All individual partial parameters are controlled with miniature switches and potentiometers. Up to 9 bells share the 51 available partials. This paper gives a technical overview of ISABEL; it does not deal with bell acoustics.

Introduction

The need for a bell synthesizer was put forward in 1980 by the Royal Opera in Stockholm. Church bells are called for in the scores of many operas, but real bells are impractical in live performances because of their size and their fixed tuning. A bell and chime synthesizer is also useful in music acoustics research, when studying the perception of bell sounds.

In response to these demands, an instrument for the Synthesis of Assorted Bells (ISABEL) has recently been built. ISABEL is a self-contained, portable instrument intended for use in live performances, in conjunction with the theatre's own loudspeaker system.

General Properties of ISABEL

In contrast to the prevailing digital trends in music synthesis, ISABEL is for the greater part based on analog techniques. The machine uses no software, and cannot be interfaced to a computer. Put the other way round, ISABEL is a prototype musical instrument and a stand-alone "chime workshop", which can be operated with only a small screwdriver for adjustments.

The synthesis is done by the addition of sine wave partials, which are produced by about fifty independent hardware Partial Generators. The parameters of the sine waves, such as frequency and envelope shaping, are adjustable using miniature switches and potentiometers. The frequencies of all partials are derived from a master oscillator via counters and phase-lock loops.

*) This report is a condensed version of the report on the author's thesis work. The latter is a comprehensive user's manual for ISABEL in English.
Functional Structure

The various functions of ISABEL are organized in a modular hierarchy with three Levels:

- **Input** (from keyboard)
- **1. Master Level**
- **2. Group Level**
- **3. Partial Level**
- **Output** (to power amps and loudspeakers)

*Fig. III-A-1.*

At the **Master Level** are those functions which are common to and shared by all the bells that ISABEL can produce. These functions include a remote keyboard, a master oscillator and an output mixer.

At the **Group Level** (the sound of a bell can be regarded as a group of partials) we find the functions which are specific for each Group (i.e. for each bell), but which are common to the constituent partials of the Group. Among these are an attack generator, which produces the leading flank of the partial envelopes, a noise gate, and a transposer which can shift the pitch of the Group. ISABEL can accommodate up to nine Groups.

Finally, the **Partial Level** houses the Partial Generators (PG’s). When triggered by a pulse from the Group Level, a PG will send to the Group Level a sine wave which decays exponentially with time. This sine wave becomes part of the sound we hear. A PG consists mainly of 1) a frequency counter; 2) sine wave, decay and wobble* generators; and 3) multipliers, which combine the sine wave with its envelope. ISABEL has space for up to 51 Partial Generators.

The Levels are connected with each other in a tree-like structure, which branches out as we descend from one level to the next. As an example, consider a setup using three Groups and twelve partials. (See Fig. III-A-2.)

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*Warble* is the campanological term for a periodic amplitude variation of a partial. It is caused by asymmetries in the casting or the ornamentation, which may split a resonance into two neighbouring ones. These two will interfere with each other, giving the impression of a single partial which varies in amplitude. To economize on Partial Generators, this is simulated in ISABEL with "wobble", i.e. a sinusoidal amplitude modulation of a single partial, which for low warble frequencies sounds exactly the same. (Ref. 1, p. 106; Ref. 2)
This setup would be used for a fairly simple synthesis of three separate bell sounds, each composed of four partials. Different trees may be built by rearranging the printed circuit cards, and by assigning the keyboard keys to different Groups, via a key patch.

Let us now turn to the signals that pass through the branches of the "tree". Rather similarly to the horizontal Levels, ISABEL has three vertical Routes along which signals propagate through the Levels. I call them the Pulse, Pitch and Sound Routes, respectively:

The Pulse Route receives the push-button signals from the keyboard and pass them on as pulses which trigger the production of partial envelopes. The Pitch Route distributes a reference frequency which may be transposed at the Group Level before it is passed down to the partial generators. The Sound Route collects the many Partial audio signals and brings them to the outputs. A stereo mixer is included to simulate a spatial separation of the Group sounds.
Fig. III-A-4. Block diagram of ISABEL. For clarity, only one (of 9) Groups is shown, and one (of 51) Partials.
To increase the spectral density of the attack, a burst of square waves at the partial frequencies may be inserted during the onset and earliest decay of the sound. They are taken from the frequency counters (dashed arrow in Fig. III-A-3). I call this burst "rattle".

Specifications

The following sound parameters are adjustable:

Partial: - frequency; Range .04-6 kHz in discrete steps. The increment is proportional to f^2, (5 Hz at 1 kHz)
- relative loudness; 0-100%
- decay time; (from strike to silence) .5-40 s
- wobble depth; (amplitude modulation index) 0-100%

The wobble frequency is preset to some probable value (.3-10 Hz) but may be altered by changing a few components.

Groups: - relative loudness; 0-100%
- rise time; of partial envelopes (0-50 ms)
- rattle rise time; 0-5 ms
- rattle decay time; 0-2 s
- frequency ratio; of the transposer (± 1 octave)

Master: - total loudness; 0-100%
- orchestral pitch; a_4 = 435-450 Hz in 12 increments
- stereo pan position; of Groups, left-right

The musician's keyboard, which is a separate box with an umbilical cable to ISABEL, has a volume control, a headphone output, and nine keys which may be connected to the Groups in any combination.

Final Comment

The fidelity of the synthesis is of course a subjective matter, for its evaluation will depend on the context in which ISABEL is to be used. The decay part of the sound can be made (for all practical purposes) indistinguishable from that of real bells. The attack transients are not quite as overpowering as those of bell blows, when compared to a recording of the real thing made in the steeple tower itself. But that is not where we usually listen to bells; indeed, it is not to be recommended.

The main obstacle to achieving a convincing synthesis is not knowing how to tune the partials. Some hints based on my own and others' analyses of real bells are given in the user's manual for ISABEL. Since the partial parameters, and the partial frequency in particular, are easily adjustable, the synthesizer lends itself well to the study of all manner of percussion and plucked instruments that have prolonged resonances at well-defined frequencies.
Acknowledgement

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References*


*) Rossing (3) has made available a comprehensive list of references on bell acoustics.