POLYPHONIC TIMBRAL CONSTRUCTION IN "ANDROGYNY"

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ABSTRACT:
The polyphonic POD compositional system allows construction of composite sounds of complex timbre, such as are used in the composer's recent work Androgyny. The structure of the work, based on relations between harmonic and inharmonic spectra, will be discussed with tape examples of the component elements. The use of FM sound as a building block in complex timbral construction will be illustrated and evaluated, and the compositional procedures used to derive the large scale structure of the work from the timbral level will be described.

I. Introduction: Some New Directions

My work in computer composition has in the past few years taken two major directions which together define the basis of my compositional thinking and philosophy. Both directions have been inspired and made possible by working within a composer-machine environment, specifically within the evolving framework of my POD system for polyphonic sound synthesis and interactive composition. It is the realization of the enormous influence that this kind of computer work has on the process of composition, the very way one thinks about sound and its organization, that has led me to declare elsewhere that the major importance of computers to music is the way in which their use influences the process of composition, the way composers think, as well as the way in which musical knowledge is represented. A precedent can be found in the history of the analog studio in the 1950's: composers such as Ligeti who worked in the early
studios in Cologne and Paris often report themselves as being tremendously influenced as composers by their experience in those studios, even when they returned to instrumental composition. Computers all the more powerfully have the potential of influencing the compositional thinking of the contemporary composer, as well, of course, as merely duplicating the efforts of the traditional composer.

The first of the "new directions" I have referred to in my work is a trend towards working systematically and structurally. This direction is not surprising since the compositional basis of the POD system involves working with sound structures organized as "distributions" of sound events, and specifying the conditions under which the sound events are determined by the available algorithms. One is always working with relationships and control parameters; hence, a systematic way of thinking about structures is encouraged.

In my 1976 piece Nautilus for solo percussion and tape, and likewise in the 1977 piece Sonic Landscape No. 4 for organ and tape, the entire structure of the live and tape parts were worked out as sets of control data in advance of any specifics being determined through use of the program. Although one might compare this procedure to a composer working out a score before having it performed, there is at least one significant difference. In my case, every detail of how I was thinking about the organization of the sound was inspired by the way in which the program treats the various acoustic parameters and relations between them. The feedback between the composer and the program is not only at the level of output, but also at the level of process.

The works referred to above both unfold as single gestures; each involves a single process which when set in motion continues until completed. All the specific details derive from the definition of the general process and are implied by it. Characteristically, both are about 10 minutes in length. Few
"single gesture" pieces, no matter how complex, extend much longer than that. When I came to thinking about Androgyny this year, it quickly became apparent that the ideas involved were too large to be realized within a single process. In addition, the two previous pieces had been realized before the polyphonic compositional system was complete, even though they were able to be synthesized with polyphonic sound. One of the reasons I was able to compose their structures beforehand and somewhat abstractly was because the years of experience working interactively with the program had given me a good predictive basis for working less interactively with it. However, once the polyphonic program was completed, in late 1977, new techniques had to be invented and tested in order to realize its capability. Put very simply, smaller sub-processes had to be worked out individually whose outputs would later be combined, in the mixing studio, into the final work.

The second direction is probably less familiar and less shared among composers. I think of it as placing a greater emphasis on materials, namely the properties of sound and its behaviour in the broadest sense. Although there are many parallels to this emphasis in the visual arts in this century, instrumental composers have tended to rely more on tradition and other sources of ideas. Electronic and tape composers naturally have learned to compose their sounds as well as their structures, but in many cases, the limitations and idiosyncrasies of the hardware have tended to leave them liking and using what they got from the machines rather than getting exactly what they would have liked. In addition, there has been a certain tardiness of composers, and lack of education in music schools, in dealing with the acoustic and psychoacoustic basis of compositional craft. One really has had to study music to appreciate how very little its teaching has to do with sound!
In an age where familiarity with tradition, contemporary or otherwise, is becoming less and less a part of the average person's education, in an age where the concert audiences, and even less the critics, are seldom reacting on the basis of familiarity with musical idioms, I feel that it is increasingly imperative to develop a musical language of equal expressive communicative effectiveness to the great musical languages of the past and of other cultures (and I do not think we should be afraid to make such comparisons - I'm sure audiences do!) This kind of new musical language needs to be developed. I see it as not being based on tradition, but rather on the only thing shared now by people at all, namely everyday acoustic and psychoacoustic experience and most of all, listening. I believe that acoustic and psychoacoustic language is the only adequate system for representing synthesized sound, and that the behaviour of sound in its broadest sense as a communicating medium, including both its objective and subjective behaviour, its functional uses in society and the environment, is the only basis of knowledge and source of new insights which is useful to me as a composer. Moreover, lacking a working knowledge of tradition, the audience can only be relied upon to exercise the aural sensibilities they have been practising (or neglecting) from birth in everyday acoustic communication.

The principal theme I wished to develop in Androgyny was based on the acoustic phenomena of harmonic and inharmonic timbre. Although the terms may be related to their musical manifestations, I am using them only in their acoustic sense as referring to sounds with harmonic overtones on the one hand, and inharmonic partials on the other. The distinction between harmonic and inharmonic implies a duality, even an opposition; however, what interested me about the
phenomenon was the possibility of exploring relationships that could exist within the duality - showing a complementarity, creating an interdependence, and demonstrating the fluidity with which one could transform into the other along a continuum of intermediate possibilities.

There is a sense in which sound and music only expresses itself, only reveals its own properties, and behaves only according to its own rules. Perhaps this is what Stravinsky was getting at when he made the famous comment about music not being able to express anything. However, man and culture fashion sound into languages, systems of organization which put sound to work in expressing human meanings. Sound is a willing workhorse for our tasks: it dutifully disappears once its message is delivered, and can be recalled at any time in limitless quantities. But most remarkable of all, I think, is the way in which sound reflects our own images, our culture, and our archetypes. We may organize it, but in its behaviour we can sense a reflection, purer and more abstract than language can ever achieve, of ourselves. And if it reflects ourselves, then it also mediates our communication with others. If we work with the duality of the properties of harmonic and inharmonic, then we reflect and refer to all dualities without having to be limited to any particular one; if we work with the continuum of relationships within a duality, then we explore all such relationships, whether acoustic or not. Ironically, it seems to me, if we try to refer to non-acoustic relationships directly with sound, such as with so-called political music, we fail and the sound dies, whereas if we work only with the materials, the sound itself, it seems to speak to us about all such relationships, by invoking meaning from within us.

To summarize what I have tried to say thus far about the importance of the use of computers in composition, about my own development as a composer,
and about the basis of the work in question: the importance of computer music seems to me to lie in its influence on the compositional process, in terms of both the precision of the materials which may be generated and the structural methods with which they may be organized; my own direction has led me toward a more systematic method of working, making control structure decisions as opposed to specific event decisions, and toward an aesthetic and compositional orientation in which analysis of the materials at hand leads to the design of the larger scale structure and ultimately its meaning; and finally, that in the specific work Androgyny, I have been interested in exploring and portraying relationships between harmonic and inharmonic spectra that, instead of polarizing their duality, tend to reveal the continuum of possibilities that exists between them, and that as its highest goal, the piece attempts to invoke the energy of the archetype referred to in the title, the archetype of a unity within which a duality is embodied.

II. Polyphonic Timbral Construction

Since new techniques are involved in the realization of the work, I will discuss them first in detail before returning to the larger structural aspects of the piece. Every sound in the piece is the result of digital mixing of at least three separate component sounds. The effect of this mixing is richer, more complex timbre, and therefore I have called the process polyphonic timbral construction. It occurs when two or more layers which have identical or very similar time structures are mixed together. The parameters which can vary between the layers to be mixed are:

1) slight differences in frequency and attack time, which results in the acoustic choral effect;
2) larger differences in frequency, which produce clusters or chords;

3) different c:m ratios which are related by the fact that they produce identical spectra, and therefore guarantee timbral fusion;

4) different c:m ratios which produce different spectra, and therefore create complex, additive timbral results similar to those produced with multiple modulating frequencies;

5) different modulation index envelopes and peak index values, which result in complex internal dynamics;

6) different binaural stereo positions assigned to the events in each layers, creating a spatially distributed timbre.

Most of these techniques have been used in the work, and in many cases, more than one at a time. All of the effects noted are the result of straightforward digital addition of signals, and therefore require no extra software. The exception is the use of binaural stereo, in which case the sample has to be doubled, stored at a different location in the array, and later sent to the second output channel.

A principal feature of the technique being described is that one or more variants of the same structure have to be generated first, then combined with the original. The set of programs in the POD system which perform these tasks can be seen in Figure 1. The output of the basic compositional program POD6 is in the form of diskfiles containing the compositional data of a single distribution. This file can be used by the SCORE program for a translation of the data into a coded form of traditional notation, or as well, it can be edited with the PODFIL program. The editing program allows event by event editing, or group editing as well as data generation by simple means. For the techniques in question, the use of systematic editing of the entire file is of greatest interest in that
Figure 1. Block diagram of the polyphonic POD system. Solid lines denote existing data exchange permitted between programs (POD5, POD6, SCORE, PODFILE, MERGE, POD7) and storage files (diskfiles, merge diskfiles). Dashed lines indicate proposed additions to the present system. "Input" denotes event-by-event data specification, an alternative to use of the first-level composition programs.
it allows the user to operate on the given data to create a variant. The operators currently available are:

1) linear increment, decrement, or transposition;
2) percentage increment, decrement or transposition;
3) random change within some specified percentage range;
4) inversion around a fixed point.

The pitch parameter may be treated linearly in Hz by these operators, or else logarithmically in tempered semitones. The frequency modulation parameters in POD are specified in the set of "sound objects", for which the POD6 program provides systematic editing capability. These operators, which may be applied to any parameter for any or all of the given data, provide a simple but flexible tool for the creation of variants. It should also be noted that the data in the files can be treated in forward or reverse order as well.

All data files, whether originals or variants, may be combined by the MERGE program with variable offset or entry delays. The program merely combines the two time structures into a composite data file, called a merge file, noting the time structure by the entry delay between events and the individual event durations. If requested, the program can also tag each "voice" or component with a voice number, from 1 to 8. At the moment, the only use of this voice number is to assign a specific spatial position to events with that voice number, as will be illustrated later. Note in Figure 1 that the MERGE program can be used recursively; that is, merge files can be combined with themselves or with non-merged files. Hence, data structures of great complexity can be built up from relatively modest initial structures. However, in the realization of such structures, the maximum amplitude of the resultant signal must be considered in order to avoid clipping and distortion of the signal if it exceeds the integer
capacity of the data storage or the D/A converter.

I will now present specific examples drawn from Androgyny which illustrate the techniques that have been described, and which introduce the timbral and psychoacoustic implications of those techniques.

III. Examples
A. High frequency glissando:

The first example shows a simple application of the variant technique. A set of six variants were created in which each variant was derived by operating on the previously generated one. In each case, a random variation of frequency was requested, the choice to be made within 10% of the previous value. Each file was then merged with a two second offset time from its predecessor. The impression is of a "random walk" glissando. At each two second interval, the carrier frequency shifts either up or down by a random amount, but by 10% maximum. In many cases, the change is micro-tonal, in others it changes by a discernible interval. Had there not been an offset time, the result would have been clusters of frequencies in a band; in this case one hears the sound overlapping with the shifted frequency of the next component in a slow glissando effect. Each component also has a different spatial position, proceeding left to right, although with the high frequency ranges involved, binaural time delays are not interpreted as accurately by the brain as with lower frequencies; intensity differences would have had to be added for an accurate localization. In the tape example you will hear several of these glissandi at once, enriched with digital reverberation.
B. Inharmonic timbral construction:

In my article on the organization of $c:m$ ratios, I pointed out that those ratios of the form:

$$\frac{c}{n \cdot m} : m$$

for $n = 0, 1, 2, 3, \ldots$ would produce identical spectra, provided the $c:m$ ratio used to generate the family of ratios was in so-called "normal form", that is, where the carrier frequency was the fundamental, or more precisely, where $m$ was greater than or equal to twice $c$. The set of ratios produced with values of $n = 1, 2, 3, \ldots$ could be thought of as members of the same family. As you can see from the example with the ratio of 2:5, the sidebands produced by each family member belong to the same set, with the carrier frequency simply becoming one of the sidebands of the set produced by the normal-form ratio.

Now, keep in mind what happens when the modulation index sweeps from zero upward: the bandwidth of the spectrum increases around the carrier frequency, allowing more and more of the high order sidebands to figure in the spectrum. This pattern, which can be analyzed with the aid of Bessel functions, has resulted in the much maligned "FM sound" which it has become fashionable to criticize over the last year or so. Indeed, there is a rather predictable timbral variation which constant and unimaginitive sweeping of the modulation index always upward from zero produces. However, it often seems that those who tire most easily from this so-called "typical FM sound" never seem to complain of the similar redundancies of "typical woodwind sound" or "typical brass sound"; indeed they strive endlessly after it! However, a simple way to avoid this problem in FM sound is simply to mix different versions of the same spectrum as produced by different $c:m$ ratios of the same family. Even if the same modulation index envelope is applied to each sound, the fact that each component has a different carrier frequency means that the composite sound, even
<table>
<thead>
<tr>
<th>Family/Member</th>
<th>1 (Normal Form)</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
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<td>7:5</td>
<td>8:5</td>
<td>12:5</td>
<td>13:5</td>
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<tr>
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<td>3:8</td>
<td>5:8</td>
<td>11:8</td>
<td>13:8</td>
<td>19:8</td>
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<td>7:9</td>
<td>11:9</td>
<td>16:9</td>
<td>20:9</td>
<td>25:9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Fundamental Hz</th>
<th>Note</th>
<th>Interval To Fundamental</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:9</td>
<td>120</td>
<td>B</td>
<td>2:1</td>
</tr>
<tr>
<td>3:7</td>
<td>116</td>
<td>B^b</td>
<td>27:14 (1.928)</td>
</tr>
<tr>
<td>2:5</td>
<td>108</td>
<td>A</td>
<td>9:5 (1.8)</td>
</tr>
<tr>
<td>3:8</td>
<td>101</td>
<td>A^b</td>
<td>27:16 (1.687)</td>
</tr>
<tr>
<td>2:7</td>
<td>77</td>
<td>E - E^b</td>
<td>9:7 (1.286)</td>
</tr>
<tr>
<td>2:9</td>
<td>60</td>
<td>B</td>
<td>1:1</td>
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</tbody>
</table>
with 2 or 3 components, will have an extremely complex internal variation of
the amplitude of each sideband. The result loses the more redundant aspects
of simple FM sound. The key is in seeing simple FM sound as a building block.

In the next set of examples, you will hear various bell-like sounds,
produced by the combination of the first six family members of the six c:m
ratios in normal form (4:9, 3:7, 2:5, 3:8, 2:7, 2:9) which are present in the
c:m series of order 9. This means c:m ratios which produce inharmonic spectra
where m does not exceed 9. Since the six members of any one family all produce
the same spectrum, there is a guarantee of timbral fusion when they are combined.
In some instances in the tape you will also hear some very thick, dissonant
timbres, much like those produced by hitting undamped piano strings. These were
obtained by combining the family members vertically, that is, combining members
of different families, thereby preventing timbral fusion and creating thick
composite textures with many unrelated sidebands.

A second phenomenon you will undoubtedly notice is a kind of modal pitch
structure with strong octave and perfect fifths. These derive from the properties
of the 6 inharmonic c:m ratios. If we keep the modulating frequency constant at
270 Hz, then the fundamental of the 2:9 ratio will be 60 Hz, which is the
fundamental frequency used in Androgyny, its tonal centre. The ratio 4:9
produces a fundamental exactly an octave above that produced by 2:9, namely at
120 Hz in this example. The frequencies of the other ratios are shown with
their approximate note names and interval ratios with the lowest one. The 2:5
ratio produces a minor seventh or 9:5 interval, and the 3:8 ratio produces a
fundamental a semitone below that. The 3:7 and 2:7 ratios produce notes that
don't fall into an exact chromatic relationship, although they're close to the
notes shown, but on the other hand, there is a strong perfect fifth interval
between their two fundamentals, and the lower note comes close to forming a perfect fourth with the lowest pitch in the series. The result is an unusual scale pattern which I decided to keep throughout the piece, though in different pitch ranges. A comparison could be made to a peal of bells with fixed pitches. Structurally, it became an important way of relating harmonic and inharmonic sounds, namely by tuning the strong octave pitch relations in the inharmonic sounds to the fundamental drone of the harmonic ones.

C. Multiple modulating frequencies:

The next example attempts to create composite timbres that proceed from harmonic to inharmonic in a somewhat smooth fashion. Eight families of ratios were used, but in this case the members in the family do not produce similar spectra. Instead they are characterized by having the first reflected lower sideband fall with a particular interval against the carrier fundamental. With the ratio 60:121, for instance, the lower sideband will be 2 Hz above a fundamental of 120 Hz and will therefore beat with it. As the $m$ part of the ratio increases, so does the interval between the fundamental and the first reflected sideband. In the eight families, the $c:m$ ratios change at different rates as it were from left to right in the 15 members of each family. Each sound you hear is the composite of 8 different components, which are in fact the 8 $c:m$ ratios aligned vertically in the chart. A choral effect of 0.2% to 0.8% pitch variation further increases the richness of the resultant spectrum. At the beginning of the sequence, one hears first a pure harmonic spectrum composed of 8 components in choral effect. Then we switch to the 1:2 ratios, producing odd harmonics, and then further along the 8 components start "pulling apart" as it were, at first beating strongly with the fundamental, then creating a strong, dissonant rough texture around the fundamental. The 8 components become more widely separated as the sequence continues, and at some point reach a maximum.
# Multiple Modulating Frequencies

<table>
<thead>
<tr>
<th>Family/Members</th>
<th>(60:M)</th>
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<tr>
<td>I</td>
<td>60 120 120 120 120 120 120 120 120 120 120 120 120</td>
</tr>
<tr>
<td>II</td>
<td>60 120 120 121 122 123 124 125 126 127 128 130 131 133 135</td>
</tr>
<tr>
<td>III</td>
<td>60 120 121 122 124 126 128 130 132 134 137 140 143 146 150</td>
</tr>
<tr>
<td>IV</td>
<td>60 120 122 124 127 130 133 136 140 144 148 153 157 163 169</td>
</tr>
<tr>
<td>V</td>
<td>60 120 123 126 130 135 139 144 149 155 161 168 175 183 192</td>
</tr>
<tr>
<td>VI</td>
<td>60 120 124 129 134 140 146 152 159 167 175 184 194 204 216</td>
</tr>
<tr>
<td>VII</td>
<td>60 120 125 131 138 145 152 160 169 179 189 200 212 225 240</td>
</tr>
<tr>
<td>VIII</td>
<td>120 240 240 240 240 240 240 240 240 240 240 240 240 240 240</td>
</tr>
</tbody>
</table>

Fundamentals: 115 → 380 Hz
6 tones/octave (312 → 507)

Mod. Index:
- Max. = 3
- Env. = 1

Choral Effect: .2% → .8%

Start Spectrum: \( f_0 = 120 \text{Hz}: 120 \ 360 \ 600 \ 840 \ldots \)

End Spectrum: \( f_0 = 120 \text{Hz}: 120 \ 150 \ 180 \ 218 \ 264 \ 312 \ 360 \ 390 \)
- 420 458 480 504 552 556 600 648 660
- 690 720 744 796 840 888 894 1080
- 1320

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The fundamental pitches of the notes involved are in the range of 115 to 380 Hz, a range in which the critical bandwidth is approximately constant at 100 Hz. The component frequencies of the spectrum created by combining the 15th member of each family are shown at the bottom, where it will be seen that they start at approximately 30 Hz apart for a fundamental of 120 Hz; however, at the top end of the range, 360 Hz, this will increase to approximately the size of the critical bandwidth at which point the resultant spectrum should be at least smooth, if not actually consonant; the effect may be described as a smooth dissonance without roughness. After this point, the sequence quickly reverses itself and returns to the consonant end of the range.

Another typical feature of the construction of this sequence is that for any individual component sound, its maximum modulation index is low, about 3, and the envelope variation is quite simple, basically just an increase followed by a decrease. It becomes clear that the internal dynamics so important for creating a rich, lively sound are not being generated by sweeping the modulation index around wildly. Rather, the complexity arises from a complex interaction of the components of the polyphonic mix, a combination which is being achieved with the spectacular precision of digital synthesis.

In the final work, four versions of the basic structure were used, two of which were heard in that sequence. The other two are derived by playing the same tape at half speed and eliminating the pauses. The result is a sequence of fantastic energy, and extremely complex spectra, beginning with harmonic spectra in choral effect, pitched at whole tone intervals, gradually expanding and pulling apart into dramatic dissonant timbres, all the time with a background and underpinning of the same sequence at lower pitch.
D. Harmonic Drone:

The final example is perhaps the most complex. It is created this time with the harmonic c:m families of ratios, five members per family, with the ratios of 1:1 through to 1:5. The family membership guarantees timbral fusion again, but in this case, somewhat similarly to the high glissando sequence, the components are deliberately overlapped to form a seamless drone. Moreover, binaural time delays are used to produce a left-right axis, and differing maximum amplitudes produce a foreground-background sense of depth. The result is a harmonic drone which, on headphones, appears to circle in front of the listener in a ring. The c:m family members are positioned so that the higher order family members occur when the amplitude is least and the sound seems farthest away. Because the carrier frequency is actually quite high in the spectrum produced by this ratio, the spectral energy will favour the upper sidebands, leaving the fundamental quite weak, whereas the normal form c:m ratio occurs at the middle in front and at this point the fundamental will be strongest and the harmonics weakest. This kind of attenuation of low frequencies with distance is found environmentally only in very open spaces with few obstacles to sound propagation, such as occurs on the Canadian Prairies, where typically a train horn is heard more prominently in the upper frequencies than in the lower ones.

Ten discrete spatial positions were assigned left to right, with the interaural time differences being calculated at 0.1, 0.4, and 0.6 milliseconds with the left channel leading for the left-hand spatial positions, and the right one leading for the others. The three-part amplitude envelopes of the sound, each two seconds long, overlap with each other precisely, maintaining a constant overall resultant amplitude. The changing amplitudes of each envelope also function to "pull" the sound smoothly between discrete spatial positions, giving a sense of continuous circular motion.
### Harmonic C:M Ratios

<table>
<thead>
<tr>
<th>Family/Member</th>
<th>A (Normal Form)</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
<tr>
<td>I</td>
<td>1:1</td>
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<td>II</td>
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<td>III</td>
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<tr>
<td>IV</td>
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<tr>
<td>V</td>
<td>1:5</td>
<td>4:5</td>
<td>6:5</td>
<td>9:5</td>
<td>11:5</td>
</tr>
</tbody>
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**Circle Drone**

- **Left**
  - (-0.6ms) 8
  - (-0.4ms) 7
  - (-0.1ms) 6

- **Right**
  - (+0.6ms) 3

- **AMP.**
  - 1 (+0.1ms)
  - 2 (+0.4ms)
  - 4

- **C**
- **D**
- **E**

- **Axes:**
  - **X**
  - **Y**

- **Legend:**
  - **X:** Discrete spatial position
  - **= Fundamental strong; harmonics weak**
  - **= Fundamental weak; harmonics strong**

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The example suggests some very powerful and enticing possibilities of creating a binaural space of varying dimensions in which timbre can be distributed. In the environment, many sounds are not point sources, and do not move around in point trajectories; often sounds of complex timbre occur spatially distributed, as in waves on a beach, for instance. The emphasis on amplitude differences in mixing, and creating "phantom images" between speakers, seems to have made composers ignore the possibilities of creating spectra whose components are distributed in space, and which can move independently through that space. In binaural synthesis such construction is possible with great accuracy and fidelity.

The drone was used at both the beginning and end of Androgyny. In both cases its fundamental is 60 Hz, not coincidentally the frequency of North American electrical hum. At the end of the piece it is accompanied by a half speed version of the same sequence, both versions rotating in the same direction but at different speeds. Both proceed through 9 revolutions, from the 1:1 family through to the 1:5 family, one family per revolution, and then back to 1:1, and therefore back to the greatest concentration of energy in the fundamental. Since both versions of the tape are started simultaneously, it is the long descent of the slower one that forms the conclusion of the piece. At the beginning of the piece, an inharmonic drone, constructed very similarly, is combined with the harmonic one of the same fundamental. The inharmonic drone is circular but the harmonic one goes through random spatial movement, giving a more ambiguous effect.
To summarize the implications of the techniques used to realize the examples you have heard, I think that it is clear that an additive approach to FM sound is capable of producing sounds of great richness and complexity. Moreover, combining similar versions of the same sound, with slight differences in tuning or different c:m ratio family members, avoids the objectionable, simple kind of spectral change that characterized the technique of sweeping the modulation index from zero all the time, and that resulted in what has been called "typical FM sound". FM with sine/cosine modulation remains, in my opinion, an extremely powerful tool for synthesis provided it is seen as a building block in timbral construction. Moreover, when combined with binaural output, this method of timbral synthesis allows the further possibility of spatial deployment of the timbral components, and opens a new field for tape compositions designed for the intimacy of headphone listening as well as loudspeaker performance. I believe that Androgyny is the first piece of computer music to be completely synthesized in binaural stereo. Although the loudspeaker version is quadraphonic, there remains a left side and a right side which are directly mixed down to the binaural stereo version.

IV. Conclusion:

As I stated earlier, Androgyny does not result from a single process or gesture. The overall structure of the piece does not derive from a single idea, but it does rest on two major kinds of structures for which I have just presented component examples. The first structure is the drone, which exists in both harmonic and inharmonic versions. These constitute the beginning and ending of the piece; at the beginning, the inharmonic drone is fused with the harmonic one, and at the end, the harmonic drone is reinforced an octave lower by a half-speed version of the same sequence. At the end, however, the inharmonic sounds make
their appearance as very high "fuzzy" bells, tuned still to the same pitch as the fundamental of the harmonic drone. Whereas the drone is low pitched, continuous and smooth, the inharmonic bells are Poisson-distributed, high pitched and occur at different depths of reverberation. The two types of sounds retain their duality right to the very end by remaining opposed in timbre, rhythmic character, pitch and spatial displacement. However, the tuning procedure holds them together, and they appear in a balanced equilibrium.

The second major structure in the piece is the transformational sequence that proceeds from harmonic to inharmonic and back. The four versions of the sequence have already been referred to. Together they create an energetic, even stormy texture, punctuated at intervals by thunderclaps of deep inharmonic bells. The key transition in the piece comes at the end of that sequence where, as its energy subsides, the harmonic drone enters to re-establish the tonal centre, now supported at a 30 Hz fundamental. This is the point of maximum contrast and drama.

Another section of the piece, which bridges the initial drone to the transformational sequence has not been discussed here, since it does not add anything new in timbral technique. However, it is constructed from pitches which are the harmonics 8 to 16 of the 60 Hz fundamental plus the subharmonics 8 to 16 of 960 Hz which is the 16th harmonic of 60 Hz. Additional sequences of the high glissandi and inharmonic bells fill out the texture at various places. The use of strong pitch relationships in the piece is not the result of traditional thinking. Instead, they all derive from properties of the harmonic and inharmonic series or c:o ratios as I have described, and all are based on the 60 Hz fundamental.
Therefore, they are not designed independently of timbre.

Timbral considerations predominate in the piece and other parameters, such as pitch organization, rhythmic organization in terms of Poisson distributions or continuous drones, and spatial deployment, all serve to reinforce the intricate set of relationships which exist between the various timbral types. It is this aspect of the compositional approach which I referred to earlier as being dependent on an analysis of the sound materials. Basic acoustic relationships at the micro-acoustic level, so to speak, suggest larger-scale structures and relationships at the macro level. The inter-relationships found at the micro-acoustic level of the timbral event are used to explore relationships within the duality of a powerful human archetype.
REFERENCES


