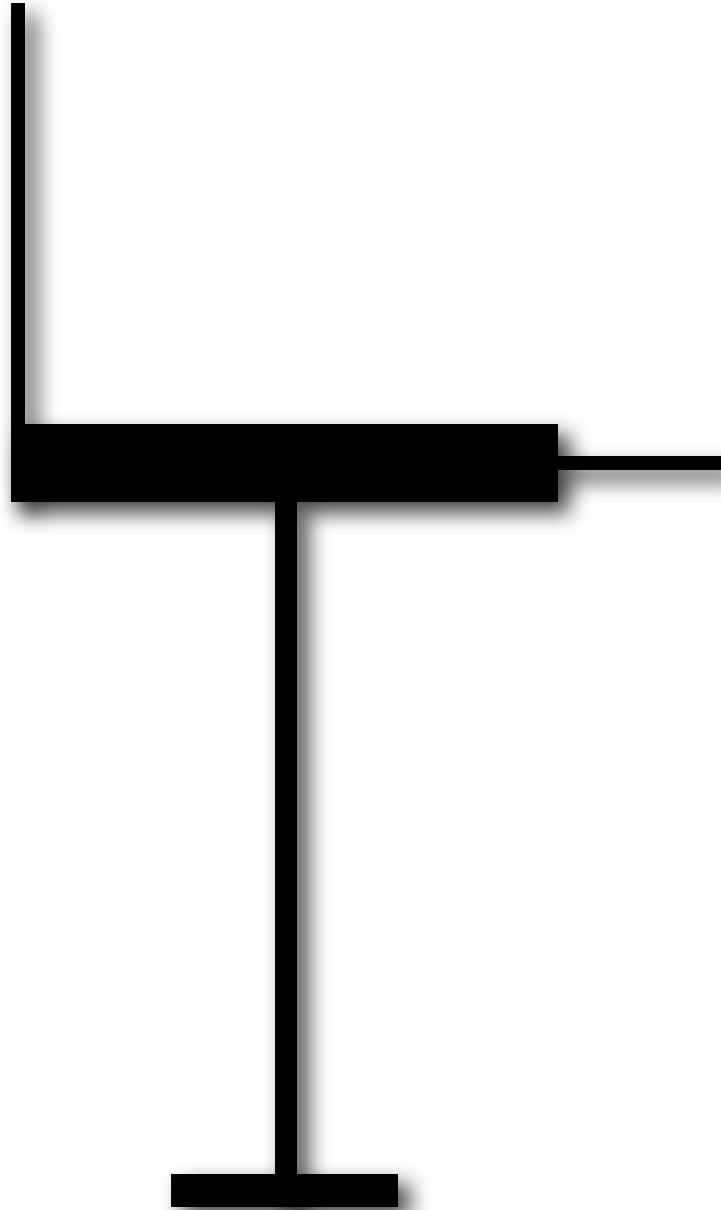


THE BEAT FREQUENCY METHOD

THEREMIN FOR THE SONIC EXPLORER



AN UNCONVENTIONAL APPROACH
TO CREATING ELECTRONIC MUSIC
ON A UNIQUE AND VENERABLE
ELECTRONIC INSTRUMENT

BY GORDON CHARLTON

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CAVEAT LECTOR

This document is not intended for the classical thereminist. It does not contain any advice about melodic playing. It does contain suggestions which are contrary to accepted wisdom and which may not be compatible with classical technique.

PREFACE

I bought my first theremin on a whim, knowing the sound from old science fiction movies and intrigued by the notion of playing an instrument without physical contact.

As a melodic instrument it presents a formidable challenge, requiring excellent pitch discrimination and a great deal of practice simply to play in tune before one even starts to think about playing well. The majority of tutorial material is focussed on this goal and advocates ear training, rote and classical tuition.

Such ear training as I had; the record collection I listened to over and over as a teenager, forming my musical understanding and taste, was not melodic – I listened to old school industrial and electronic music, punk rock, experimental recordings, strange excursions away from the mainstream. In short, the unconventional.

I enjoy figuring out things from first principles and learning through exploration more than I enjoy the student-teacher relationship or learning by rote, so I set myself a different challenge, to rediscover the theremin as an unconventional instrument, to find ways to take best advantage of its unique user interface and to make the sort of music I know best.

But how can we model invisible, intangible fields? How can we learn to interact with them meaningfully? How would music have developed if the theremin had been the first musical instrument? How can we draw on our other creative skills and apply them to a different field? How can we achieve this with simple tools? These questions are the basis of my explorations.

THE INSTRUMENT

The theremin is a very simple synthesizer, consisting of two parts; an oscillator and an amplifier; the first to generate an audible frequency and the second to adjust its amplitude. Each of these is controlled via a variable capacitor, each consisting of two conductors, one fixed and one variable. The fixed conductors are the pitch rod and the volume loop, and the variable conductors are the corresponding hands of the player, the pitch hand and the volume hand.

Additional synthesizer functionality is achieved by dexterous manipulation of the hands within the electrical fields surrounding the rod and loop. As it is not possible to see or feel these fields it will be helpful to have a model of their behavior when we move within them and an idea of their shape.

The fields are not static, they change as you move; both your hands and the rest of your body. Consider a jug mostly full of water. This corresponds to, say, the pitch field (the volume field is the same.) The top of the water corresponds to the lowest note, the bottom of the jug to the highest note. Notes are spaced relative to these two points. So a particular note is, say, two thirds of the way down the water. To play that note requires you to reach into the jug, which causes the water level to rise, so the note is always two thirds of the way down, but where that is exactly depends on the mass of your arm - a larger volume (corresponding to an object that can accept a lot of charge) causes the water to rise more, spreading the notes out, and a smaller volume alters the water level less, moving the notes less. So, for example, very slow, controlled, minute changes in pitch are best made by extending one or two fingers only, after moving the body closer to the rod.

The field around the pitch rod is roughly cylindrical around the rod, with a hemispherical dome over the top like a glass dome clock, and with the notes arranged like the layers of an onion, or a Russian doll, the higher notes being closer to the rod.

In a little more detail, the field pinches in towards the top and bottom of the rod, so it is usual to keep the pitch hand mostly at a height about half way up the pitch rod. In an idealized theremin the notes would all be evenly spaced within the field, like the notes on a piano keyboard – this is called linearity. In practice there is always some deviation from linearity, with the notes getting closer together the higher in pitch they are, like a stringed instrument such as a violin or guitar.

Additionally the notes get closer together around the very lowest notes. This is because the audio oscillator of the theremin derives its tone from the difference between two radio frequency oscillators, one which generates a constant frequency, and one which is varied by the proximity of the pitch hand to the pitch rod. As the frequencies of the two RF oscillators become closer the audio frequency gets lower and the two oscillators interact and pull towards the same frequency (which ultimately results in silence – this part of the pitch field is called the zero beat zone.)

The field around the volume loop is likewise composed of concentric layers, with the loudest sounds being furthest from the loop. This time the layers are oval, like a rugby football planted point up in the volume loop. The key feature to note is that the layers are more widely spaced above the volume loop, allowing more subtle control of volume, and more closely spaced to the side of the loop, allowing more rapid changes in volume.

THE PLAYER

As described above, the theremin player is literally a part of the theremin circuit, so can be considered as a part of the instrument, with the disposition of the whole body, not just the hands, affecting both pitch and volume. Pitch in particular is sensitive to minute movements in either the theremin or the player, and this can impact negatively on a performance when a note that should be unvarying in pitch wanders perceptibly. To minimise this, both the theremin and the player should be as wobble-free as possible. For the player this means adopting a stable stance and practicing the necessary skill of standing still.

I suggest using the postures adopted by either Peter Pringle or Barbara Buchholz. Both have this in common, that they are similar to stances used in martial arts; tai chi and karate respectively. Assuming a right handed player – it is strongly recommended that pitch be played with the dominant hand – the Pringle stance involves pointing the right foot towards the pitch rod with the knee slightly bent and the left foot perpendicular to the right foot and about the same distance away from it as the width of one's shoulders, leg straight and back straight. This stance permits controlled movement of the body towards the pitch rod, which can be used to overcome non-linearity in the higher notes.

The Buchholz stance is more powerful, placing the player in a dominant position over the theremin, encouraging a more assertive playing style. For this the feet should both point towards the theremin, and be a shoulder width apart. Both legs are very straight, body leaning forwards with the back arched inwards, locking the knees in position and making the legs rigid. It is better suited to players with a lower centre of gravity.

The disposition of the pitch hand varies from that adopted by the majority of classical, melodic players. I suggest holding the pitch hand as if holding a pen, thumb and forefinger touching the base of the sternum, and drawing a horizontal arc from the centre of the chest to the pitch rod. I suggest the same disposition as that used in handwriting because that is an activity that requires a steady hand and fine motor control with which the player is undoubtedly familiar. The upper arm should be straight down, or thereabouts. The volume hand should be above and towards the closer edge of the loop, with the elbow raised and forming a right angle to reduce the transfer of vibrations from the volume hand to the rest of the body, affecting the pitch. The muscles should be relaxed.

The correct stance will minimise movement to a certain extent, but it will not eradicate it. The primary key to all theremin playing is audio feedback. The player should be focussed on the sound at all times, and over time will develop the appropriate hand-ear coordination, just as a person learns to balance a bicycle effortlessly over time from wobbly beginnings. For long steady notes audio feedback can be augmented with visual feedback, by looking past the thumb and forefinger of the pitch hand and keeping them steady relative to a distant object, as one might sight along the barrel of a rifle.

It is advisable to always start playing from the same stance, and at the same distance from the theremin, and to tune the pitch field so that the same low note (or silence) is achieved when the pitch hand is furthest from the pitch rod, for consistency. The advanced method is to tune so that a consistently repeated hand movement causes a known change in pitch. This is called tuning to an interval.

CONCERNING CONSONANCE

The theremin is a continuous pitch instrument in a musical world dominated by consonance, wherein lies the challenge faced by the classical thereminist; of playing specific pitches to a high degree of precision, which is a time consuming business.

Consonance is an acoustic phenomenon; when enough of the various frequencies composing two or more sounds coincide the sounds fuse into a single, more complex sound in a harmonious manner. Sounds created by vibrating columns of air, or by vibrating strings, for instance, are made up of frequencies which are in simple ratio to one another, so consonance is likely to be chanced upon readily by any experimenter, and figured in the very earliest music, dating to the dawn of civilization. One can imagine cavemen knocking rocks against each other rhythmically, and noticing that certain rocks sound more pleasing than others. In Western culture this was studied by Pythagorus using the mathematics of rational numbers, which formed the basis of music theory. This had the dual effect of opening up many avenues of research into harmony, and of revealing some of the hidden complexities of the system. While research continues to this day in the form of microtonal systems, the common practice in Western music is a compromise which approximates consonance while giving the composer a great latitude within the system.

By abandoning consonance in order to explore the potential of the theremin as a continuous pitch instrument we move from rational numbers to the mathematics of real numbers; calculus and its geometric cousin, trigonometry, and we consider other acoustic phenomena which have a lesser standing in conventional Western music.

THE TROGLODYTE AND THE THEREMIN

As we can imagine our cave dwelling forebears chancing upon musically interesting rocks, so we might imagine one of them chancing, inexplicably, upon a theremin. Without dwelling on the unlikelihood of this event we shall proceed to wonder, rhetorically, what he would do with it, and answer; he would take it back to his cave to investigate it.

This is fortuitous, as caves abound with interesting acoustic phenomena and cavemen knew about the acoustic properties of caves. In certain places in caves they painted stampeding mammoths and left a small pile of rocks. In these places the echoes of the rocks knocked together reverberate like a herd of stampeding mammoths. In long, narrow passageways they discovered resonant nodes, places where the right sung note builds up on itself and becomes louder, and here they marked the place with small dots on the top of the tunnel wall. And what better tool to explore cave acoustics than an instrument that can generate any frequency at any volume and for any duration.

So, as the rock musicians are discovering the fundamental unit of a music based on rational mathematics, the note – a sound of fixed pitch, our early thereminist will move his hands within the fields, finding sounds of varying pitch. He will consider the pitch at the start and end of a stroke, and also the speed of the stroke, and the way it accelerates and decelerates, and so on.

And while he is playing with the fundamental unit of a music based on real mathematics, the stroke, he will be realising that the cave's acoustics enrich the instrument, adding a range of musically interesting acoustic phenomena to explore.

THE SHAPE OF A SOUND

Before we can master the fine control necessary to use a pen for writing or sketching we hone our skills by drawing simple shapes and patterns. Similarly, before using the theremin in a musical way we can hone our skills playfully by emulating familiar sounds that vary in pitch and volume in simple and well defined ways. In this way we will build up a palette of moves for the pitch hand and the volume hand which can be combined in various ways to create a broad palette of sounds for the player to draw upon.

Examples of suitable familiar sounds might be the call of a seagull, a mewling cat or the howl of a wolf, a wolf-whistle or the whistle used to hail a cab, a Doppler-shifting train whistle or a police car siren. We will consider the police siren in detail.

The police siren is constant in volume, so the volume hand should stay at a constant distance from the loop. The pitch, however, varies sinusoidally, which is to say that the hand should slow down as it approaches the highest and lowest pitch of the sound, and speed up as it moves towards the middle pitch. This is difficult to achieve evenly and consistently just moving the hand to the left and right – towards and away from the pitch rod, so we shall take advantage of the fact that vertical movements of the pitch hand have a negligible effect on the pitch, and apply some simple trigonometry.

By describing small circles with the pitch hand at a constant speed (at first you may care to try this while actually holding a pencil and imagining drawing on an upright board – I found it helped) we know from trigonometry that the horizontal component will vary sinusoidally, which is just what is required.

From a synthesizer point of view we can think of this wrist movement as being a low frequency oscillator generating a sine wave to modulate the pitch. Moving the hand just left and right at a constant speed would approximate a triangle wave.

As a stroke it is useful to think of the circle as composed of four simpler strokes, each a quarter arc. Assuming a clockwise motion and a right handed player, the first quarter arc – from 12 o'clock to 3 o'clock – would be a rising, decelerating pitch, from 3 to 6 would be a falling, accelerating pitch, from 6 to 9 a falling, decelerating pitch and from 9 to 12 a rising, accelerating pitch. These and other simple strokes can be combined in different ways to create a range of more complex strokes. The simplest stroke is one with no variation in pitch, corresponding to a note.

We could also create a more complex stroke by adding another low frequency oscillator at the elbow, moving the pitch up and down slowly and over a wider range of frequencies at the same time as we describe small circles with the wrist. We might liken this to the sound of a police siren as the sound is Doppler-shifted as it drives around a roundabout.

To increase the complexity again we might add a third LFO, this time tighter and faster to give a vibrato effect. This we do with a rapid twisting movement of the forearm, as if trying to wriggle loose a key stuck in a lock, holding it with the thumb and forefinger. Keeping the other fingers loose and relaxed will damp the acceleration at the ends of the twist, making it more sinusoidal and less triangular. For a more triangular vibrato one might use a quick left and right motion, as if polishing a coin with a cotton bud. For a random vibrato one can wriggle the fingers about rapidly.

One can apply a low frequency oscillator with the volume hand in the same way. If both hands move identically the two oscillators will be 90° out of phase as with the volume loop it is the vertical component that is significant, and we will hear only the falling portion of the sound (for a right-hander and clockwise circles.) Moving to a different phase is possible, by increasing the speed of one hand for a while, as is rotating one hand at a multiple of the speed of the other. This can be tricky at first and while the ability to pat one's head and rub one's stomach at the same time is not a prerequisite, it helps.

More commonly, however, the volume hand functions as a manual expression pedal, played above the loop, and using the flat of the hand to vary the volume throughout a phrase. It is possible to punctuate phrases by briefly punching the finger tips into the loop and out again, and this suggests another way of considering the volume hand, as an envelope generator, another synthesizer component.

For a particularly sharp attack play from the side of the loop where the field is tightest, with the back of the fingers to the loop and then snap them smartly away, curling the fingers and bending the wrist at the same time to create a plucked sound. The pitch field should be as small as possible. The opposite of this, the slow attack and fast release familiar as a "reversed tape" sound is better done above the loop to avoid jogging the theremin. These techniques were devised by Pamela Kurstin.

For a rapid tremolo, point the fingertips towards the edge of the loop, hand horizontal, and, moving the hand only, flick the fingers above and below the loop, taking advantage of the loop's symmetry. Moving the hand close to the loop gives an effect reminiscent of a mandolin.

A PORTABLE CAVE

As it is not always convenient to perform in a cave we can use the electronic equivalents, reverbs and delays, to similar effect. This seems entirely appropriate for an electronic instrument. They are available in a variety of forms. We will consider the simplest and most economical, the guitar effects pedal.

Without a little reverb the theremin can sound very artificial. The subtle use of reverb adds richness to the sound and makes it more natural. The excessive use of reverb, coupled with a random vibrato, gives a smooth cluster drone with an aeolian quality to it. This effect can be increased by the use of one or more delay pedals, with delay times which are not in simple ratio to one another, to avoid building up a rhythm.

Uses of an echo pedal can be broadly divided into several categories. With strokes that are longer than the duration of the delay we are looking at layering up the sound. With strokes of fixed pitch (a note) this thickens the sound and stabilizes the note by averaging out miniscule variations in pitch, as rather than wandering in pitch the sound phases organically as the variations in pitch cause constructive and destructive interference. With a slow stroke of constant speed the phasing becomes a rapid beating or tremolo, akin to the celeste stop on an organ. As the speed of a stroke increases so the separation between the pitch and its delayed copies becomes larger and the sound opens out into several distinct tones.

These properties can be useful during practice, as phasing makes smaller changes in pitch more apparent while holding a long note, and a stroke of constant speed will yield evenly spaced beats.

When the delay is longer than the strokes played within it the strokes are repeated periodically and add a rhythmic content to the music. Coupling this with rhythmic playing at a speed in simple ratio to the length of the delay, allows chords and arpeggios to be constructed and developed over time.

Again, longer delays have a use during practice. When developing a combination of pitch and volume hand movements into a compound stroke it is useful to get the immediate feedback offered by a long echo.

Very short delays, on the order of a few milliseconds, and with a lot of feedback, turn an echo pedal into a resonant comb filter, resonating on a low frequency and on multiples of that frequency. This introduces an element of consonance into the music, as an overtone series such as this is highly consonant. The precise effect will vary from delay pedal to delay pedal, but in general some frequencies will resonate as a stroke passes through them, causing a note to be sustained within the pedal. The duration of the note will depend in part on the ability of the pedal to exactly repeat the waveform, so a digital delay with an option to repeat without filtering or otherwise changing the waveform is preferable, as is a pedal which offers very close to 100% feedback.

A ping-pong or multi-tap delay gives the opportunity to add an element of stereo to the performance, or to modify one of the outputs with another delay, or any other effects pedal, before recombining the two signals with a mixer.

Some guitar effects pedals can be overwhelmed by the strength of their output. A simple solution is to attenuate the signal with an inexpensive low impedance inline volume pedal.

A SECOND VOICE

Theremins are single voice instruments. Delays provide a form of pseudo-polyphony. Another way of increasing the number of voices is by using a pitch shifter or whammy pedal. As with delays, shifters offer different facilities, based on generating a new tone at a fixed or variable interval from the original. Its timbre is an approximation to the timbre of the original signal.

Just as the concept of being “in tune” does not apply to a stroke of varying pitch as it applies to a note, so a constant interval between two pitches can be harmonic or otherwise, but the concept does not apply to a variable interval, which requires use of a treadle to control the interval whilst playing.

Operating a treadle, such as a whammy pedal or an expression pedal connected to a pitch shifter (or a wah pedal – incidentally another useful addition to the theremin, giving the facility to control the timbre, as well as the pitch and volume, in real time) requires the Tai Chi stance. The treadle is operated with the foremost foot, the one corresponding to the pitch hand. The hinge of the treadle should be in line with the tibia to minimise body motion induced by rocking the foot, and the device should be robust enough to operate smoothly with the player’s weight on it.

Some pedals offer separate outputs for the two tones. This allows different delays to be applied to the two tones, for example. Other facilities can include a feedback loop to generate multiple additional voices, and harmonizing, which presumes a tuned instrument, and in a continuous pitch instrument has the effect of quantizing the pitch, turning the theremin into an air harp.

FROTHATRILLS AND TWANGULATORS

The capacitive fields of the theremin offer an opportunity for a unique form of effect. Rather than modifying the audio output of the theremin in the effects chain, we can introduce devices other than our hands into the fields; electromechanical effect devices that can affect the fields in ways not possible by hand.

A Frothatrill is an electromechanical LFO, oscillating faster than the hand can move. A simple frothatrill can be constructed from a hand-held, battery powered milk frother, with a short length of wire tangled into the whisk, one end jutting out like a single propellor blade. Orienting the frother so that the blade moves towards and away from the pitch rod creates a rapid, even vibrato akin to the trilling of the mogwai Gizmo in the film Gremlins.

By strapping a long steel ruler by one end to the top of a dining chair and positioning the other end under the volume loop one constructs a Twangulator. This modulates the volume distinctively. It can be operated by tapping at its resonant frequency, or by twanging, like a ruler on a school desk.

The *bacchetta di intervalli* or Interval Wand causes an instantaneous change in pitch. It is a screwdriver, around 40cm long with an insulated handle, held in the pitch hand. It is operated by touching the metal stem with the index finger. The interval varies with the wand's orientation to the pitch rod.

Although not an electromagnetic effect, I also mention here the Articulation Regulator; historically a forerunner of the volume loop. It is a handheld kill switch (press to break button) in the audio cable, giving an instantaneous attack or release.

PANIC BOX AND WHISTLE PIG

The ring modulator or amplitude modulator, like the theremin and the delay, dates to the earliest electronic music. There is an appropriateness to its use with a theremin, as the process of creating an audible tone from the beat frequencies in the difference between two RF oscillators, *heterodyning*, is identical.

I use a custom built active two input ring modulator which I call the Panic Box, after Pan, the god of rustic music. The modulated output is passed through an adjustable low pass filter with adjustable resonance, called the Whistle Pig (even though it does not self-oscillate) which also provides mixing facilities between the two dry inputs and the wet output.

The Panic Box can be fed by the wet and dry outputs of a pitch shifter, which gives a familiar ring-mod tone to the sound, or, more interestingly, it can be fed by a ping-pong delay.

A ring modulator's output is the sum and difference of its inputs – two new sounds, different from but related mathematically to the input sounds. The sound which is the sum of the inputs has a pitch half way between the inputs, and an octave higher. The difference of the sounds has a pitch lower than either, and it is this that is interesting: when fed by the delay it acts as a *difference engine* – a steady input tone to the delay produces silence, a steadily rising tone produces a constant tone, a steadily accelerating tone produces a steadily rising tone, a sinusoidally varying tone produces another, 90° out of phase with the first, and so on.

The sounds produced are, in some ways, akin to those described in the Futurist manifesto *The Art Of Noises*.

PAINTING NARRATIVE SOUNDSCAPES

The inspiration for any music, whether at the conscious level or not, is the sounds we hear. So first, *listen!* Listen intently to the sounds around you as you might a new CD or a concert, hearing everything. Consider, for example, a train journey.

It starts with the click of a door lock, and continues with quiet footfalls down an empty street accompanied by the distant drone of cars on a main road and intermittent bird song. And then the complex pattern of rhythms, the hisses, clunks, swooshes and screeches of an underground train pulling into a station, random snippets of libretto – a young female voice saying “I was soooooooo drunk,” brief bursts of incongruous melody from mobile phones and the tinny hiss of an iPod’s earpieces cut short by the sudden blare of a horn, the echoing patter of two hundred or more shoes ascending a stone staircase. And so on.

Next, configure your instrument. For a celebration of machinery and velocity, a journey down into the underbelly of the dark metropolis such as this, I would consider a ping-pong and Panic Box combination, and look to produce sounds evocative, if not directly imitative, of those I heard.

Finally, apply your strokes with certainty, playing the song of this journey with confidence and simplicity and control. Invoke the feeling and impressions it inspired in you, and while the sounds will undoubtedly be aleatoric to some extent, your task is to imbue it with sense, so be mindful of the mnemonic; A Completely Random Output Never Yields Meaning.

Enjoy your music and set yourself high standards. Now play...

AFTERWORD

Had this document been written eighty years ago it would doubtless have proclaimed the birth of a revolutionary new musical form, dismissing earlier forms as old, tired and predictable. But we live in less idealistic times, and the truth is that there is nothing new under the sun, and other forms of music are not the enemy, so it was written primarily for my own benefit; to consolidate some of what I have learned and discovered over the last few years. Nonetheless, it would be a vanity to presume that I am unique in all the world in my view of the theremin and of music in general, so I make it freely available on the Internet in the hope that it might reach those of a like mind.

Does it work? I do not know. The appreciation of music is subjective, so a better question is, does it work for you? It might very well not. A large portion of musical appreciation is familiarity, so it may be that this is an acquired taste, and one that you prefer not to acquire at that. But it works for me, the results have a hand-made, immediate quality that I appreciate, and I feel I have made steps toward achieving my goal.

To judge for yourself I invite you to listen to the album *The Chordless Chord* by Beat Frequency, which is my first attempt to put the principles and techniques described here into practice. The album is available online at the iTunes store.

Better still, try these ideas out. I strongly believe that the best way to learn is by exploration and experimentation, and by building on what has gone before.

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