Relating Spectrum and Tuning of the Classical Thai *Renat Ek*

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ABSTRACT

This paper discusses the relationship between the frequency spectrum of a Thai metallophone called the *Renat Ek* and its traditional tuning. A spectral analysis of the instrument produces a dissonance curve with consonance minima at ratios very close to the 7-tone equal-temperament scale often used in Thai classical music, as well as the tuning of one specific *Renat Ek*, suggesting a strong correlation between spectrum and tuning. Analysis of several musical performances shows the 1st, 5th and 6th scale degrees to be the most consonant (and the 2nd and 7th the most dissonant), a fact that is also supported by the relative consonance implied in the dissonance curve.

BACKGROUND

The discussion of consonance and dissonance and the relationship between timbre and tuning seems to begin with Hermann von Helmholtz characterizing dissonance in terms of the rapid beating between sine waves in close frequency proximity; an interval would be dissonant if some of the sine waves involved were close enough in frequency to produce a fast beating. After Helmholtz, others began to explore the idea of tuning in a mathematical sense; Joseph Yasser searched for a new system in the wake of atonality and Harry Partch challenged the dominance of traditional Western tuning with his use of ratios. The mathematical relationship between timbre and tuning, however, took its next big step when Plomp and Levelt measured musical intervals in terms of the harmonic series present in each sound. By adding the dissonances between each partial of each tone and plotting that dissonance according to the frequency ratio at each measurement, they introduced the dissonance curve. This curve shows the areas of most consonance (the dips in the curve) and most dissonance (the peaks in the curve), allowing an objective way to evaluate intervals in terms of nothing more than an instrument's timbre. This also introduces a connection between instrument and scale—if the dips in the dissonance curve match the notes of the scale, the two are a good match. This relationship is explored in depth and a modern take on the subject is presented in William Sethares' text Tuning, Timbre, Spectrum, Scale. The culmination of all these sources is that we now have connections between instrument, tuning and music played and an objective way to predict and evaluate those relationships.

DESIGN

In order to objectively evaluate the relationship between an instrument's spectrum and its tuning, it makes sense to use an instrument whose sound and musical context are unfamiliar. For this reason, I chose the *Renat Ek*, which is a traditional soprano metallophone used primarily in classical Thai music.

The Renat Ek

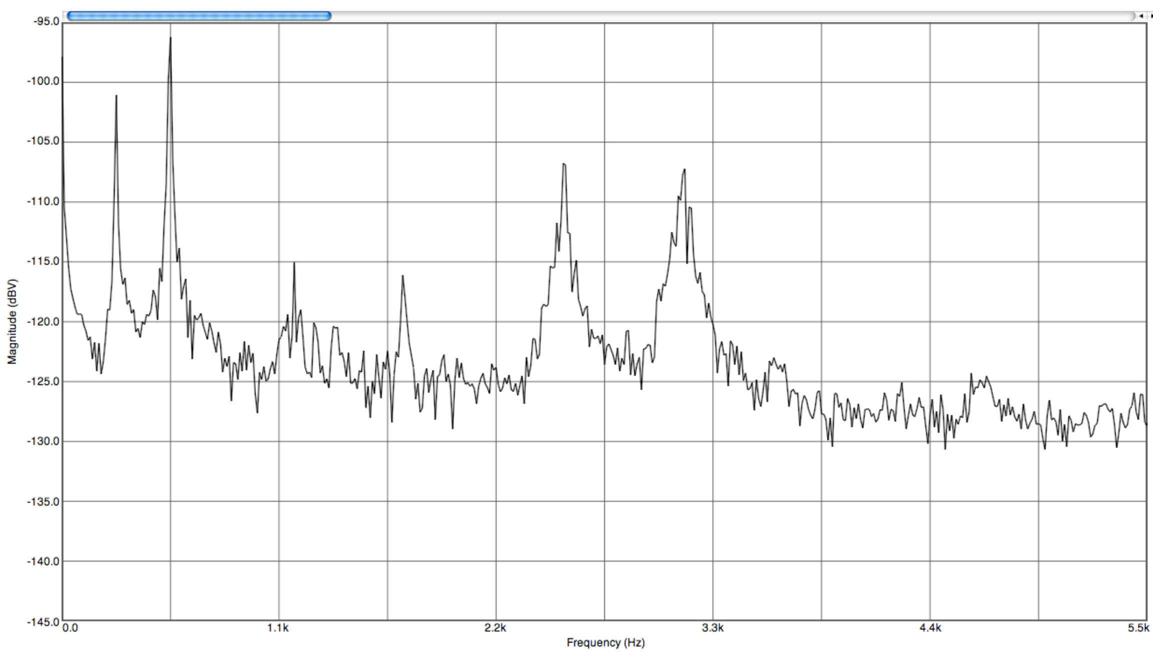
The instrument resembles a xylophone with 21 wood bars that are struck with either hard (wood) or soft (cord) mallets, depending on the desired tone. Because of its bright timbre and higher pitch, it is often the most recognizable sound in classical Thai music and featured prominently in orchestral settings (D3 p.7). Like most Thai instruments, the *Renat Ek* is tuned to a seven-tone scale. The scale is often considered 7-tone equal-temperament, but "in practice some [steps] are more equal than others" (D1 p.3). This introduces a difficulty when evaluating classical Thai instruments: there is no standard in terms of absolute tuning (Miller p.237). For this reason, I used one specific *Renat Ek* in my analysis and ensured that it was the only instrument of its kind present by working with a recording of the Siamese music ensemble known as a *Piphat*—one which featured a single *Renat Ek*.

Aside from its utilization of non-Western tuning, the *Renat Ek* is useful in terms of relating timbre to tuning because of the inharmonicity of its spectrum—a characteristic shared by most percussive instruments (Sethares p.202). Such a departure from the evenly spaced harmonic series of traditional Western instruments will produce a dissonance curve very different to the 12-tet curves we are used to and provide good objective ground to draw a correlation between timbre and tuning.

The process of the experiment itself was straightforward. From a recording of the *Renat Ek* in performance, I captured several samples of isolated hits. A spectral analysis of these samples using a demo version of the *Electroacoustics Toolbox* software led to a set of frequencies and corresponding amplitudes that were characteristic of the *Renat Ek*. Then, using a MATLAB program written by Sethares, I calculated the dissonance curve implied by these partials. I compared the tuning implied by the dissonance minima of the curve to the actual tuning of the instrument sampled, as well as the idealized 7-tet tuning. I also established a ranking of intervals from most consonant to most dissonant and assessed recordings of the *Piphat* to see if the intervals were used in a "stereotypical" way; this assessment was done both objectively (with spectrograms) and subjectively (my own experience). What follows are the detailed results of my work.

RESULTS

From the performance of the "Afternoon Overture" by Fong Naam (D2), I isolated the cleanest hit of the *Renat Ek* that I could find and found its spectrum to be the following:



FFT of Renat Ek from intro of "Flying Song"

This graph shows six prominent partials:

FREQUENCY	RATIO
275.6 Hz	*F*
551.3 Hz	2.00*f*
1,180 Hz	4.28*f*
1,731 Hz	6.28*f*
2,547 Hz	9.24*f*
3,164 Hz	11.5*f*

In order to verify that this inharmonic series was an accurate representation of the *Renat Ek*, I compared the ratios of the partials to the ratios from two other hits.

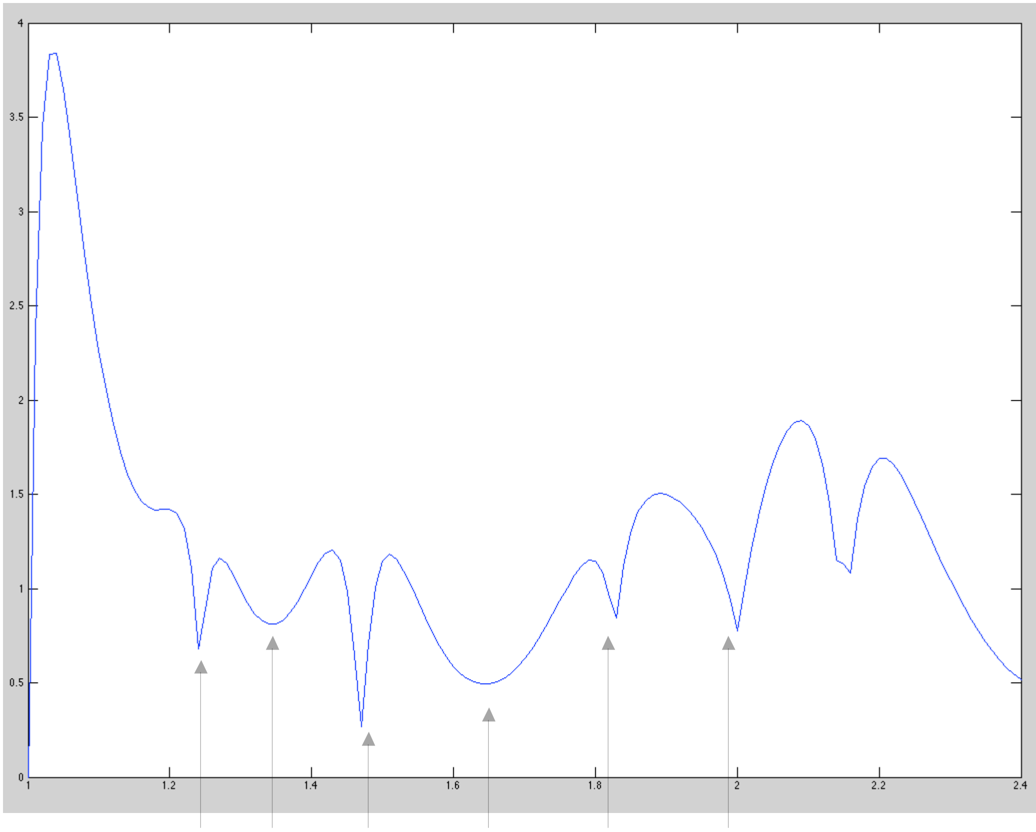
FREQUENCY	RATIO	FREQUENCY	RATIO
275.6 Hz	*f*	452.0 Hz	*f*
407.9 Hz	1.48*f*	904.1 Hz	2.00*f*
551.3 Hz	2.00*f*	--	--
1,169 Hz	4.24*f*	2,844 Hz	6.29*f*
2,547 Hz	9.24*f*	4,140 Hz	9.16*f*
3,164 Hz	11.5*f*	5,198 Hz	11.5*f*

The first of these two hits is the same note as the first, although much less isolated. The spectra of the two were very similar, with the exception of an extraneous partial at 1.48*f*. The second was a higher note and was missing the third partial, but the ratios were otherwise similar. I considered this evidence enough that the first spectrum was an accurate representation of the *Renat Ek*.

I then used these six frequency values and their corresponding amplitudes to calculate a dissonance curve. I used the MATLAB function "dissmeasure.m" (see appendix) written by Sethares to calculate the dissonance between intervals, and then I used the following code to call the function for every interval in the set of frequencies.

```
freq=[275.6 551.3 1180 1731 2547 3164]; amp=[0.9 1.0 0.61 0.59 0.78 0.78];
range=2.4; inc=0.01; diss=[0];
for alpha=1+inc:inc:range,
f=[freq alpha*freq];
a=[amp, amp];
d=dissmeasure(f, a);
diss=[diss d];
end
plot(1:inc:range,diss)
```

(I tested the accuracy of this method by using an ideal harmonic series with steadily falling amplitudes and found the expected 12-tet dissonance curve presented by Sethares in his article "Relating tuning and timbre.") The result is the following dissonance curve:



Ratio: 1.24 1.34 1.48 1.65 1.82 2

This dissonance curve reveals the intervals of most consonance to be at the ratios of: 1.00, 1.24, 1.34, 1.48, 1.65, 1.82 and 2.00. To evaluate these ratios and their relationship to the traditional tuning of the *Renat Ek*, they should be compared to both the idealized 7-tet system and the tuning of the instrument itself. The best way to make the comparison to 7-tet is to calculate the interval ratios within the 7-tet octave. To do this I divided an octave by 7 in terms of cents, getting a value of 171.429 cents, and solved the following equation to convert cents to frequency ratio, based on the equations in Appendix 2 of Howard and Angus:

$$\textit{Frequency Ratio} = 10^{[(n*171.429)/3986.3137]}$$

Solving for n values 0–7 gives the eight frequency ratios in a 7-tet octave.

$$10^{[(0*171.429)/3986.3137]} = 1.00$$
$$10^{[(1*171.429)/3986.3137]} = 1.10$$

$$10^{[(2*171.429)/3986.3137]} = 1.22$$
$$10^{[(3*171.429)/3986.3137]} = 1.35$$
$$10^{[(4*171.429)/3986.3137]} = 1.49$$
$$10^{[(5*171.429)/3986.3137]} = 1.64$$
$$10^{[(6*171.429)/3986.3137]} = 1.81$$
$$10^{[(7*171.429)/3986.3137]} = 2.00$$

The other collection of ratios necessary to evaluate the dissonance curve is the set of ratios in the tuning of the *Renat Ek* itself. To obtain these values I isolated hits of every different pitch played in the first octave (275.6 Hz through 551.2 Hz) and found their fundamental frequency by doing a spectral analysis. I verified each pitch by rendering sine waves of that frequency in the audio synthesis language Csound and making sure the pitches matched those on the recording. The frequency values I obtained were the following:

FREQUENCY	**RATIO**
275.6 Hz	1.00
308.7 Hz	1.12
341.8 Hz	1.24
363.8 Hz	1.32
407.9 Hz	1.48
452.0 Hz	1.64
496.1 Hz	1.80
551.2 Hz	2.00

Now there are three sets of ratios; one based on the dissonance minima, one on the actual *Renat Ek*, and one on 7-tone equal-temperament:

#	**DISSONANCE CURVE**	**RENAT EK**	**7-TET**
1	1.00	1.00	1.00
2	---	1.12	1.10
3	1.24	1.24	1.22
4	1.34	1.32	1.35
5	1.48	1.48	1.49
6	1.65	1.64	1.64
7	1.82	1.80	1.81
8	2.00	2.00	2.00

The final element of the dissonance curve that is important to note is the relative consonance of the ratios. Based on the height of each dissonance minima, a ranking of the ratios from most consonant to most dissonant can be obtained. The results are presented in the following table:

	RATIO #
most consonant	1
	5
	6
	3
	8
	4
	7
most dissonant	2

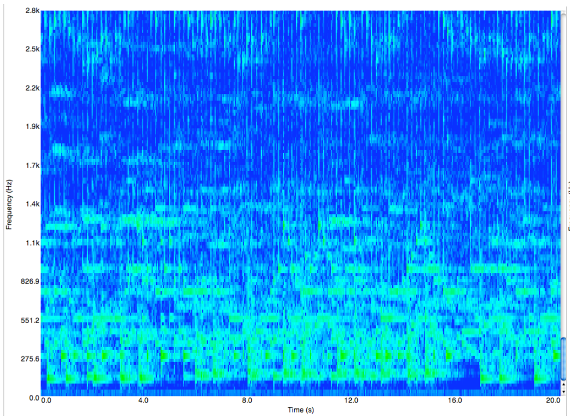
CONCLUSIONS

The three sets of frequency ratios are very similar, which in and of itself suggests a strong relationship between the timbre of the *Renat Ek* and the way it has come to be tuned. In particular, the ratios of the dissonance curve and the instrument analyzed are almost identical, and the areas of variation seem to follow the behavior of the curve as well. Specifically, areas where consonance is narrow (the sharp points at the 3^{rd} and 5^{th} ratios) have little variation, while areas where consonance is wide (the rounded areas at the 4^{th} and 6^{th} ratios) seem to vary slightly. This would seem to make sense because tuning the less defined ratios would be more difficult, making variation likely. The perimeter ratios, however, are the exception; there seems to be substantial variation (0.2) in both the 2^{nd} and 7^{th} ratios. The 2^{nd} is not marked at all on the dissonance curve, which would probably explain a variation in tuning, but the 7^{th} is very well marked on the curve. Perhaps the heightened dissonance between the 7^{th} and 8^{th} ratios (the only more dissonant area is between the 1st and 2nd) would explain why the 7th scale degree is tuned lower (and the 2nd scale degree is tuned higher, for that matter)—away from those areas of the most dissonance.

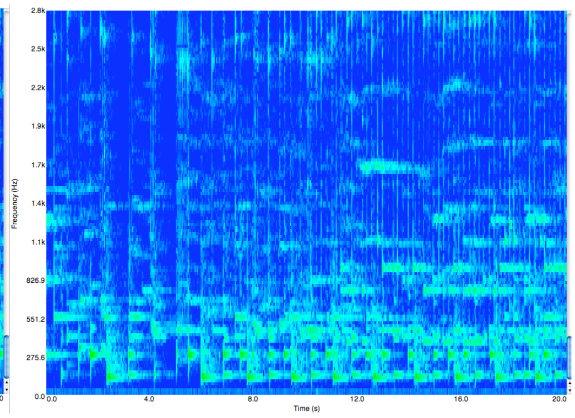
In terms of the 7-tet ratios, there is a bit more variation, which would explain the earlier quote about some intervals being "more equal than others." Nevertheless, it is surprisingly close and that supports why classical Thai music is often thought of as 7-tet.

The other element to consider is the relative consonance and dissonance of each ratio and how accurate that matches areas of consonance and dissonance in classical Thai music. This task is made difficult because the structure of Thai music is not based on harmonic motion like Western music; the composition does not move purposefully from areas built with dissonant intervals to areas built with consonant ones. Rather, every instrument performs their own variation of a single melody line, each embellishing it differently without considering the other instruments at all. This style of performance, known as heterophony (D3 p.10), does produce harmonies, but they are incidental and vary so much from performance to performance that harmonic analysis (in the Western sense) is essentially trivial. However, there is still a sense of forward movement and noticeable areas of resolution, implying that consonance and dissonance do exist and are purposefully placed—they just exist within the melody line.

I found that the best way to evaluate these single melody lines in terms of consonance and dissonance was to compare them to the fundamental. The base frequency plays such an important role in Thai music and is the most frequently heard pitch in every performance analyzed. To test this constant presence of the fundamental frequency objectively, I took several spectrograms of recordings by the Siamese *Piphat* whose *Renat Ek* I analyzed. Below are two 20-second screenshots from different pieces:



20-second Spectrogram of "Movement Music"



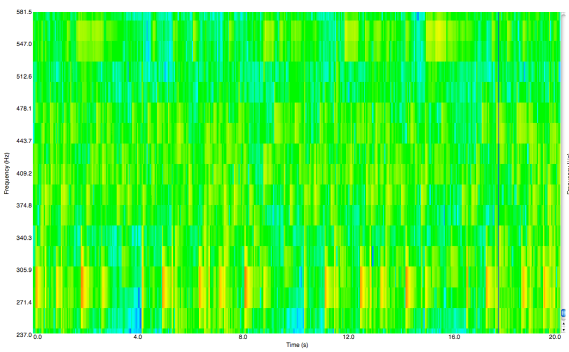
20-second Spectrogram of "Boat Song"

From the above spectrograms and others like it, it is obvious that there is almost constant presence at the 275.6 Hz fundamental frequency in the performances of this specific orchestra. The only other pitch that is as consistently prominent is at 110.3 Hz and is the frequency of the *Tapone*, a two-sided drum that plays steadily throughout most pieces. Considering the fundamental frequency to be consistently present introduces a new way of assessing consonance and dissonance in the music. Specifically, every note in the scale can be thought of in terms of relative consonance and dissonance, a ranking that has already been introduced above. For example, when the 1st, 5th and 6th notes of the scale are played, the resulting sound is most consonant; and, when the 2nd and 7th notes are played, the resulting sound is most dissonant.

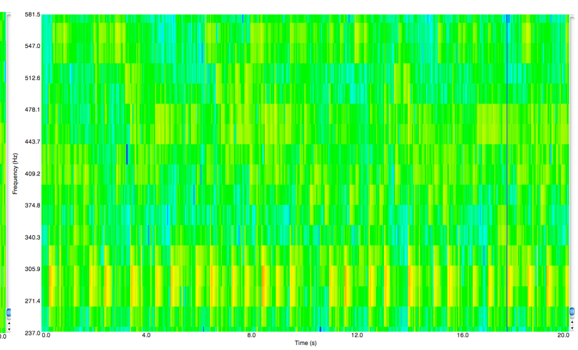
With the objective measurement of consonance and dissonance in this heterophony established, I searched for subjective support in the performances of the *Piphat*. Specifically, I analyzed the "Afternoon Overture" (D2), which has a wide variety of subject matter in its pieces—everything from "Music for Casting Spells" to "Water

Music" and "Hinting Song, Farewell Song." I found two specific uses of consonance and dissonance.

The first, on a more macro scale, is the overall presence of dissonance to accompany the topic at hand. For instance, in "Hinting Song, Farewell Song" the amount of presence at the 7th scale degree is noticeable on a spectrogram, while "Tree Planting Song" shows hardly any at all. Below are 20-second glimpses of those spectrograms:



20-second Spectrogram of "Tree Planting Song"



20-second Spectrogram of "Hinting Song"

While these are just short glimpses, there is obviously more activity in the area around 496 Hz of "Hinting Song, Farewell Song" than "Tree Planting Song." This general behavior would seem to suggest that more dissonance is written into melodies with more serious or somber subject matter, while lighter fare remains primarily consonant. Moreover, most Thai music is meant to proceed or accompany rituals and ceremonies (D2 p.5); for instance, the "Afternoon Overture" presented is meant for the daily activities described in each title. This fact serves to highlight the importance of musical subject matter to Thai culture, and thus it can be said that the overall "feel" of a piece is deliberate, providing support for this sort of large-scale consonant/dissonant analysis.

More showing, however, is the use of dissonance for propulsion and consonance for resolution. This behavior is one often found in Western harmonic motion; for example, seventh chords (and the dissonant intervals within) are commonly used to move compositions along, while major chords (with the consonant perfect 5th) end most resolving cadences. The resolving nature of consonance is easily seen in the "Afternoon Overture," where each one of the ten performances ends on either the 1st scale degree or the 5th (the two most consonant intervals). It is more difficult to evaluate the use of dissonance because there is so much (at least from a 12-tet Western point-of-view). I did, however, find several instances similar to the following. In the opening of "Flying Song," the *Renat Ek* plays alone on scale degrees 1, 4, 5 and 6 successively. After this short intro, there is a pick up (played along with the *Pi Nai*) of scale degrees 9 and 8 before the melody continues with 6, 5, 4. Scale degree 9 can be thought of as equivalent to scale degree 2 (and the dissonance curve earlier supports that comparison), which is the most dissonant pitch relative to the fundamental. For this reason, it makes a very effective pickup, propelling the melody ahead before it settles into more consonant territory with scale degree 6.

Both investigations (the comparison of frequency ratios in three different tunings and the assessment of consonance and dissonance in idiomatic music) seem to support the theory that the frequency spectrum of an instrument and the intervals of consonance and dissonance implied can accurately predict that instrument's traditional tuning and how it has come to be played in a musical context. Of course, this case study is quite specific and multiple studies would need to be done to say anything for certain. The evidence I found, however, is quite convincing, and I feel comfortable saying that there is definitely a strong relationship between spectrum and tuning—at least in the specific case of the classical Thai *Renat Ek*. As for which came first, the timbre or the tuning, it is hard to say, especially considering the absence of notated music from Thailand's culture, but the evidence is too strong for the relationship to be coincidence.

APPENDIX

The function "dissmeasure.m" written by William Sethares and used to calculate the dissonance curve. Online at [http://eceserv0.ece.wisc.edu/~sethares/comprog.html].

```
function d=dissmeasure(fvec,amp)
%
% given a set of partials in fvec,
% with amplitudes in amp,
% this routine calculates the dissonance
%
Dstar=0.24; S1=0.0207; S2=18.96; C1=5; C2=-5;
A1=-3.51; A2=-5.75; firstpass=1;
N=length(fvec);
[fvec,ind]=sort(fvec);
ams=amp(ind);
D=0;
for i=2:N
Fmin=fvec(1:N-i+1);
S=Dstar./(S1*Fmin+S2);
Fdif=fvec(i:N)-fvec(1:N-i+1);
a=min(ams(i:N),ams(1:N-i+1));
Dnew=a.*(C1*exp(A1*S.*Fdif)+C2*exp(A2*S.*Fdif));
D=D+Dnew*ones(size(Dnew))';
end
d=D;
```

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