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A Graphic Method to Get the Inverse Fourier Transform Using a Psychoacoustic Experiment

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Abstract

Strong low frequencies comprise the hearing spectrum that a human being hears the less in its daily activities. This is the reason why a low frequency sound of any nature such as a helicopter flying low over your house, an explosion in the neighborhood or low voice behind you calls our attention immediately if we listen to it unexpectedly. In most songs the bass sound, understand the low frequencies, plays the main role of the melody which is called the rhythmic base. In this paper the authors compared two groups of carefully selected bass concept recordings analyzing the differences in each octave frequency to choose the song with the deepest bass. Afterward, from the real-time spectrum analyzer of the song a sample complex wave was obtained using the inverse Fourier transform (IFT). To resolve this IFT the authors created an experimental graphical method based on the additive synthesis. It is expected that the complex wave obtained through this method and other similar waves of the song that could be achieved in some further studies, inspired on this experiment, serve as a guide to critical listening followers, equalizing researchers and sound equipment manufacturers.

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Introduction

With the advance in technology on music reproduction, we know there are equalizer presets for pop, rock, and jazz that we can find in cars and portable MP3 players. One can ask himself if there are trustworthy settings that would make the songs sound the best. Also, the on-going debate between those who defend the Critical Listening [1] and those who support only the measurements to qualify audio components tell us there is a long way to go in Applied Psychoacoustics.

It is well known that the sound that we can expect from a bass, timpani or a taiko drum be thunderous and rich in low frequencies. The long surface of the battery head and its elasticity gives us the perfect medium needed to create deeper low sounds. The low frequencies waves need bigger material oscillations and more power to be generated.

A musician by changing the hatter tuning to extremes or a recording-engineer by varying the release and attack time controls of a Compressor unit (Audio Dynamic Processor) can produce an unnatural sound far from the intended original acoustic signal. Because of this, it is possible to get that a big drum, designed to emit the lowest waves, utter the sound of a shorter element of a drum set.

In the case of dynamic processors like a compressor the intent of the engineer is not to change the nature of the typical instrument sound. His goal is to keep a stable dynamic range, for example to fix a bad beat technic of a drummer. His purpose is that if a sound is too low, then raise it and if too high, then lower it.

The first dynamic processors came out during the 30's to control de dynamic range on the radio transmissions. But they arrived in the 70's at recording studios to solve the "hiss" sound of the magnetic tape recorders. When the sound of a song decreased below a certain low-level value, the tape recording shows the undesirable reproduction of the magnetic system noise, known as "hiss." From that noise reduction technology, the audio engineers found that this kind of dynamic processors helped them to keep the dynamic range stable.

Besides, the Audio Engineers found that this dynamic processors could help them to get a louder sound too. However, the indiscriminate use of this tool with that purpose brought about alteration of the frequency of the sound sources. Particularly, the elegance and depth of the low frequencies that were decreased.

In this paper, the authors focus primarily on the low frequencies because, in addition to be an impacting powerful psychoacoustic factor for listeners, it is easy to study, given its slow motion on the screen of a real time spectrum analyzer.

To study the music low-frequencies, the authors chose five records that have used before to teach students the psychoacoustic subject on the appreciation of the low- tonal variations courses, for more than 17 years. The reason why those records were selected is because, in the mixing, the bass guitar was used as the main outstanding sound over the rest of the instruments. From the characteristics of the depth of the bass sound of the songs, and based on our experience, we can tell that the recording engineers used nothing or few compressions on three of them.

Spectrum Selection

The records selected for this paper are: 1. "Gaudi" by Alan Parson, Track #1 (La Sagrada Familia). 2. "The Soul Cages" by Sting, Track#2 (All This Time). 3. "Heart Shaped World" by Chris Isaak, Track#5 (Wicked Game). 4. "The Sweet Keeper" by TanitaTikaram, Tracks #5 (Consider the Rain), and Track #7 (Little Sister Leaving Town. (See Figure 1).

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The authors made a survey with a group of students who had to listen to the songs several times to determine which of the four records above mentioned had a deeper bass. The system used and the only one available to the authors was a Sansui™ AU-9500 Amplifier, two Altec Lansing™ Monitor loudspeakers Model 19 with a frequency response of 20 Hertz to 20 kHz, and a Phillips™ CD Player. All tone controls were flat (Figure 2).

Figure 2: Psychoacoustic test system.

Results of the song selection

Our survey tickets (figure 3) determined that the songs which had deeper bass were Tanita Tikaram's tracks #7 Little sister leaving town and #5 and Chris Isaak's Wicked Game, in this order. The songs with less bass were Alan Parson's track #1 and Sting's track #2. All students chose Tanita Tikaram's tracks, but only 50% preferred Chris Isaak's. The authors concluded, based on their personal experience, that some of them confused the louder sound of the audio compression with the deeper bass.

Studying the Songs Low Frequencies With A RTSA

For the measurements the authors used the only two real time spectrum analyzers available to them. One of them was the model Driverack RTSA by dBX™ and the other was the fo-Kannon by toon, LLC™ [2].

Once decided what songs to study, we proceeded to measure the low frequency response of each song, at a point where the bass was the deeper. The authors were interested in the frequencies between 20Hz and 200Hz specially.

The measurements were made at distance of 1 meter from the loudspeakers with a mean Sound Pressure Level of 95dB. Also, we tried to capture all the songs sections without the singer's voice to

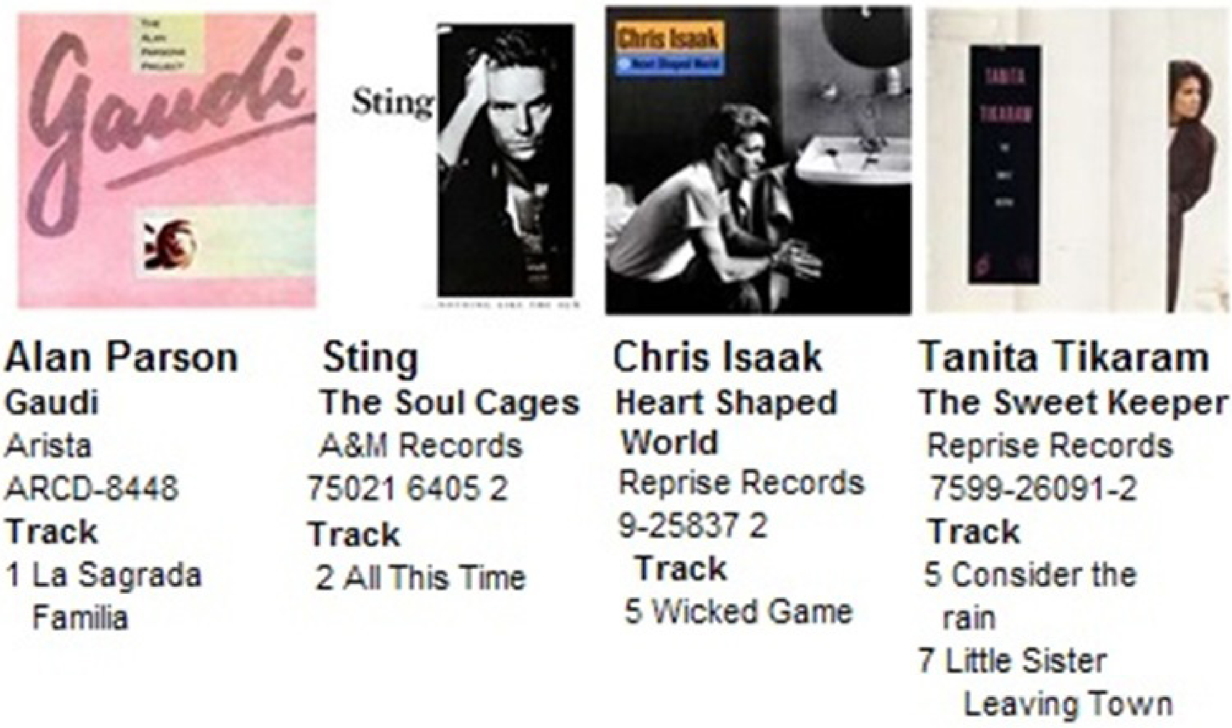

Figure 1: Original Compact Discs.

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avoid mixing some voice low harmonics with the percussion or the melody base. Table 1 show the times (in seconds) in which a picture of the spectrum analyzer was taken for each of the songs.

In each song we look for the softer passage, trying to catch the peak of the deepest bass. Furthermore, we preferred the sound of the bass string release instead of the attack moment.

Graphics obtained with the measurements

For the song "Leaving sister leaving town" the authors found two bass accords of interest, at 0:00 and at 0:05 seconds in our Compact Disc,

SONG	TIME OF TEST
La Sagrada Familia	3:28
All This Time	0:21
Wicked Game	0:08
Consider the Rain	0:23
Little Sister leaving Town	0:06

Table 1: Track time.

Figure 3: Survey tickets.

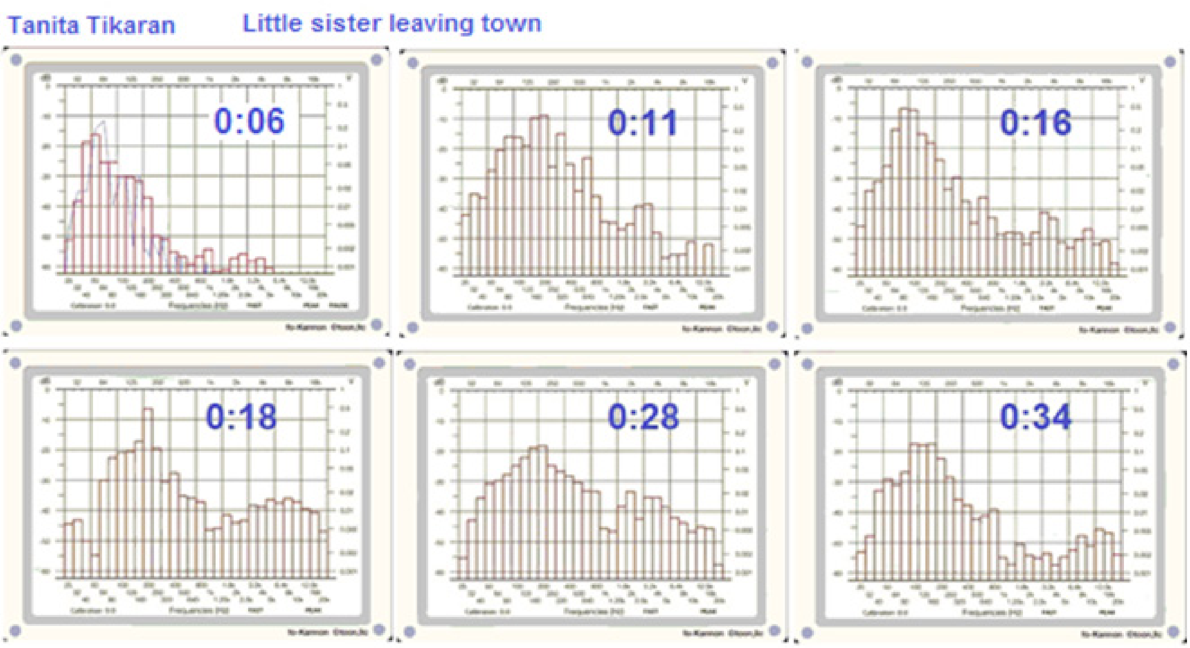

Figure 4: RTSA takes for the song Little sister leaving town.

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and on a YouTube video at 0:06 and 0:11 seconds respectively. The authors took six snapshots of similar passages during the song. The times of the pictures taken from the YouTube video are shown on Figure 4.

Applying a Graphic Method to get the Inverse Fourier Transform

In this part of the document the authors wish to start with an explanation of the Fourier Transform [3] (Figure 5). The drawing shows the two-ways how the Fourier Transform works. We can use

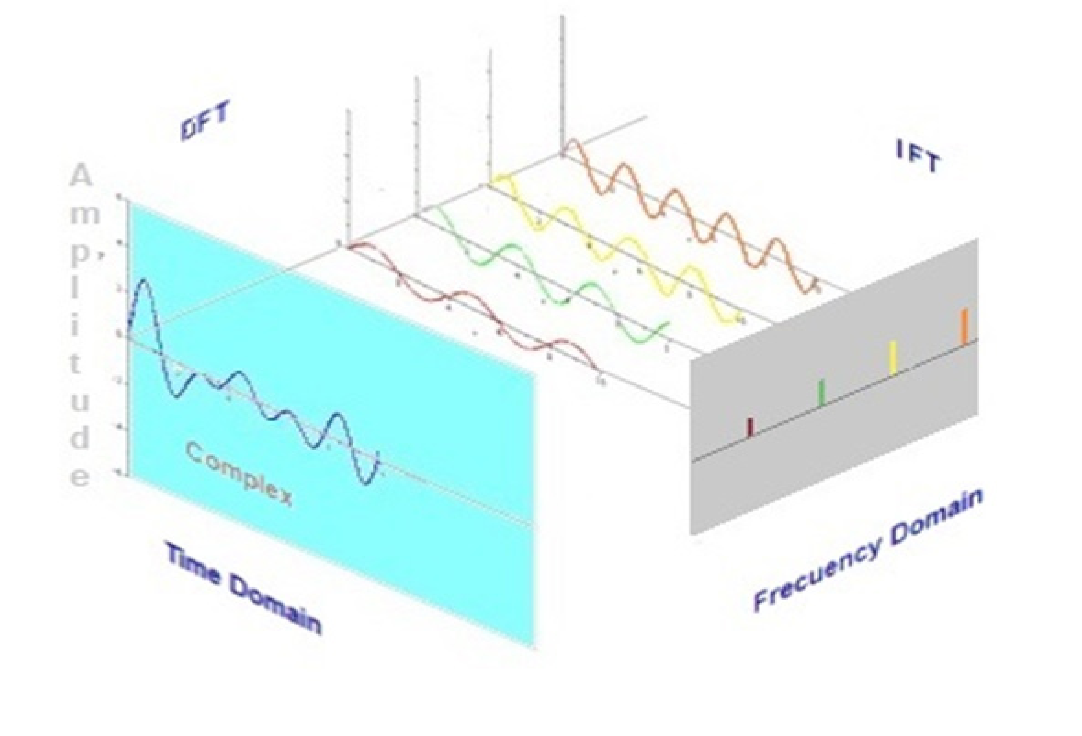

Figure 5: Fast Fourier Transform.

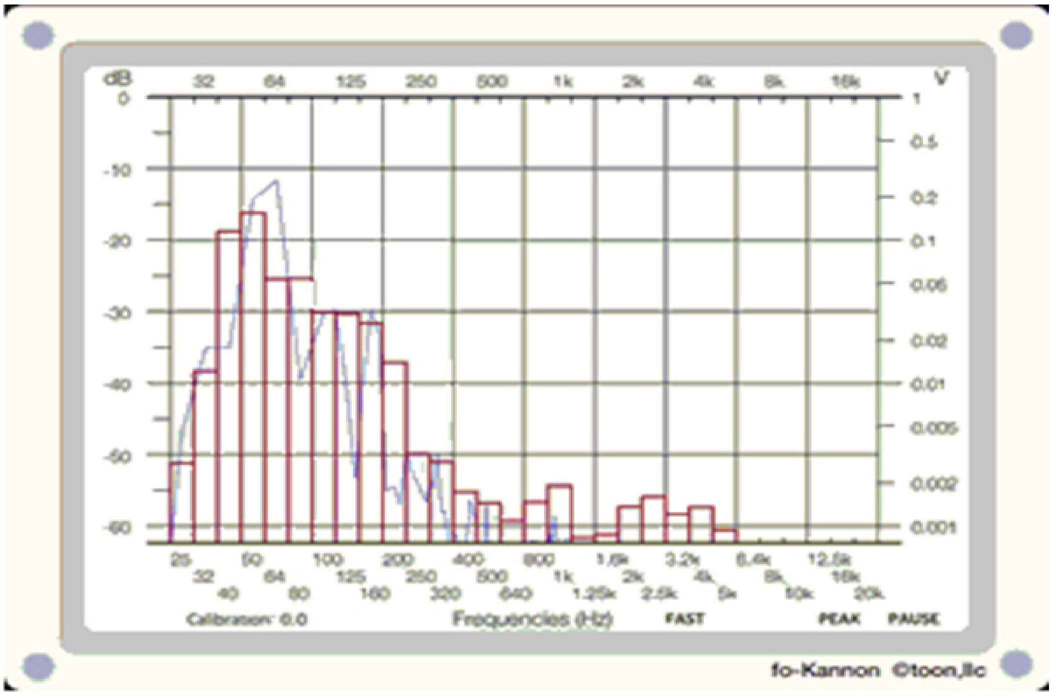

Figure 6: Little sister leaving town RTSA on time 0:06.

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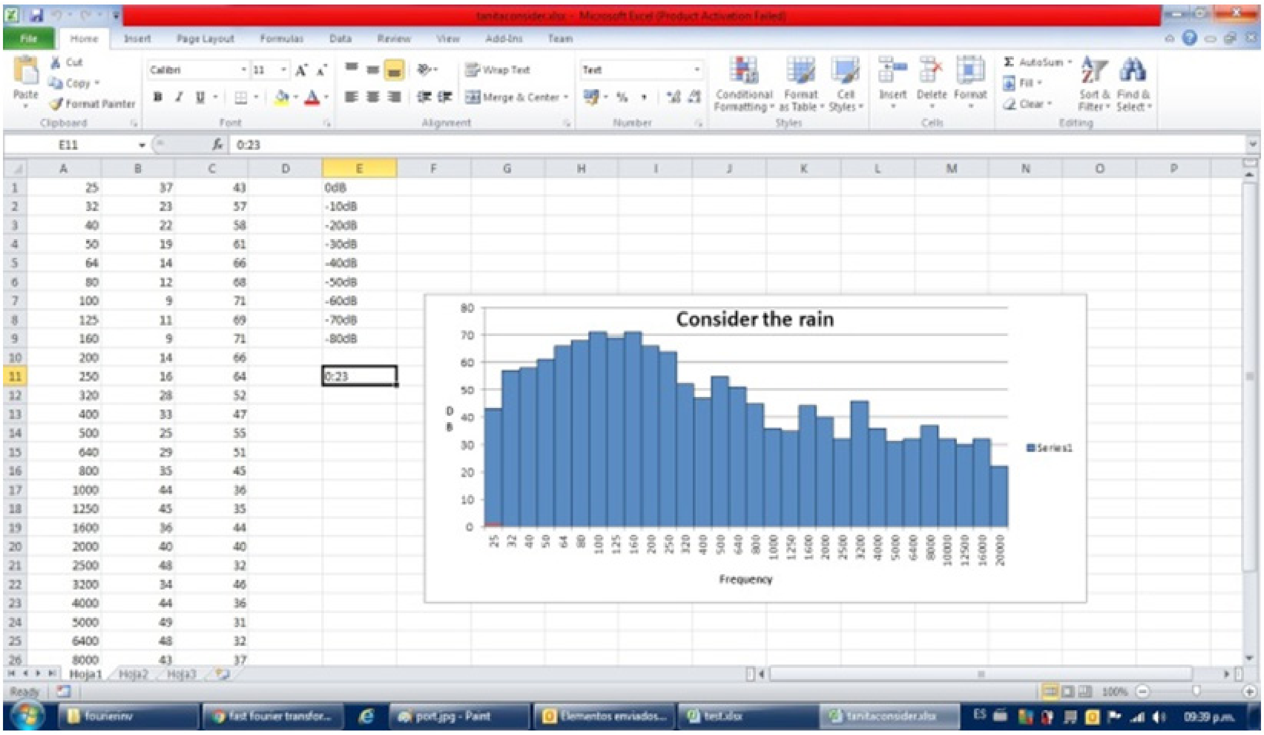
the Discrete Fourier Transform (DFT) to get the Frequency Domain from the Time Domain of a complex wave or The Inverse Fourier Transform (IFT) [4] to get the Time Domain from the Frequency Domain.

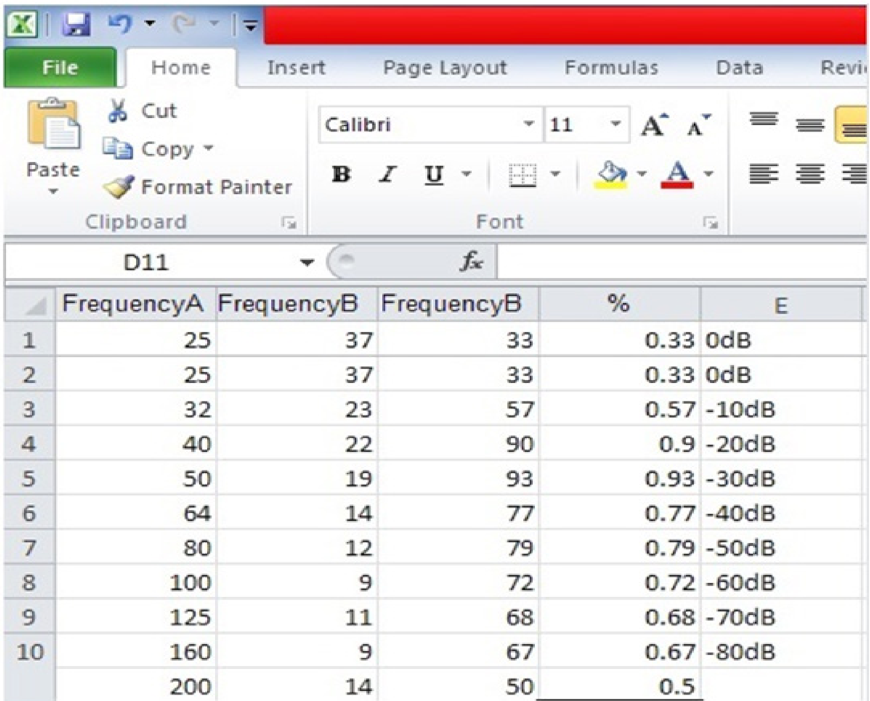
The authors wanted to obtain the IFT from the following spectrum analysis shown on Figure 6. Because we were interested in the low frequencies, we only worked with the ten lower ones, from 25Hz to 200Hz. We used also the frequency values of the real time spectrum analyzer fo-Kannon of toon, LLC.

Table 2 shows the frequencies and their amplitudes on an Excel spreadsheet.



	A	B	C	D	E
1	25	37	43		0dB
2	32	23	57		-10dB
3	40	22	58		-20dB
4	50	19	61		-30dB
5	64	14	66		-40dB
6	80	12	68		-50dB
7	100	9	71		-60dB
8	125	11	69		-70dB
9	160	9	71		-80dB
10	200	14	66		
11	250	16	64		0:23
12	320	28	52		
13	400	33	47		
14	500	25	55		
15	640	29	51		
16	800	35	45		
17	1000	44	36		
18	1250	45	35		
19	1600	36	44		
20	2000	40	40		
21	2500	48	32		
22	3200	34	46		
23	4000	44	36		
24	5000	49	31		
25	6400	48	32		
26	8000	43	37		

Figure 7: View of the Excel Spreadsheet.



	FrequencyA	FrequencyB	FrequencyB	%	E
1	25	37	33	0.33	0dB
2	25	37	33	0.33	0dB
3	32	23	57	0.57	-10dB
4	40	22	90	0.9	-20dB
5	50	19	93	0.93	-30dB
6	64	14	77	0.77	-40dB
7	80	12	79	0.79	-50dB
8	100	9	72	0.72	-60dB
9	125	11	68	0.68	-70dB
10	160	9	67	0.67	-80dB
	200	14	50	0.5	

Figure 8: Amplitude percentageover a 100 scale.

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Figure 7 shows the histogram obtained from Table 2.

The vertical values of the y-axis were converted to percentages as shown in Figure 8.

Frequency Hz	Amplitude
25	33
32	57
40	90
50	93
64	77
80	79
100	72
125	68
160	67
200	50

Table 2: Frequency Vs Amplitude on Little sister leaving town.

Figure 9 shows the Excel Graphic function of the spectrum.

Using the Maple Software

Now we can use any math software to plot the values as sine functions (Figure 10).

In our case, we used Maple™ 14 [5] to draw the plot. Due to the view resolution the authors chose to divide each frequency by ten. So, for example, 40Hz will be 4 cycles in the plot. The sine arguments to get the needed quantity of cycles and their amplitudes are the following:

plot([.33*sin(1.6*x)+.57*sin(2*x)+.9*sin(2.52*x)+.93*sin(3.14*x)+.77*sin(3.8*x)+.79*sin(5.05*x)+.72*sin(6.3*x)+.68*sin(7.7*x)+.67*sin(10.1*x)+.5*sin(12.6*x), .33*sin(1.6*x), .57*sin(2*x), .9*sin(2.52*x), .93*sin(3.14*x), .77*sin(3.8*x), .79*sin(5.05*x), .72*sin(6.3*x), .68*sin(7.7*x), .67*sin(10.1*x), .5*sin(12.6*x)], x = 0 .. 4, y = -8 .. 8, discont = true, title = "y = sin(x)")

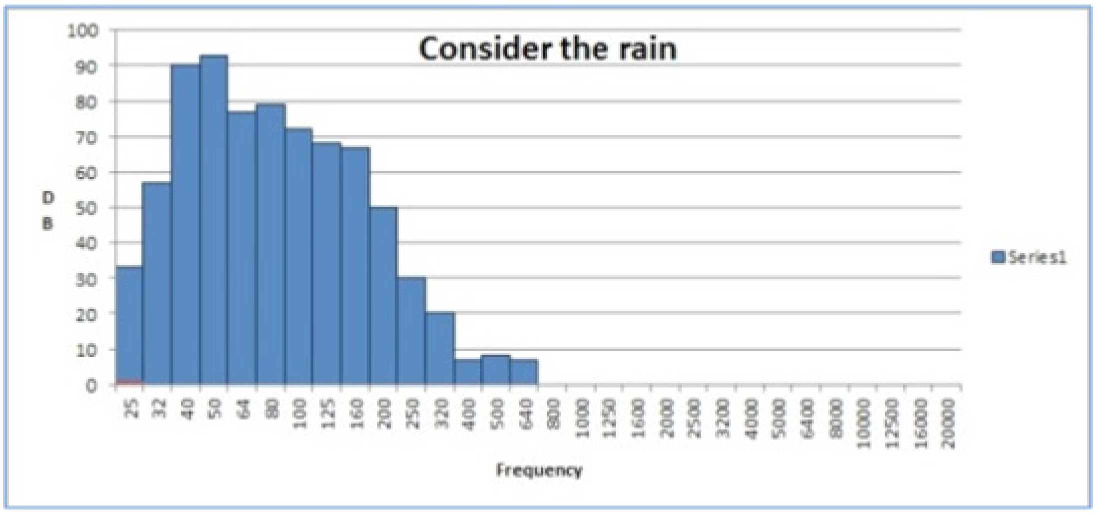

Figure 9: Excel Graphic of the Spectrum.

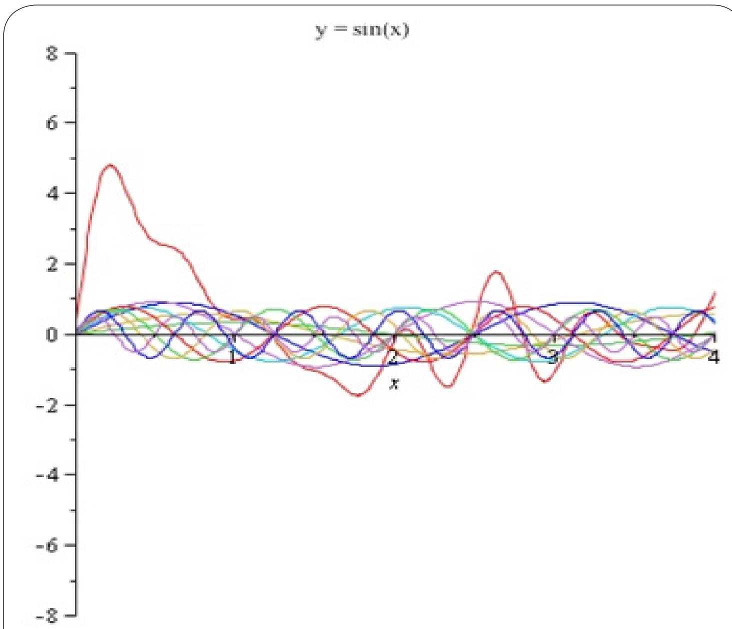

Figure 10: Maple Plot.

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The plot obtained is shown on Figure 10.

Test to Get the Complex Wave with an Oscilloscope

The authors made an experiment to obtain the complex wave of the reading at the points of the samples. The measurement system [6], of Figure 11 shows an amplifier Sansui AU-9500, loudspeakers Altec Lansing Model 19, Phillips CD player, Equalizer Teac™ GE-20, Microphone Audio Technica™ Kick drum, Mixer Notepad Soundcraft™, Tektronik™ Oscilloscope and a Sony™ SD Video Camera.

The authors then proceeded to play the exact passage of the sound to register the wave behavior that matches our results in the graphic method explained above (Figure 12).

Conclusion

The methodology used in this document to use a graphic method to solve IFT problems shows that, even though it does not have a high accuracy and precision, it can be used as a guide for measuring behavior of the waves under considerations.

We also can conclude that it is always possible to perform a study that depends on human individual's appreciation and quantifying it to design a system that can recreate quantitatively that perception.

The sound appreciation (Critical Listening) and its quality for the musical reproduction is a subject of further discussion and debate. With this methodology, once fixed the parameters by an competent commission of Sound Engineers, it is possible to get waves forms that sound system manufacturers can use as a guide to design their electronic circuits aimed to perfect the sound quality always looking for a better one.

Figure 11: Complex Wave on Screen.

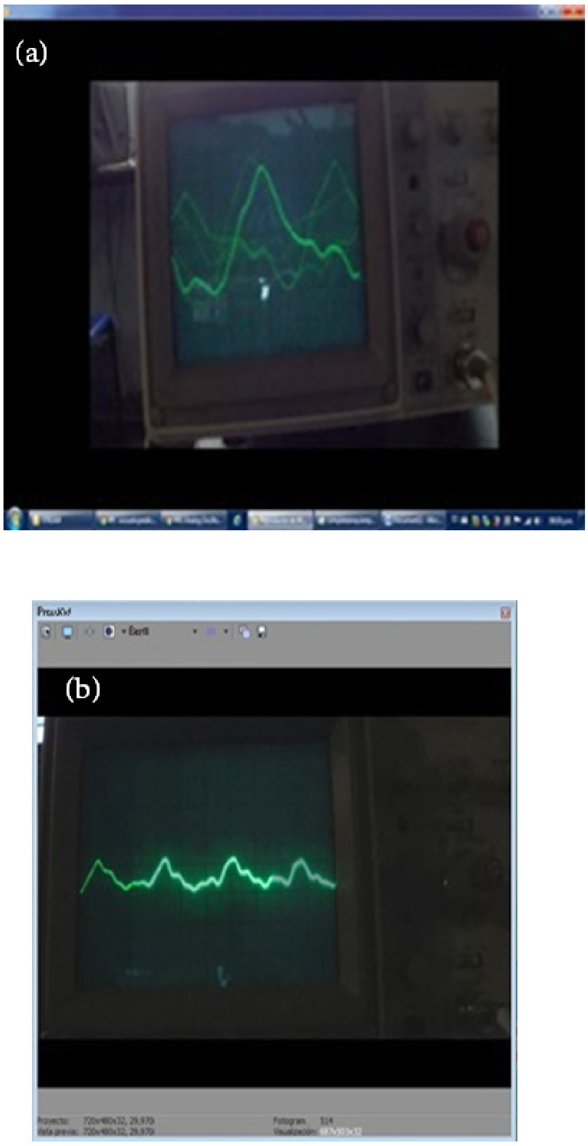

Figure 12: (a) and (b) Oscilloscope reading.

Competing Interests

The authors declare that they have no competing interests.

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