Dual-Tone Multi-Frequency (DTMF)

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1. INTRODUCTION

DTMF is the generic name for push-button telephone signaling that is equivalent to the Touch Tone system in use within the Bell System. DTMF also finds widespread use in electronic mail systems and telephone banking systems in which the user can select options from a menu by sending DTMF signals from a telephone.

In a DTMF signaling system a combination of a high-frequency tone and a low-frequency tone represent a specific digit or the character "*" and "#".

	Col 1: 1209 Hz	Col 1: 1336 Hz	Col 1: 1477 Hz	Col 1: 1633 Hz
Row 1: 697 Hz	**1**	**2**	**3**	**A**
Row 2: 770 Hz	**4**	**5**	**6**	**B**
Row 3: 852 Hz	**7**	**8**	**9**	**C**
Row 4: 941 Hz	*****	**0**	**#**	**D**

Let f_L and f_H be the low-frequency and high-frequency tone, the signal tone is defined as

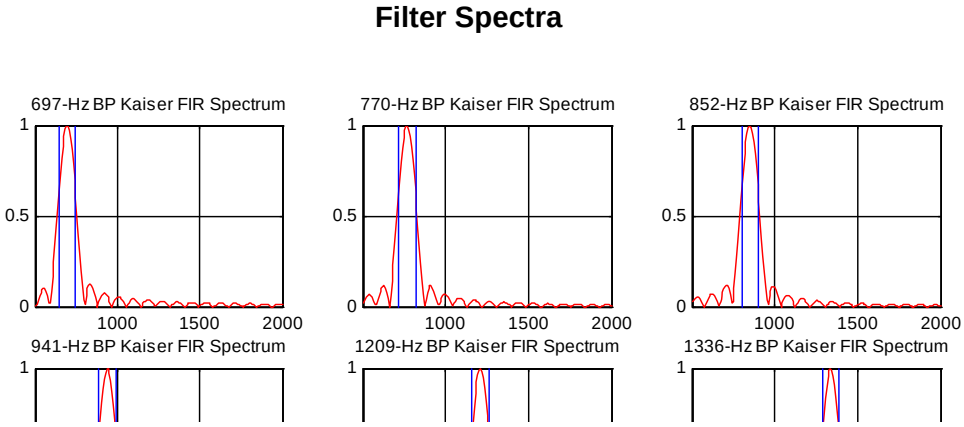
$$x(t) = \sin(2\pi f_L t) + \sin(2\pi f_H t)$$

we will consider 2 approaches:

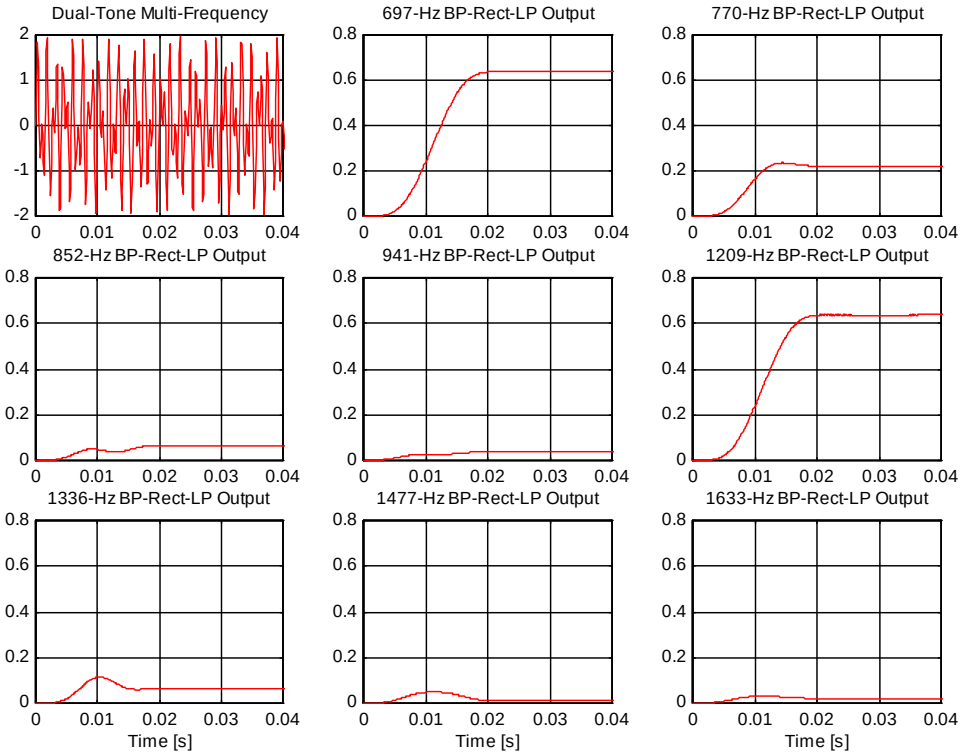
- a bank of 8 parallel bandpass filters corresponding to 8 frequencies above, 4 LF and 4 HF, a rectifier and a lowpass filter;
- a spectrum analyzer using the FFT for all frequencies.

2. RESULTS

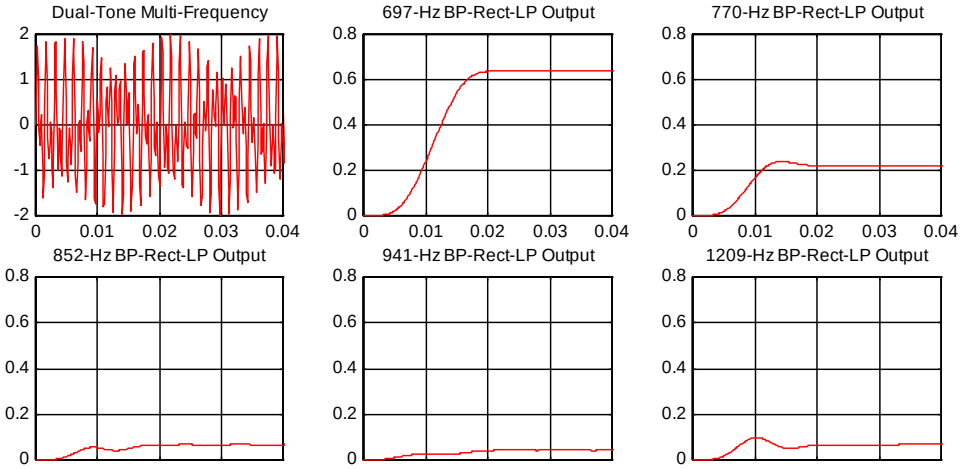
2.1. Filter Bank: Bandpass + Rectifier + Lowpass



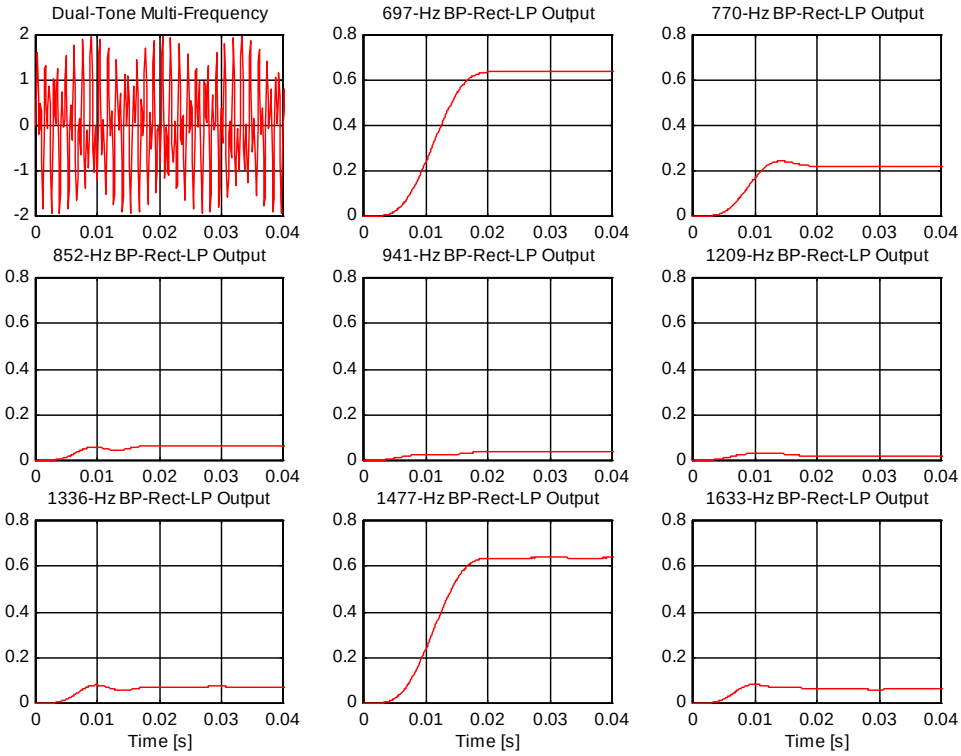
$f_L = 697$ Hz, $f_H = 1209$ Hz



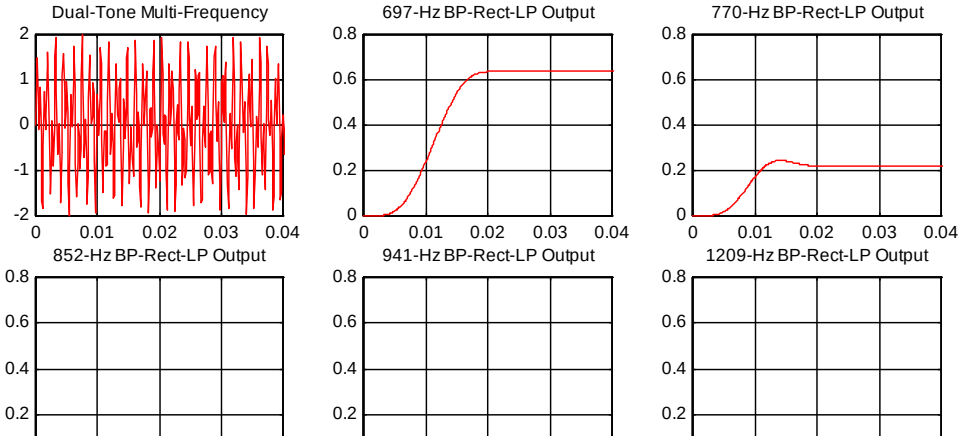
$f_L = 697$ Hz, $f_H = 1336$ Hz



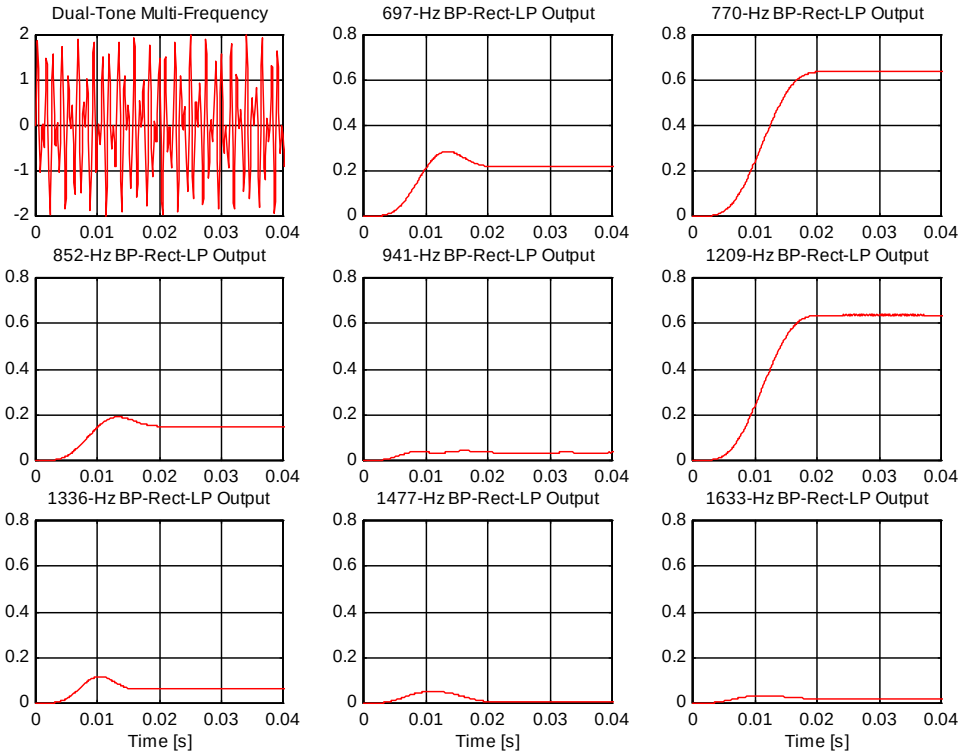
$f_L = 697$ Hz, $f_H = 1477$ Hz



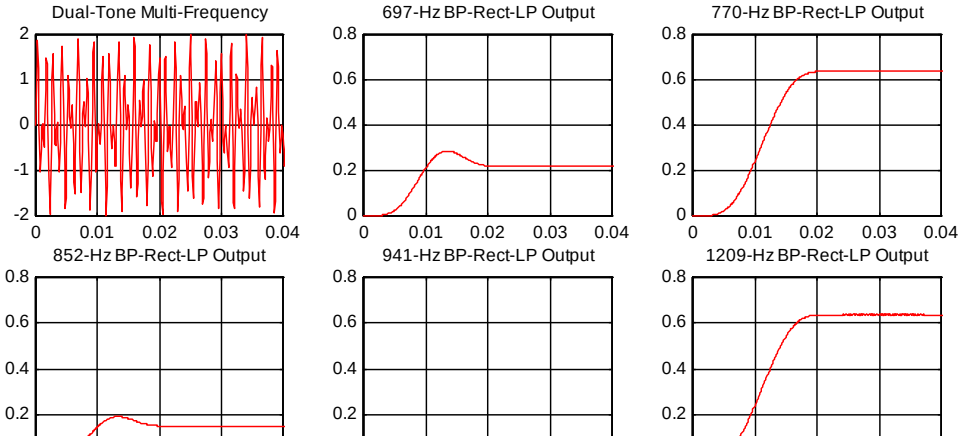
$f_L = 697$ Hz, $f_H = 1633$ Hz



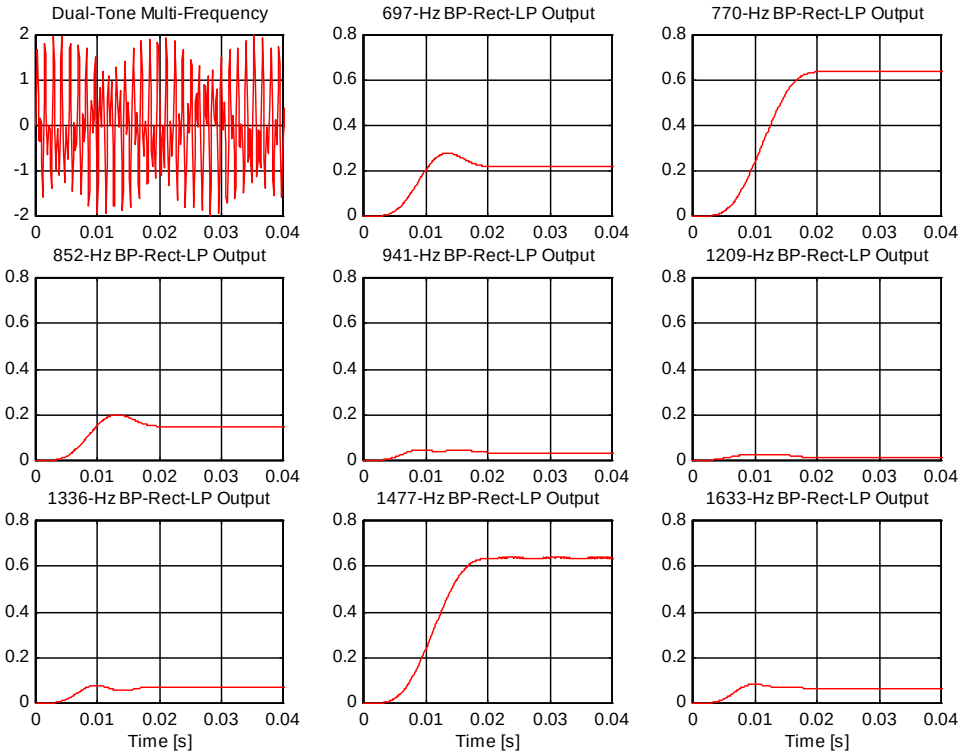
$f_L = 770$ Hz, $f_H = 1209$ Hz



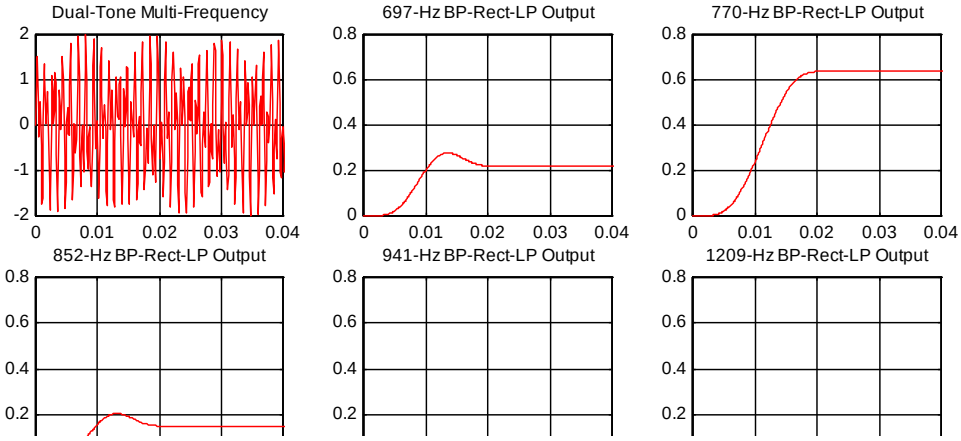
$f_L = 770$ Hz, $f_H = 1336$ Hz



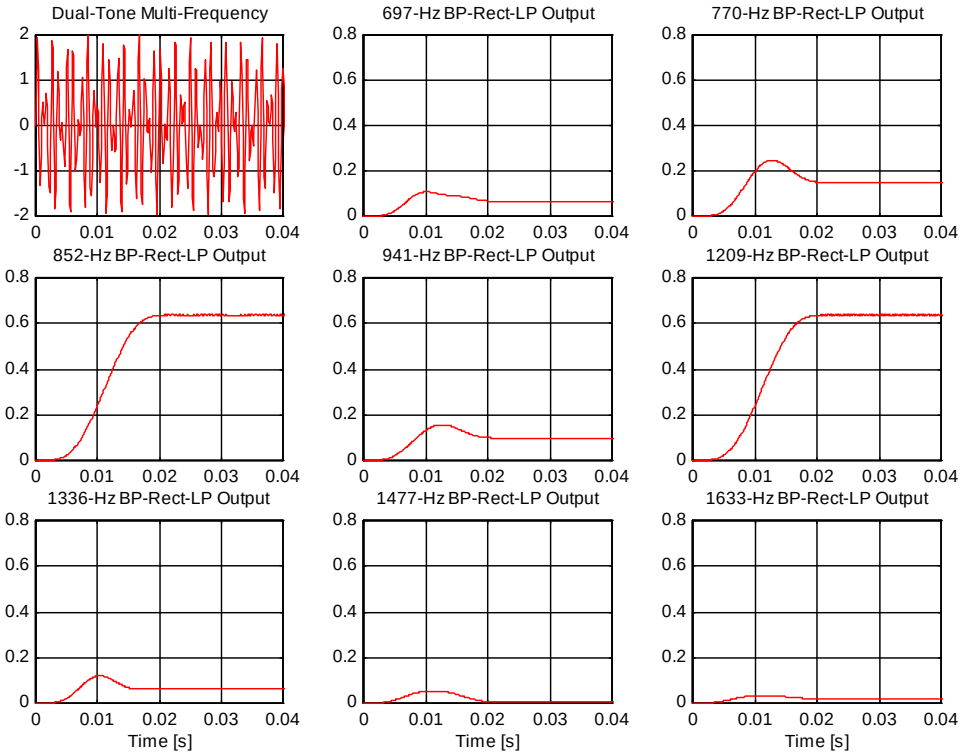
$f_L = 770$ Hz, $f_H = 1477$ Hz



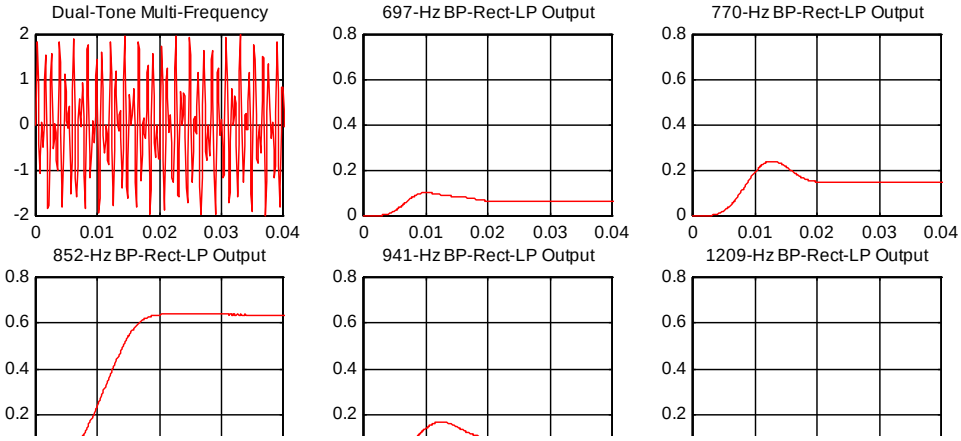
$f_L = 770$ Hz, $f_H = 1633$ Hz



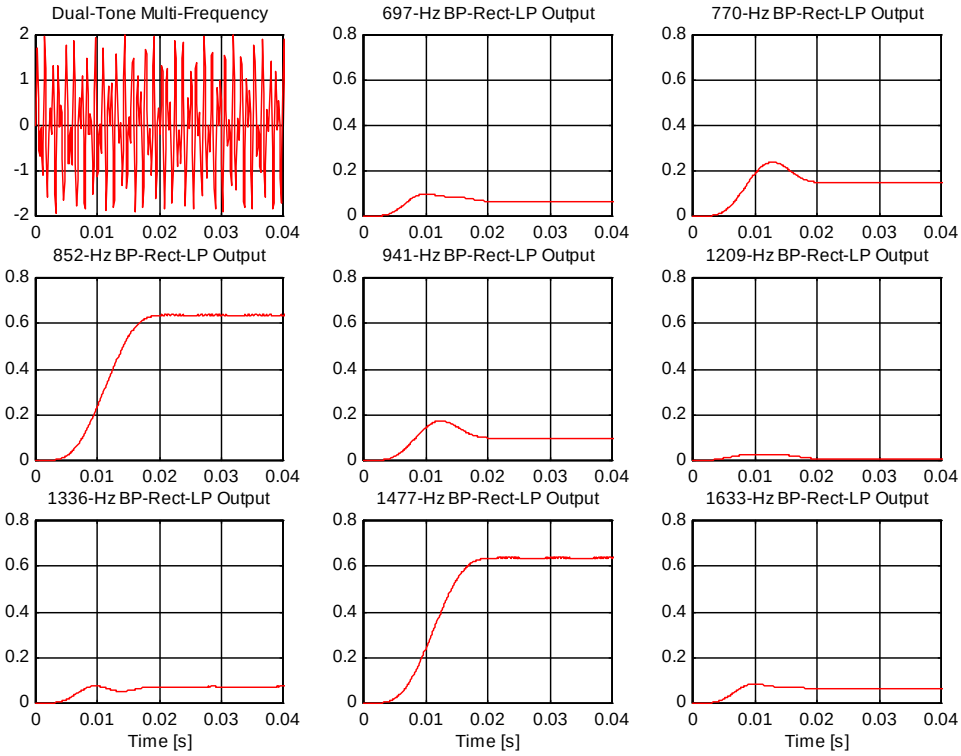
$f_L = 852$ Hz, $f_H = 1209$ Hz



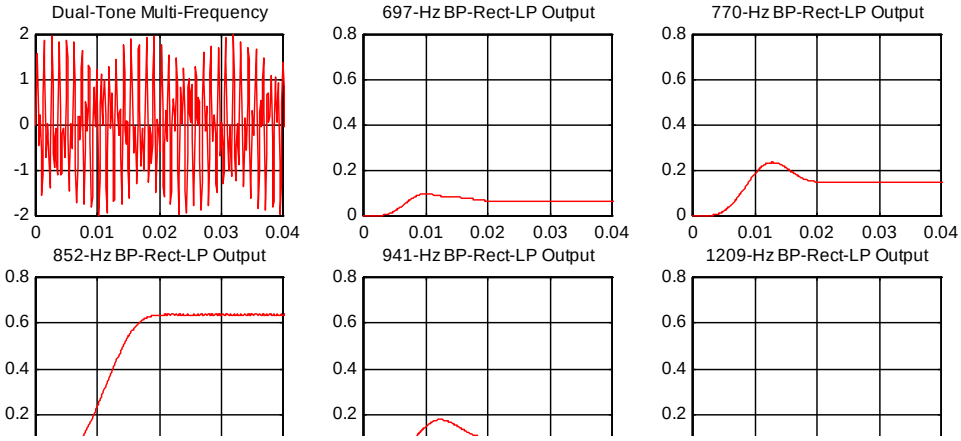
$f_L = 852$ Hz, $f_H = 1336$ Hz



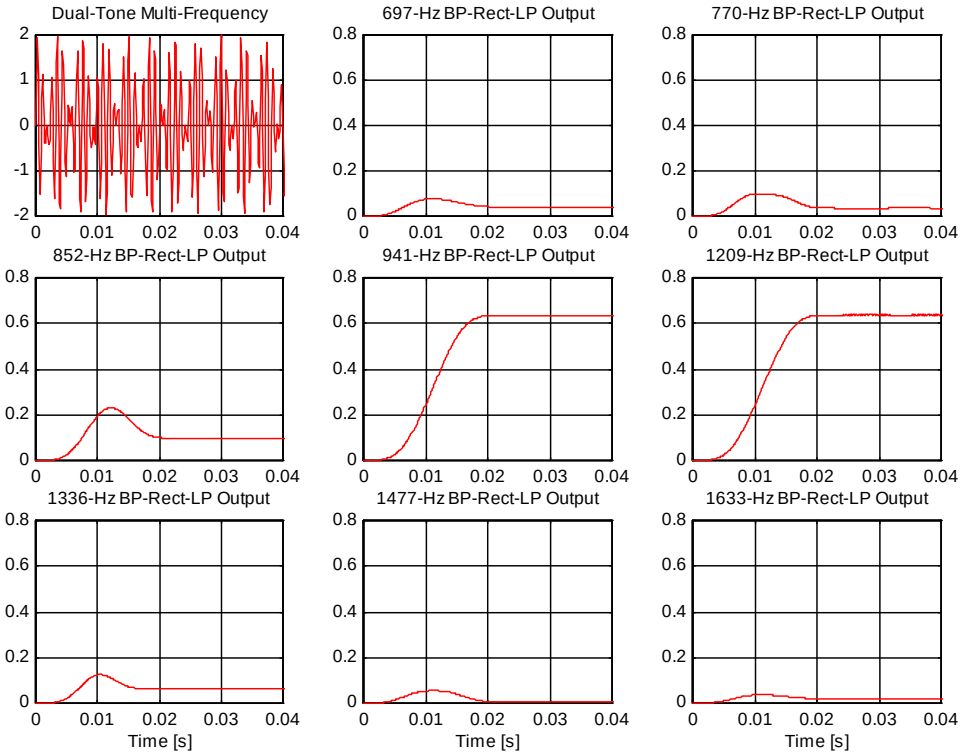
$f_L = 852$ Hz, $f_H = 1477$ Hz



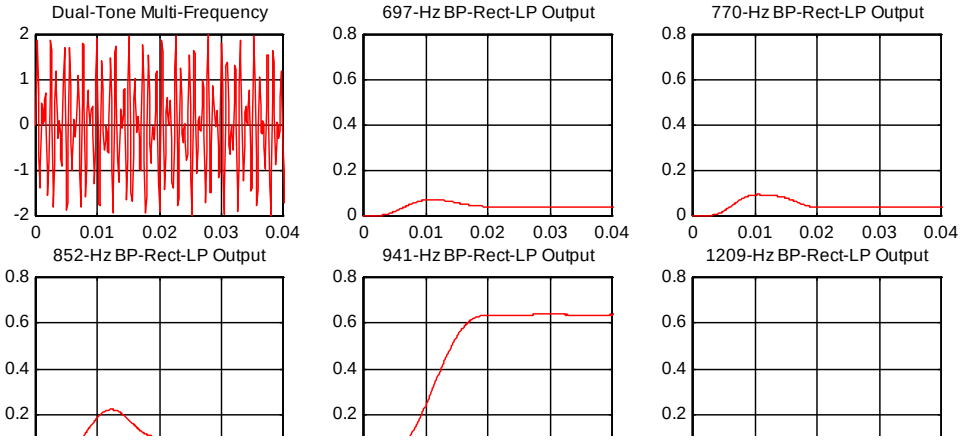
$f_L = 852$ Hz, $f_H = 1633$ Hz



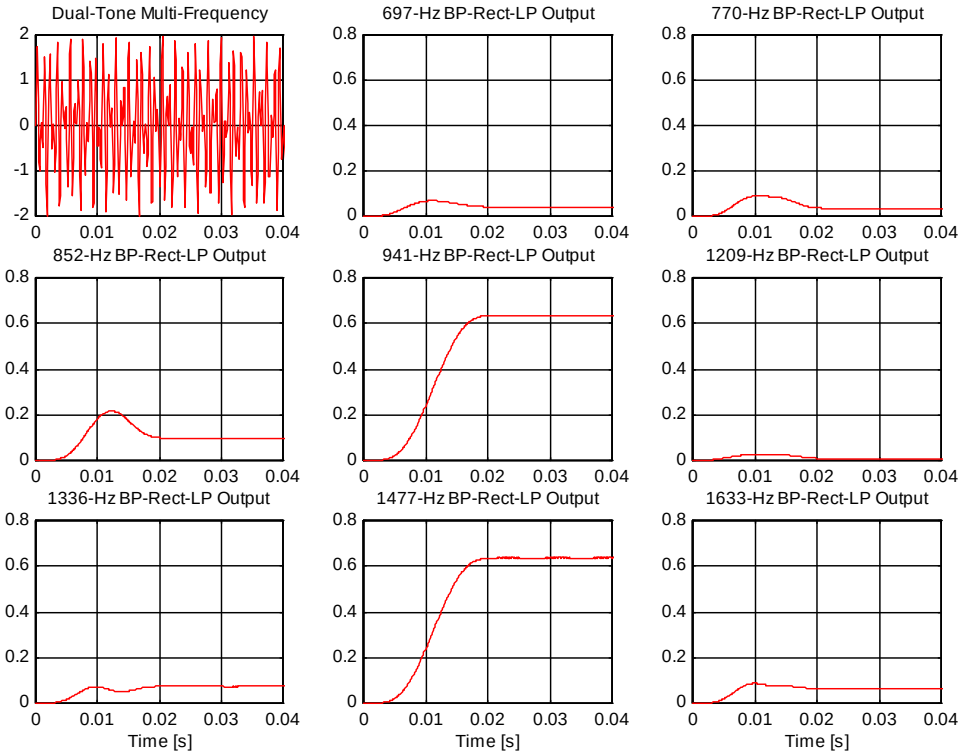
$f_L = 941$ Hz, $f_H = 1209$ Hz



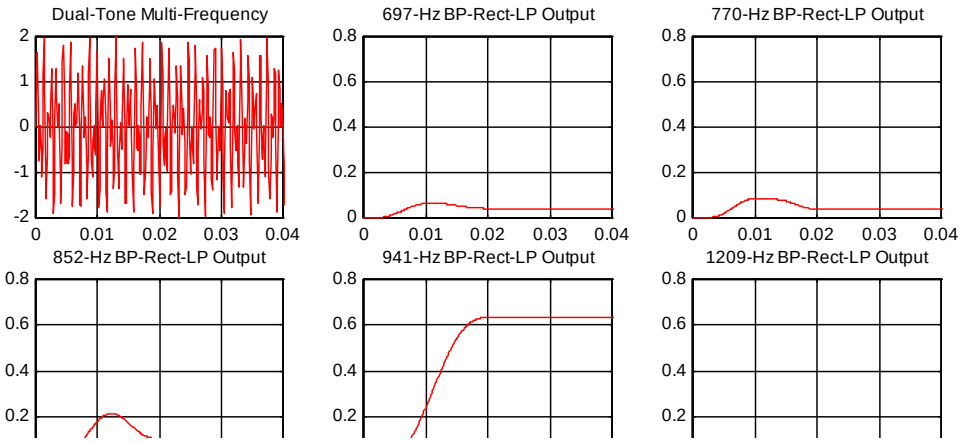
$f_L = 941$ Hz, $f_H = 1336$ Hz



f_L = 941 Hz, f_H = 1477 Hz



f_L = 941 Hz, f_H = 1633 Hz



The recognized tone has a magnitude of 0.6 compared to 0.2 of the maximum of the others. The filter bank of highpass + rectifier + lowpass executes in 0.204 sec for 512 samples using a machine i486DX2-66. From the graphs, the filter bank can recognize at 0.02. Since 512 samples correspond to 0.064 sec (Fs = 8 Khz), the recognition time is 0.0637 sec.

2.2. 512-Point FFT of 2-Radix

We have the multi-frequency as

$$\mathbf{MF} = [697,\ 770,\ 852,\ 941,\ 1209,\ 1336,\ 1477,\ 1633]$$

the FFT spectrum analyzer recognize as

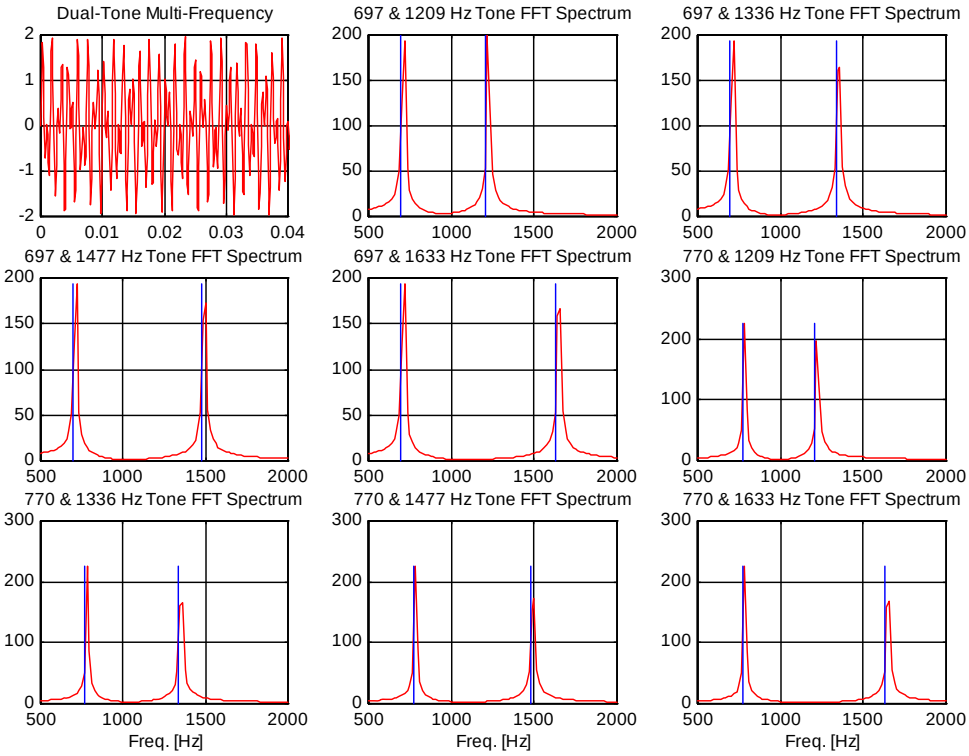
$$\mathbf{MF}_{\mathbf{FFT}} = [718.8,\ 781.2,\ 875.0,\ 953.1,\ \langle 1203.1, 1218.8\rangle,\ 1343.8,\ \langle 1484.4, 1500.0\rangle,\ 1640.6]$$

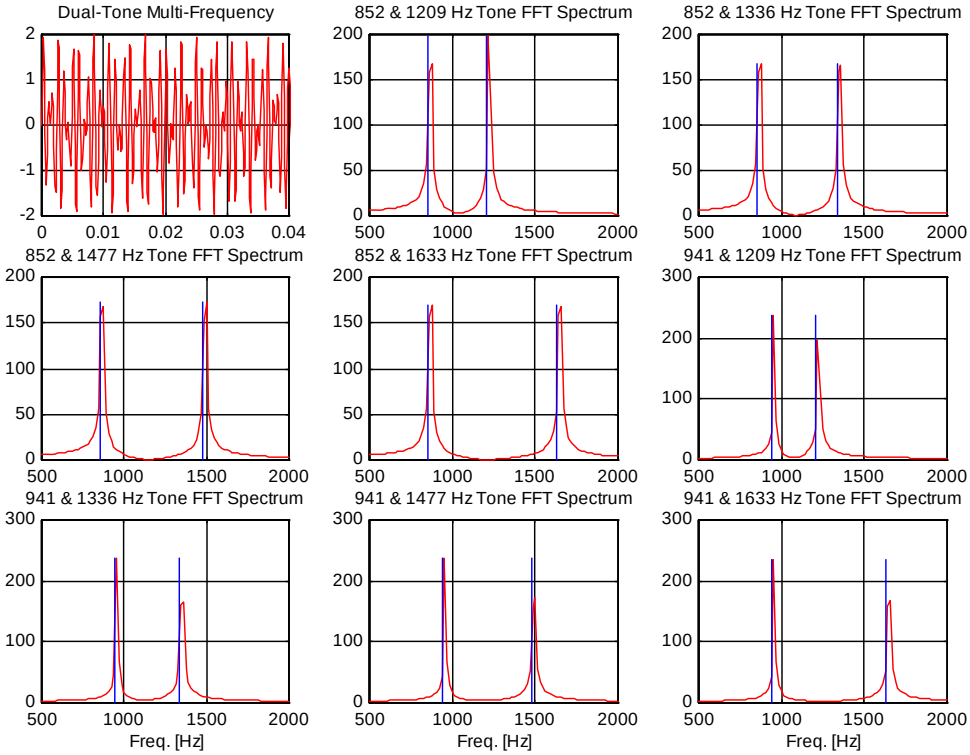
then the relative errors are

$$\mathbf{Err\_Rel} = [0.0312,\ 0.0146,\ 0.0270,\ 0.0129,\ \langle 0.0049, 0.0081\rangle,\ 0.0058,\ \langle 0.0050, 0.0156\rangle,\ 0.0047]$$

Thus, the errors are less than 3.12 %. If the FFT is doubled to 1024 points, the errors are less than 1.46 %; however the execute time is double.

512-Point FFT executes in 0.017 sec using a machine i486DX2-66.





3. CONCLUSION

The FFT approach is more efficient than the filter bank since it can recognize any frequency and 3.74 times faster.

Since the maximum frequency of tones is 1633 Hz, the decimation method can be used to obtain a sampling rate of 4 Khz. In case of the filter bank, the same number samples must be used to obtain the recognition, however the filter lengths can be halved, so the execute time is also halved. The length of FFT is reduced by 2 for the same recognition error, that is 3.12 % for 512-FFT and 3.12 % for 256-FFT using decimation. This is because the FFT uses the signal waveform whereas the filter processes signal sample by sample.

Since the filkter bank uses 8 bandpass+rectifier+lowpass filters, compared to the filter bank, the FFT approach using decimation is thus 8 times simpler than the filter bank, and

- 3.12 % tolerance: 3.75 (3.74) times faster
- 5.52 % tolerance: 7.5 (7.48) times faster
- 10.04 % tolerance: 15 (14.96) times faster

Since the tolerance of the multi-frequency is 10 %, we can use the tolerlance of 5.52 % for the FFT spectrum analyzer.