DTMF Signal Decoding

DTMF Signaling

- Dual-tone multi-frequency (DTMF)
  - The generic name for push-button telephone signaling
  - Used in ARS, telephone banking, etc., in which users can select options from a menu by sending signals with a telephone

DTMF Digits

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

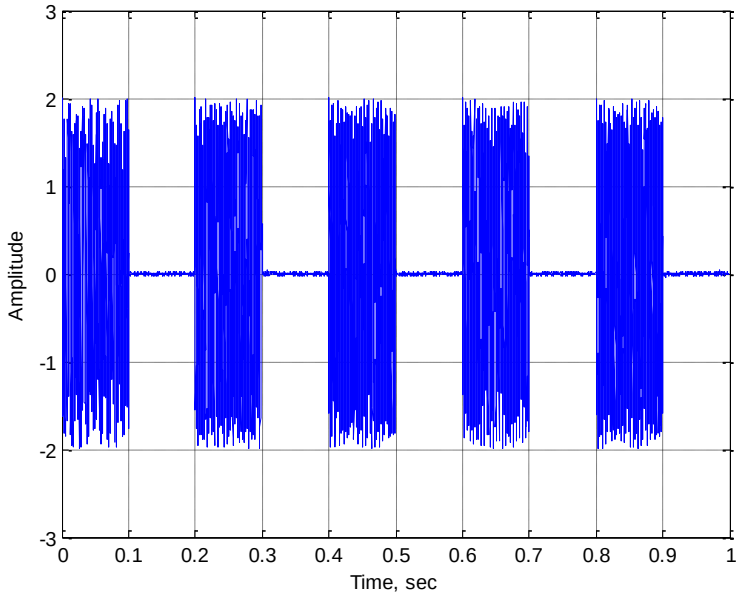
ITU Specifications for DTMF Signaling

Signal frequencies	Low group High Group	697, 770, 852, 941 Hz 1209, 1336, 1477, 1633 Hz
Frequency tolerance	Valid Reject*	≤ ±1.5% ≥ ±3.5%
Signal duration	Valid Reject*	≥ 40ms ≤ 23ms
Pause duration	Valid	≥ 40ms
Signal Interruption*	Valid	≤ 10ms
Signal strength*	SNR Power	≥ 15dB ≥ -26dBm
Twist*	Normal Reverse	≤ 8dB ≤ 4dB

* In the detection of DTMF signals

DTMF Signal Generation

- Two-tone signals with frequency tolerance within ±1.5%, signal duration of minimum 40ms, and pause duration of minimum 40ms



DTMF signals with 100ms signal and pause duration

DTMF Decoding

- Frequency component detection and validation
  - Block processing : block size for frequency detection?
  - Determine whether the detected frequency components are valid (then, select the digit) or not
- Separation and decoding

Frequency Component Detection

DFT:

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{nk}, k = 0,1, \dots, N-1$$

Goertzel algorithm:

$$X(k) = W_N^{-kN} X(k) = \sum_{m=0}^{N-1} x(m) W_N^{-k(N-m)}$$

$$y_k(n) = x(n) * h_k(n) = \sum_{m=0}^{n} x(m) W_N^{-k(n-m)}, y_k(N) = X(k)$$

$$\begin{pmatrix} h_k(n) = W_N^{-kn} u(n),\ H_k(z) = \dfrac{1}{1 - W_N^{-k} z^{-1}} \\ x(n) = 0, n < 0 \text{ or } n > N-1 \end{pmatrix}$$

Frequency Component Detection

Difference equation:

$$y_k(n) = W_N^{-k} y_k(n-1) + x(n), y_k(-1) = 0$$

Difference equation with real coefficients:

$$v_k(n) = 2\cos\frac{2\pi k}{N} \cdot v_k(n-1) - v_k(n-2) + x(n), v_k(-1) = v_k(-2) = 0$$

$$y_k(n) = v_k(n) - W_N^k v_k(n-1)$$

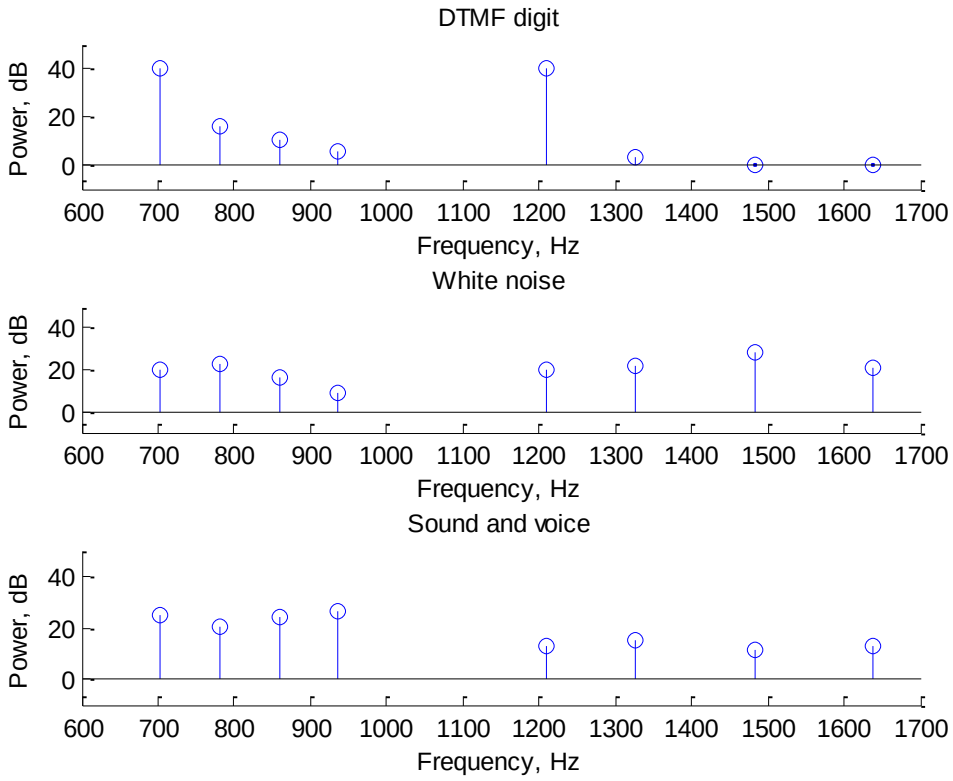
Modification for DTMF signal detection:

$$|X(k)|^2 = |y_k(N)|^2 = |y_k(N-1)|^2 = \left|v_k(N-1) - W_N^k v_k(N-2)\right|^2$$

$$= v_k^2(N-1) + v_k^2(N-2) - 2\cos\frac{2\pi k}{N} \cdot v_k(N-1)v_k(N-2)$$

Frequency Component Validation

- Select the largest component in each group and examine its portion of power in each group



Separation and Decoding

- Declare a valid DTMF digit if more than two consecutive blocks are detected to have valid DTMF frequency components