Learning Objective 6.2: I can decode DTMF tones from a captured audio signal.

Show your work. Write a **Documentation** line at the end (**None** if you did not collaborate). The keypad grid: rows 697, 770, 852, and 941 Hz carry 1 2 3 A, 4 5 6 B, 7 8 9 C, and * 0 # D; columns are 1209, 1336, 1477, and 1633 Hz, left to right.

1. **Reading the grid.**

   (a) Which two tones does the '8' key send? The '#' key?

   8:

   #:

   (b) A receiver's bins show 941 Hz and 1209 Hz in one digit and 770 Hz and 1633 Hz in the next. Which two keys were pressed?

   (c) In one block, the 697 Hz and 770 Hz bins are both strong and about equal, and so is the 1336 Hz bin. Which test of the L13 decoder rejects the block, and what could cause a signal like that?

2. **Timing.** An auto-dialer sends each digit as 70 ms of tone followed by 15 ms of silence.

   (a) How long does one digit take, tone plus gap, and how long does an 11-digit number take, from the first tone to the end of the last one?

   digit: _____

   number: _____

   (b) Lesson 13 says DTMF tones last 40 ms or longer and gaps 20 ms or longer. Which does this dialer break? You set the same tone and gap on the sliders of `L13-dtmf-link.grc` and dial 7195550148. What would you expect to see in the Digits label?

3. **A shorter Goertzel block.** You want to try Goertzel blocks of $N = 136$ samples at $f_s = 8$ kHz in `L13-dtmf-rx.grc` instead of the lesson's 205.

   (a) Find the block time and the bin spacing, which is also the distance from a bin to its first null.

   block: ____

   spacing: ____

   (b) What do you change in the flowgraph, and what happens to the eight Goertzel blocks' Length and the two time sinks that plot the bins?

   (c) Compared with $N = 205$, what do you expect the shorter block to do better, and what worse? Answer in words.

4. **Twist on the display.** A capture of the '9' key has a row tone of amplitude 0.20 and a column tone of amplitude 0.12.

   (a) In `L13-dtmf-rx.grc`, each stock Goertzel block feeds a Complex to Mag, which shows half a tone's amplitude. What heights do the 852 Hz and 1477 Hz traces reach?

   852: ____

   1477: ____

   (b) Which tone arrives weaker? Which slider in `L13-dtmf-link.grc` makes the same kind of signal, and what happens to the Digits label as you push that slider further the same way?

   (c) Why does the column tone often arrive weaker over a telephone line? Answer in one sentence.

5. **The decision rules.** The values below are one block's shares of its energy in each bin, as the L13 decoder sees them. Its tests: (1) the best row and column bins together hold at least 0.35; (2) each beats every other bin in its group by 6 dB, about four times the share; (3) the column share is between a tenth and four times the row share; (4) three blocks in a row agree.

Bin (Hz)	697	770	852	941	1209	1336	1477	1633
Block A	0.02	0.41	0.03	0.01	0.01	0.02	0.38	0.02
Block B	0.12	0.10	0.02	0.01	0.03	0.30	0.02	0.01

(a) Apply tests 1 to 3 to block A. Which digit does block A hold?

(b) Which test does block B fail?

(c) Block A alone does not produce a digit. What else must happen before the decoder reports '6', and what does that requirement reject?

6. **Noise.** You run `L13-dtmf-link.grc` and lower the SNR slider from 20 dB to 0 dB.

   (a) Describe what you see on the spectrum and in the Numbers label as the SNR comes down.

   (b) At 3 dB the tones barely show above the noise on the spectrum, yet every number still decodes. Explain in words why the decoder can still hear them.