FMCW IM

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Assume that we are going to send the following base-band complex chirp.

$$x(t) = \exp\left(j2\pi\Big(\frac{1}{2}\alpha t^2 + \beta t + \gamma\Big)\right), \quad 0 \leq t \leq T. \tag{1}$$

Then its instantaneous frequency at $0 \leq t \leq T$ is equal to

$$f(t) = \frac{1}{2\pi}\frac{d}{dt}\left(2\pi\Big(\frac{1}{2}\alpha t^2 + \beta t + \gamma\Big)\right) = \alpha t + \beta \in \Big[\beta, \alpha T + \beta\Big]. \tag{2}$$

We are going to place information bits in changing bandwidth, i.e., $f(T) - f(0) = \alpha T$, and initial frequency, i.e., $f(0) = \beta$. In the case of bandwidth, the instantaneous frequency will vary from $-B_\ell/2$ to $B_\ell/2$, and we will utilize bandwidth B_ℓ from the set

$$\left\{B_{\min} + \ell\frac{B_{\max} - B_{\min}}{L},\, \ell = 0, 1, \ldots, L-1\right\}, \tag{3}$$

which has L members. Thus, we can transmit $\log_2 L$ bits using this index modulation setup. In this case, α and β will be

$$\beta = -\frac{B_\ell}{2}, \tag{4}$$

$$\alpha = \frac{B_\ell}{T}. \tag{5}$$

In the case of initial frequency, the instantaneous frequency will vary from $f_m - \frac{B}{2}$ to $f_m + \frac{B}{2}$, and we will utilize the initial frequency f_m from the set

$$\left\{f_{\min} + m\frac{f_{\max} - f_{\min}}{M},\, m = 0, 1, \ldots, M-1\right\}, \tag{6}$$

which has M members. Thus, we can transmit $\log_2 M$ bits using this index modulation setup. In this case, α and β will be

$$\beta = f_m - \frac{B}{2}, \tag{7}$$

$$\alpha = \frac{B}{T}. \tag{8}$$

We can also place information bits in both the initial frequency and bandwidth, resulting in the following values α and β and enabling the transmission of $\log_2 ML$ bits.

$$\beta = f_m - \frac{B_\ell}{2}, \tag{9}$$

$$\alpha = \frac{B_\ell}{T}. \tag{10}$$

For your project, please follow these instructions:

- Generate a sequence of 256 chirps, encoding 7 bits of information by varying the bandwidth from 400 MHz to 800 MHz and 6 bits by changing the initial frequency from -100 MHz to 100 MHz. This will result in the transmission of a total of 13 bits.
- Consider the following system parameters:

$$\begin{aligned} f_c &= 62.64\,\text{GHz} \\ f_s &= 2 \times 10^9\,\text{samples/sec} \\ T_c &= 15.2\,\text{microseconds.} \end{aligned}$$

- Introduce a 0.1 microseconds guard time at the end of each chirp to enhance system performance. This additional time is beneficial for?
- Transmit the chirp sequence through an AWGN channel with signal-to-noise ratios (SNR) set to 0 dB, 10 dB, and 20 dB.
- Simulate the codebook-based receiver, comparing each received chirp with all possible transmitted chirps and selecting the one with the minimum distance.
- Utilize Short-Time Fourier Transform (STFT) to analyze the chirp sequence more effectively.
- Once you are confident that the transceiver is operational, request a practical received chirp for decoding.
- Compose a 4-page English report with the following structure:

  Page 1: Introduction, stating the importance and definition of index modulation and joint radar-communication systems. Page 2: System model. Page 3: Explanation of the receiver, its complexity, and your proposal for a simpler receiver. Page 4: Explanation of how one-bit transfer is achieved using upchirp/downchirp and on-off keying. Include a simulation figure in the report displaying the transmitted and received chirps (two or three consecutive chirps) in the STFT domain.

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