Enable TX beamforming

1. The concept of TX beamforming

The concept of TX beamforming is to transmit multiple TX channels simultaneously and coherently to achieve higher gain/longer range in the main focused field of view.

In TI mmwave radar, each TX channel of each device has a 6-bit configurable phase register with a step size of 5.625 degrees. Users can program different phase value to each TX channel based on where the main beam should be focused. Due to the coherent gain achieved in TX beamforming mode, its detection range will be much longer than that achievable in MIMO mode. The TX beamforming results in a narrower field of view (FOV). Users need to scan the beam to different angle to cover a wider FOV.

In the following sections:

- Section 2 – explains how to find the phase values associated with a specific beam angle
- Section 3 – explains how to translate the phase values into the mmWave SDK input
- Section 4 – example configuration (provided on TI Resource Explorer)

2. Phase value calculation for beamforming

The amount of phase value to be programed to each TX channel is computed as a function of array factor and target angle. Assuming N TX channels, with TX1 as a reference, the distance between every other antenna and TX1 is the known distance when the antenna array is designed during board development.

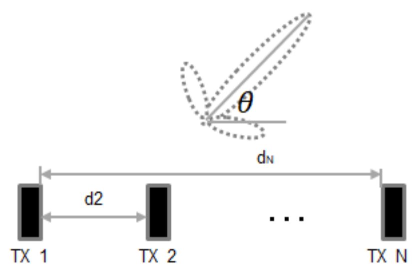

Figure 1 TX array for beamforming

Given the notation in Figure 1, the phase value for each TX channel is calculated as:

$$\vec{\emptyset} = [\emptyset_1\ \emptyset_2\ \emptyset_3\ \ldots\ \emptyset_N] = [0 \quad 2\pi\frac{d_2}{\lambda}\sin\theta \quad 2\pi\frac{d_3}{\lambda}\sin\theta \quad \ldots \quad 2\pi\frac{d_N}{\lambda}\sin\theta]$$

The ideal phase value is further quantified by the allowed phase step size of 5.625 degree to calculate the integer value to be programed to the registers:

$$\overrightarrow{\emptyset_{int}} = \lfloor [\emptyset_1\ \emptyset_2\ \emptyset_3\ \ldots\ \emptyset_N]/5.625 \rfloor$$

As an example, for TI ISK EVM, if we use 2 TX antennas (TX1 and TX3) for beam steering, we have $[d2 = 2\lambda]$. If the desired azimuth steering angle is 20 degrees, then the phase vector is as shown below in degrees.

$$\vec{\emptyset} = \frac{[0 \quad 4\pi\sin 20^o\ ]}{\pi} * 180$$

If we only care about narrow elevation angle close to zero, we can consider use 3 TX antennas (TX1, TX2 and TX3) for beam steering. Then we have$[d2 = \lambda, d3 = 2\lambda]$. If the desired azimuth steering angle is 20 degrees, then the phase vector is as shown below in degrees.

$$\vec{\emptyset} = \frac{[0 \quad 2\pi \sin 20^{o} \; 4\pi \sin 20^{o} \;\;]}{\pi} * 180$$

TI mmWave radar device supports both chirp based beam steering and frame based beam steering. Advanced frame configuration is used for either case.

3. Profile based beam steering

In currently SDK, users can program phase shifter for three TX in profileCfg. In profileCfg, there is 32 bit field called "txPhaseShifter". This field defines the additional phase shift to be introduced on each transmitter output. And here is the detail:

> @brief Concatenated phase shift for TX0/1/2,
> b1:0 reserved (set to 0b00); b7:2 TX0 phase shift value
> 1 LSB = 360/2^6 = 5.625 degrees
> b9:8 reserved (set to 0b00); b15:10 TX1 phase shift value
> 1 LSB = 360/2^6 = 5.625 degrees
> b17:16 reserved (set to 0b00); b23:18 TX2 phase shift value
> 1 LSB = 360/2^6 = 5.625 degrees
> b31:24 Reserved
>
> This field defines the additional phase shift to be introduced on each transmitter output.
> In IWR6843 ES1.0, only 0 degree phase is supported.

Each profile configuration is associated with phase values for the TX array, calculated based on the corresponding desired steering angle. Therefore, each desired beam angle will need to use a different profile configuration. There will many ways to configure the system, here are two examples:

Configuration 1: Program multiple beams within one sub-frame, like Figure 2.

Configuration 2: Program just one beam in one sub-frame, like in Figure 3.

Current SDK only support SIMO or TDM-MIMO for each sub-frames. Configuration 2 can be treated as SIMO mode. But Configuration 1 will need some change during detection and DOA stage in the signal processing chain. ***Therefore, Configuration 2 can be used without much change on SDK. But the limitation is that SDK only support up to 4 sub-frames.*** The example software, Long Range People Detection, provided in TI Resource Explorer Industrial Toolbox, is designed to handle configurations like configuration 2 (Figure 3). The software processes each subframe separately, then stitches the point cloud together after the last subframe before sending the data to the tracker.

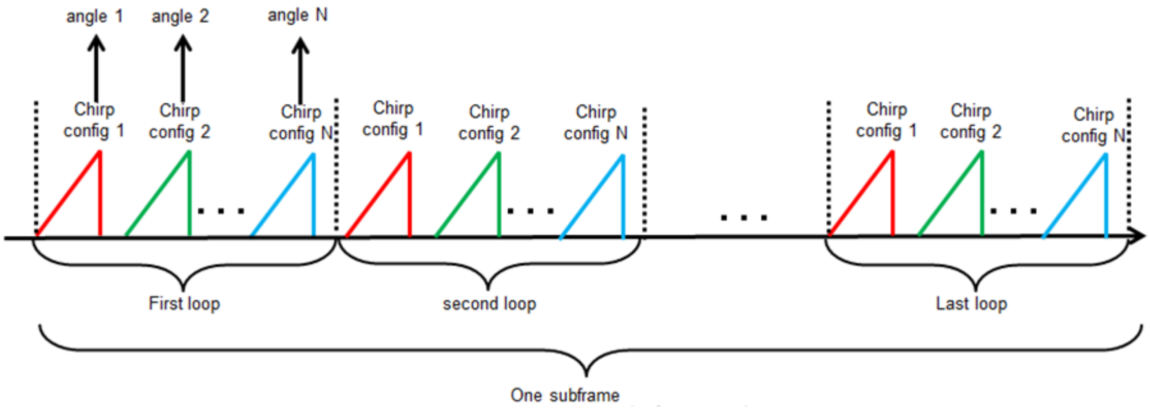

Figure 2 Multiple beam in one subframe.

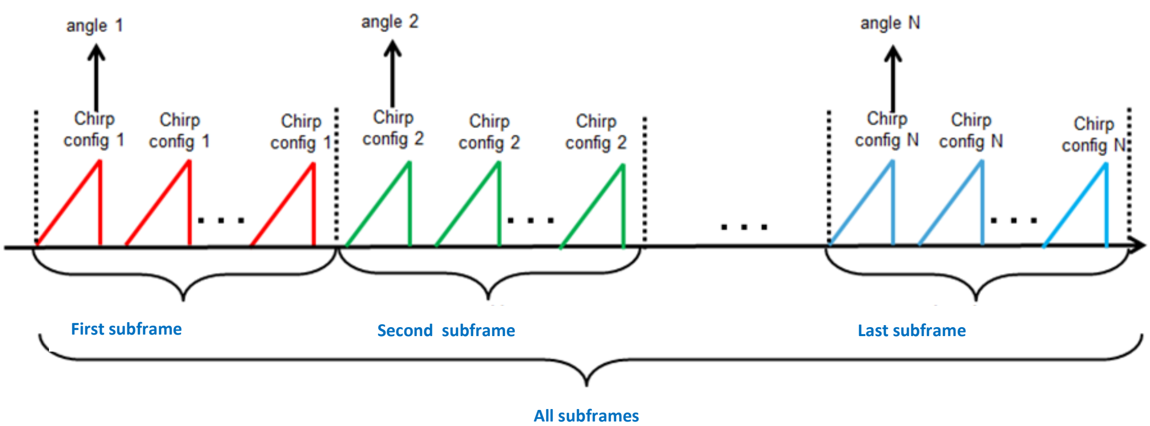

Figure 3 One TX beam in one subframe

Examples:

In the following example, we create 4 subframes. All 3 TX is enabled at the same time. These four sub-frames are aiming to focus on the angle of [-33.75 -11.25 11.25 33.75].

```
profileCfg 0 61.0 10 6 135 0 14970880 1.8 1 256 2000 0 0 48

profileCfg 1 61.0 10 6 135 0 10276864 1.8 1 256 2000 0 0 48

profileCfg 2 61.0 10 6 135 0 6565888 1.8 1 256 2000 0 0 48

profileCfg 3 61.0 10 6 135 0 1871872 1.8 1 256 2000 0 0 48

chirpCfg 0 0 0 0 0 0 0 7

chirpCfg 1 1 1 0 0 0 0 7

chirpCfg 2 2 2 0 0 0 0 7

chirpCfg 3 3 3 0 0 0 0 7

advFrameCfg 4 0 0 1 0

subFrameCfg 0 0 0 1 128 80 0 1 1 80

subFrameCfg 1 0 1 1 128 80 0 1 1 80

subFrameCfg 2 0 2 1 128 80 0 1 1 80

subFrameCfg 3 0 3 1 128 80 0 1 1 160
```

A MATLAB script is given below to calculate the phaseShifter value for a desired beam steering angle.

```
theta_desired = -33.75;
m_ind = [0 1 2];   % antenna distance in unit of lambda
phaseInc = 5.625;  % step size for the phase shifter

phaseTX_rad = 2*pi*(m_ind*sind(theta_desired));
phaseTX_deg = (phaseTX_rad)*180/pi;
phaseTX_deg_wrap = wrapTo360(phaseTX_deg);
phaseShifter = round(phaseTX_deg_wrap/phaseInc) * [ 0, 2^8, 2^16].' * 4
```