SS Block : Synchronization Signal Block.

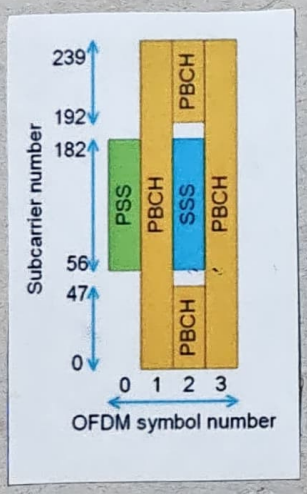
SS Block is a self synchronization block, which contains 3 different types of signals / channels.

(i) PSS – Primary Synchronization Signal

(ii) SSS – Secondary Synchronization Signal

(iii) PBCH – Physical Broadcast channel (contains MIB)

These 3 signals/channels are being transmitted in a particular fashion as shown below.



- PSS goes in first symbol of SSB
- SSS goes in third symbol of SSB
- And, around the SSS is PBCH.

The SSB takes 4 OFDM symbols in Time domain, and 240 subcarriers in Frequency domain.

240 Subcarriers ⇒ 20 PRBs

The SCS of SS Burst can be

15 KHz / 30 KHz, if FR1 band

120 KHz / 240 KHz, if FR2 band

The SSBs can be repeated in a 5 ms window, which is called SS Burst.

Now, the NO. of SSBs inside a SS Burst depends on the operating band. (can be 4 / 8 / 64).

SS Burst → Set of 1 or more SSBs

PSS

7.4.2.2 Primary synchronization signal

7.4.2.2.1 Sequence generation

The sequence $d_{PSS}(n)$ for the primary synchronization signal is defined by

$$d_{PSS}(n) = 1 - 2x(m)$$
$$m = \left(n + 43N_{ID}^{(2)}\right) \bmod 127$$
$$0 \le n < 127$$

where

$$x(i+7) = (x(i+4) + x(i)) \bmod 2$$

and

$$[x(6)\ \ x(5)\ \ x(4)\ \ x(3)\ \ x(2)\ \ x(1)\ \ x(0)] = [1\ \ 1\ \ 1\ \ 0\ \ 1\ \ 1\ \ 0]$$

PSS is the first DL signal rcd UE use for RF synchronization. This signal helps UE to find out the symbol boundaries. PSS signal is generated using m-sequence. The length of the PSS signal is 127. (ie) 1 OFDM symbol in time and 127 subcarriers in frequency.

In order to generate PSS signal, we initiate the m-sequence $x(m)$ as shown in specification, and then do BPSK modulation to generate the sequence $d_{PSS}(n)$

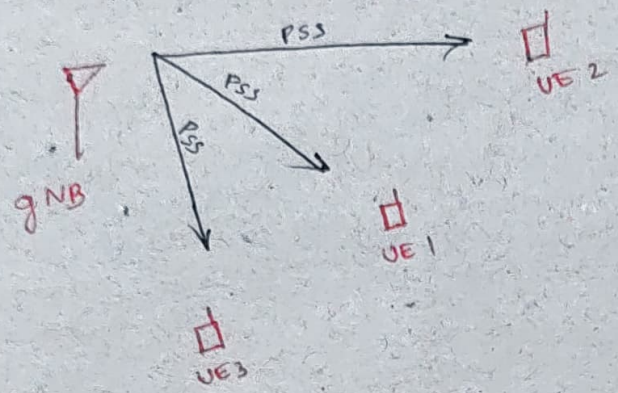
Along with frame synchronization, PSS also gives cell Identity (0 to 1007).

$$\boxed{cell_id = 3 * N_{ID}^{1} + N_{ID}^{2}}$$

where, N_{ID}^{1} takes values 0 to 335

N_{ID}^{2} takes values 0, 1, 2.

$\therefore$ N_{ID}^{2} takes 3 values, there can be 3 different d_{PSS} sequences, which are blindly decoded by UE and finds out which among the 3 was transmitted.



The PSS signal is transmitted by gNB. The UEs locally generate the PSS sequence (3 different sequences with $N_{ID}^{2} = 0, 1$ and 2). UE tries to correlate the received signal with the locally generated PSS sequences, and finds out where the correlation is above the threshold.

If the correlation is above the threshold, UE will assume that, "this is probably the place where PSS was transmitted by gNB".

SSS

7.4.2.3 Secondary synchronization signal

7.4.2.3.1 Sequence generation

The sequence $d_{SSS}(n)$ for the secondary synchronization signal is defined by

$$d_{SSS}(n) = [1 - 2x_0((n+m_0) \bmod 127)][1 - 2x_1((n+m_1) \bmod 127)]$$

$$m_0 = 15\left\lfloor \frac{N_{ID}^{(1)}}{112} \right\rfloor + 5N_{ID}^{(2)}$$

$$m_1 = N_{ID}^{(1)} \bmod 112$$

$$0 \le n < 127$$

where

$$x_0(i+7) = (x_0(i+4) + x_0(i)) \bmod 2$$
$$x_1(i+7) = (x_1(i+1) + x_1(i)) \bmod 2$$

and

$$[x_0(6)\ \ x_0(5)\ \ x_0(4)\ \ x_0(3)\ \ x_0(2)\ \ x_0(1)\ \ x_0(0)] = [0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 1]$$
$$[x_1(6)\ \ x_1(5)\ \ x_1(4)\ \ x_1(3)\ \ x_1(2)\ \ x_1(1)\ \ x_1(0)] = [0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 1]$$

SSS is allway transmitted as a part of SS Burst along with PSS and PBCH.

Similar to PSS, SSS also takes 1 OFDM symbol in time and 127 subcarriers in frequency. The generation of SSS is based on m-sequence, we initialize $x_0(m)$ and $x_1(m)$ as shown in spec, using which we generate the sequence $d_{SSS}(n)$. with BPSK modulation.

Here, using N_{ID}^1 and N_{ID}^2 we find Cell Identity. and also m_0 and m_1.

SSS signal along with PSS helps UE to find out cell ID. cell ID is very important parameter to further decode the next channel (PBCH, PBCH-DMRS for Channel estimation).

Along with PSS, SSS is used for Radio Frame synchronization. When the BS transmits PSS + SSS, the UE first decodes PSS and then SSS.

SSS correlation happens in frequency domain. Once PSS location in Time domain is found, the relative SSS location can be found (possible locations) since SSS and PSS are transmitted together.

So, we extract 127 SSS subcarriers, correlate with the locally generated SSS (by taking FFT on the extracted samples) and find out N_{ID}^{1}.

And, with N_{ID}^{2} we found from PSS, we calculate cell ID, and use this cell ID to decode PBCH.

Since SSS is at the middle of PBCH, it can also be used as a reference signal for PBCH, assuming that the channel is constant and does not change drastically.

This is one of the additional application of SSS.

PBCH and PBCH - DMRS

PBCH carries

- MIB (Master Information Block) (24 bits)
- Information to decode SIB1, SFN, and all (8 bits)

SFN ranges between 0 to 1023. (10 bits). Out of 10 bits, 6 bits are carried by MIB. Remaining 4 bits are added while generating the PBCH payload.

HFI (Half Frame Indicator) distinguishes 0 to 5 ms vs. 5 to 10 ms region, which takes (1 bit)

SSB Index (i_SSB) identifies the SSB within a burst, which takes (6 - bits.)

Spare / Reserved. for future use takes (1 bit)

So, the total PBCH payload = 32 bits.

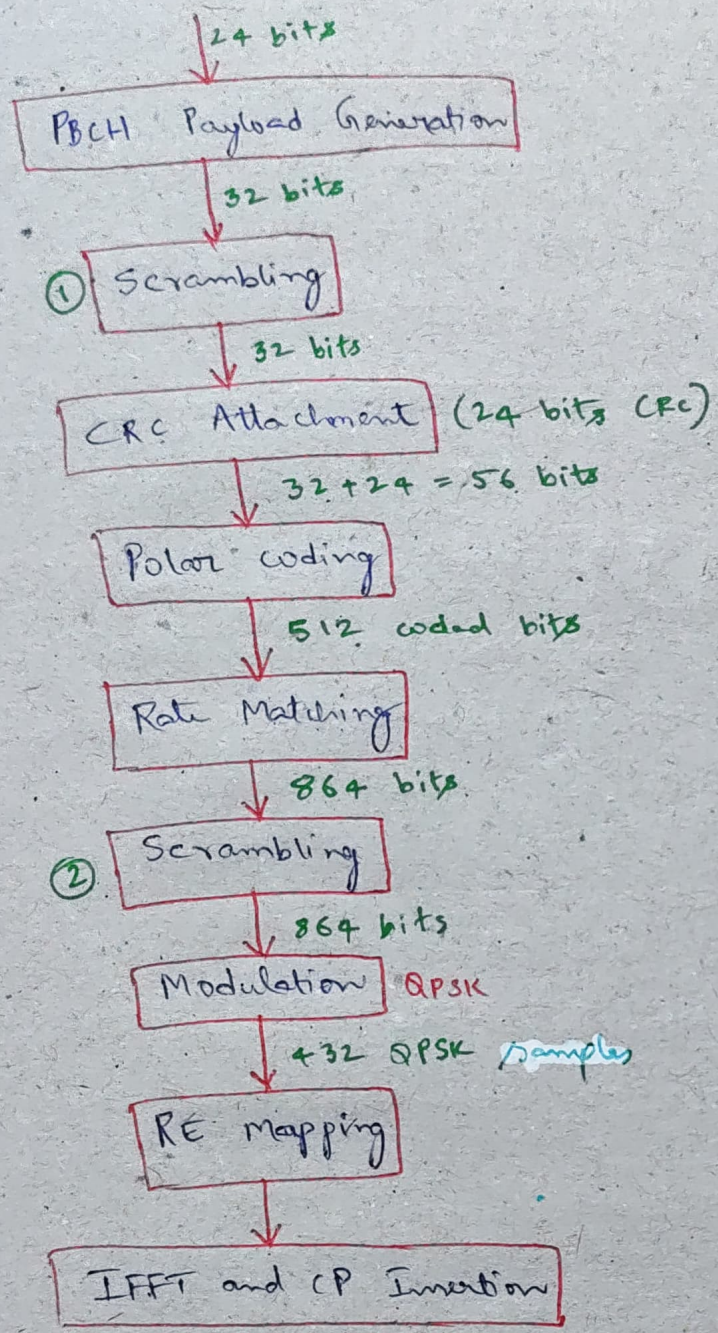
MIB is an RRC message, and the periodicity of MIB is 80 ms. (ie) after 80 ms, the MIB (24 bits) can be changed.

SFN (10 bits) →

MSB	LSB
6 bits	4 bits.

→ Value ranges b/w 0 to 15 (ie) 16 possible values.

So, for every 80 ms, this 10-bit SFN can be changed. Also, for every 160 ms, the LSB 4-bits of SFN can be changed. So, everytime we form the PBCH payload, we generate this 4-bits and append.



There are 2 scramblings in PBCH. After PBCH payload generation, we do a first level of scrambling. This scrambling is a function of 2nd and 3rd bits of SFN. Normally, we don't consider 1st bit of SFN coz if PBCH is transmitted on every even frame, then the first bit is something that's not going to change. It will remain constant.

After first level of Scrambling, we do CRC attachment. Here in PBCH, we have to use 24-bit CRC. So, after CRC attachment, we have 32 + 24 = 56 bits in total.

After CRC attachment, we do Polar encoding. Since the length of MIB is fixed, and this is an initial message, Polar encoding does a different kind of scrambling and gives a constant output. After Polar encoding, we get 512 coded bits.

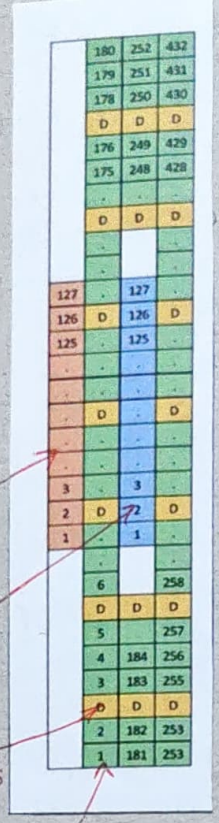
Then we do Polar Rate Matching. We Rate Match this 512 coded bits to the Number of REs allocated for PBCH (i.e) 432 samples. So, 512 coded bits are Rate Matched to 864 bits.

Then we do Second level of Scrambling, which is a function of SSB Index. So, inside a frame, SSB can be transmitted at multiple different locations, based on the SSB Index, carrier frequency, and all. (We'll see later). When we finally have the Frame number, SSB Index will help to identify the location inside the Frame where SSB is transmitted.

Then we do QPSK modulation, after which the 864 bits becomes 432 QPSK samples.

Note that, we have Rate Matched 32 + 24 = 56 bits to 864 bits. So, the code Rate $= \frac{56}{864} \approx 0.06$, which is a very low code Rate. (i.e) Lowest in any channel.

Then we map the 432 QPSK samples to the resources and the mapping is done as follows.



We see that, 3 OFDM symbols are allocated for PBCH. The 432 QPSK samples are mapped as shown in the figure, excluding the DMRS and SSS locations.

Location of DMRS is not fixed, and it depends on the cell_ID. (v) cell_id % 3

Specifically, the subcarrier indices for PBCH DMRS are

$$k = (n \bmod 3) + 3m,$$

where, $m = 0, 1, 2, \ldots$

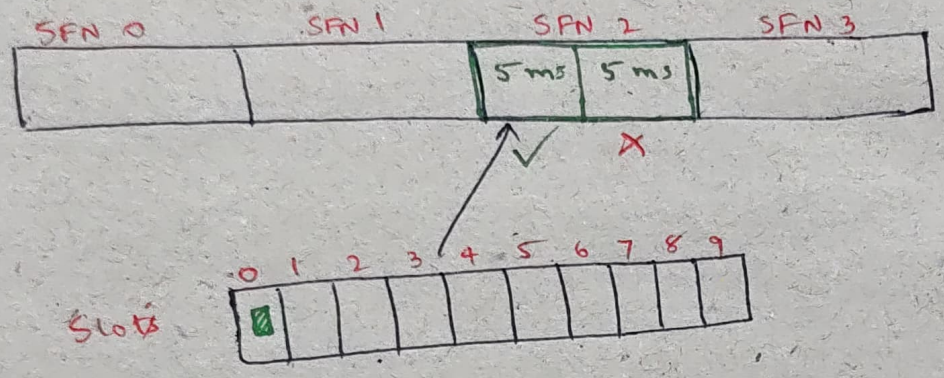
n = cell_id. (0 to 1007)

k = subcarrier index within the 240 subcarrier block.

And, the DMRS sequence generation is a function of SSB_index and cell_ID.

At the receiver side, we first decode the PSS and SSS, from which we get the cell_ID. And we dont know the Frame Number / slot number, as-of-now. With the cell_id, we find the location of DMRS. And, since we dont know the SSB index, we have to blindly decode. Say we pick SSB_index = 0 and try to decode and find whether the CRC pass/not. If fail, try with next SSB_index, and carry on until SSB_index is found. This is how we blindly decode SSB_index to extract the 24-bit MIB.

Now that, we know the exact location (Frame number) (i.e) SFN and also the HFI (Half Frame Indicator) inside the Frame (5 ms window):



Assume, the subcarrier spacing was 30 KHz, so we have 10 Slots. Now, based on the SSB_index, we get to know the Slot number and Symbol number.

So, we kind of decoded

- Symbol index
- Slot index
- Half Frame number
- SSB index
- 24 bits MIB.

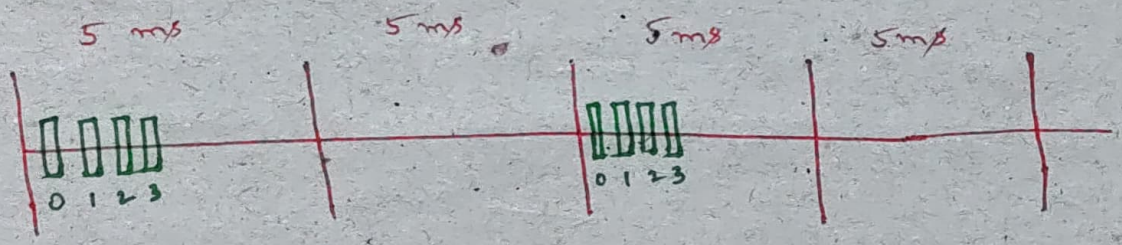
Time and Frequency locations of SS-Block

Time Locations

Based on the Operating band, the maximum number of beams are defined in the specification.

		L_{max}
1	Operating band $\leq$ 3 GHz	4
2	3 GHz < operating band $\leq$ 6 GHz	8
3	Operating band $\geq$ 6 GHz	64

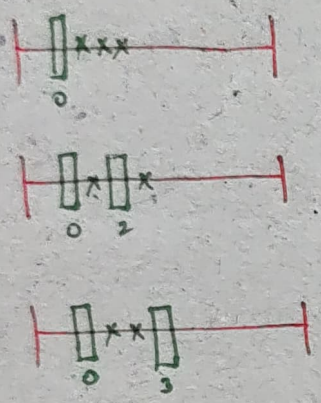
For each beam, there is a SSB transmitted, and each beam is associated with SSB_index. And all their beams or SS Blocks are confined to 5 ms window. (or) they're transmitted always in 5 ms window.



Now, lets consider a particular case, where operating band is $\leq$ 3 GHz, and $L_{max} = 4$. So we have SSBs transmitted as above, with indices 0, 1, 2 and 3.

Now, on top of this, there is a SSB periodicity which can be 5 ms / 10 ms / 20 ms / 40 ms / 80 ms / 160 ms. The most used periodicity is 20 ms. For our example, lets consider the SSB periodicity as 10 ms. So these 4 blocks will be repeated after 10 ms as shown above.

Now, it is not necessary that the gNB will always transmit all 4 beams. For example, it might transmit just index 0, or it might transmit index 0 and 2, or it might transmit index 0 and 3, and so on. as shown below.



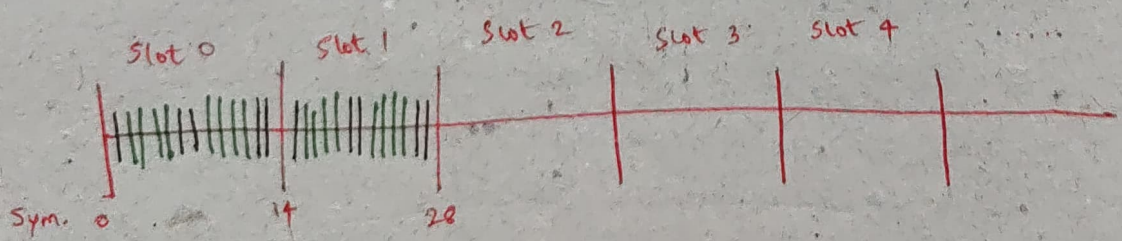
At max, there are 2 SSB, in a single slot.

There are different cases defined for SSB transmission.

<u>Case A:</u>

This case is for 15 kHz SCS, where the SSB location are 2, 8, 16, 22,... There are OFDM symbol location for all 4 SSBs inside a frame.

Index	0	1	2	3
SS beams location (symbol #)	2	8	16	22



This is how the SSBs are transmitted in case A.

Case B:

This case is for 30 KHz, where the SSB locations are 4, 8, 16, 20, ...

Case C:

This case is for 30 KHz; where the SSB locations are 2, 8, 16, 22, ...

Case D:

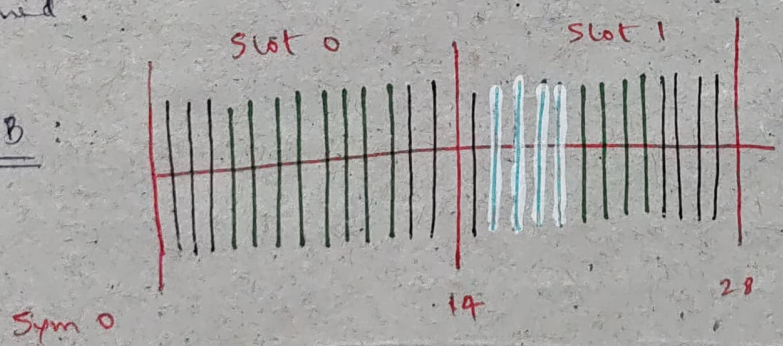
This case is for 120 KHz, where the SSB locations are 4, 8, 16, 20, ...

Case E:

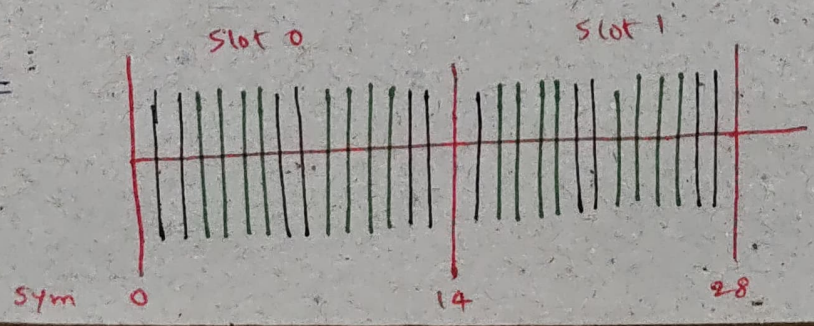
This case is for 240 KHz, where the SSB locations are 8, 12, 16, 20, ...

This is how the different cases are defined. Notice that, there are 2 different cases for 30 KHz (Case B and C) We cannot pick any case for any operating band. In specification, for different bands, different cases are defined.

Case B:



Case C:



In case B, SSB will take symbol number 4, 5, 6, 7, 8, 9, 10, 11, 16, 17, 18, 19 and 20, 21, 22, 23.

In case C, SSB will take symbol number 2, 3, 4, 5, 8, 9, 10, 11, 16, 17, 18, 19 and 22, 23, 24, 25.

In case B, we can have PDCCH taking 3 OFDM symbols, whereas in case C, we can have PDCCH taking 2 OFDM symbols. This is one difference.

Another difference is that, in case C, there are 2 OFDM symbols available in between 2 consecutive SSBs. (i.e) symbol 6 and 7. So, in case C, we can utilize symbols

0, 1 → for PDCCH

2, 3, 4, 5 → for SSB data

6 → DL – UL switch

7 → UL ACK/NACKs

This particular case (case C) can facilitate URLLC kind of applications, where in seven symbols we can have PDCCH, SSB, DL-UL switch and UL ACK/NACKs. and then we can proceed again with the second SSB. This is another difference b/w case B and C.

Frequency Location

Unlike LTE, in 5G, SSB can be transmitted anywhere in the frequency. WKT, SSB takes 240 subcarriers (20 PRBs) and it can be transmitted anywhere in the frequency. The frequency location is mainly controlled by 2 different parameters

1. Move in terms of PRBs (offset to Point A)
2. Move in terms of subcarriers (k_{SSB}) (Subcarrier offset)

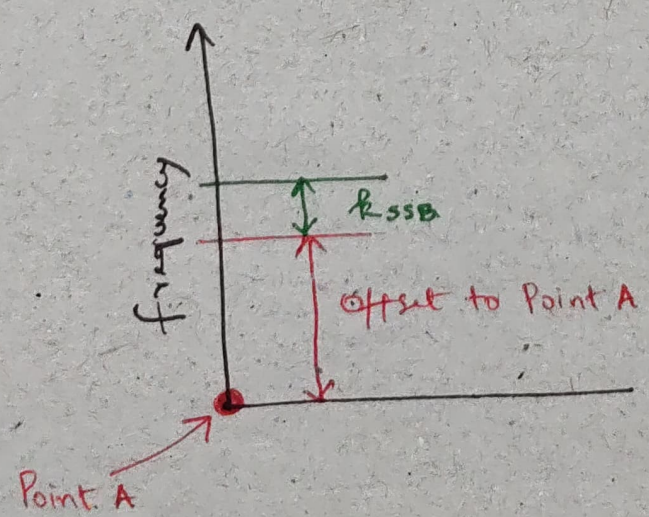
For FR1, both offset to Point A and k_{SSB} are defined in terms of 15 kHz.

And in FR2, offset to Point A is defined in terms of 60 kHz, and k_{SSB} is defined in terms of either 60/120 kHz.

For FR1, k_{SSB} values goes from 0 to 23.

For FR2, k_{SSB} values goes from 0 to 11.

So, based on the offset to Point A and k_{SSB} values, we can move the SS Burst anywhere in the frequency.



Say, the offset to Point A is 30 PRBs in terms of 15 kHz for FR1.

The offset to Point A is 15 PRBs in terms of 30 kHz SCS.

This is to move in terms of PRBs.

Also, we have another flexibility, to move in terms of subcarriers. Lets say, we want to go 10 subcarriers above. This is the k_{SSB} or subcarrier offset.

Offset to Point A → 30 PRBs (15 KHz),
15 PRBs (30 KHz)

k_{SSB} → 10 subcarriers (15 KHz),
5 subcarriers (30 KHz).

On top of there, we have the SS Block. And ofcourse, wherever SS Block location is, it should have a valid GSCN number.

This is how these 2 parameters controls the location of SS Burst in frequency.