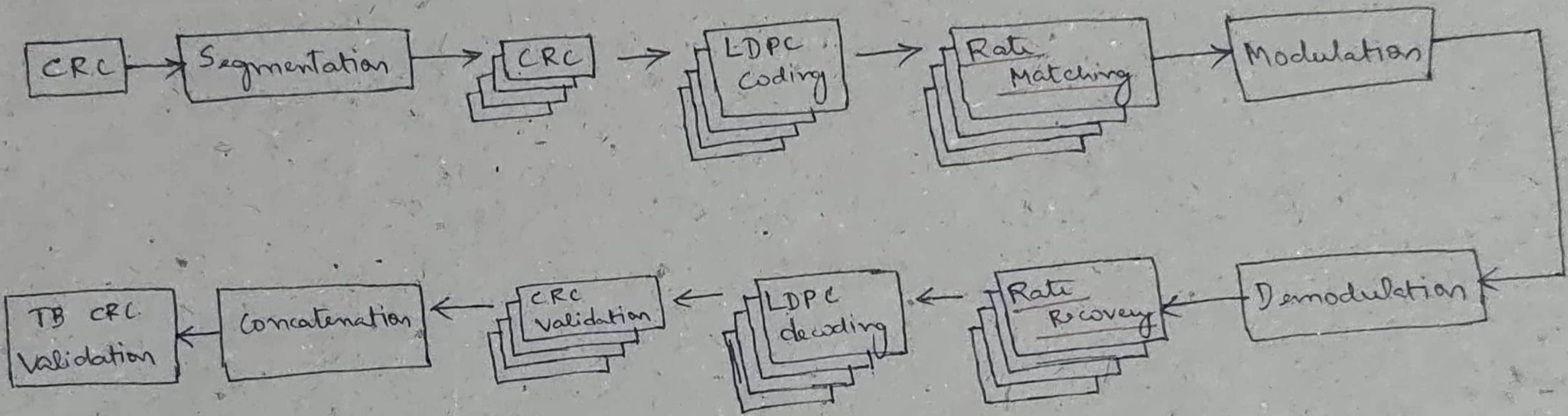
5G Transceiver chain with Rate Matching / Rate Recovery



Objective of Rate Matching - first example

- Our running example
  - Assume a user is allocated 70 RBs over a slot of 14 symbols.
  - MCS - 16 (16-QAM), which has a code rate of,

$$\frac{658}{1024} = 0.642$$

- One PRB over a slot consisting of 14 OFDM symbols will contain $12 \times 14 = 168$ REs
- Out of 168 REs, 6 are reserved for pilots. REs for transmitting data = 162
  - Total No. of bits which can be transmitted for 70 PRBS

$$G = 70\,(NPRB) \times 162\,(RE) \times \underbrace{4\,(16\,QAM)}_{4 \text{ bits per RE}}$$

$$= 45360 \text{ bits.}$$

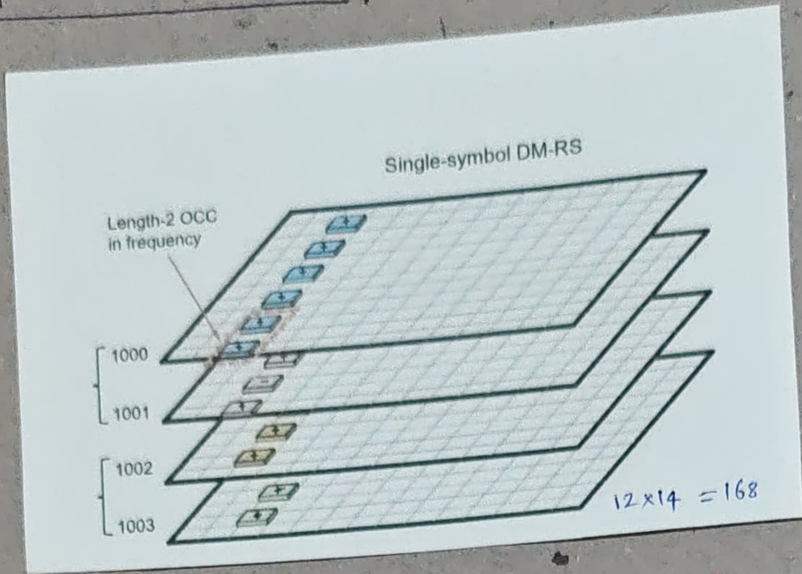
- Total No. of Segmented code blocks $C = 4$
- Length of each rate - matched block

$$E = \frac{G}{C} = \frac{45360}{4} = 11340 \text{ bits}$$

- Recall LDPC encoder output for each segmented code block

$$N = 66 \times 352 = 23232.$$

5G pilot Structure



- Six Subcarriers in a slot of 14 Symbols are reserved for pilots.
- One of the many pilots structures - will discuss in detail later.

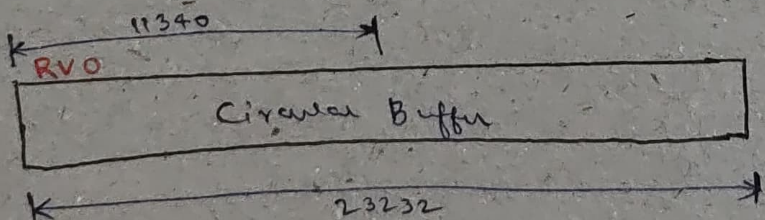
(i) First RM example - RM for first code block

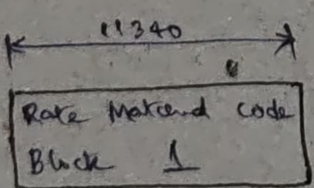
- Total No. of Segmented code blocks $C = 4$
- Length of each rate - matched block

$$E = \frac{G}{C} = \frac{45360}{4} = 11340 \text{ bits}$$

- Recall, LDPC encoder output for each segmented code block

$$N = 66 \times 352 = 23232.$$





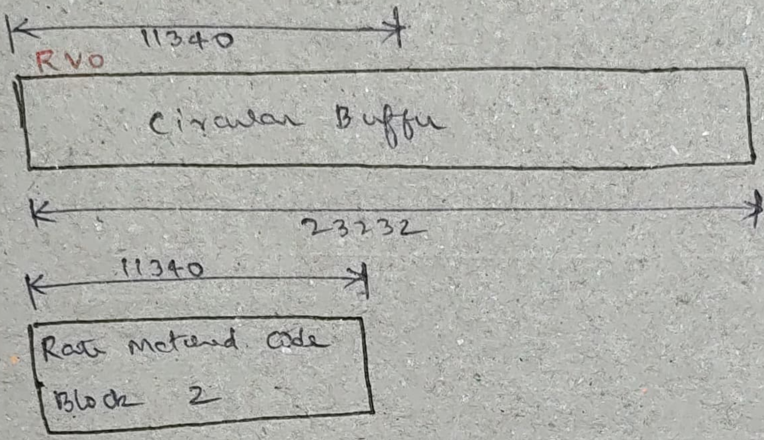
First RM example – RM for second code block.

- Total No. of Segmented code blocks $C = 4$
- Length of each Rate-matched block

$$E = \frac{G}{C} = \frac{45360}{4} = 11340$$

- Recall, LDPC encoder output for each segmented code block

$$N = 66 \times 352 = 23232$$



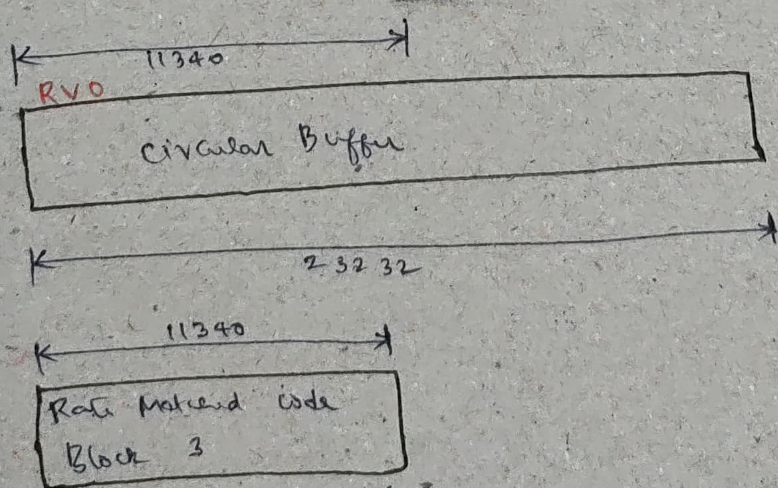
First RM example – RM for third Code block.

- Total No. of Segmented Code blocks $C = 4$
- Length of each Rate-matched block

$$E = \frac{G}{C} = \frac{45360}{4} = 11340$$

- Recall, LDPC encoder output for each segmented code block

$$N = 66 \times 352 = 23232$$



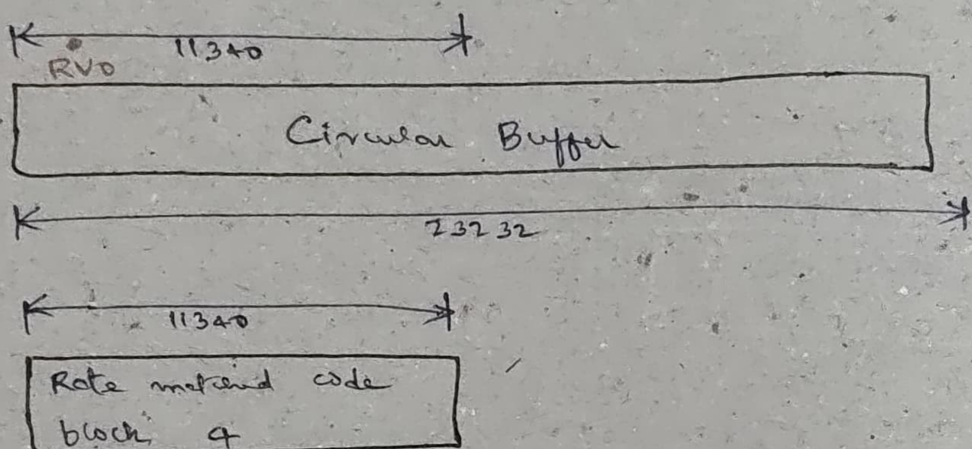
First RM example — RM for fourth code block

- Total No. of Segmented code blocks $C = 4$
- Length of each rate-matched block

$$E = \frac{G}{C} = \frac{45360}{4} = 11340$$

- Recall LDPC encoder output for each segmented code block

$$N = 66 \times 352 = 23232$$



(ii) Second RM example.

- MCS-0 (4-QAM) for which code rate is $\frac{120}{1024}$.

Consider $N_{PRB} = 10$ over one slot.

- Effective Transport block size $= 368 + 24 = 392$.

Total No. of coded blocks $= 1$.

Set Index 'i_{LS}'	Set of Lifting sizes Z_c
0	{2, 4, 8, 16, 32, 64, 128, 256}
1	{3, 6, 12, 24, 48, 96, 192, 384}
2	{5, 10, 20, 40, 80, 160, 320}
3	{7, 14, 28, 56, 112, 224}
4	{9, 18, 36, 72, 144, 288}
5	{11, 22, 44, 88, 176, 352}
6	{13, 26, 52, 104, 208}
7	{15, 30, 60, 120, 240}

- Minimum value of Z_c from Table 5.3.2-1 such that

$$K_b \times Z_c = K \geq K'$$

$$\Rightarrow 22 \times 18 = \underbrace{396}_{K} \geq \underbrace{392}_{K'}$$

- Filler bits are added to match to suitable lifting size, and it's number is

$$F = K - K' = 396 - 392 = 4.$$

- Total of one code block of size $K = 396$ bits with filler bits $F = 4$.

- LDPC encode output for each segmented code block $N_r = 66 \times 18 = 1188$

- LDPC encoder rate $= \frac{396}{1188} = \frac{1}{3}$

- Total No. of bits which can be transmitted for 10 PRB.

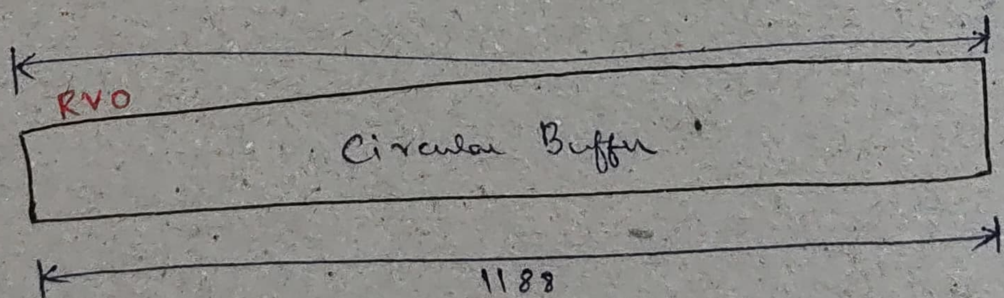
$$G = 10\,(N_{PRB}) \times 162\,(RE) \times \underbrace{2\,(4\text{-QAM})}_{2 \text{ bits per RE}}$$

$$= \underline{3240 \text{ bits}}$$

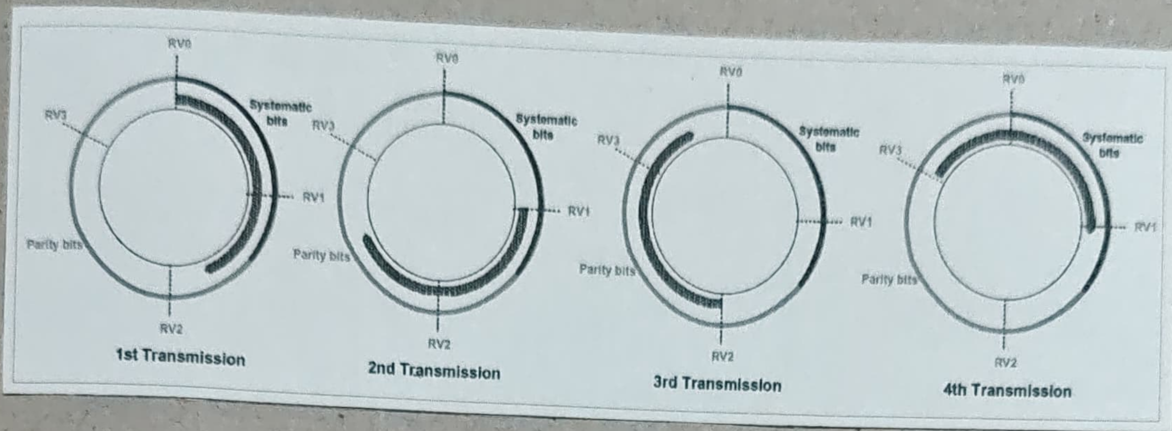
- <u>Length of rate-matched block</u>.

$$E = \frac{G}{C} = \frac{3240}{1} = \underline{3240 \text{ bits}}$$

- RV indices $k_0 = 0, 306, 594, 1008$



Objective of the Rate matching Block.



- Encoded output is directly written in a circular buffer
- Calculates No. of bits to be read for each of the Rate $\frac{1}{3}$ encoded block
- Bits are read from buffer, starting from offset position and increasing bit index.
- If bit index reaches its maximum, it is reset to the first bit in the buffer.
- Redundancy version (RV) specifies a starting point in the circular buffer.
- Different RVs are specified by defining different starting points.
- Usually RV-0 is selected for initial transmission - sends large number of systematic bits
- Scheduler can choose different RVs to support Chase and IR HARQ.
- Systematic bits are also punctured; enhances performance at high-code rates.

RV position calculation in circular buffer

rv_{id}	k_0	
	LDPC Base Graph 1	LDPC Base Graph 2
0	0	0
1	$\left\lfloor \frac{17 N_{cb}}{66 Z_c} \right\rfloor Z_c$	$\left\lfloor \frac{13 N_{cb}}{50 Z_c} \right\rfloor Z_c$
2	$\left\lfloor \frac{33 N_{cb}}{66 Z_c} \right\rfloor Z_c$	$\left\lfloor \frac{25 N_{cb}}{50 Z_c} \right\rfloor Z_c$
3	$\left\lfloor \frac{56 N_{cb}}{66 Z_c} \right\rfloor Z_c$	$\left\lfloor \frac{43 N_{cb}}{50 Z_c} \right\rfloor Z_c$

- Consider $N_{cb} = N$ in our case
- RV index $k_0 = 0$
- RV index $k_1 = \left\lfloor \frac{17 N}{66 Z_c} \right\rfloor = 5984$

$Z_c = 352$

$N = 66\ Z_c$ bits (BG1)

$= 50\ Z_c$ bits (BG2)

- RV index $k_2 = 11616$
- RV index $k_3 = 19712$

Rate matching in the Standard (Sec. 5.4.2 of 38.212)

- Recall bits output from LDPC encoder are denoted as
  $d_0, d_1, d_2, \ldots, d_{(N-1)}$
- Bits Input to rate matcher are denoted as
  $d_0, d_1, d_2, \ldots, d_{(N-1)}$
- Bits Output of rate matcher are denoted as
  $e_0, e_1, e_2, e_3, \ldots, e_{(E-1)}$

Denote by rv_{id} the redundancy version number for this transmission ($rv_{id} = 0, 1, 2$ or 3), the rate matching output bit sequence e_k, $k = 0, 1, 2, \ldots, E-1$, is generated as follows, where k_0 is given by Table 5.4.2.1-2 according to the value of rv_{id} and LDPC base graph:

```
k = 0;
j = 0;
while k < E
    if d_{(k0+j) mod Ncb} ≠ <NULL>
        e_k = d_{(k0+j) mod Ncb};
        k = k + 1;
    end if
    j = j + 1;
end while
```

Denoting by E_r, the rate matching output sequence length for the r^{th} coded block, where the value of E_r is determined as follows:

Set $j = 0$

for $r = 0$ to $C-1$

if the r^{th} coded block is not scheduled for transmission as indicated by CBGTI according to subclause 5.1.7.2 for DL-SCH and 6.1.5.2 for UL-SCH in [6, TS 38.214]

$E_r = 0$;

else

if $j \le C' - \bmod(G/(N_L \cdot Q_m), C') - 1$

$$E_r = N_L \cdot Q_m \cdot \left\lfloor \frac{G}{N_L \cdot Q_m \cdot C'} \right\rfloor ;$$

else

$$E_r = N_L \cdot Q_m \left\lceil \frac{G}{N_L \cdot Q_m \cdot C'} \right\rceil ;$$

end if

$j = j + 1$;

end if

end for

where,

$N_L \rightarrow$ No. of transmission layers that the Transport block is mapped onto.

$Q_m \rightarrow$ Modulation order

$G \rightarrow$ Total No. of coded bits available for transmission of the Transport block.

$C' = C$ if CBGTI is not present in the DCI scheduling the Transport block.

$C' \rightarrow$ No. of scheduled code blocks of the Transport Block if CBGTI is present in the DCI scheduling the Transport block.