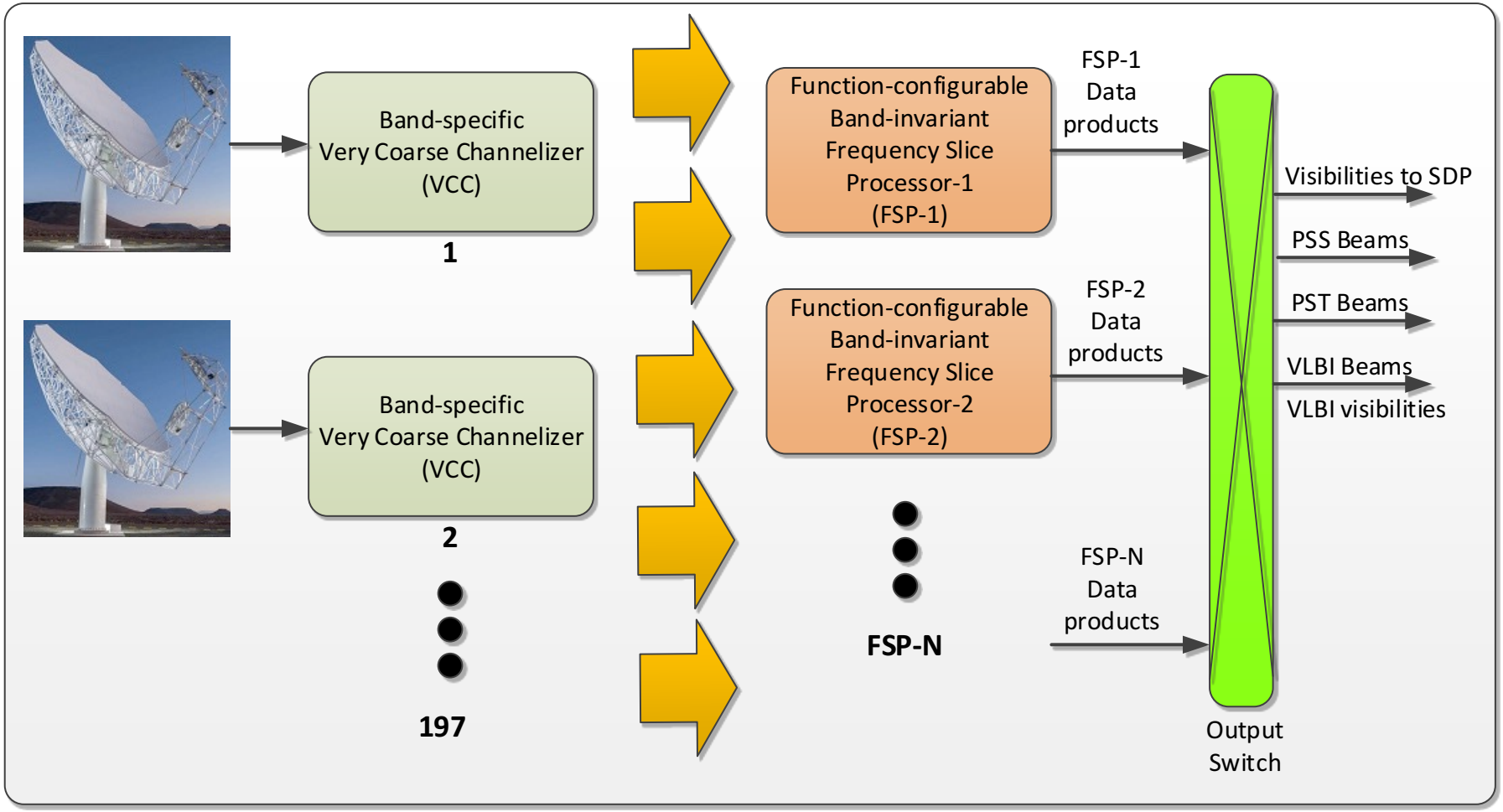
TM's View of the Mid.CBF Frequency Slice Approach

Michael P. Rupen

NRC Canada

June 13, 2017

Frequency Slice Architecture



Very Coarse Channelizers (VCCs)

- 197+1 VCCs (one VCC per dish)
- VCCs are *completely* independent
- Takes input wideband and produces:

  N x 200 MHz **Frequency Slices** to cover the full Band

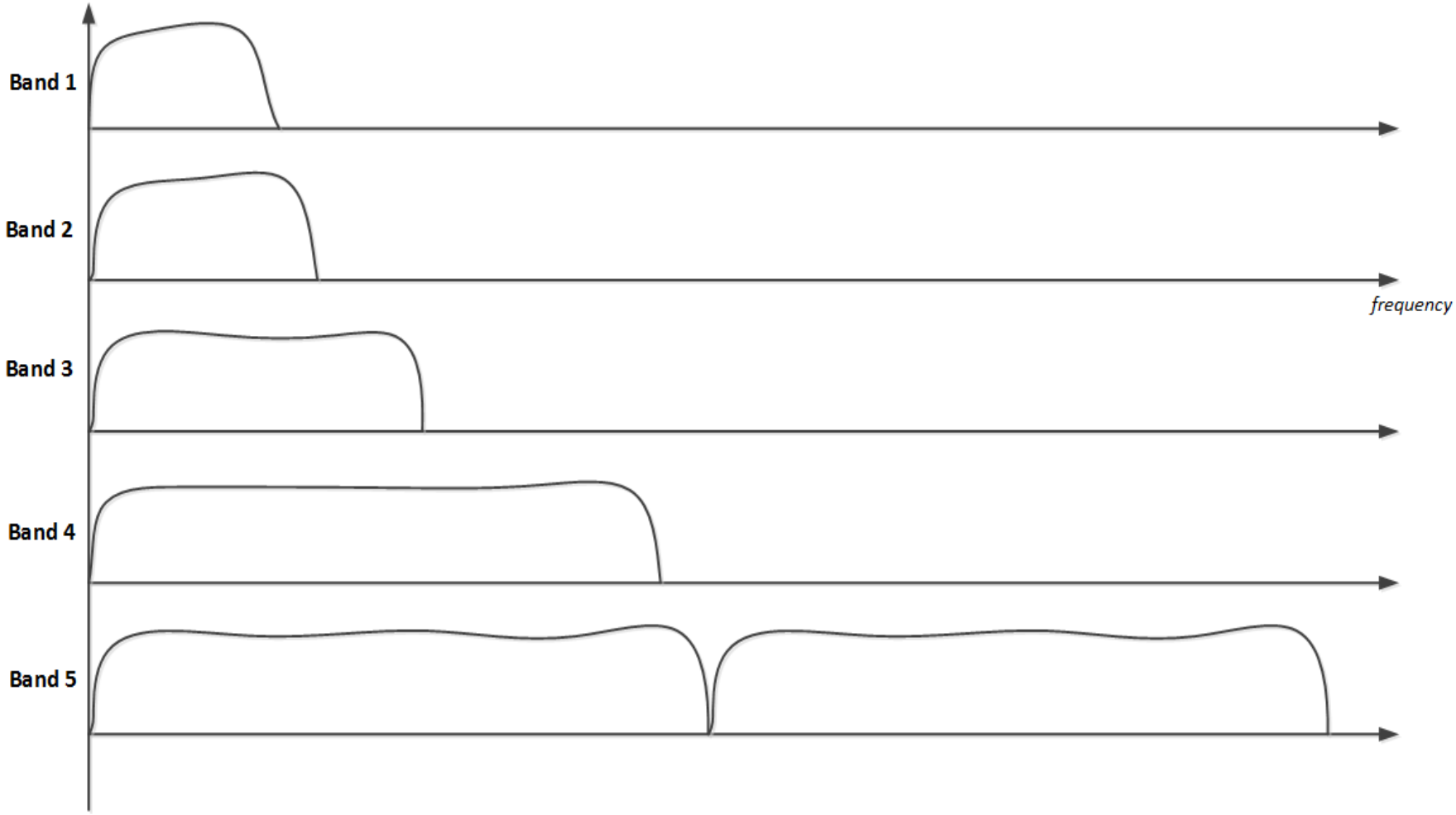
  (e.g., Band 2 BW= 810 MHz → *N*= 5)

  + 2 x 300 MHz independently tunable **Search Windows**

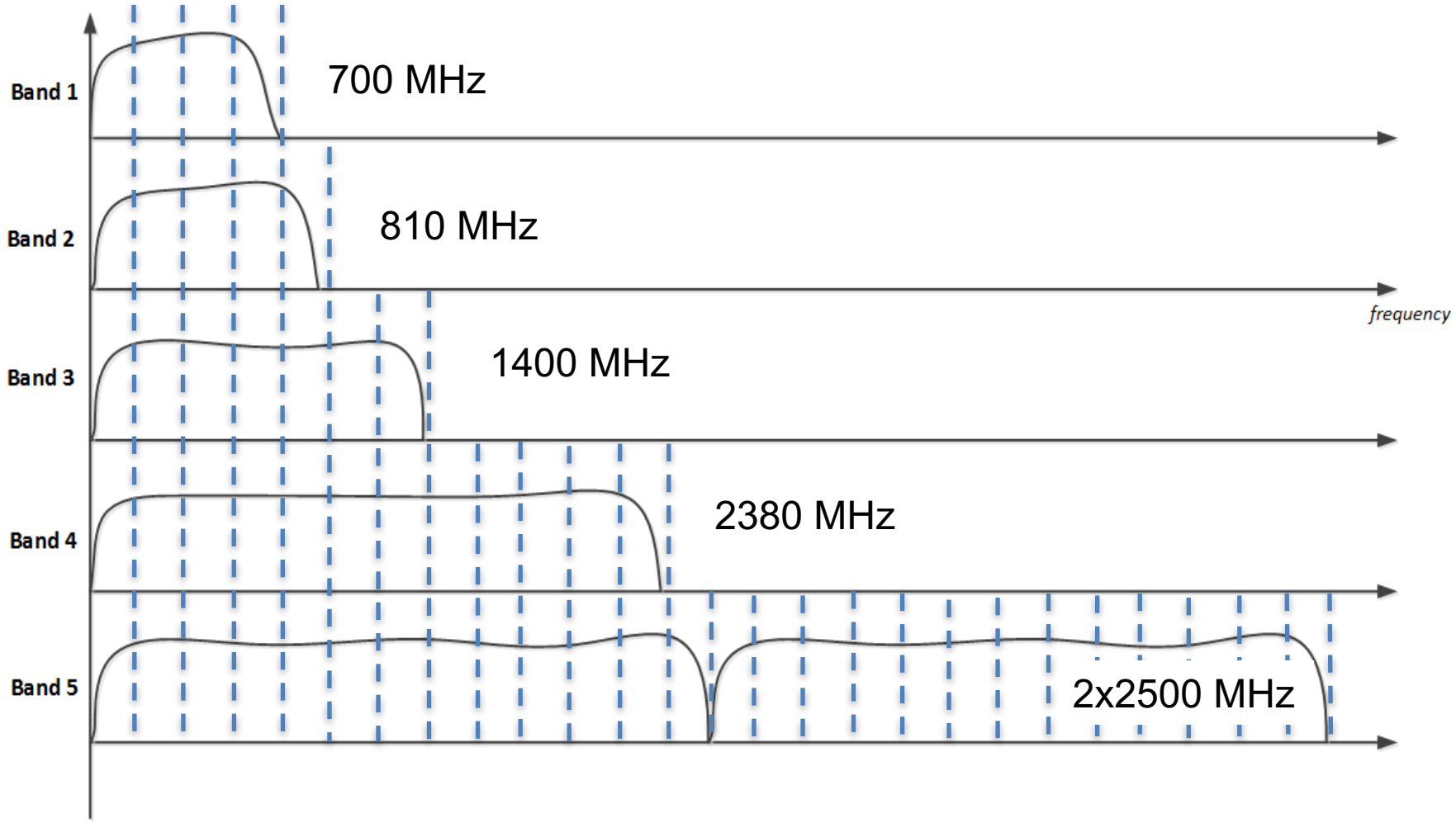
  (used for Pulsar Search and Transient Buffer capture)

- To configure a VCC:
  - Choose the observing Band (per subarray)
  - Choose a frequency shift (optional) (per subarray)
  - Choose tunings for Search Windows (per subarray)
  - Choose/pass along clock offset (per dish)

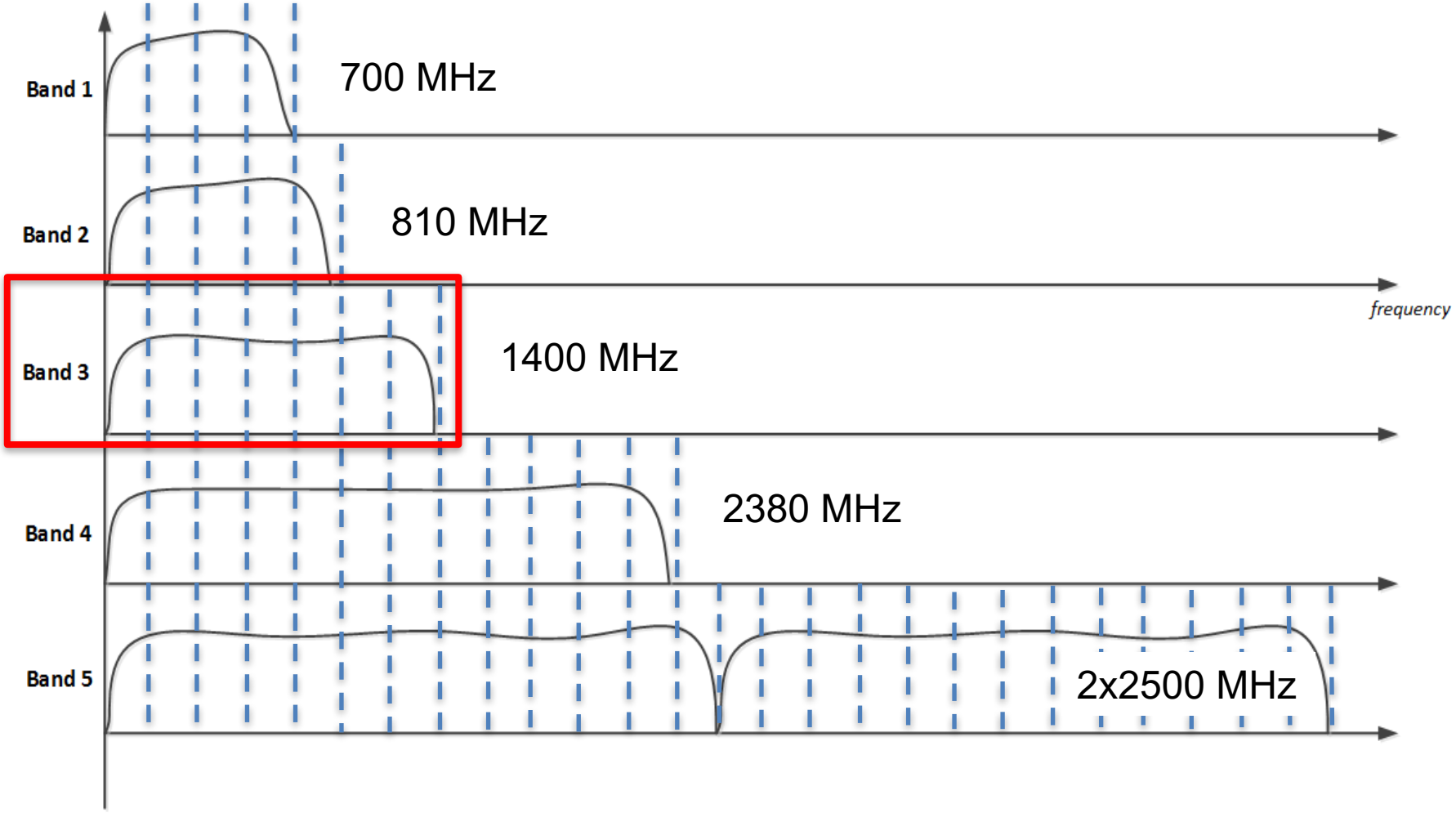
VCC Configuration



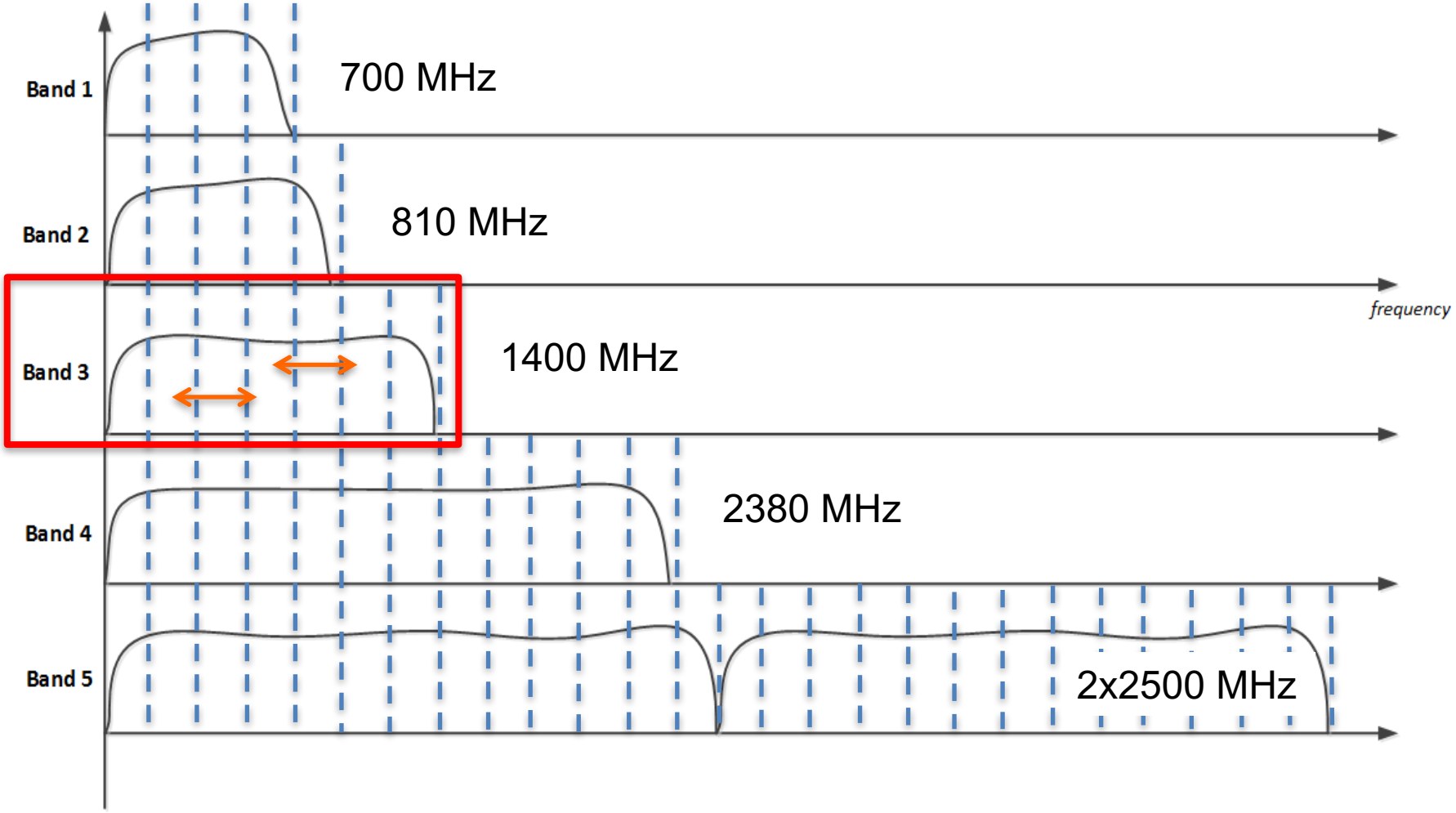
VCC Configuration



VCC Configuration



VCC Configuration



Frequency Slice Processors

- Any VCC product (Frequency Slice or Search Window) can be forwarded to *any (and any number of)* **Frequency Slice Processors** (FSPs)
- Each FSP receives one `VCC product' from *each* VCC

- Each FSP performs ***one*** function on ***one*** VCC product for ***all*** subarrays
  - CORRelation: wideband *or* zoom window (up to 16k channels)
  - PSS beamforming (192x300 MHz PSS beams, distributed over subarrays)
  - PST beamforming (16x200 MHz PST beams, distributed over subarrays)
  - VLBI: corr'n + beam-forming (2 beams/FSP for each of up to 10 subarrays)

Frequency Slice Processors

- Mid.CBF provides 26+1 FSPs
  - FSPs are *totally* independent
  - More $$ → more FSPs; less $$ → fewer FSPs

- To configure the FSPs:
  - Choose (one) signal processing mode for *each* FSP (CORR, PSS-BF, PST-BF, VLBI) (per FSP)
  - Choose one FS/Search Window to send to each FSP (per FSP, per subarray)
  - Configure appropriate mode parameters for each FSP (per FSP, per subarray)
    - E.g., CORR → BW (200, 100, …, 3.125 MHz), tuning, # of channels, integration time

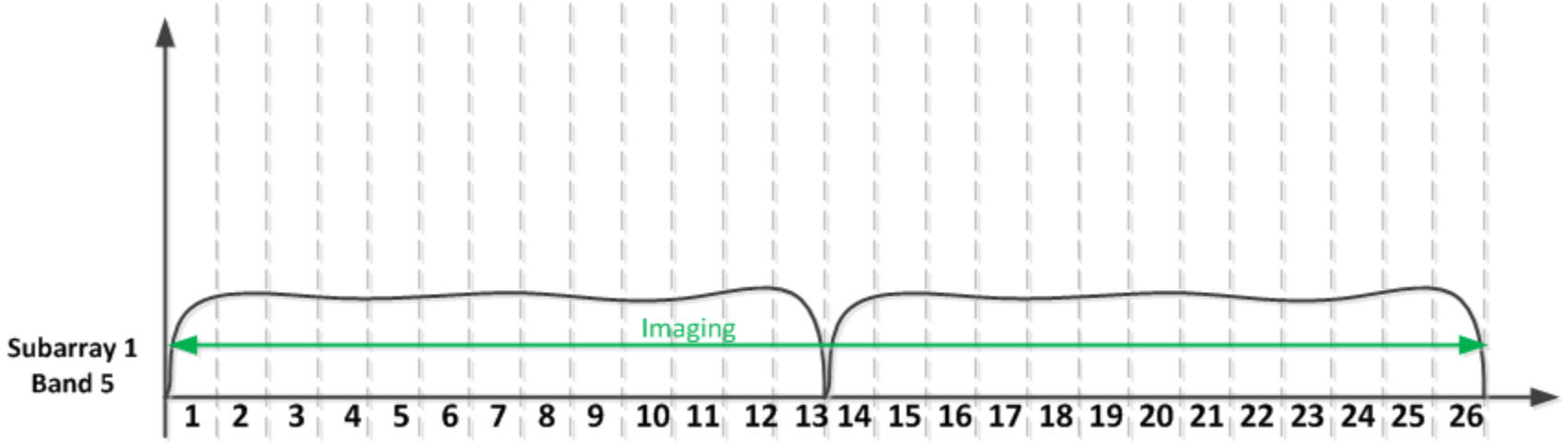
Frequency Slice Processors

- This allows a *lot* of flexibility – 26 independent CBFs!
- Need not expose all the options initially
  …although it is pretty simple: Excel spreadsheet

- Could start with a few (2-3?) "standard modes":
  - **Bands 5a, 5b: full correlation**: 2 x 2.5 GHz → 26 FSPs
  - **Bands 1,2: full commensality:**
    - Full BW correlation: 810 MHz, 200 MHz/FSP → 5 FSPs
    - 16 full-BW PST beams: 810 MHz, 200 MHz/FSP → 5 FSPs
    - 1500 x 300 MHz PSS beams: 192 beams/FSP → 8 FSPs
    - Zoom windows using left-over FSPs (26-18=8) → 8 zoom windows
  - **VLBI**

ECP 170017 Example 1:
Band 5 full-bandwidth imaging

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	5	5000.0	0	0	0.0	0		



Band 5 is sliced in 26 x 200 MHz Frequency SIIces.
Each Frequency Slice is processed (correlated) on different Frequency Slice Processor (FSP).
All 26 FSPs are used to produce a complete set of visibilities for Band5 (across full band).
Any Frequency Slice and be processed on any FSP.

ECP 170017 Example 2:
Fully commensal Band 2, & two subarrays

Subarray 1:

- *Central array core for Band 2 (L-band) imaging, pulsar search, pulsar timing (uses full capacity of FSPs 14 to 25)*
- *FSP in PSS Beamforming mode can form up to 192 PSS beams*

  1500/192 (rounded up)=8 FSPs are needed to produce 1500 PSS beams
- *810/200 (rounded up)= 5 FSPs are needed to perform Pulsar Timing in full Band 2.*

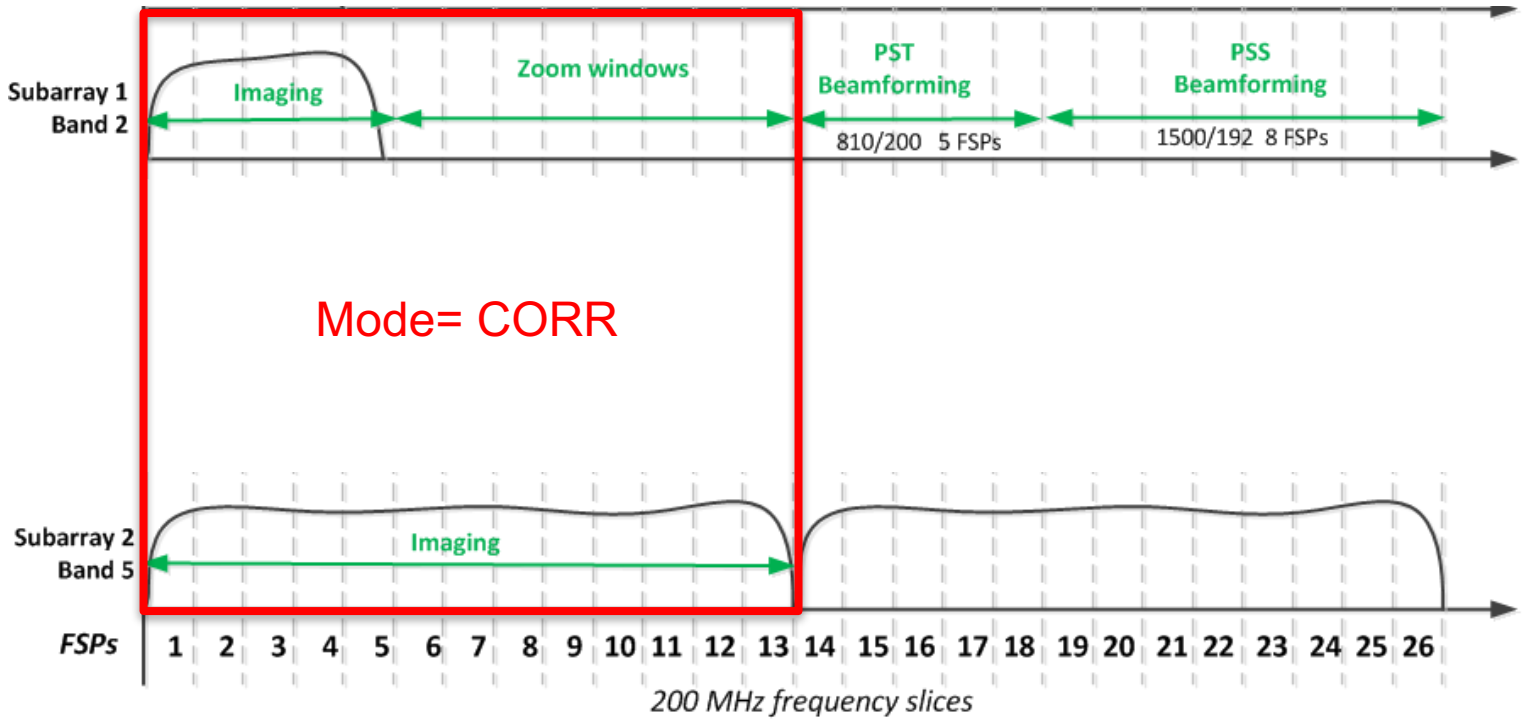
Subarray 2:

- *long-baseline (out of core) Band 5 imaging (half bandwidth)*

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	2	810.0	8	1500	810.0	16		
2	5	2500.0						

ECP 170017 Example 2:
Fully commensal Band 2, & two subarrays

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	2	810.0	8	1500	810.0	16		
2	5	2500.0						



Scan Configuration: subarrays & FSPs

```
Scan ID = 123
Subarray 1
  List of dishes = 1-10,27,38,55,108-190
  Observing Band = 2
  <RFI parameter>
  <Search Window tunings>
  FSP  1 spMode= CORR
    <CORR mode parameters>
  …
  FSP 26 spMode= PSS-BF
    <PSS-BF mode parameters>

Scan ID = 124
Subarray 2
  List of dishes= 11-26,28-37,39-54,191-197
  FSP  1 spMode= CORR
   <CORR mode parameters>
  …
  FSP 13 spMode= CORR
    <CORR mode parameters>
```

Per subarray, define member dishes & search window tunings

Per FSP (per subarray), define signal processing mode parameters

…CORR: Freq. Slice, BW, tuning, # & choice of channels, integration time

…PSS-BF: Search Window, where to send data

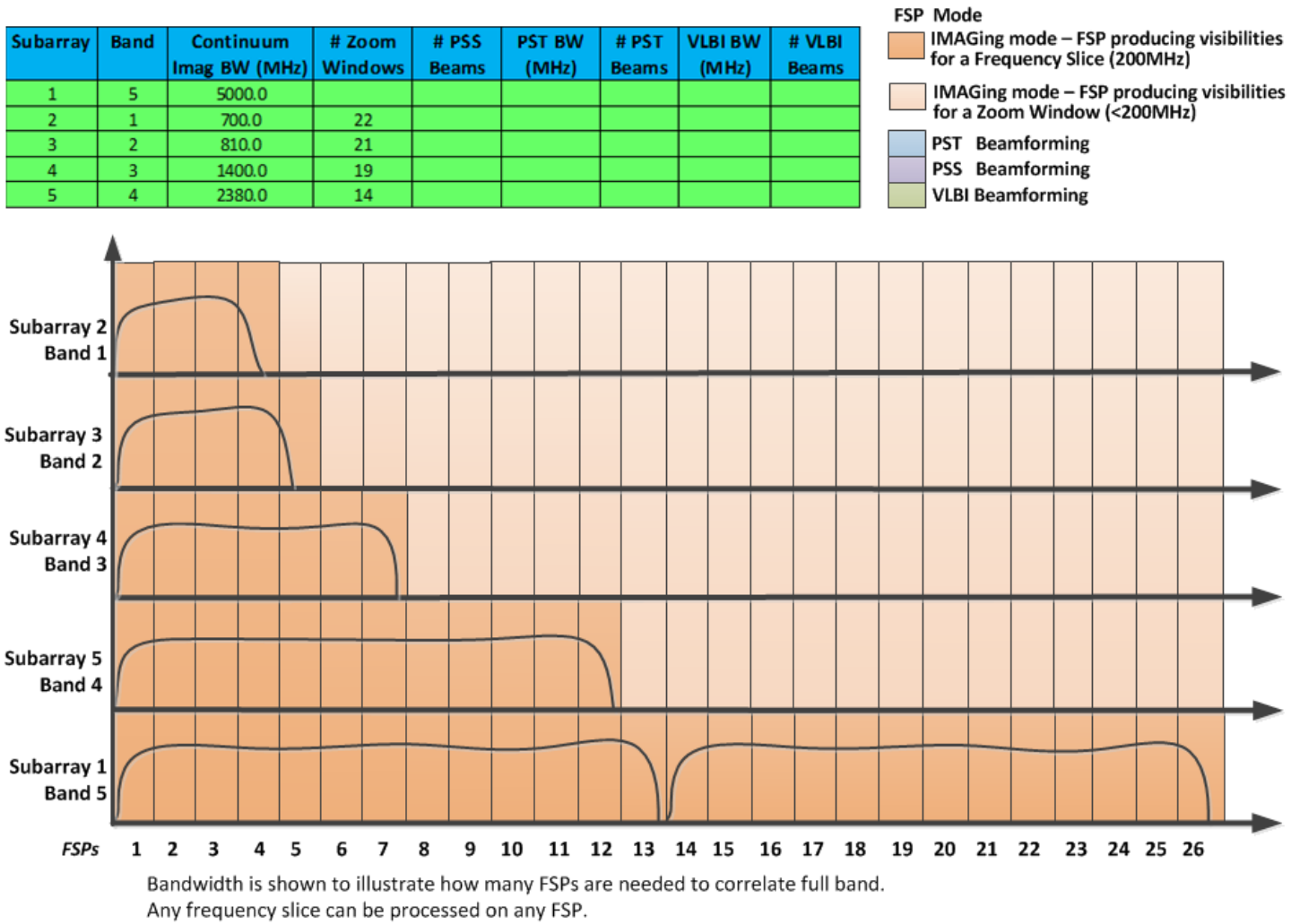
…PST-BF: Freq. Slice, where to send data

TM must ensure consistency of FSP signal processing modes across subarrays, and track who controls each PSS & PST beam

ECP 170017 Example 5:

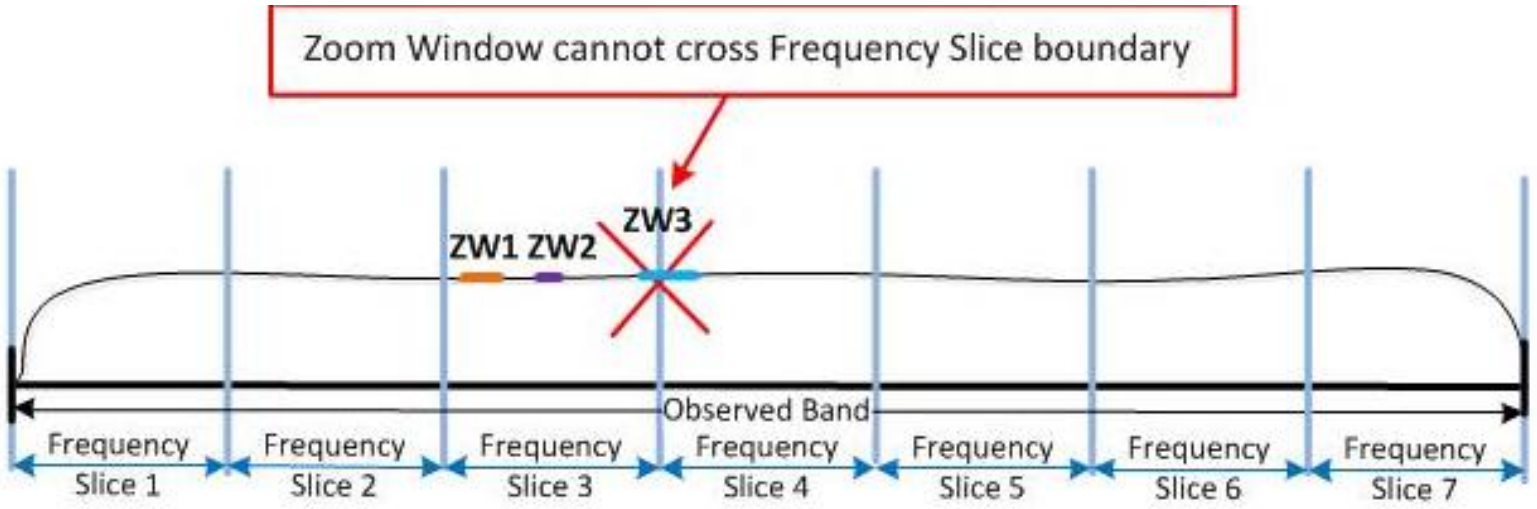
Wideband continuum: simultaneous all bands (using subarrays)

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	5	5000.0						
2	1	700.0	22					
3	2	810.0	21					
4	3	1400.0	19					
5	4	2380.0	14					



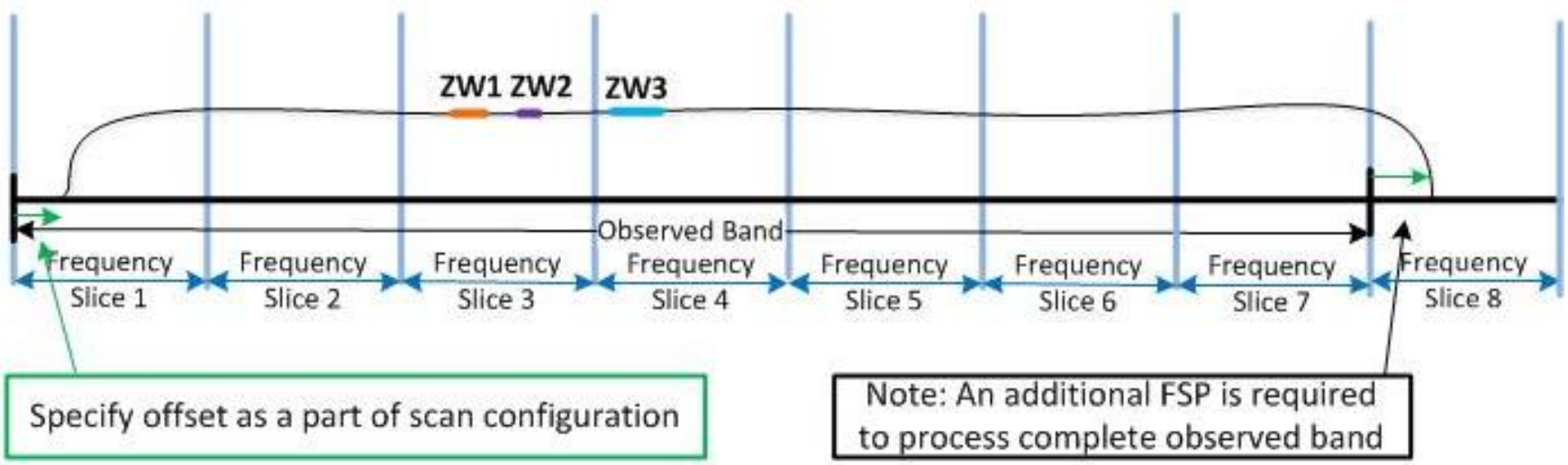
Bandwidth is shown to illustrate how many FSPs are needed to correlate full band.
Any frequency slice can be processed on any FSP.

Zoom Windows & “wideband tuning”



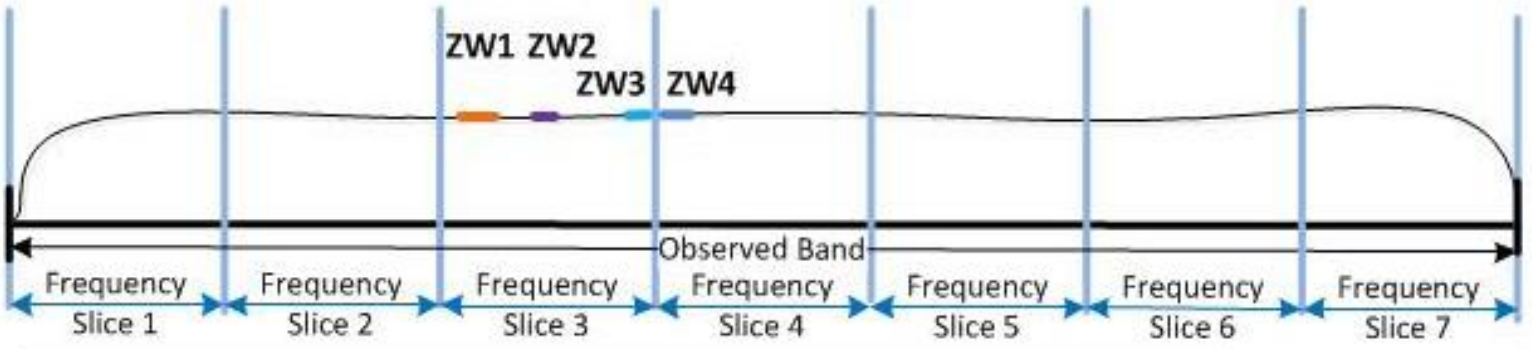
Zoom Windows & “wideband tuning”

Option 1: Shift entire observed band to accommodate Zoom Window 3



Zoom Windows & “wideband tuning”

Option 2: split Zoom Window 3 in two, so that each part ‘belongs’ to a different Frequency Slice.



Note: An additional FSP is required to process additional Zoom Window

Global Thinking

- The mode for a single FSP applies to *all* subarrays

  ➔**FSPs are a global resource**, like PSS and PST beams

- Data transfer
  - Up to ~380k channels
  - Shared links for visibilities, transient data, (maybe) VLBI
  - CORR: per-FSP, per-subarray choices of channels, channel averaging, & integration time

  ➔ **CSP-SDP data rate is another global resource**

Backup slides

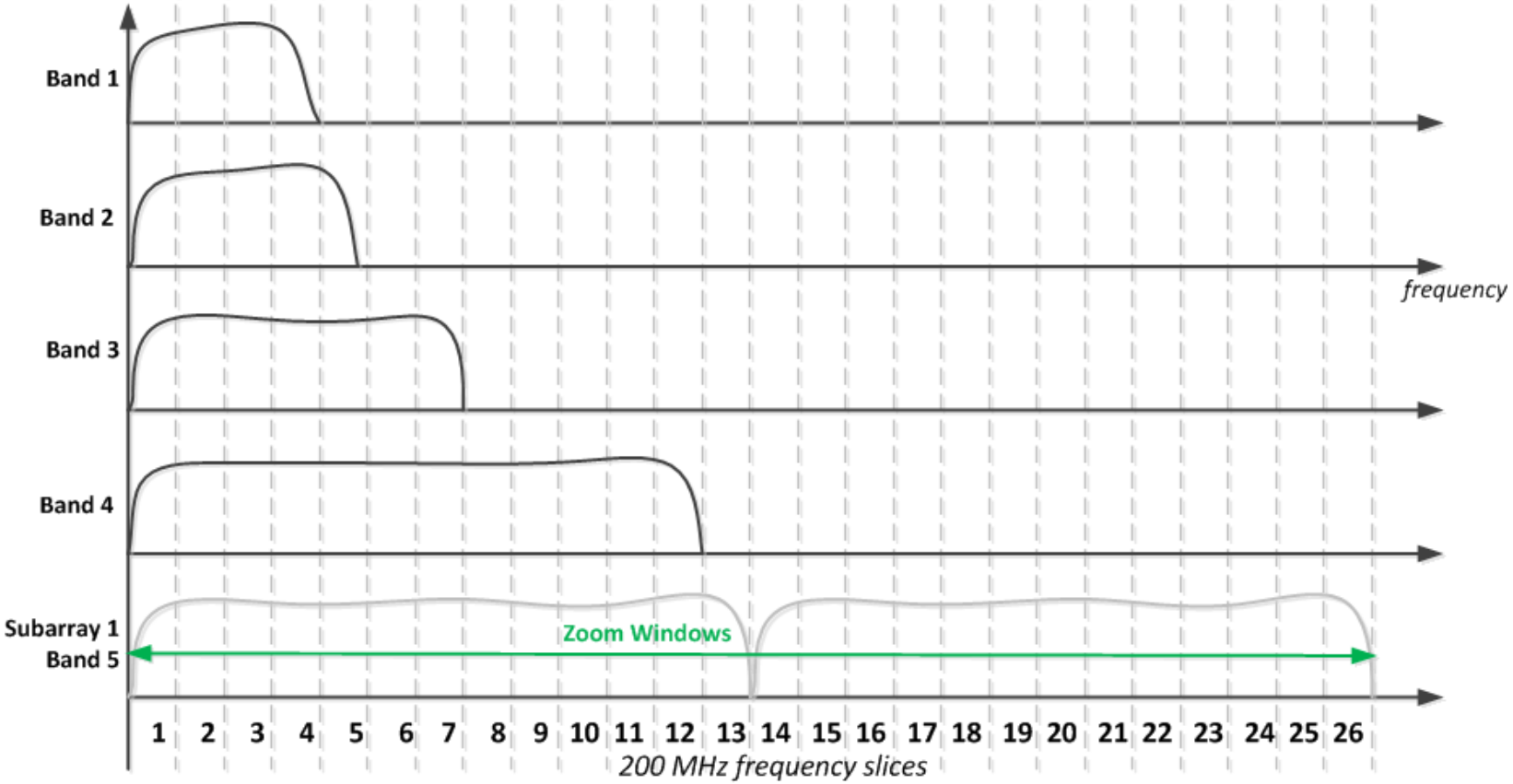
ECP 170017 Example 3:
Targeting multiple spectral lines in Band 5

- Entire array in Band 5
- All 26 FSPs: Mode= CORR, used to produce Zoom Windows
- Each Zoom Window independently tunable within *any* 200 MHz frequency slice.
- Bandwidth independently selected for each Zoom Window in range 200 MHz to 3.125 MHz.
- Total number of channels is 26 x ~15k = 390k/pp/baseline
  - channel pruning can be performed or channels can be integrated longer to reduce the data rate to the SDP.

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	5	0.0	26					

ECP 170017 Example 3:
Targeting multiple spectral lines in Band 5

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	5	0.0	26					



ECP 170017 Example 4:

Band 2: VLBI beamforming , imaging, pulsar search, and pulsar timing

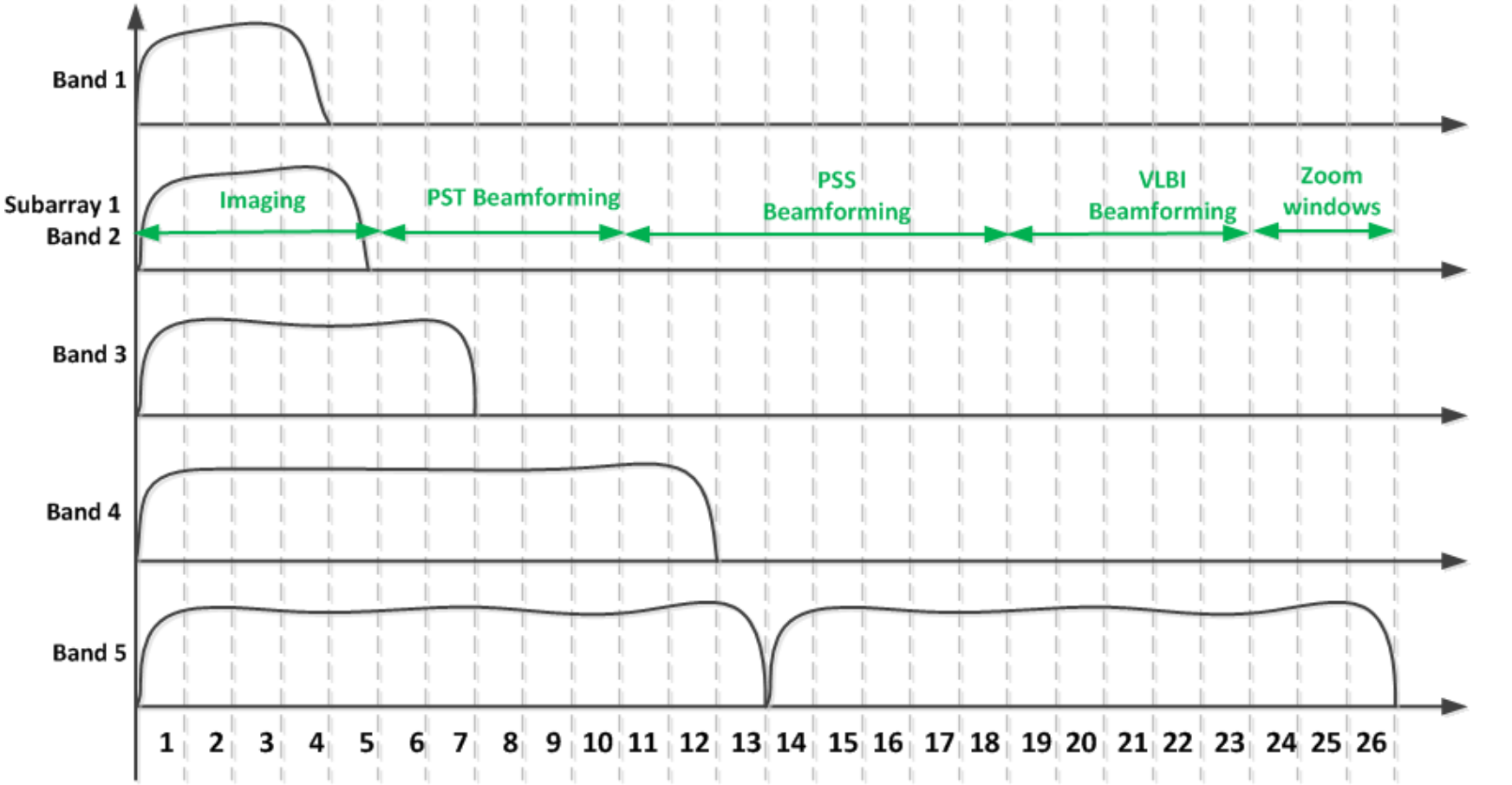
- One FSP is required for each 200 MHz of continuum BW
  5 FSPs are required to cover the 810 MHz of BW.
- One FSP can form 192 PSS Beams
  1500/192= 8 FSPs are needed to produce the PSS beams
- PST beams are formed using 200MHz ‘slices’
  810/200 (rounded up)= 5 FSPs are required for PST beamforming to ‘cover’ full Band 2 bandwidth.
- VLBI beams also require 810/200 (rounded up)= 5 FSPs, to produce 2 VLBI beams (or allocate more FSPs if more VLBI beams are required)
- Remaining 3 FSPs can be used to produce (3) Zoom Windows

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	2	810.0	3	1500	810.0	16	810.0	2

ECP 170017 Example 4:

Band 2: VLBI beamforming , imaging, pulsar search, and pulsar timing

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	2	810.0	3	1500	810.0	16	810.0	2



ECP 170017 Example 5:

Wideband continuum: simultaneous all bands (using subarrays)

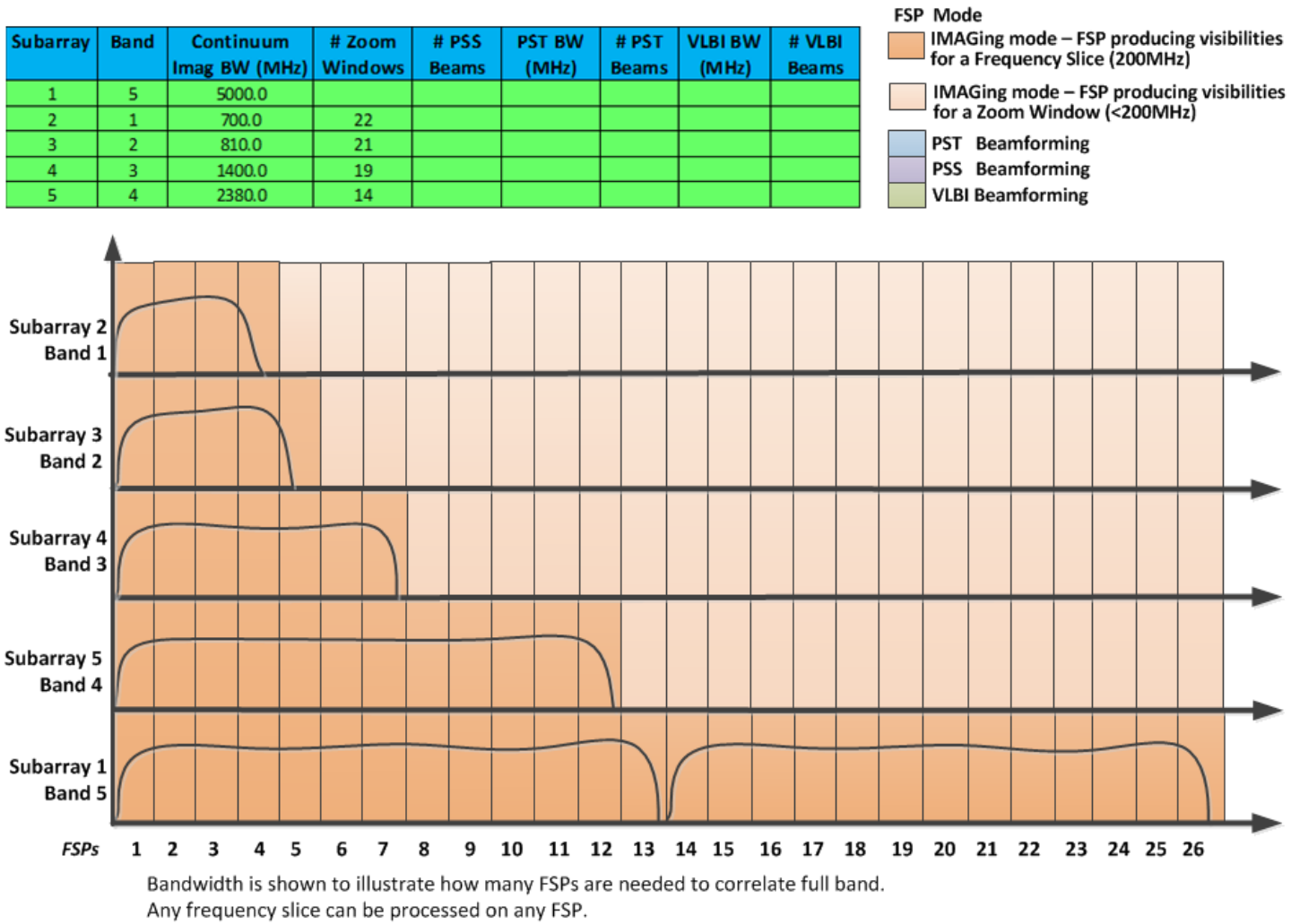
- Full Band 5 continuum bandwidth, with other sub-arrays full continuum and zoom windows
- All 26 FSPs are in Mode= CORR(elation)

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	5	5000.0						
2	1	700.0	22					
3	2	810.0	21					
4	3	1400.0	19					
5	4	2380.0	14					

ECP 170017 Example 5:

Wideband continuum: simultaneous all bands (using subarrays)

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	5	5000.0						
2	1	700.0	22					
3	2	810.0	21					
4	3	1400.0	19					
5	4	2380.0	14					



Bandwidth is shown to illustrate how many FSPs are needed to correlate full band.
Any frequency slice can be processed on any FSP.

ECP 170017 Example 6:
16 sub-arrays, each with different observing goals

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams	Subarray N_Imag_FSPs	Subarray N_PSS_FSPs	Subarray N_PST_FSPs	Subarray N_VLBI_FSPs
1	1	700.0	5	500	700.0	4	600.0	2	9	2.604	4	3
2	2	810.0	5	1000	810.0	4	600.0	2	10	5.208	5	3
3	3	1400.0	3						10	0.000	0	0
4	5	2000.0			1000.0	4			10	0.000	5	0
5	5	2000.0			1000.0	4			10	0.000	5	0
6	5	2000.0					600.0	2	10	0.000	0	3
7	5	2000.0					600.0	2	10	0.000	0	3
8	5	1000.0	5						10	0.000	0	0
9	4	2000.0							10	0.000	0	0
10	4	2000.0							10	0.000	0	0
11	4	2000.0							10	0.000	0	0
12	3		10				600.0	2	10	0.000	0	3
13	3		10				600.0	2	10	0.000	0	3
14	3		10				600.0	2	10	0.000	0	3
15	2		10						10	0.000	0	0
16	2		10						10	0.000	0	0

16 *Note: Total number of PST beams can't exceed 16--the PST sub-element limit*

1500 *Note: Total number of PSS beams can't exceed 1500--the PSS sub-element limit*

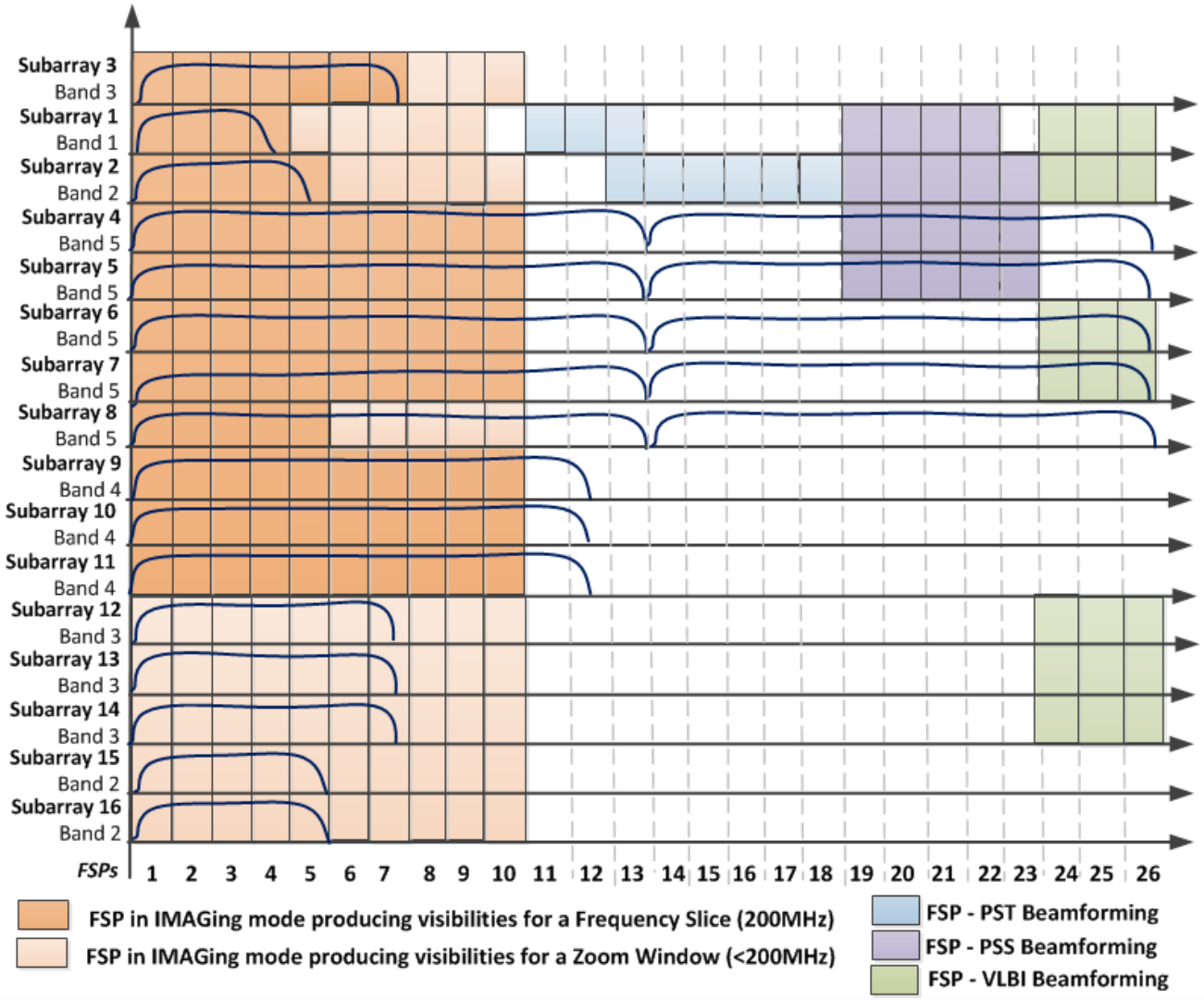
SYSTEM FSPs	
N_imag_FSPs	10
N_PSS_FSPs	8
N_PST_FSPs	5
N_VLBI_FSPs	3
TOTAL_FSPs	26

Note: Each imaging FSP can do any coarse (200 MHz) or zoom bandwidth

PSS beams are always 300 MHz wide

Note: Max 26 FSPs in the baseline system

ECP 170017 Example 6:
16 sub-arrays, each with different observing goals



- Bandwidth is shown to illustrate how much of the observed band is correlated.
- 200MHz Frequency Slice can be placed anywhere within the band.
- Each FSP receives 200MHz Frequency Slice or 300MHz Search Window for each dish.
- 200MHz Frequency Slices are used as input for CORR, PST-BF, VLBI.
- 300MHz Search Windows are used as input for PSS-BF.

Questions and Discussion?

Thank you.

SKA
SQUARE KILOMETRE ARRAY
CSP
CENTRAL SIGNAL PROCESSOR