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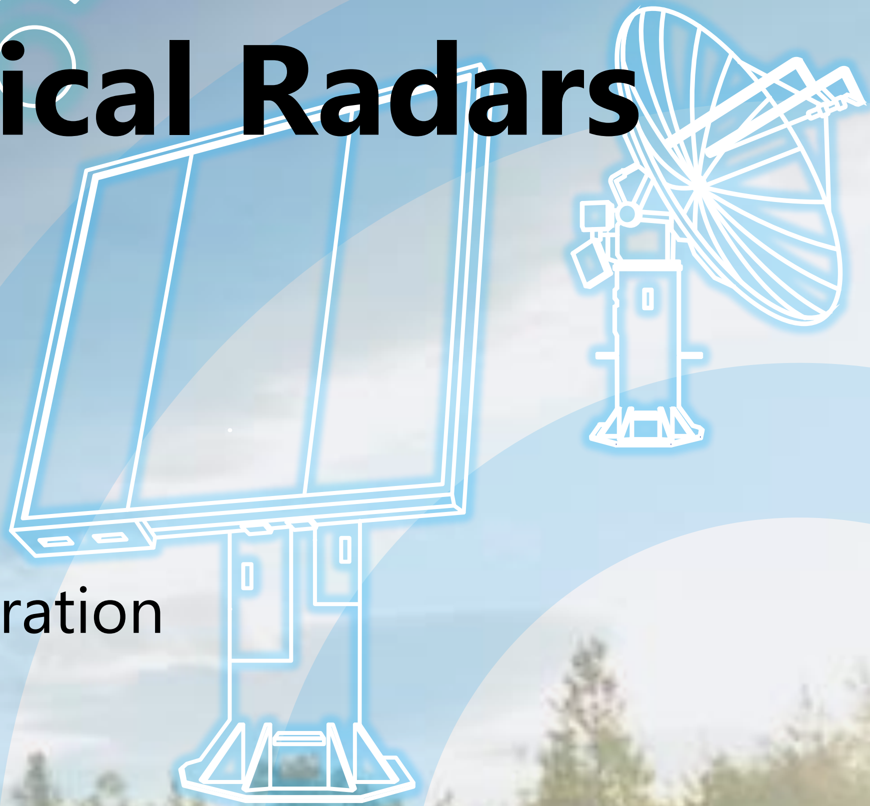
Solid-state Meteorological Radars in the C and X Bands



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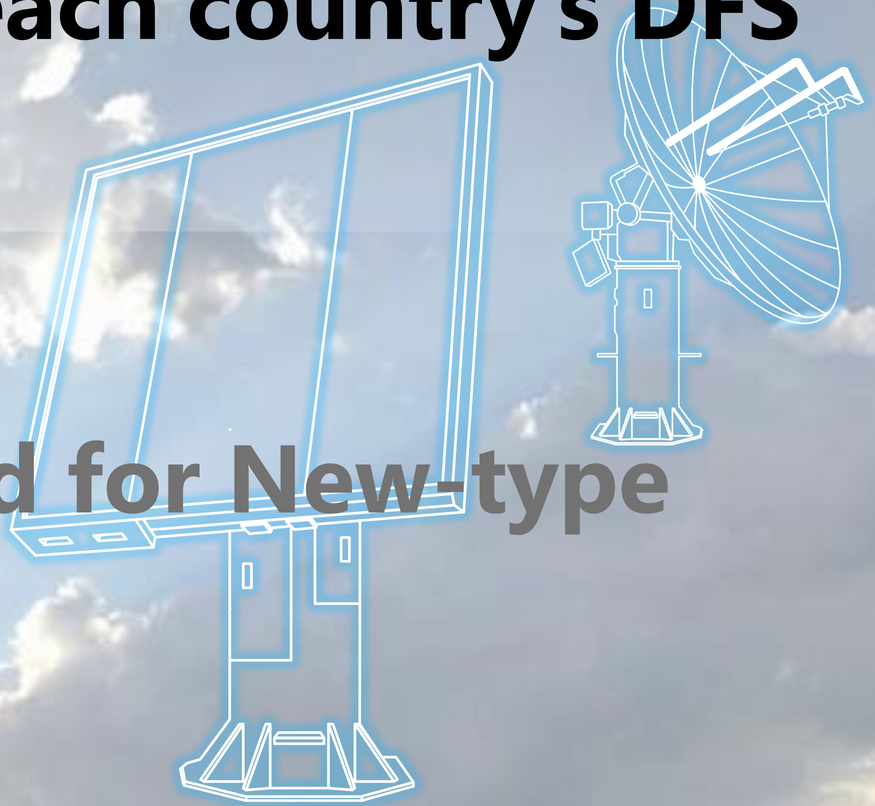
Japan

Two Problems in interference between Weather radars and Wireless communications

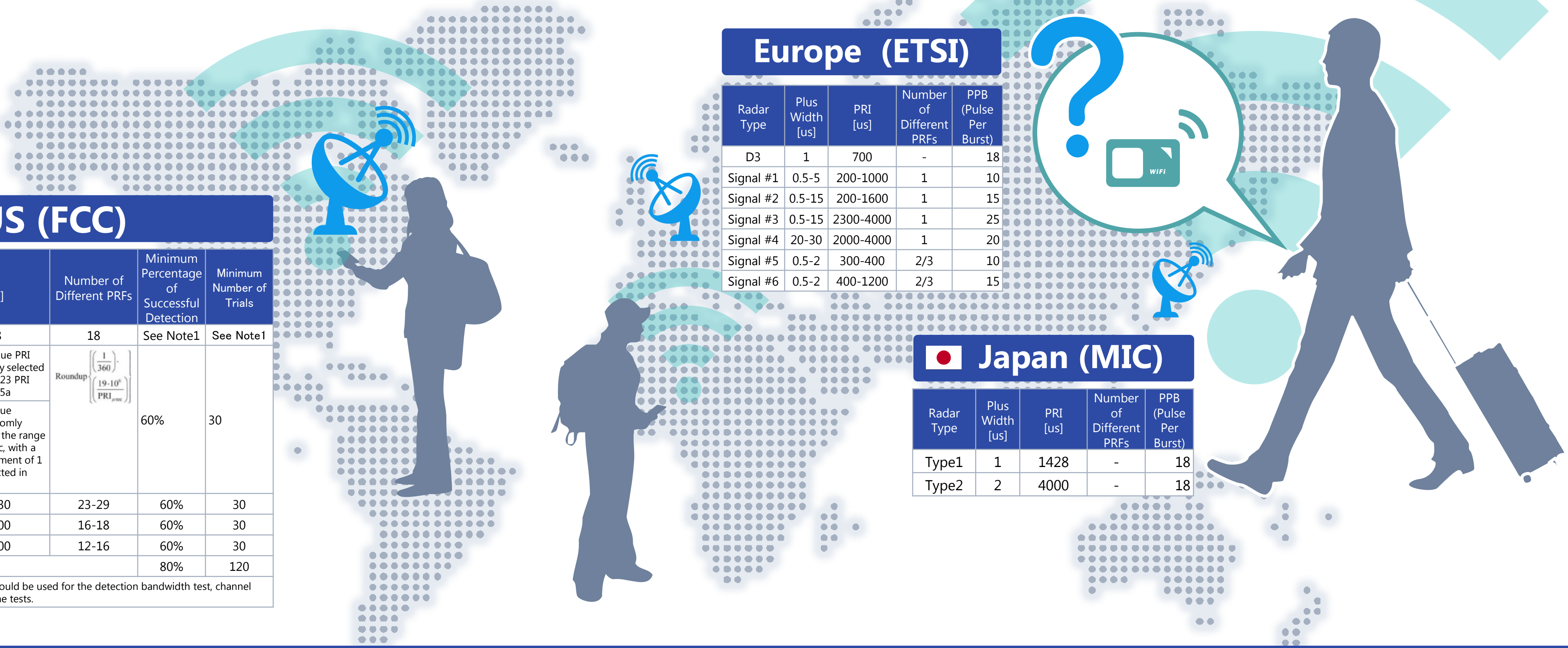
1. **Incompatibility among each country's DFS standards**

2. **Unmatched DFS standard for New-type weather radar**



Each country's DFS Technical Standard

We can illegally use the wireless communication equipment in any countries, but the technical standard of each country is different.



US (FCC)

Radar Type	Plus Width [us]	PRI [usec]	Number of Different PRFs	Minimum Percentage of Successful Detection	Minimum Number of Trials
0	1	1428	18	See Note1	See Note1
1		**Test A:** 15 unique PRI values randomly selected from the list of 23 PRI values in Table 5a **Test B:** 15 unique PRI values randomly selected within the range of 518-3066 sec, with a minimum increment of 1 PRI values selected in Test A	$\text{Roundup}\left\{\left(\frac{1}{360}\right)\cdot\left(\frac{19\cdot10^6}{PRI_{\mu sec}}\right)\right\}$	60%	30
2	1-5	150-230	23-29	60%	30
3	6-10	200-500	16-18	60%	30
4	11-20	200-500	12-16	60%	30
Aggregate (Radar Types 1-4)				80%	120

Note 1: Short Pulse Radar Type 0 should be used for the detection bandwidth test, channel move time, and channel closing time tests.

Europe (ETSI)

Radar Type	Plus Width [us]	PRI [us]	Number of Different PRFs	PPB (Pulse Per Burst)
D3	1	700	-	18
Signal #1	0.5-5	200-1000	1	10
Signal #2	0.5-15	200-1600	1	15
Signal #3	0.5-15	2300-4000	1	25
Signal #4	20-30	2000-4000	1	20
Signal #5	0.5-2	300-400	2/3	10
Signal #6	0.5-2	400-1200	2/3	15

Japan (MIC)

Radar Type	Plus Width [us]	PRI [us]	Number of Different PRFs	PPB (Pulse Per Burst)
Type1	1	1428	-	18
Type2	2	4000	-	18

- Inefficiency for RLAN manufacturers
- Risk for radar users

→ Unified standards

Two Problems in interference between Weather radars and Wireless telecommunications

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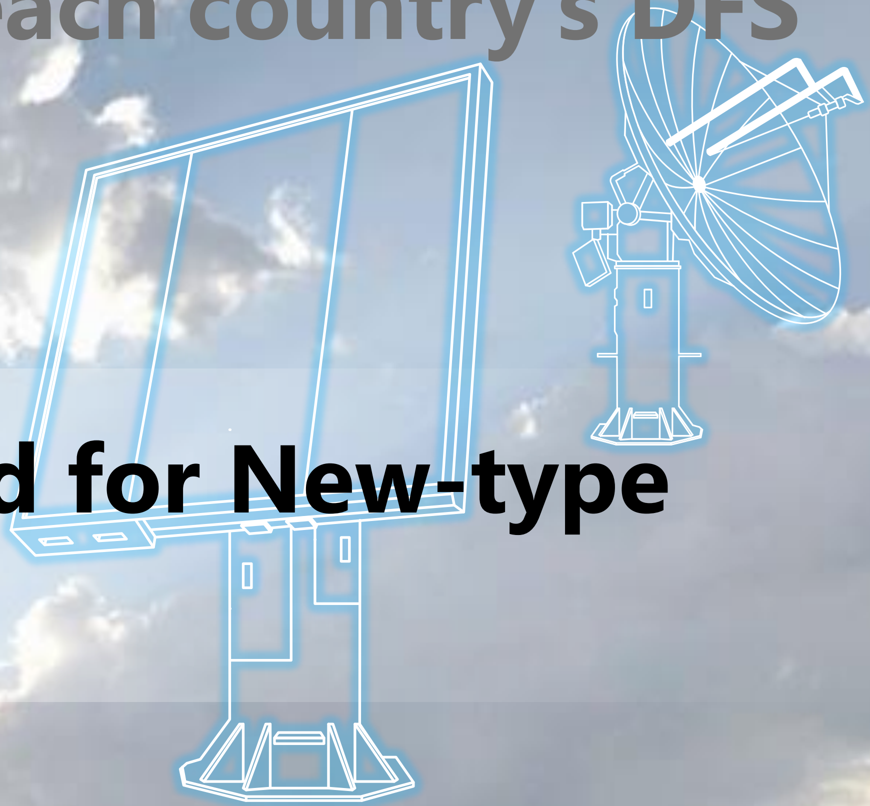
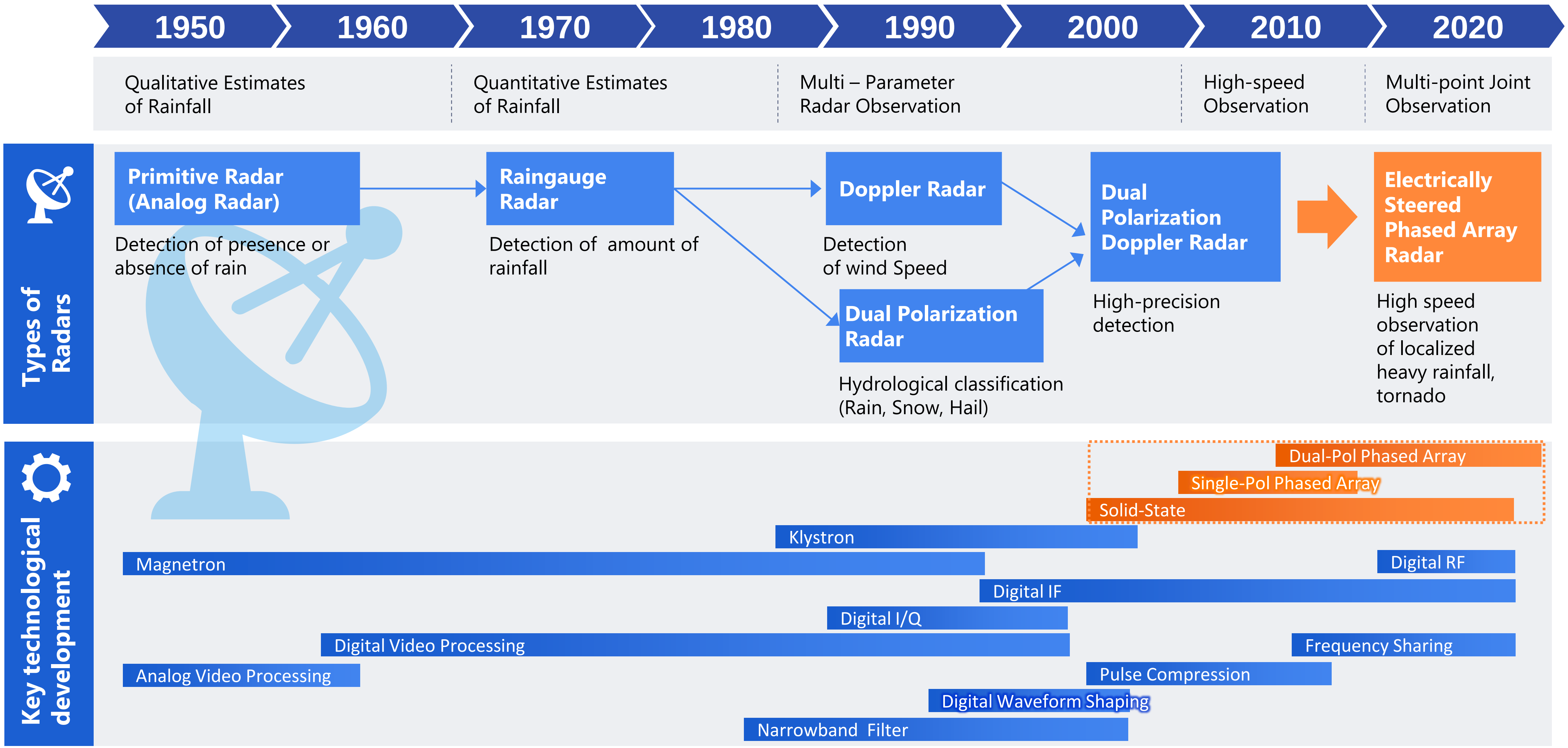
2. **Unmatched DFS standard for New-type weather radar**



Evolution of Weather Radar



Dual-Pol SSWR（Solid-State Weather Radar） in C-band

Already commercialized S-, C-, and X-band Solid-State Weather Radar

Advantages of SSWR

Accurate Observations

High quality dual polarization data

Low Life-Cycle Costs

No need for the replacement of high-cost Klystron

Operational Continuity

- Power Amp. Unit can be made redundant
- Modules can be exchanged without suspending the system

Downsizing

Reduction of the size by a factor of half compared with a Klystron transmitter

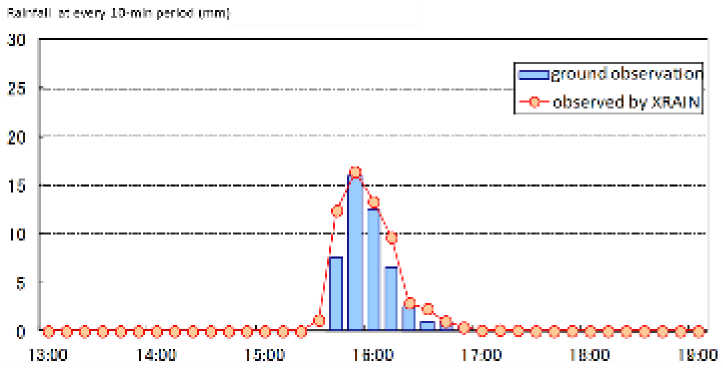
Efficient Frequency Utilization

- Less radio wave interference to the other systems
- Conform to ITU standards

Power Amp Unit (PA)

Accurate Observation

Rain gauge vs Radar, NILIM (X-Band)



Comparison between X-Band SSWR and rain gauges, 0 to 60km, 60min, MLIT, 2011

Sites	Correlation Coefficient	RMSE	Total Rainfall Ratio
Kanto	0.93	2.66	1.23
Jubu-san	0.90	2.01	1.23
Tsune-yama	0.94	2.32	1.03
Kuma-yama	0.93	2.11	1.11
Nogaibara	0.93	3.08	1.49
Usio-yama	0.91	2.99	1.58
Kusenbu	0.94	2.70	1.36
Suga-dake	0.94	2.33	1.22
Furutsuki-yama	0.92	3.03	1.16
Kazashi-yama	0.88	2.63	1.21
Sakura-jima	0.88	3.33	1.07

SSWR has high accuracy.

Operational Continuity

- Failure per radar = Num of total failure / *Num of radar
- Tx failure rate = Num of transmitter(TX) failure / Num of total failure
- Tx failure rate is lower for solid-state radar

Year		2008	2009	2010	2011	2012	2013	2014	2015	8 years total
Mag/KLY	Num of Radar	24	22	22	22	22	20	19	19	170
	Num of Total Failure	36	24	24	38	44	27	15	14	222
	Num of Tx Failure	11	5	7	12	11	10	0	2	58
	Failure per Radar [times]	1.5	1.1	1.1	1.7	2.0	1.4	0.8	0.7	1.3
	Tx Failure Rate [%]	30.6	20.8	29.2	31.6	25.0	37.0	0.0	14.3	26.1
SS	Num of Radar	1	5	5	9	9	9	12	13	63
	Num of Total Failure	1	0	0	1	7	6	5	8	28
	Num of Tx Failure	0	0	0	0	0	0	0	1	1
	Failure per Radar [times]	1.0	0.0	0.0	0.1	0.8	0.7	0.4	0.6	0.4
	Tx Failure Rate [%]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	3.6

* Num of radar : number of radar which is target of maintenance.
Not all radar systems Toshiba delivered are counted.

The number of SSWRs' failure is less than MAG/KLY Radars.

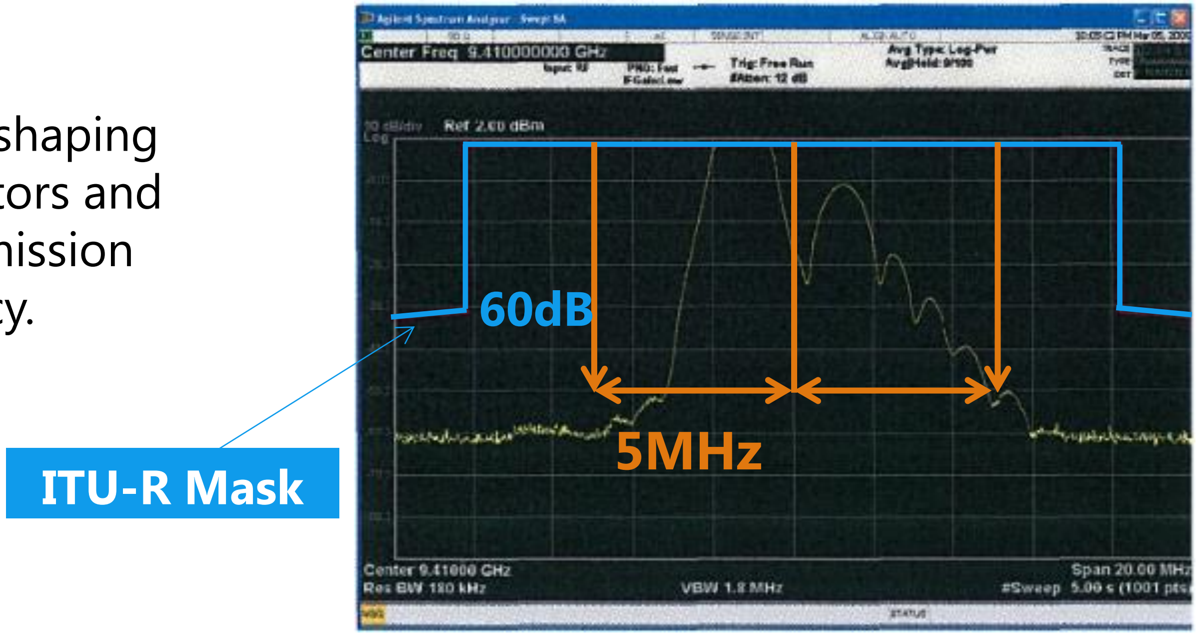
Efficient Frequency Utilization

The Spurious level of SSWRs' is lower than MAG/KLY Radars.

Reduction of vicinity spurious of transmission signal by the Solid-State radar

The solid-state transmitter facilitates waveform shaping of transmission pulse by the use of semiconductors and enables reduction of vicinity spurious of transmission signals, allowing efficient utilization of frequency.

Transmission spectrum (example)



Achieved 60dB suppression by 5MHz detuning

→ Efficient Frequency Utilization is progressing.

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Minimization of Channel Separation

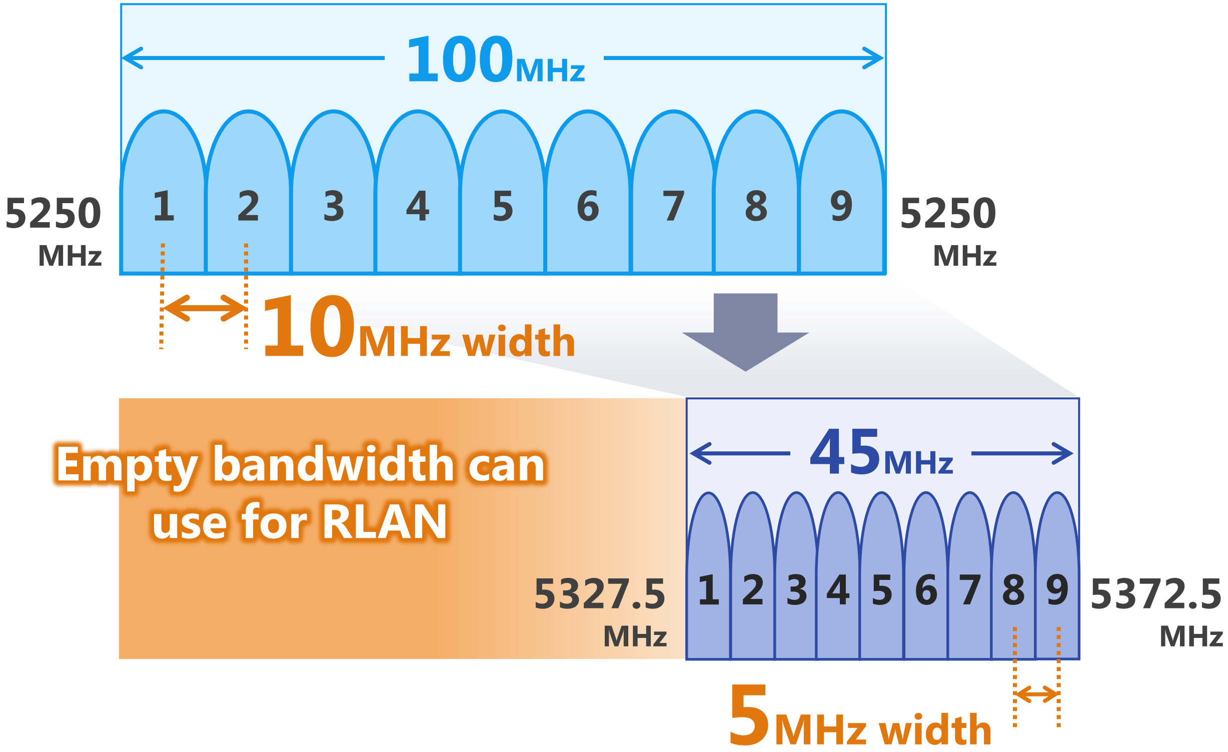
Width of Frequency Channel Assignment

	Magnetron	Klystron	**Solid - state**
Channel Separation	20 MHz	10 MHz	**5 MHz**
ITU-R standard	Non-compliant	Compliant	**Compliant**

Progress of Efficient Utilization of Frequency

Efficient Utilization of Frequency (C-Band/5GHz)

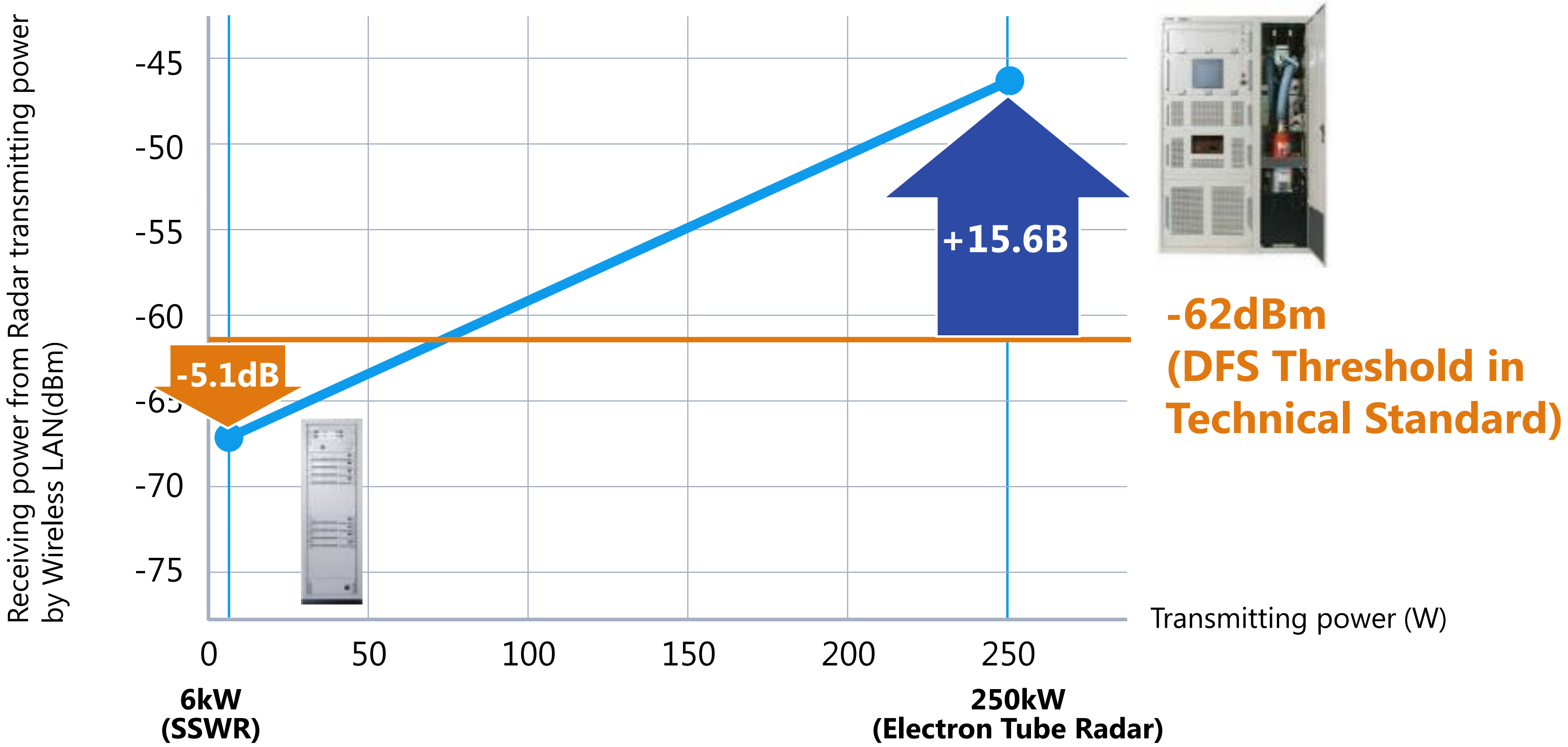
Reduce the bandwidth by one half while keeping the same number of channels (100MHz width → 45MHz width) ⇒ Reduce interference to the wireless LAN of the shared system and expand utilization



By adopting SSWR,
the usable bandwidth of RLAN will become wider.

Threshold of DFS

SSWRs have lower peak power and longer pulse width than MAG/KLY radars.

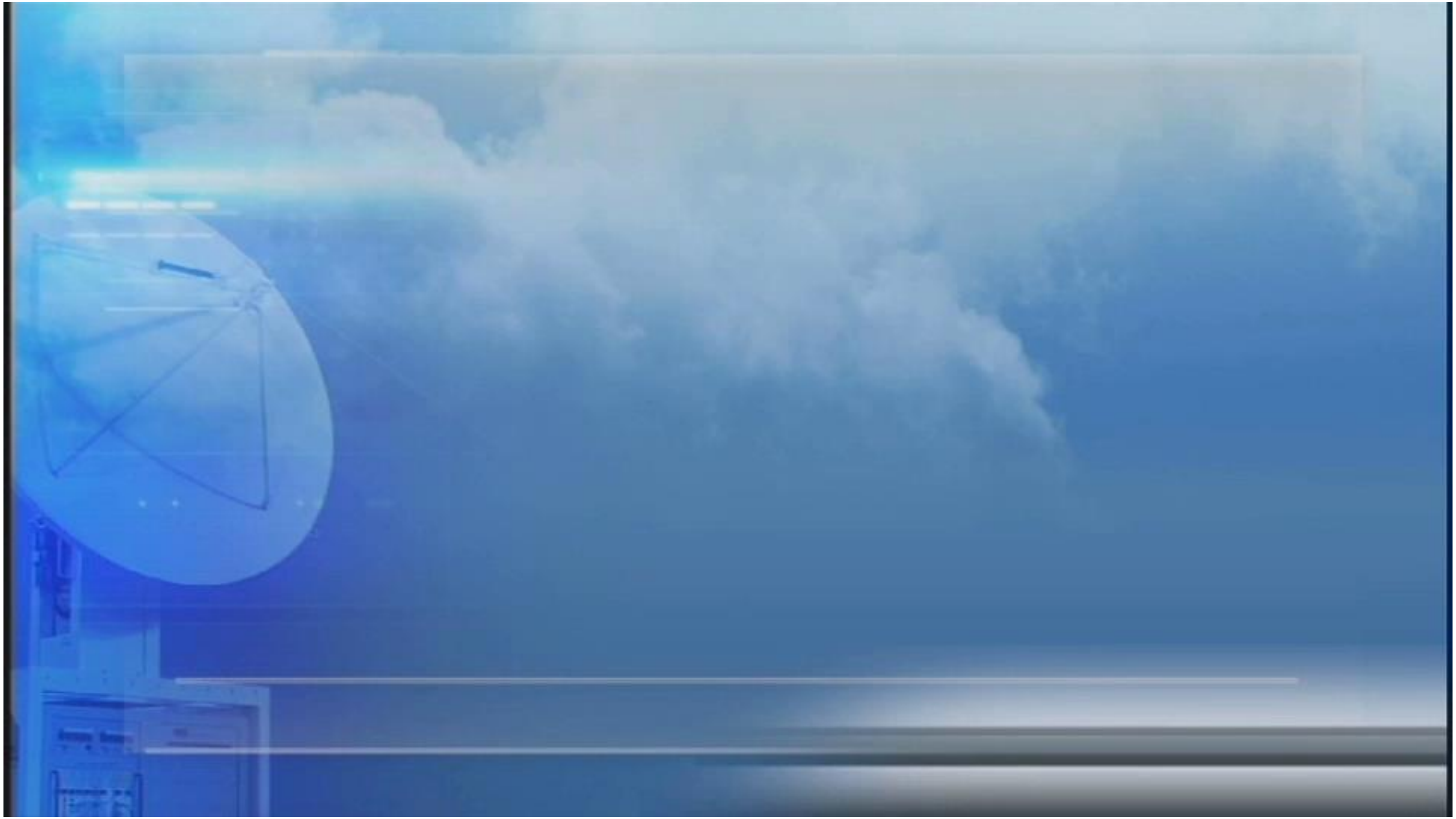


→ DFS threshold level should be lowered.

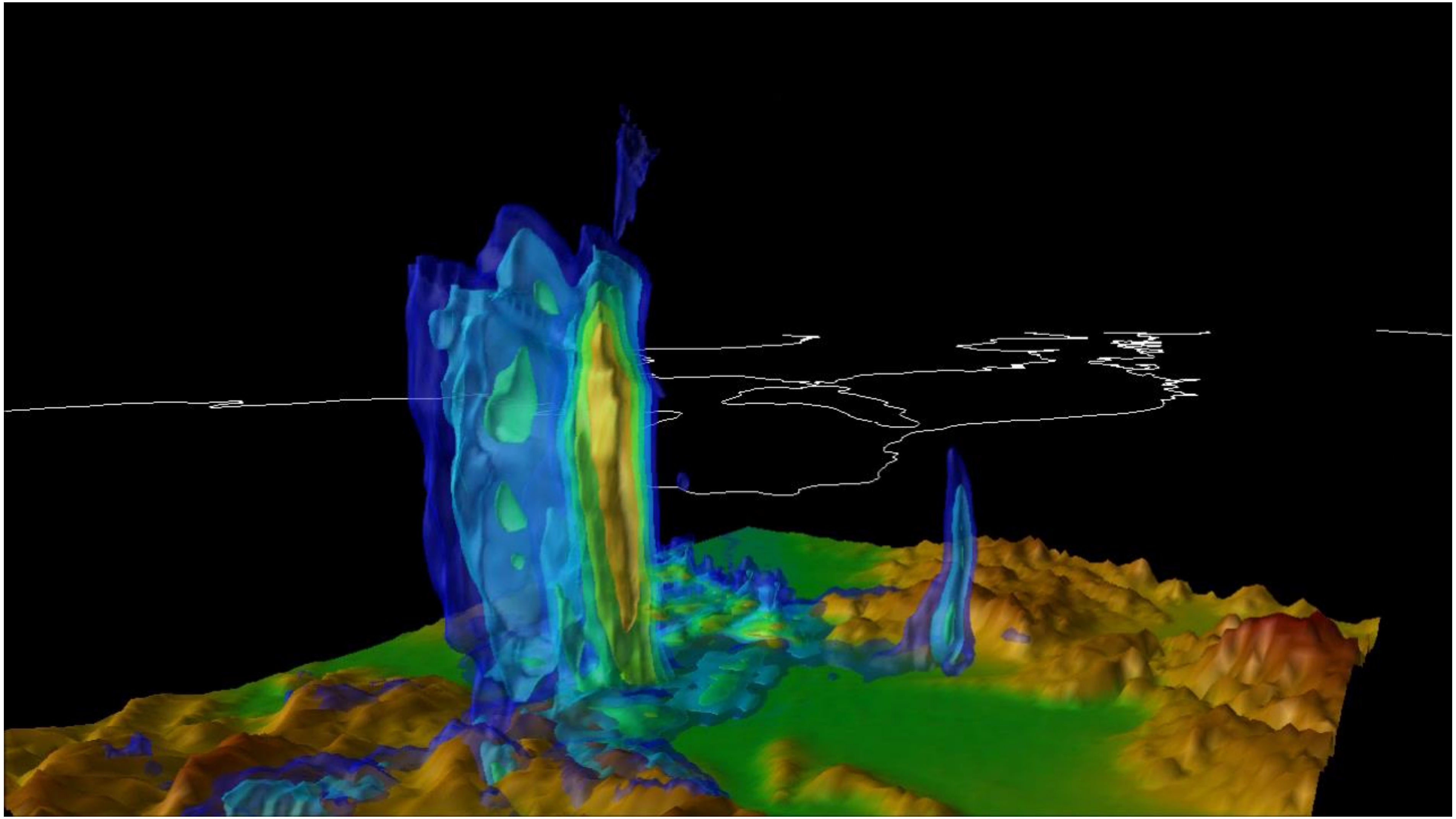
Single-pol PAWR（Phased-Array Weather Radar） in X-band

Toshiba succeeded in development of X-Band Single-pol PAWR.

Scanning Strategy



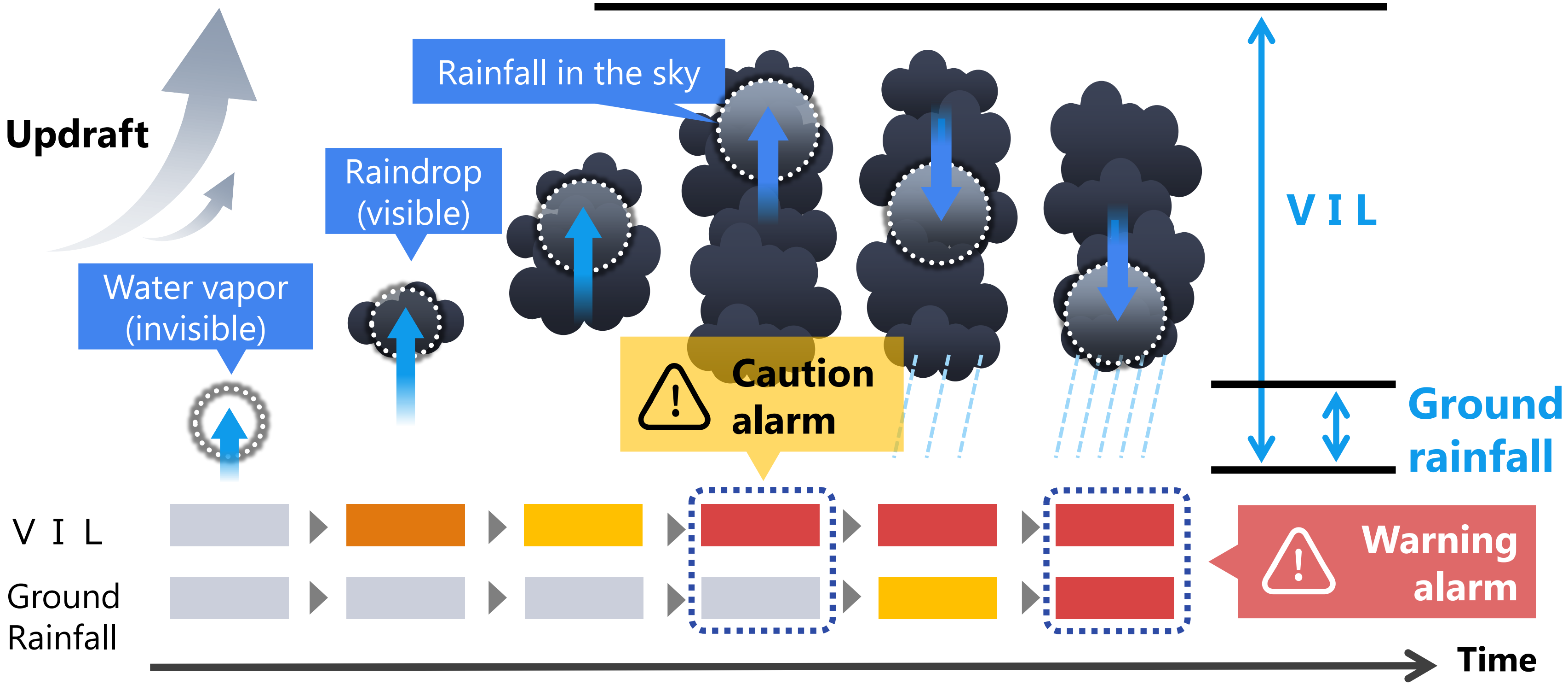
Observed Data (time interval 30sec, 300 times speed)



Courtesy of NICT

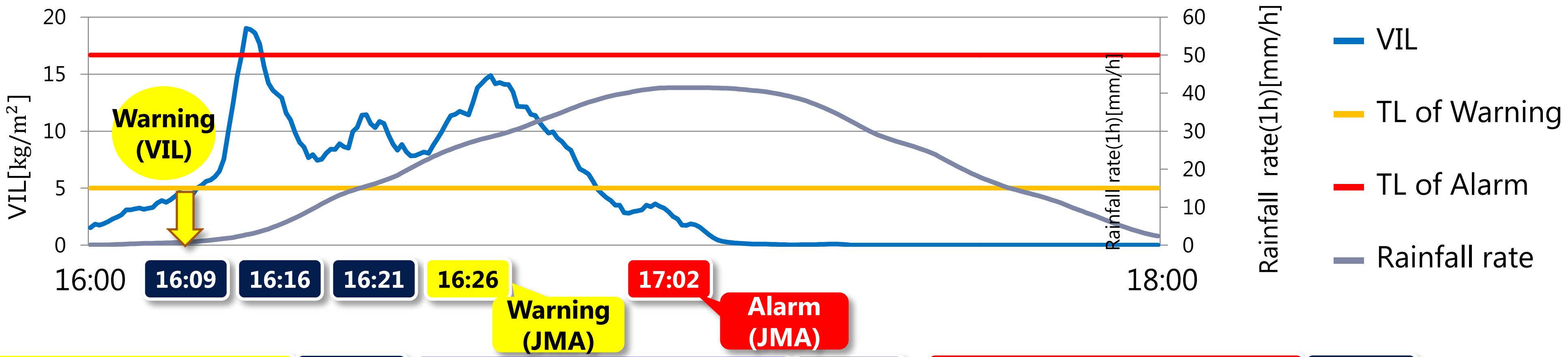
Advanced Early Warning System

- Field tests using SP-PAWR were conducted in the Kansai region, Japan.
- VIL from SP-PAWR was compared with ground rainfall observed by X-Band dual-pol parabola radar



Field Trial of Evacuation in the Park

9-Sep-2016



Warning (VIL) 16:09

Announcing warning to citizens

Evacuating 16:16

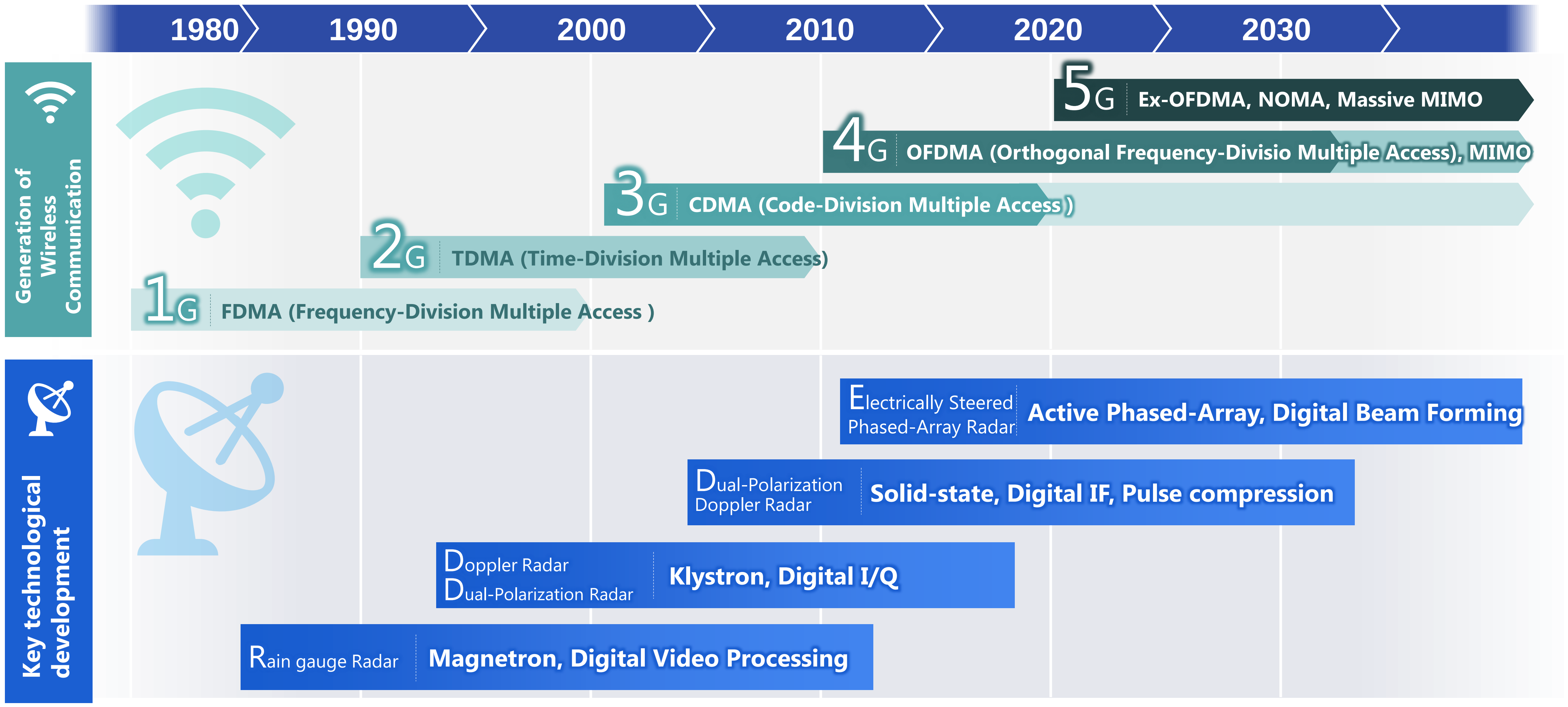
Watching evacuation by camera

Heavy rain (>50mm/h) 16:21

Heavy rain after evacuation

Succeeding Advanced Early Warning System by using PAWR

Development of wireless communication and weather radar



Weather radar technology is progressing as same as developing wireless communication technology.

Two Problems in interference between Weather radars and Wireless communications

1. **Incompatibility among each country's DFS standards**
   → It should be described the unified standard of DFS in ITU-R.

2. **Unmatched DFS standard for New-type weather radar**
   → DFS threshold level should be lowered.
   → DFS standard should be reviewed regularly (every 4 years).

Improving Efficiently Frequency Utilization of Weather radar
→ increasing the Band for RLAN

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