FEBRUARY 27, 2020

WEBINAR:

THE HOT 5G TOPIC WE DIDN'T GET TO DISCUSS AT MWC BARCELONA 2020

15:28

R E S O N A N T ®

✓ **Please visit [the events page of our website](#) to view a playback of the *Resonant 5G Technology Update Webinar* hosted on February 27, 2020.**
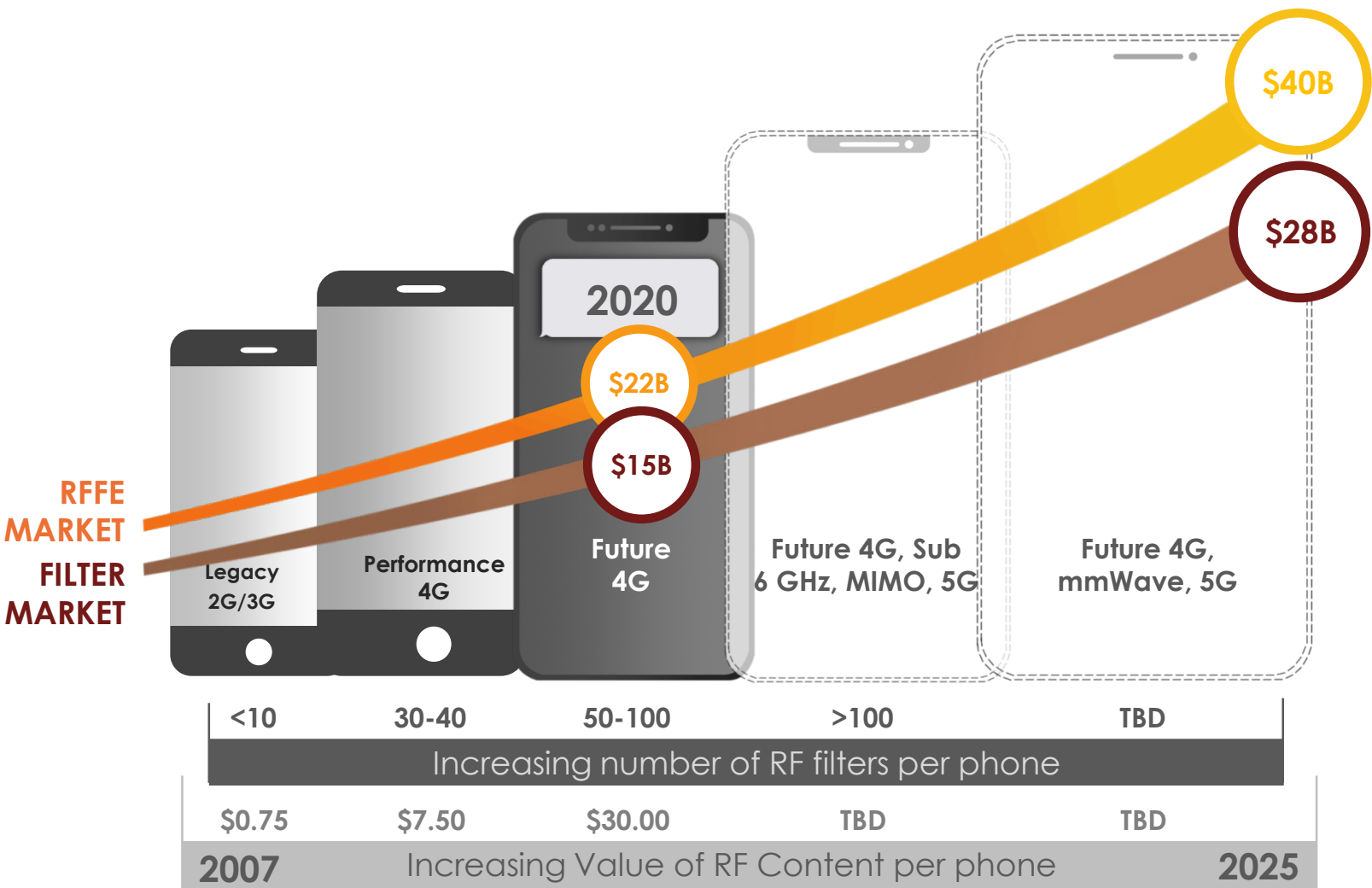
RESONANT OVERVIEW

- **Validated robust technology and IP portfolio**
  - ISN® (Infinite Synthesized Networks) multi-physics full-chip simulation platform
  - **>200 patents** filed or issued, >50 for high-frequency 5G-targeted devices

- **Demonstrated first filters known to achieve wide bandwidth required by 5G and Wi-Fi 6**

- **Foundry Program enables new entrants gain access to the filter market**
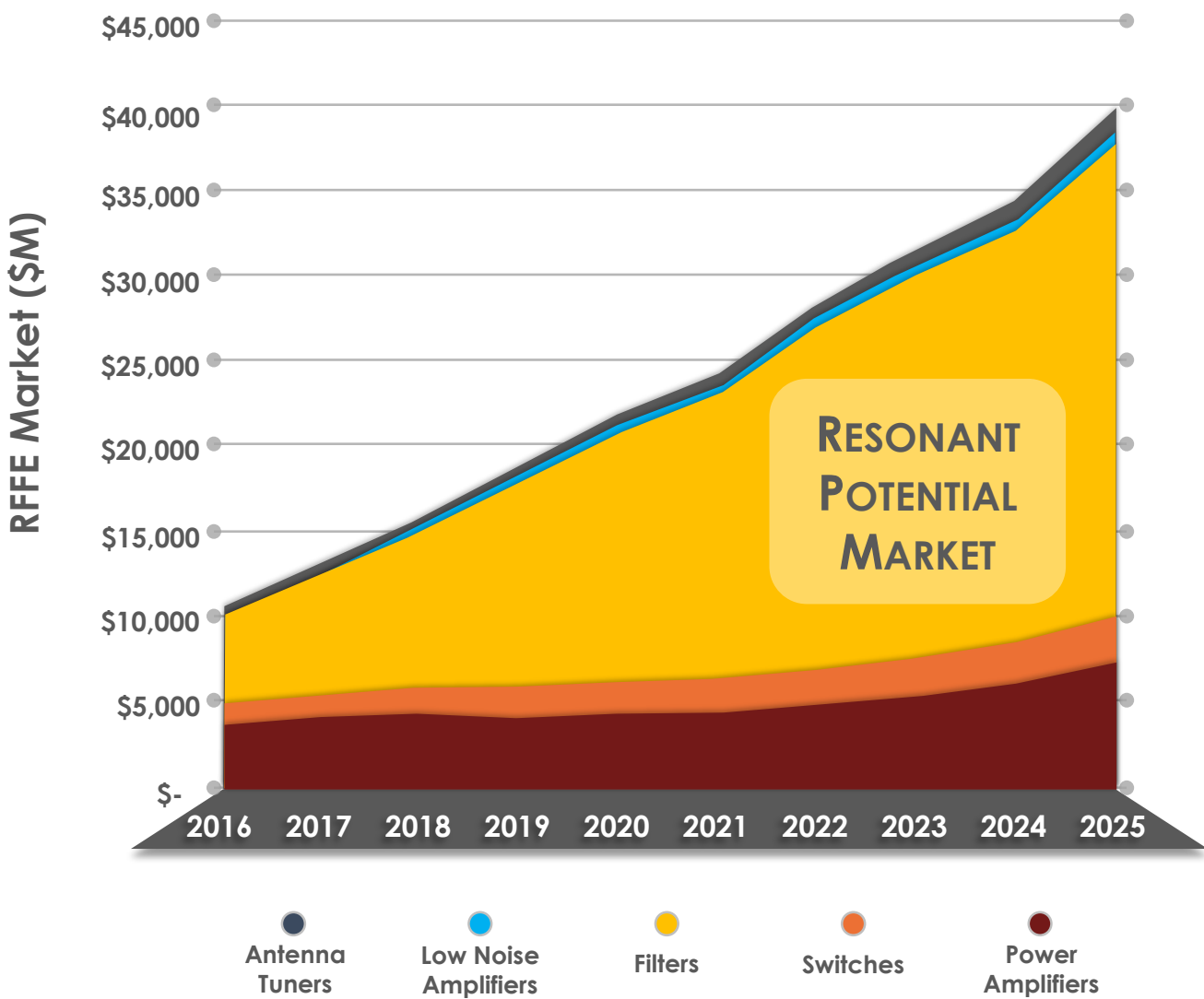 - **9 foundry partners** creating opportunities

Burlingame, Calif.
Goleta, Calif.
Austin, Texas
Neuchâtel, Switzerland
Seoul, Korea (liaison office)
Shanghai, China (sales partners)

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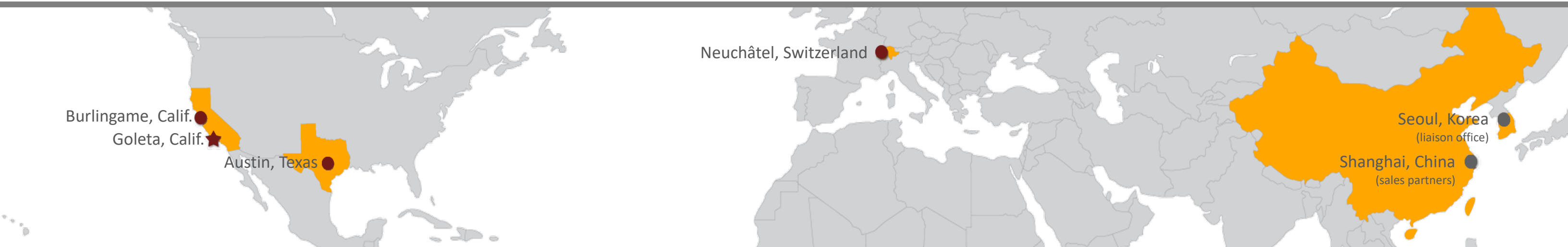
ADDRESSING LARGE AND GROWING RFFE MARKET

- **$28B filter market expected in 2025**
  - Fastest growing segment of the RF Front-End (RFFE) market
  - Streaming video driving the need for increased bandwidths and higher frequencies

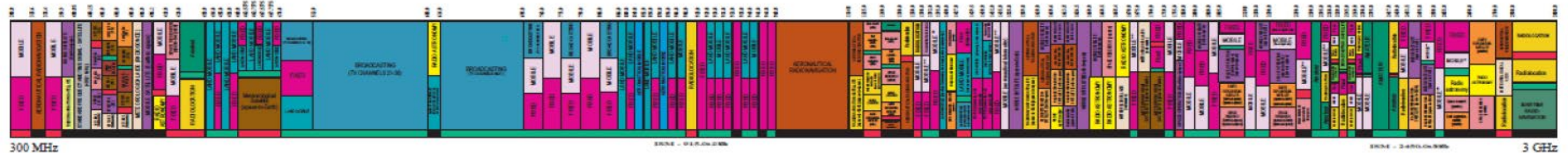## NEXT GENERATION SMARTPHONE >$30.00 RF CONTENT (PROJECTED)[1]

$40B

$28B

2020

$22B

$15B

RFFE MARKET

FILTER MARKET

Legacy 2G/3G	Performance 4G	Future 4G	Future 4G, Sub 6 GHz, MIMO, 5G	Future 4G, mmWave, 5G
<10	30-40	50-100	>100	TBD

Increasing number of RF filters per phone

$0.75	$7.50	$30.00	TBD	TBD

2007   Increasing Value of RF Content per phone   **2025**

FILTERS ARE THE LARGEST SEGMENT OF THE RFFE MARKET[2]

RFFE Market ($M)

$45,000
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$-

2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

RESONANT POTENTIAL MARKET

● Antenna Tuners   ● Low Noise Amplifiers   ● Filters   ● Switches   ● Power Amplifiers

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THE IMPORTANCE OF FILTERS

US frequency spectrum allocation

A unique filter is required for each band of operation

BAND PASSING
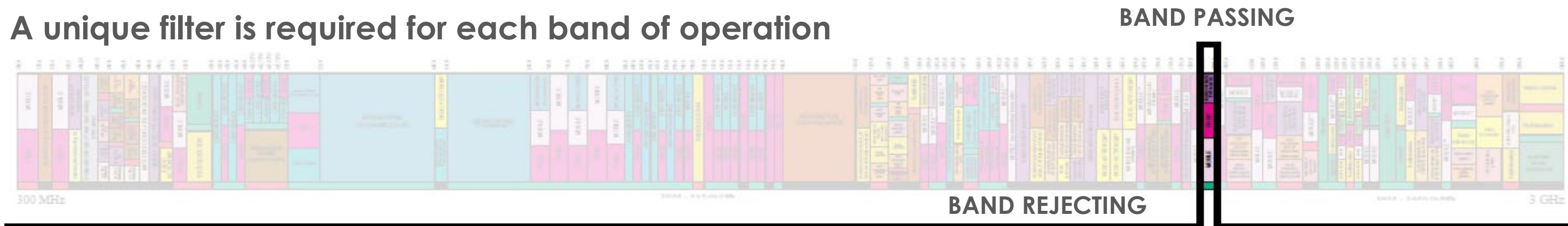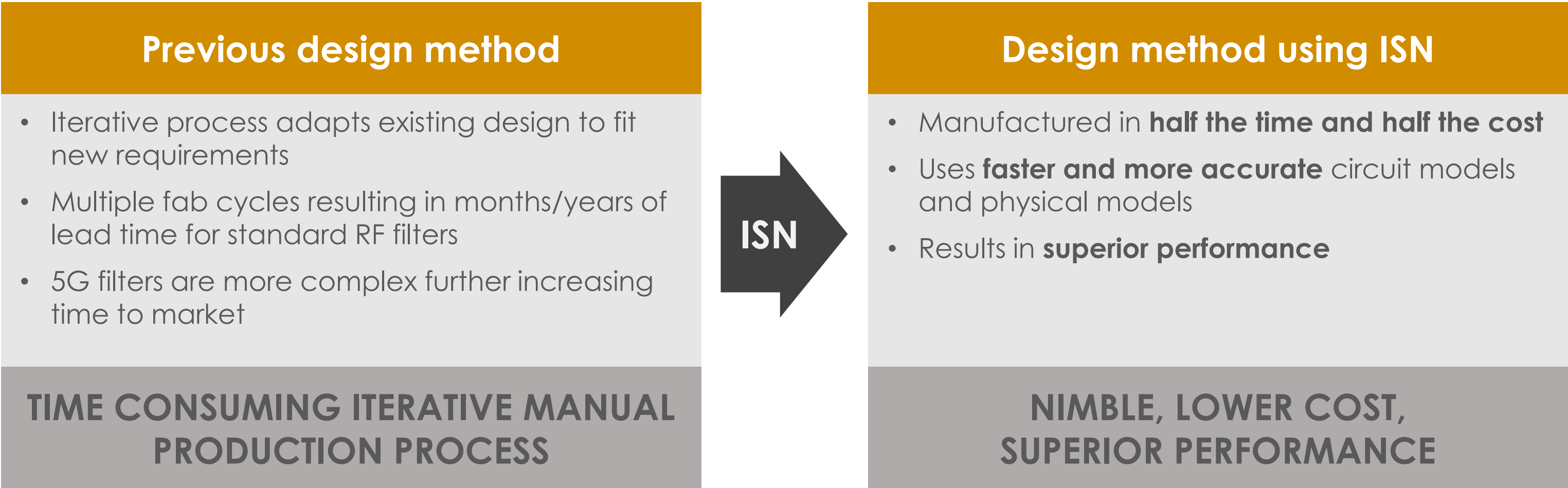
BAND REJECTING

Requirements

- Low loss → Critical for range (dropped calls), battery life, heating, and data throughput
- High rejection → Mandatory to eliminate interference from other bands which drops calls and cuts data throughput
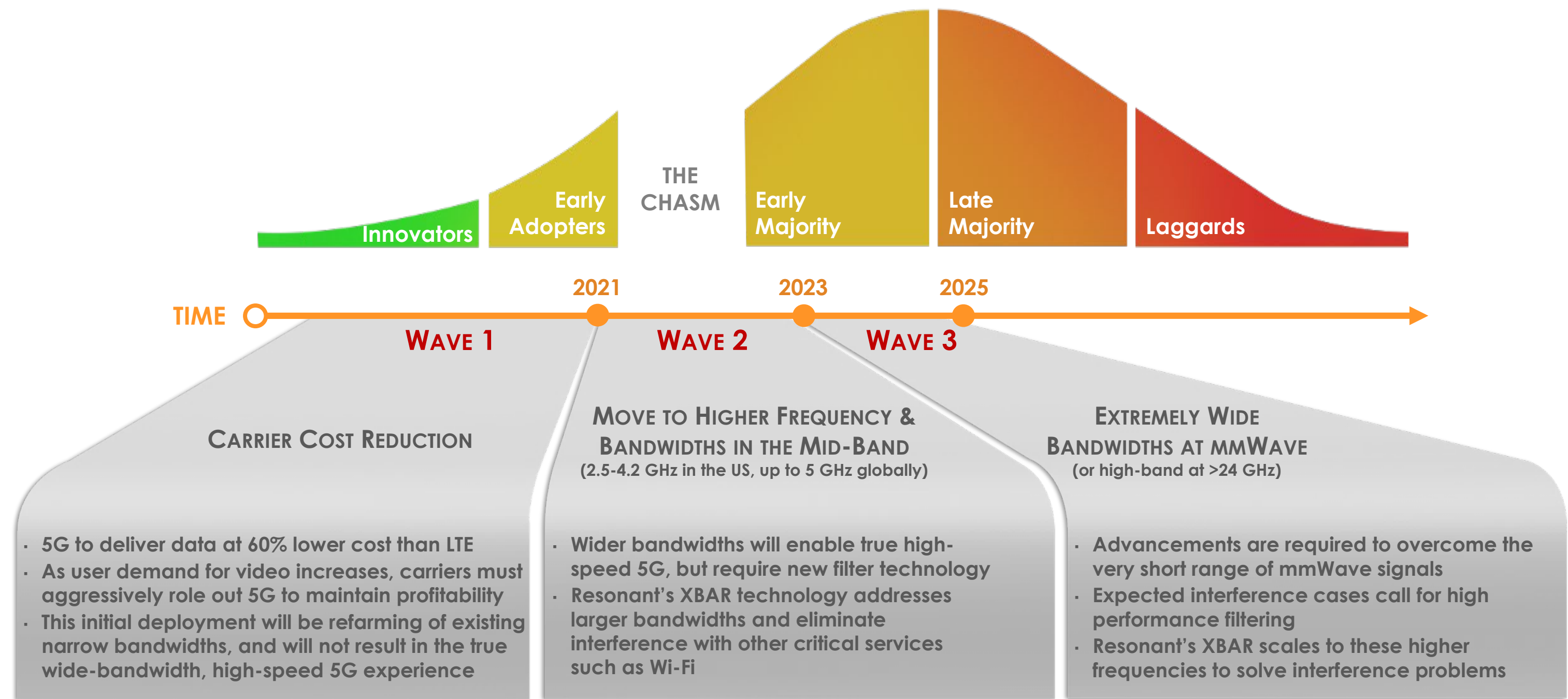
Sources: U.S. Department of Commerce.

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DISRUPTIVE TECHNOLOGY DRIVES GROWTH
RESONANT'S ISN

- **ISN** EDA platform revolutionizes filter design through full-chip, multi-physics complete simulation
- Streamlined design process creates complex filters required for both the 4G and 5G markets
- No comparable acoustic wave filter design EDA platform exists in the market today

Previous design method

- Iterative process adapts existing design to fit new requirements
- Multiple fab cycles resulting in months/years of lead time for standard RF filters
- 5G filters are more complex further increasing time to market

TIME CONSUMING ITERATIVE MANUAL PRODUCTION PROCESS

ISN

Design method using ISN

- Manufactured in **half the time and half the cost**
- Uses **faster and more accurate** circuit models and physical models
- Results in **superior performance**

NIMBLE, LOWER COST, SUPERIOR PERFORMANCE

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THE THREE WAVES OF 5G

THE CHASM

| Innovators | Early Adopters | Early Majority | Late Majority | Laggards |

TIME ————— 2021 ————— 2023 ————— 2025 —————→

WAVE 1 **WAVE 2** **WAVE 3**

CARRIER COST REDUCTION

MOVE TO HIGHER FREQUENCY & BANDWIDTHS IN THE MID-BAND
(2.5-4.2 GHz in the US, up to 5 GHz globally)

EXTREMELY WIDE BANDWIDTHS AT MMWAVE
(or high-band at >24 GHz)

- 5G to deliver data at 60% lower cost than LTE
- As user demand for video increases, carriers must aggressively role out 5G to maintain profitability
- This initial deployment will be refarming of existing narrow bandwidths, and will not result in the true wide-bandwidth, high-speed 5G experience

- Wider bandwidths will enable true high-speed 5G, but require new filter technology
- Resonant's XBAR technology addresses larger bandwidths and eliminate interference with other critical services such as Wi-Fi

- Advancements are required to overcome the very short range of mmWave signals
- Expected interference cases call for high performance filtering
- Resonant's XBAR scales to these higher frequencies to solve interference problems

WAVE 2 REQUIRES WIDE BANDWIDTH - HIGH REJECTION - HIGH FREQUENCY FILTERS

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RESONANT'S XBAR®
PROPRIETARY RESONATOR STRUCTURE

- XBAR is Resonant's revolutionary BAW resonator structure produced using standard SAW processes

  - Designed specifically to meet the exacting demands of 5G and Wi-Fi coexistence

  - Provides 3-4x larger native bandwidth than competing SAW and BAW technologies

  - Expected to outperform all other resonators in critical 5G and Wi-Fi frequencies >3 GHz

- Demonstrated better insertion loss, rejection levels, and wider passbands

  - Compared against today's 4G BAW and FBAR technologies
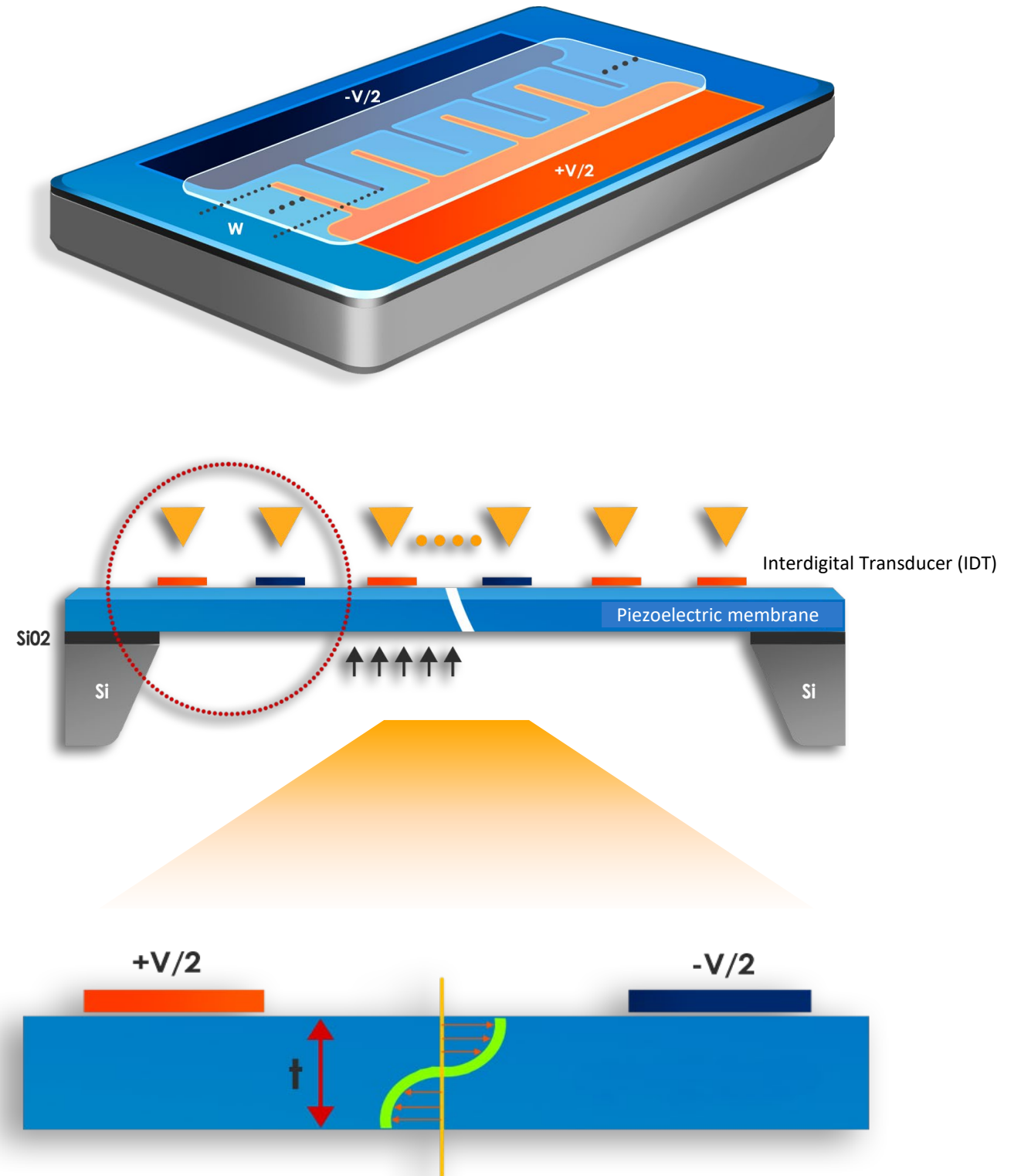
XBAR FILTERS REALIZE THE FULL 5G AND Wi-Fi POTENTIAL

WIDE BANDWIDTH XBAR DESIGNS ENABLED BY ISN
ACCURATE AGREEMENT BETWEEN MEASURED AND MODELED DATA USING ISN
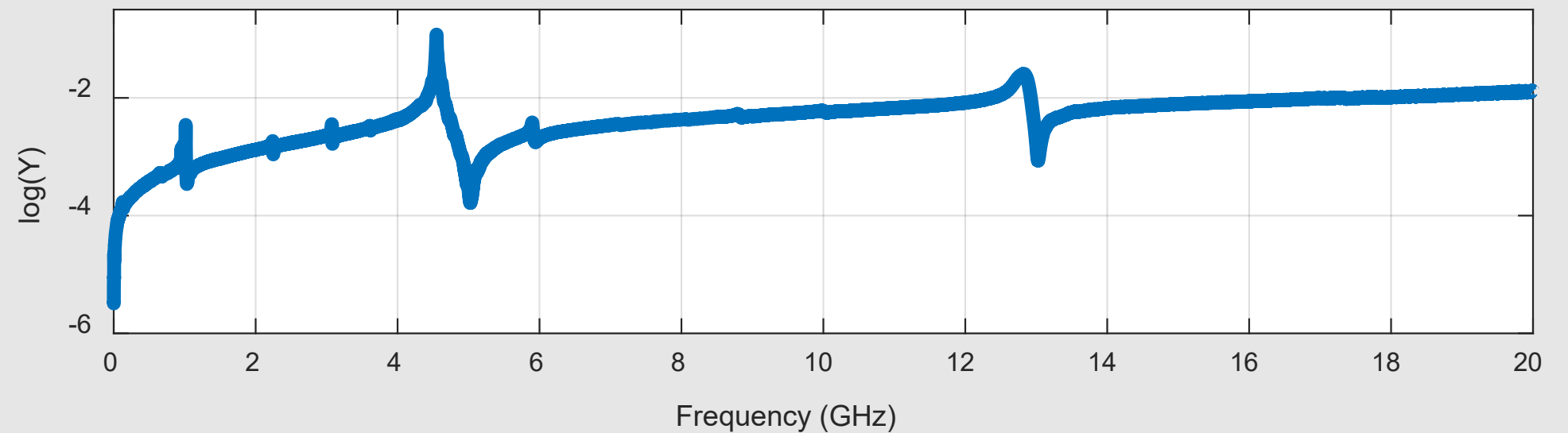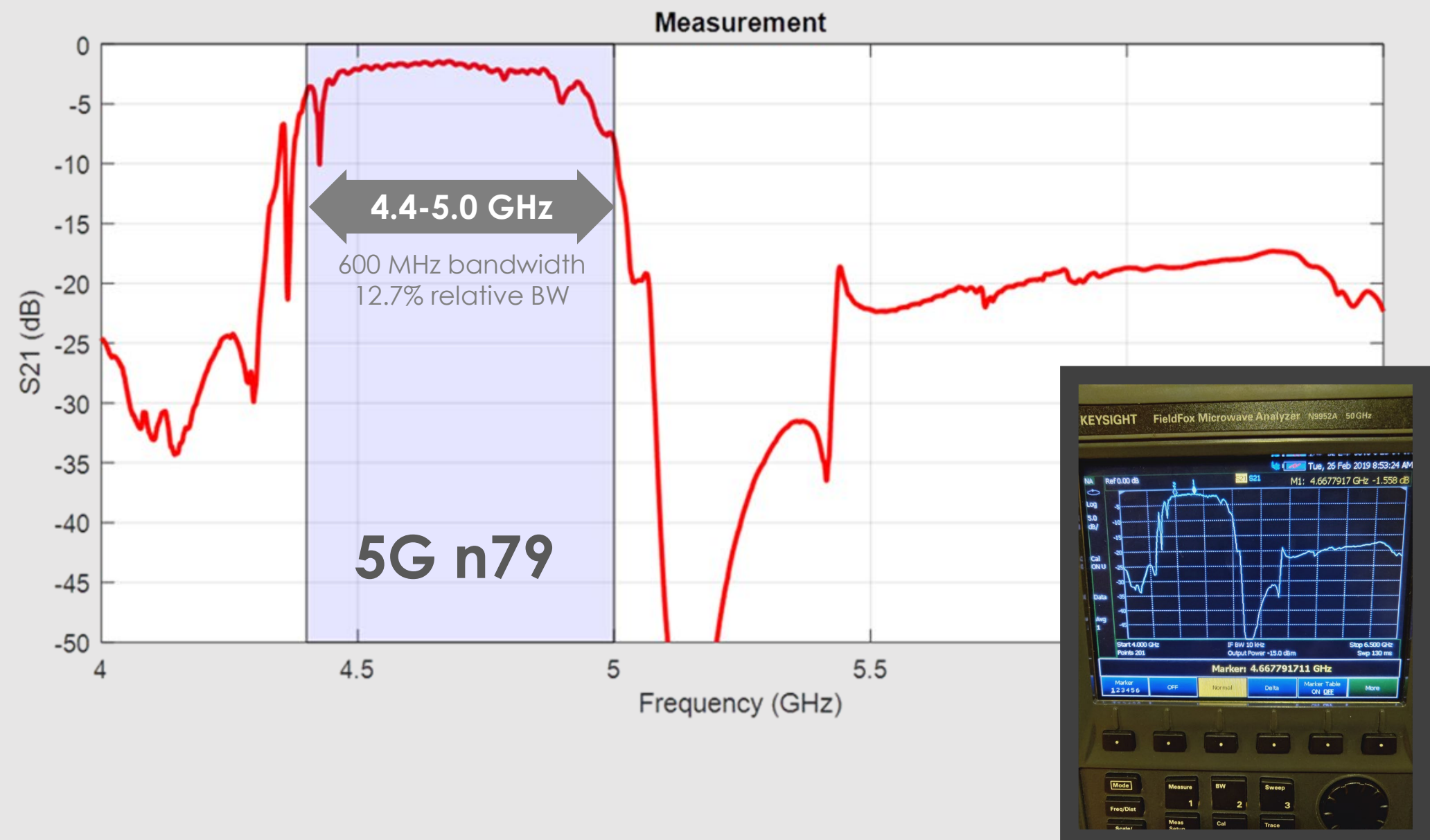
MEASUREMENT

SIMULATION
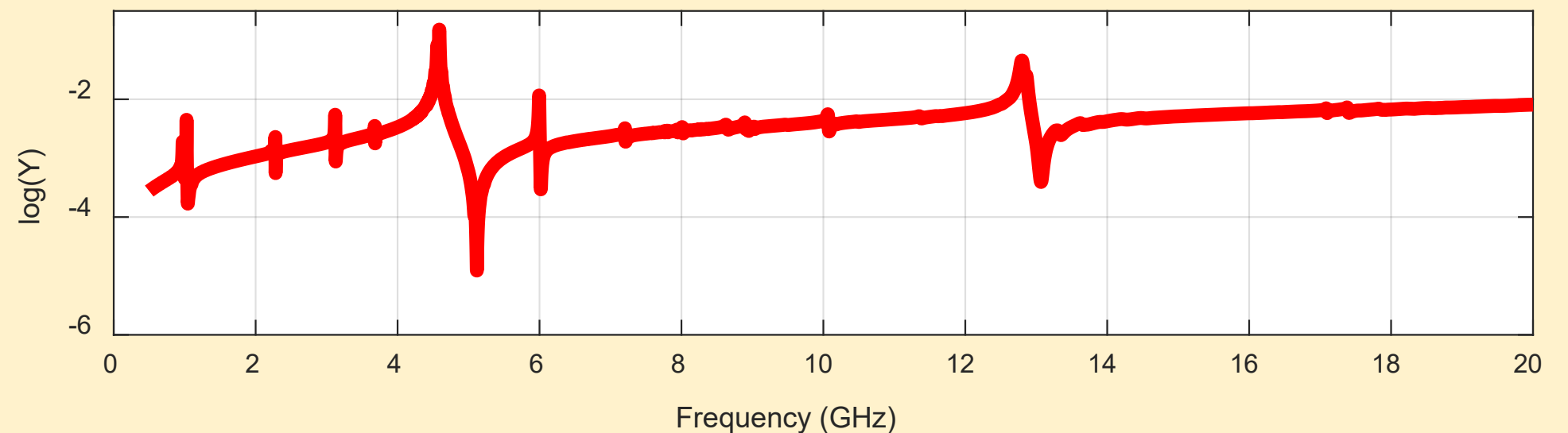
FIRST DEMONSTRATION OF VERY LARGE BANDWIDTH CAPABILITY REQUIRED FOR 5G

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LOOKING BACK ONE YEAR: INITIAL XBAR RESULTS

MEASUREMENT

- First acoustic filter to demonstrate bandwidth of ~600 MHz at 5 GHz

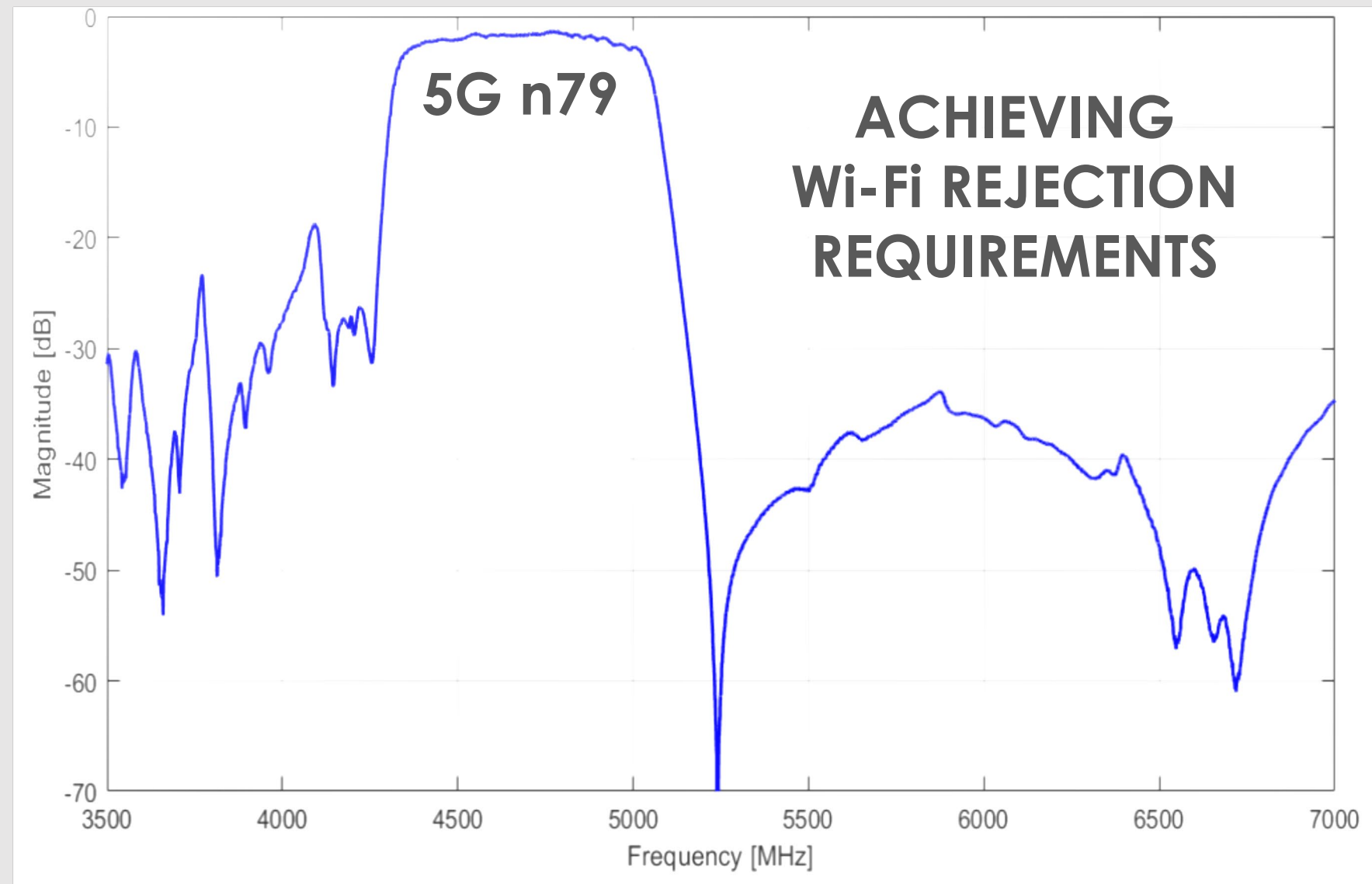- 1.5 dB minimum insertion loss with real matching applied

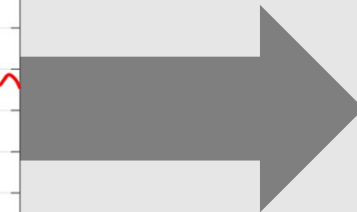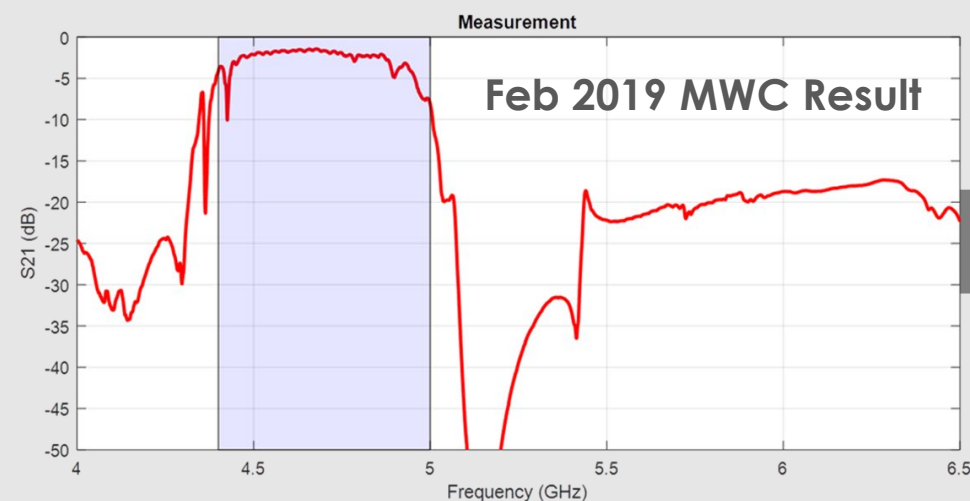**Measurement**

4.4-5.0 GHz

600 MHz bandwidth
12.7% relative BW

5G n79

1ST ACOUSTIC FILTER TO DEMONSTRATE BANDWIDTH OF ~600 MHz AT 5 GHz (>10% BANDWIDTH)

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RAPID EVOLUTION ENABLED BY ISN
MEETING 5G REQUIREMENTS

May 2019

MEASUREMENT

Feb 2019 MWC Result

5G n79

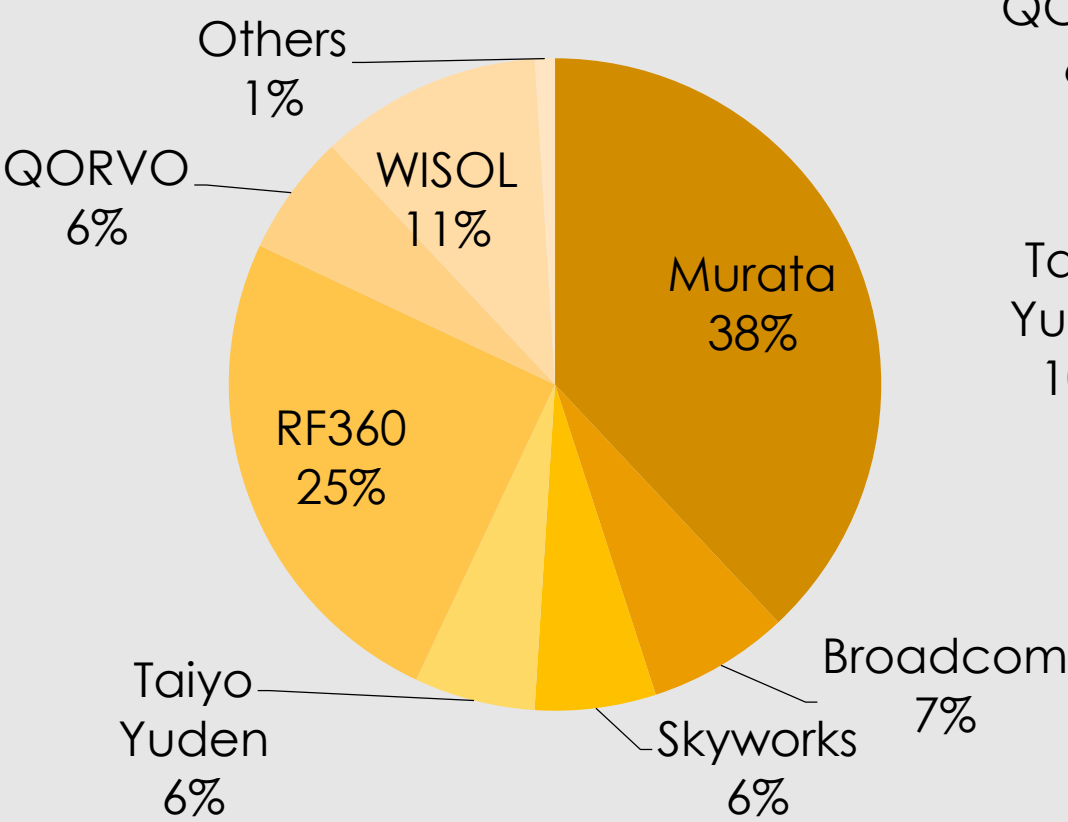### ACHIEVING Wi-Fi REJECTION REQUIREMENTS

Requirements – n79

- ✓ Wide Bandwidth: 600 MHz
- ✓ Rejection to interferers: >30 dB to Wi-Fi
- ✓ Spur-free passband
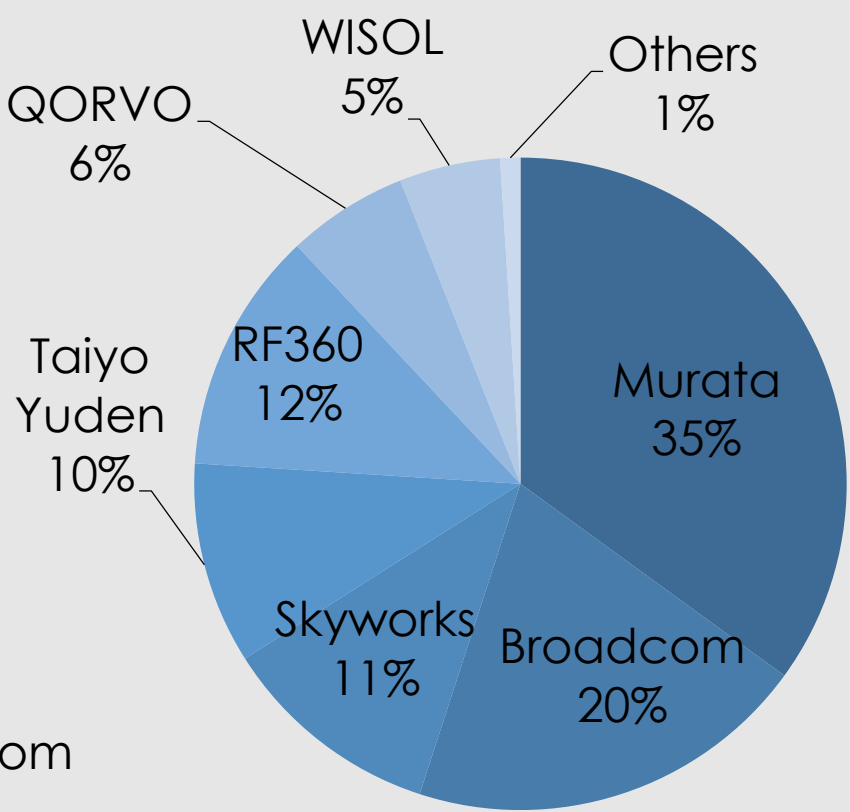- ✓ Low Loss: 1 dB center-band loss
- ✓ High Power: >31 dBm

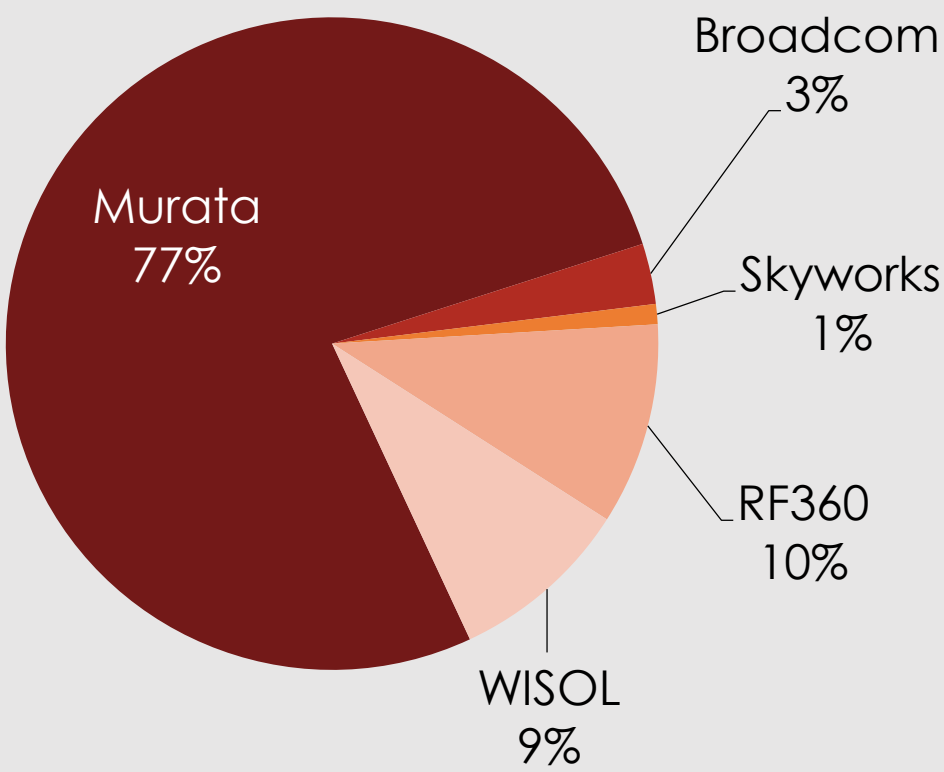# ENGAGED WITH WORLD'S LARGEST FILTER MANUFACTURER

FILTERS

Murata 38%
RF360 25%
WISOL 11%
Broadcom 7%
QORVO 6%
Taiyo Yuden 6%
Skyworks 6%
Others 1%

5 COMPANIES MAKE UP 80% OF THE FILTER AND DUPLEXER MARKETS

DUPLEXERS

Murata 35%
Broadcom 20%
RF360 12%
Skyworks 11%
Taiyo Yuden 10%
QORVO 6%
WISOL 5%
Others 1%

FEMiDs
(Front-End Module with Integrated Duplexers)

Murata 77%
RF360 10%
WISOL 9%
Broadcom 3%
Skyworks 1%

MODULE GROWTH HAS BEEN SHIFTING DUE TO RECENT MACRO ECONOMIC EVENTS

ENABLED BY XBAR HIGH-FREQUENCY, WIDE-BANDWIDTH (>10%) CAPABILITY

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Sources: Yole Development and Navian.
*2019 market share percentages.

5G AND Wi-Fi COEXISTENCE PROBLEM
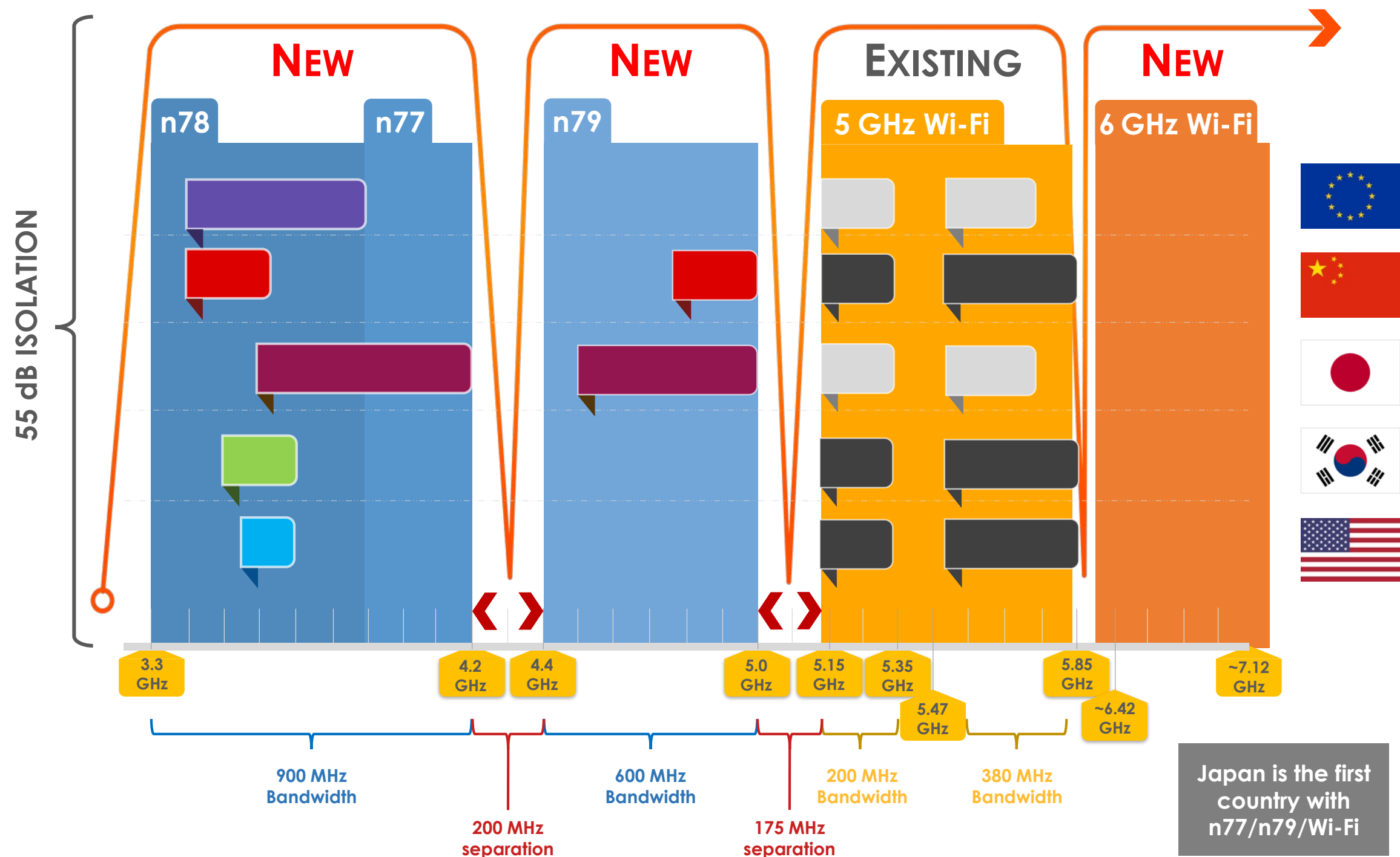## LOOMING INTERFERENCE CHALLENGE

Problem:
- 5G (sub 6 GHz) and 5 GHz / 6 GHz Wi-Fi need to operate together in 5G phones and infrastructure
- Massive potential interference problem

Requirements:
- Large bandwidths
- High isolation/rejection
- Low loss
- High Power
- Small and thin die size

Significantly different from 4G[1]

55 dB ISOLATION

NEW — n78 — n77
NEW — n79
EXISTING — 5 GHz Wi-Fi
NEW — 6 GHz Wi-Fi

3.3 GHz | 4.2 GHz | 4.4 GHz | 5.0 GHz | 5.15 GHz | 5.35 GHz | 5.47 GHz | 5.85 GHz | ~6.42 GHz | ~7.12 GHz

900 MHz Bandwidth | 600 MHz Bandwidth | 200 MHz Bandwidth | 380 MHz Bandwidth

200 MHz separation | 175 MHz separation

Japan is the first country with n77/n79/Wi-Fi

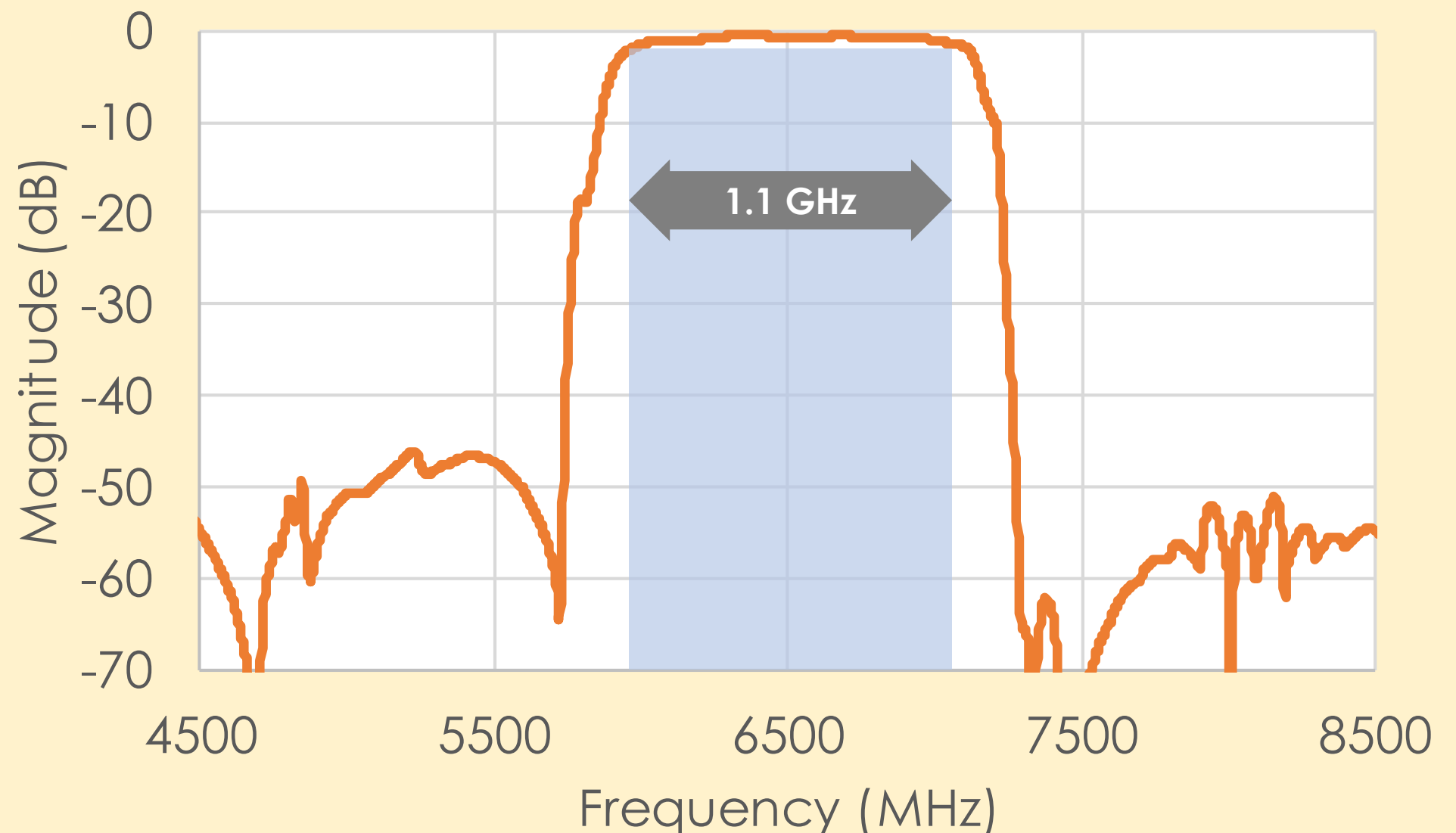## COEXISTENCE OF 5G AND WI-FI REQUIRES HIGH PERFORMANCE FILTERS

[1] Based on Resonant Management's analysis.

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XBAR 6 GHz FULL-BAND WI-FI ACOUSTIC FILTER

LATEST RESULT

- Measured 1.1 GHz bandwidth centered at 6.5 GHz
  - 17% bandwidth
  - Nearly double 2019 results

- Minimum loss < 1.0 dB

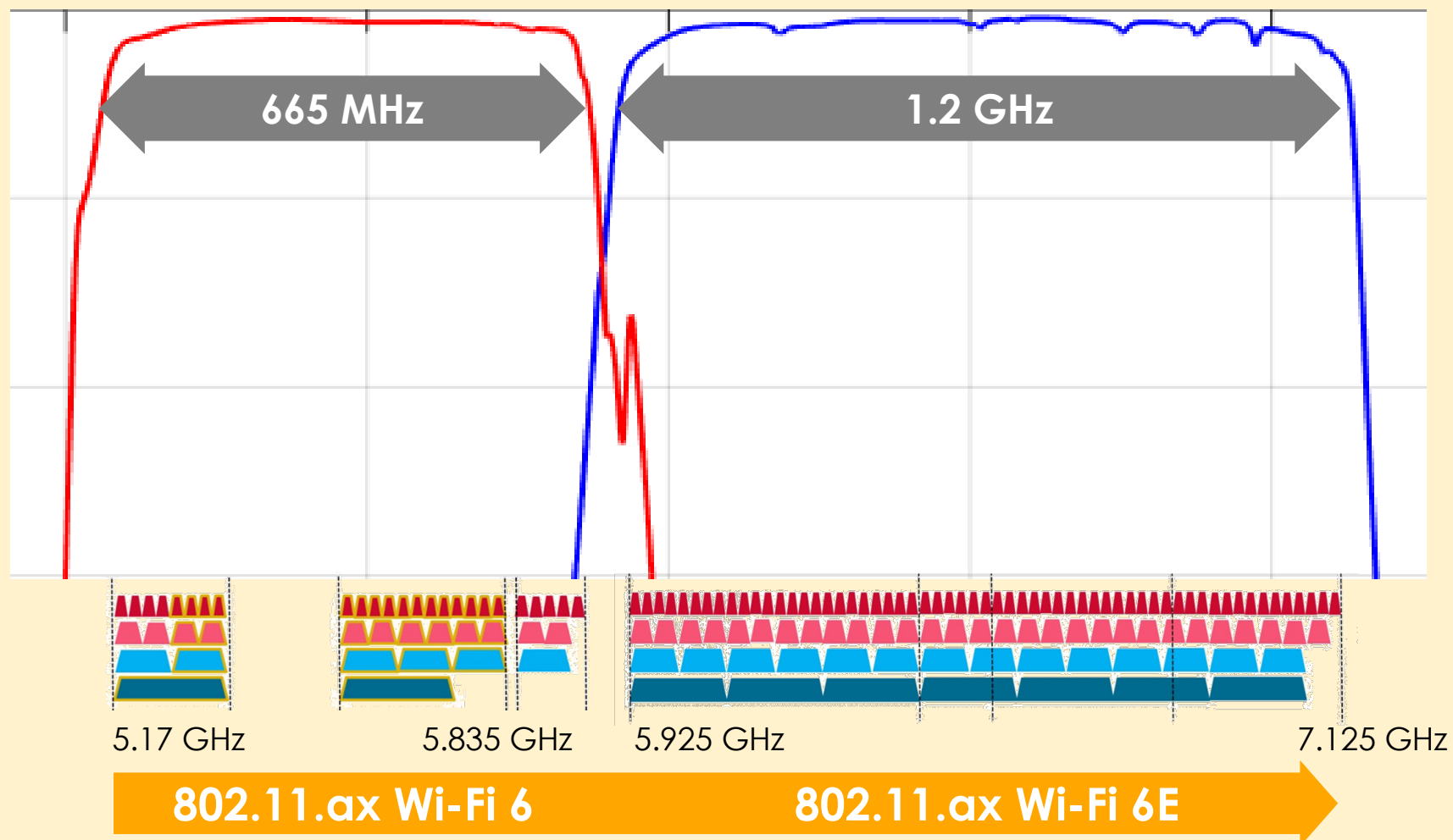- Rejection > 40 dB across neighboring Wi-Fi spectrum

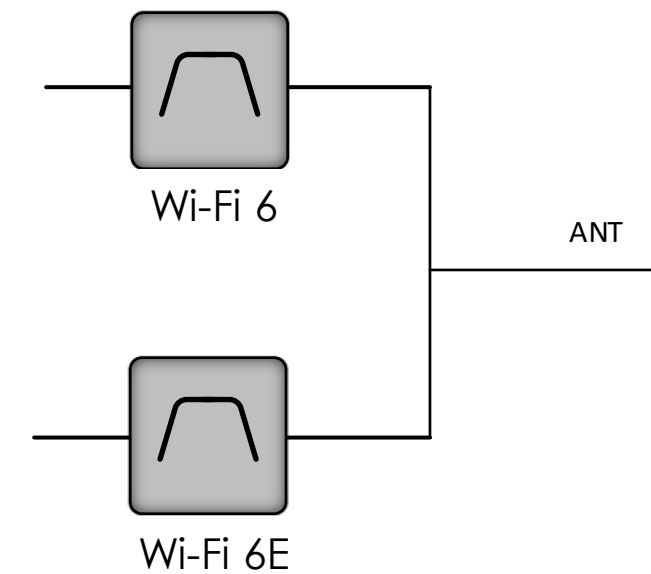**FIRST ACOUSTIC WI-FI BANDPASS FILTER DEMONSTRATING GREATER THAN 1 GHz BANDWIDTH**

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XBAR WI-FI DIPLEXER

SIMULATION

665 MHz

1.2 GHz

5.17 GHz   5.835 GHz   5.925 GHz   7.125 GHz

802.11.ax Wi-Fi 6   **802.11.ax Wi-Fi 6E**

XBAR Wi-Fi Diplexer Structure:

Wi-Fi 6

ANT

Wi-Fi 6E

- Enables Maximum Bandwidth
- Rejection to each band for simultaneous operation
- Low passband Insertion Loss
- Wide bandwidth capability of XBAR is the key

ENABLES MAXIMUM POSSIBLE BANDWIDTH IN A SINGLE DEVICE

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IN SUMMARY

- User demand for increasing data through-put is driving 5G and Wi-Fi to higher frequencies and wider bandwidths

- Coexistence of 5G and Wi-Fi is an emerging and large challenge to real-world deployments

- Utilizing ISN, Resonant has developed the breakthrough XBAR resonator structure to address these demands

- XBAR provides a unique, best-in-class solution to enable co-existence of these systems through low-loss, wide-bandwidth, high rejection filtering

- Engineering samples to be provided to customers mid-2020

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THANK YOU

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