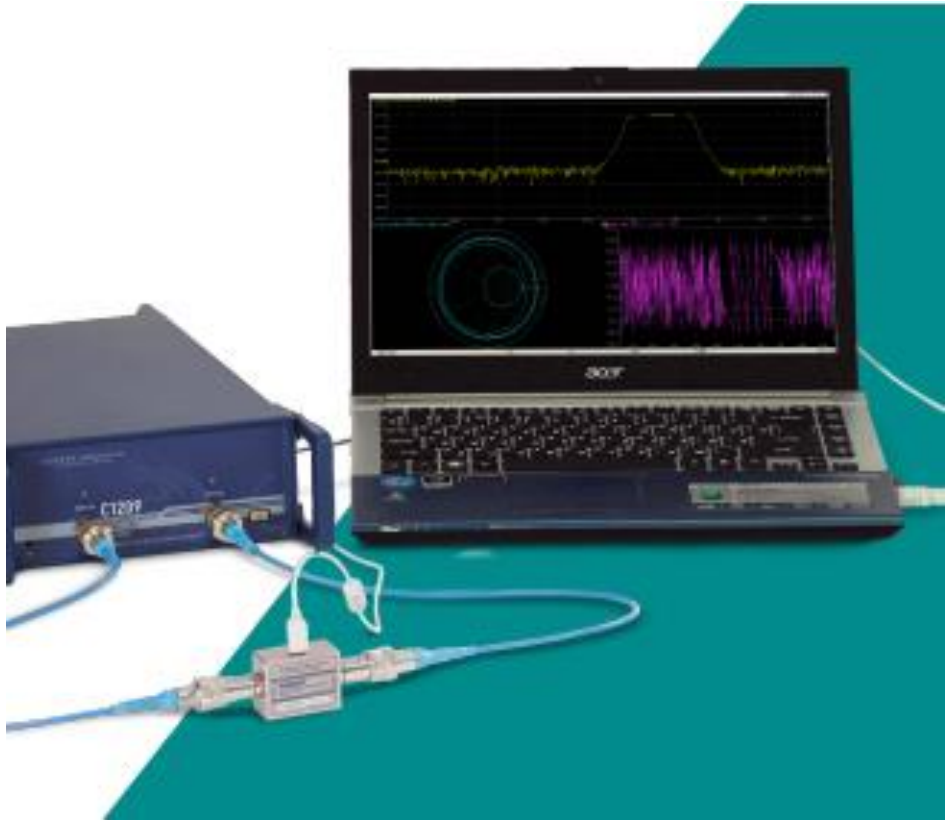


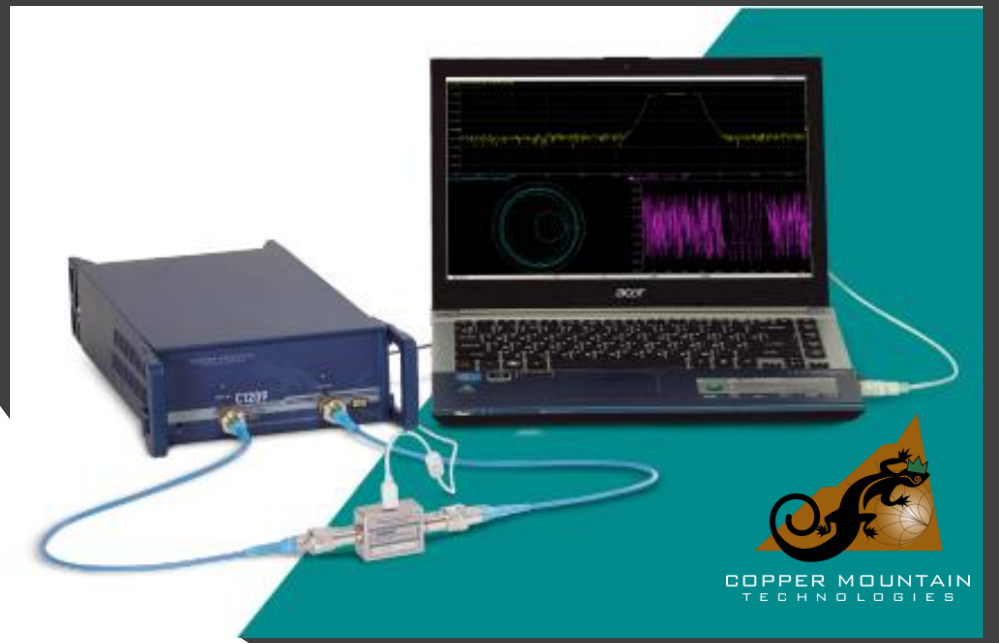
USB형 VNA의 주요 특징과 5G 통신용 안테나 측정사례

2017.10.26

제이윌테크놀로지
지충선 대표

JWILL TECHNOLOGY
Innovating Test Automation

목차



웨비나 목적과 대상

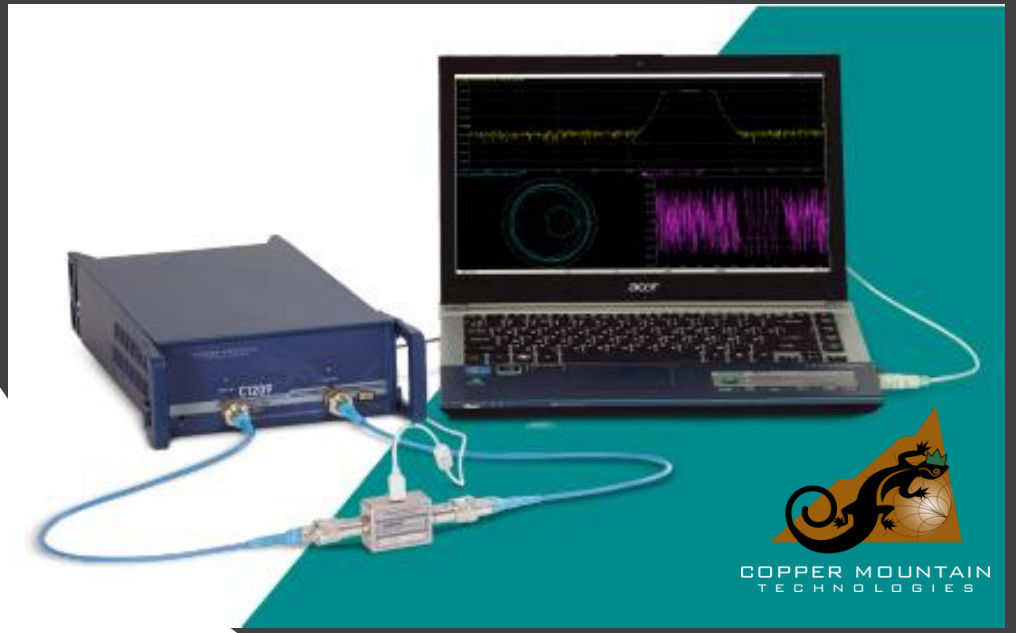
웨비나 목적과 대상

목적

- 일체형 VNA대비 훨씬 작고, 가벼워 설치 공간의 활용성이나 휴대성이 탁월하며, 총소유비용(Total Cost of Ownership) 또한 저렴하여 가성비가 뛰어난 Copper Mountain Technology사의 USB VNA를 소개, 고객에게 더 큰 편익을 드리기 위함.

대상

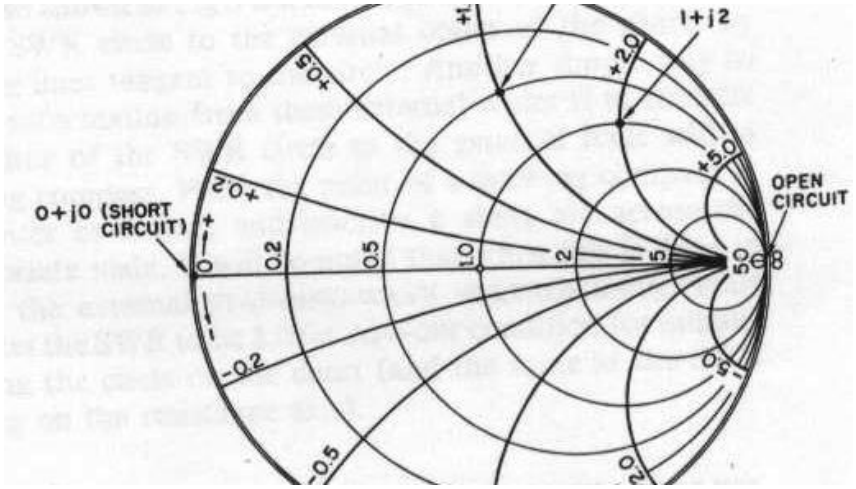
- RF / Microwave 전자 응용 부품/모듈/시스템 연구소, 혹은 산업체의 연구/개발/생산/서비스 엔지니어
- RF / Microwave 전자 응용 테스트 시스템 개발/제조업체
- RF / Microwave 전자 교육기관
- 기타 USB VNA에 대해 관심있으신 분

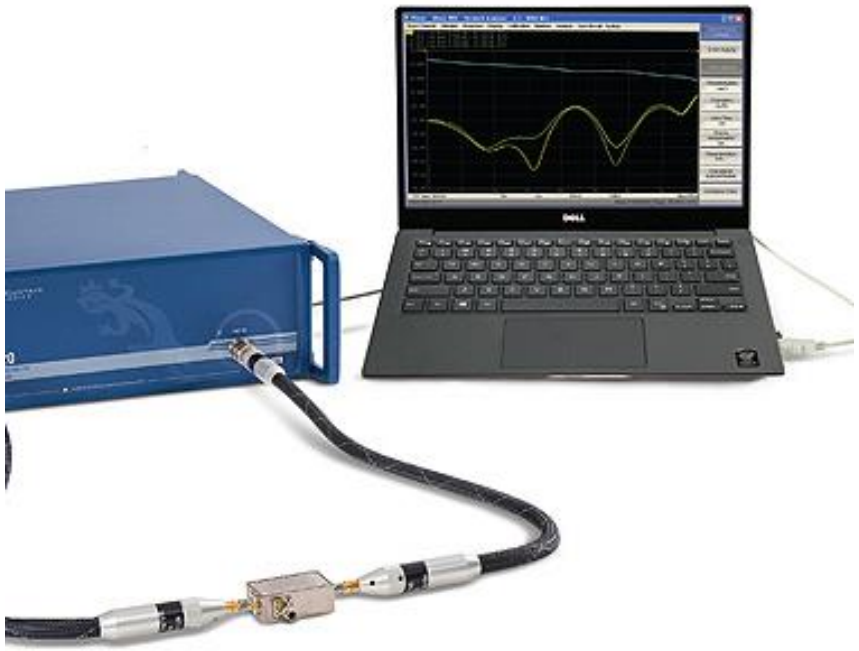


VNA기초

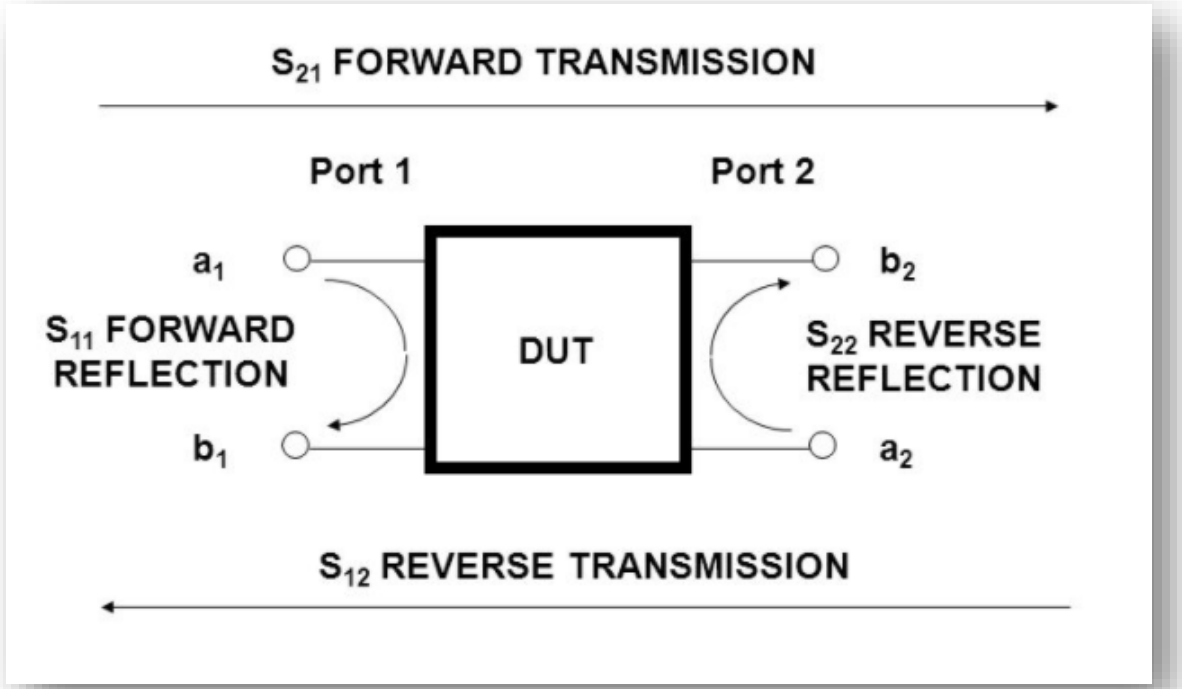
Network Analyzer 정의

- 유무선 통신망 계측기(ex. telecom wireless protocol/packet analyzer)가 **절대 아님**.
- 고주파 이상의 대역(HF, RF, Microwave, etc)의 부품, 모듈, 서브시스템의 **입/출력단의 신호 전송 혹은 반사특성 (S-Parameters)**을 시험, 측정, 분석하는 계측기
- 2가지 유형
  - **Scalar Network Analyzer (SNA)**
    - *Magnitude* 만 측정
  - **Vector Network Analyzer (VNA)**
    - *Magnitude* 및 *Phase* 모두 측정





S-Parameters

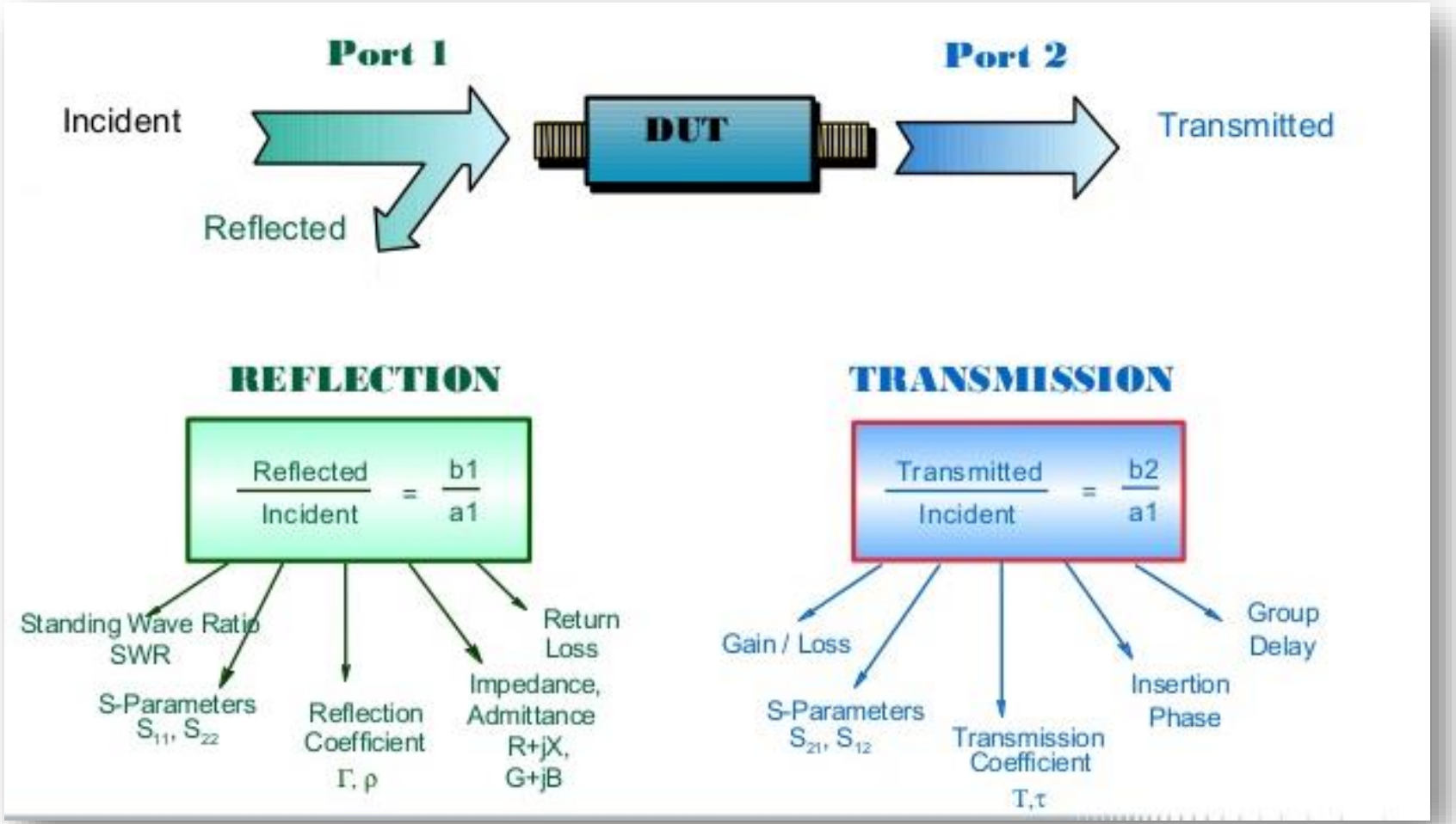


$$b_1 = S_{11}a_1 + S_{12}a_2$$
$$b_2 = S_{21}a_1 + S_{22}a_2$$

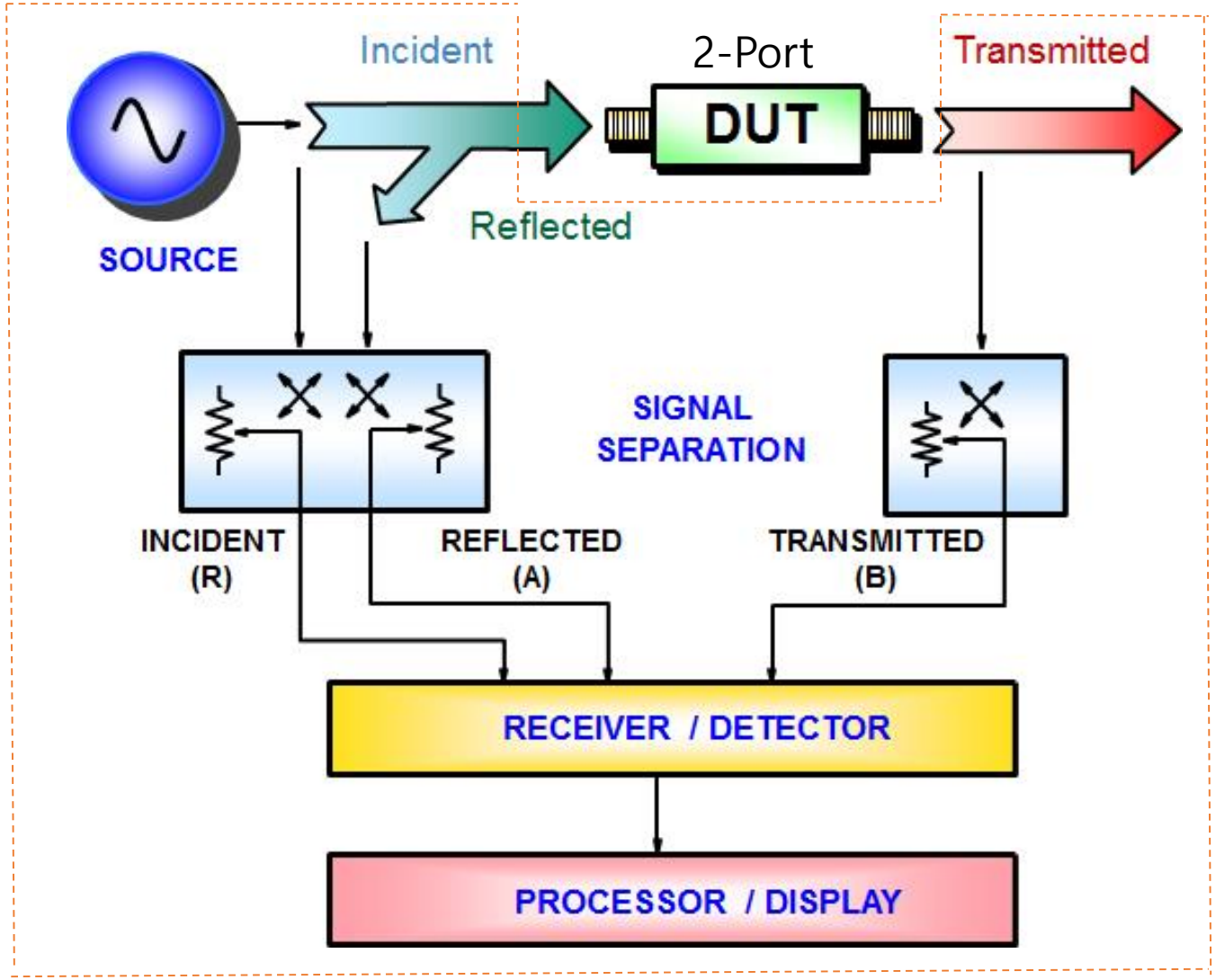
$$S_{11} = \frac{Reflected}{Incident} = \frac{b_1}{a_1}\Big|_{a_2=0}$$
$$S_{21} = \frac{Transmitted}{Incident} = \frac{b_2}{a_1}\Big|_{a_2=0}$$

$$S_{22} = \frac{Reflected}{Incident} = \frac{b_2}{a_2}\Big|_{a_1=0}$$
$$S_{12} = \frac{Transmitted}{Incident} = \frac{b_1}{a_2}\Big|_{a_1=0}$$

S-Parameters
- Reflection
- Transmission

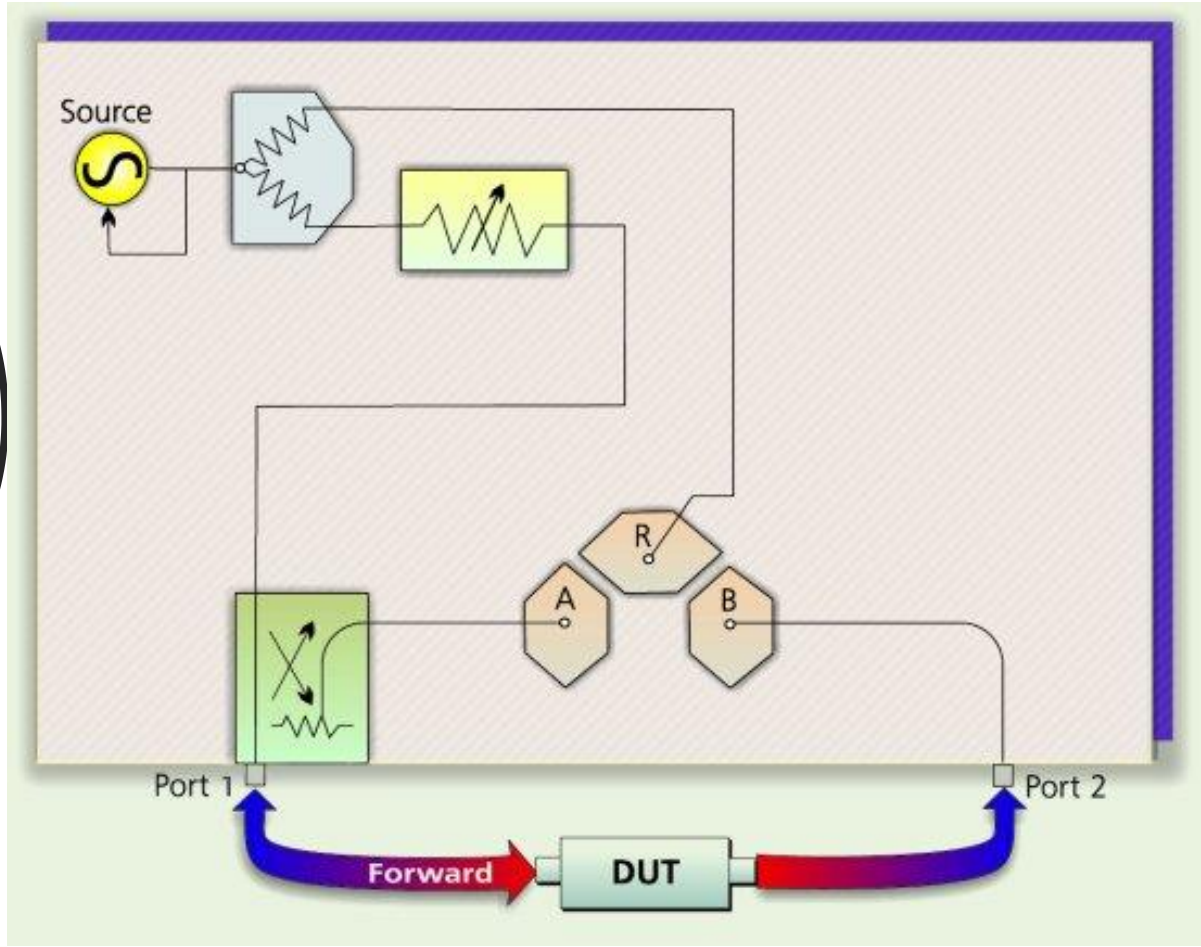


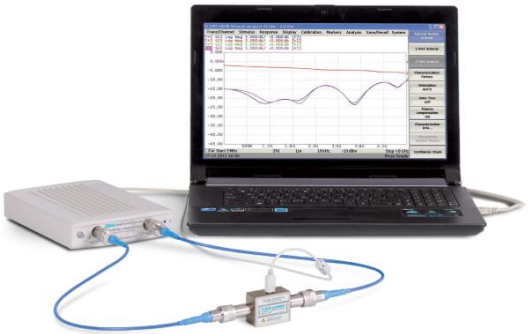
Vector Network Analyzer Block Diagram



2-Port / 1-Path VNA

Vector Network Analyzer Block Diagram

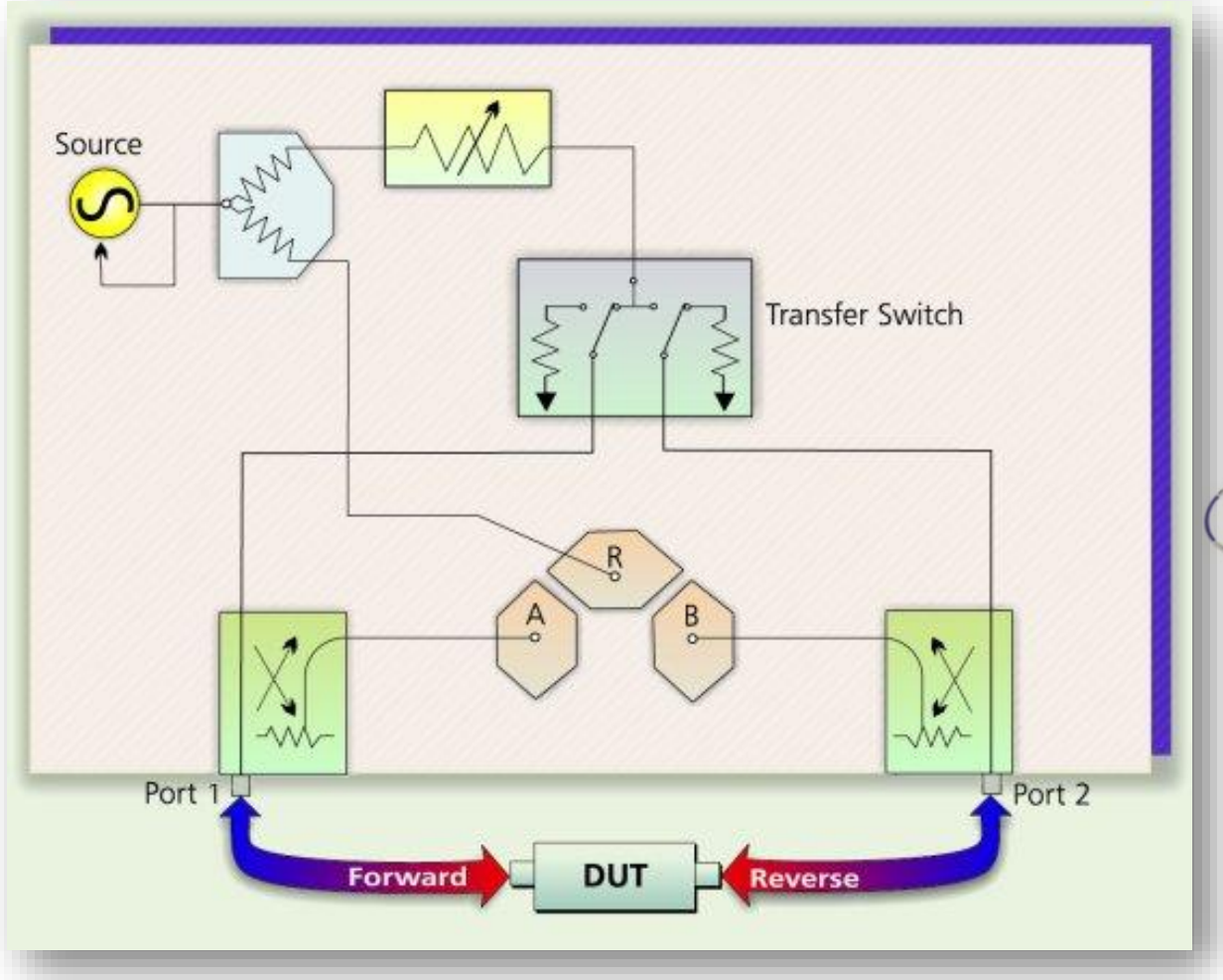


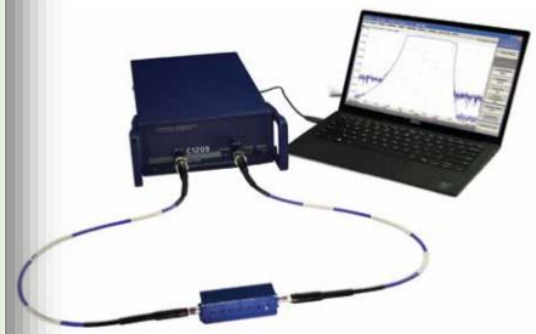


TR5048

2-Port / 2-Path VNA

Vector Network Analyzer Block Diagram



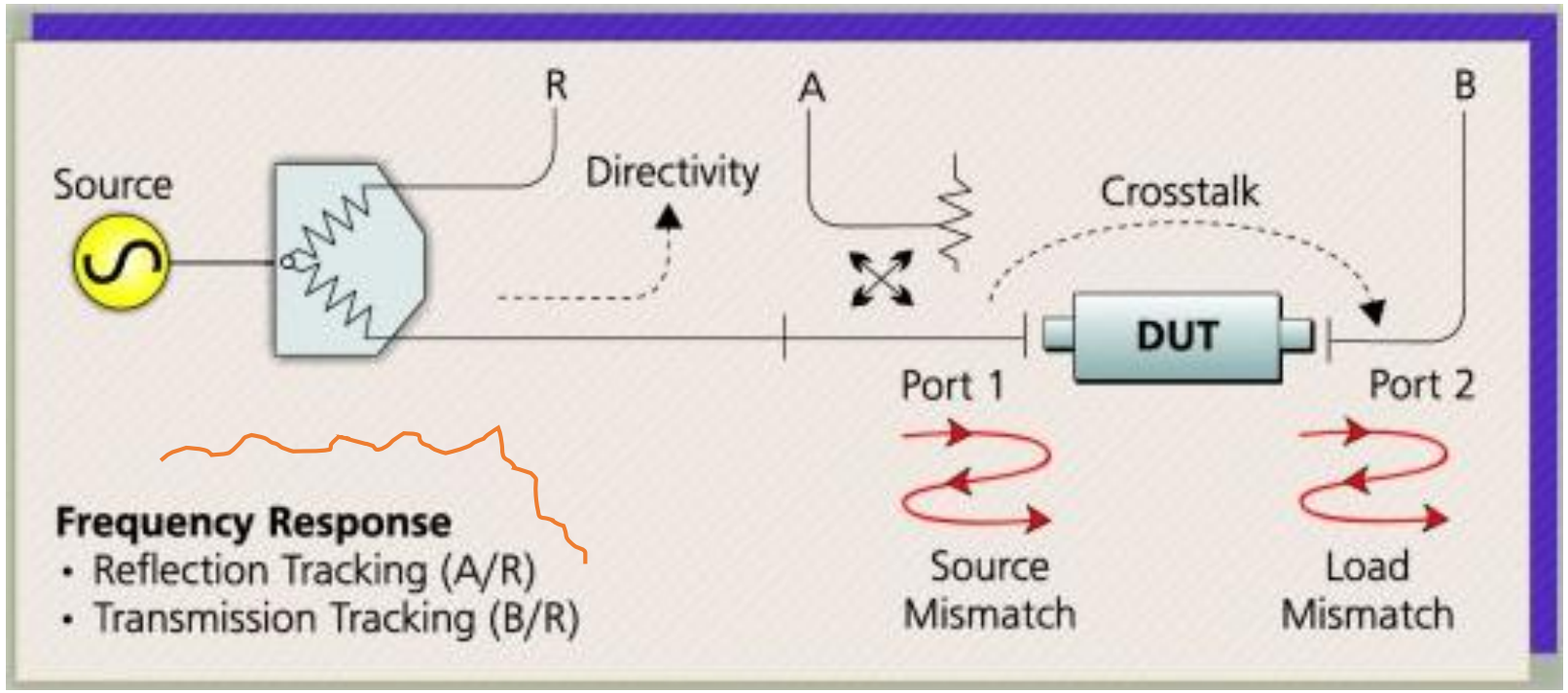


C1209

Measurement Errors

- **Random Errors**
  - ✓ Noise fluctuations / Thermal drift in electronic components
  - ✓ Changes in the mechanical dimensions of cables / connectors due to temperature drift
  - ✓ Repeatability of connections or cable bends
  - ✓ Unpredicatble
  - ✓ Can’t be eliminated in calibration
- **Systematic Errors**
  - ✓ Imperfections in the components of measurement system
  - ✓ Occurs repeatedly
  - ✓ Time invariant
  - ✓ Predictable
  - ✓ Can be reduced by performing mathematical correction of measurement results.

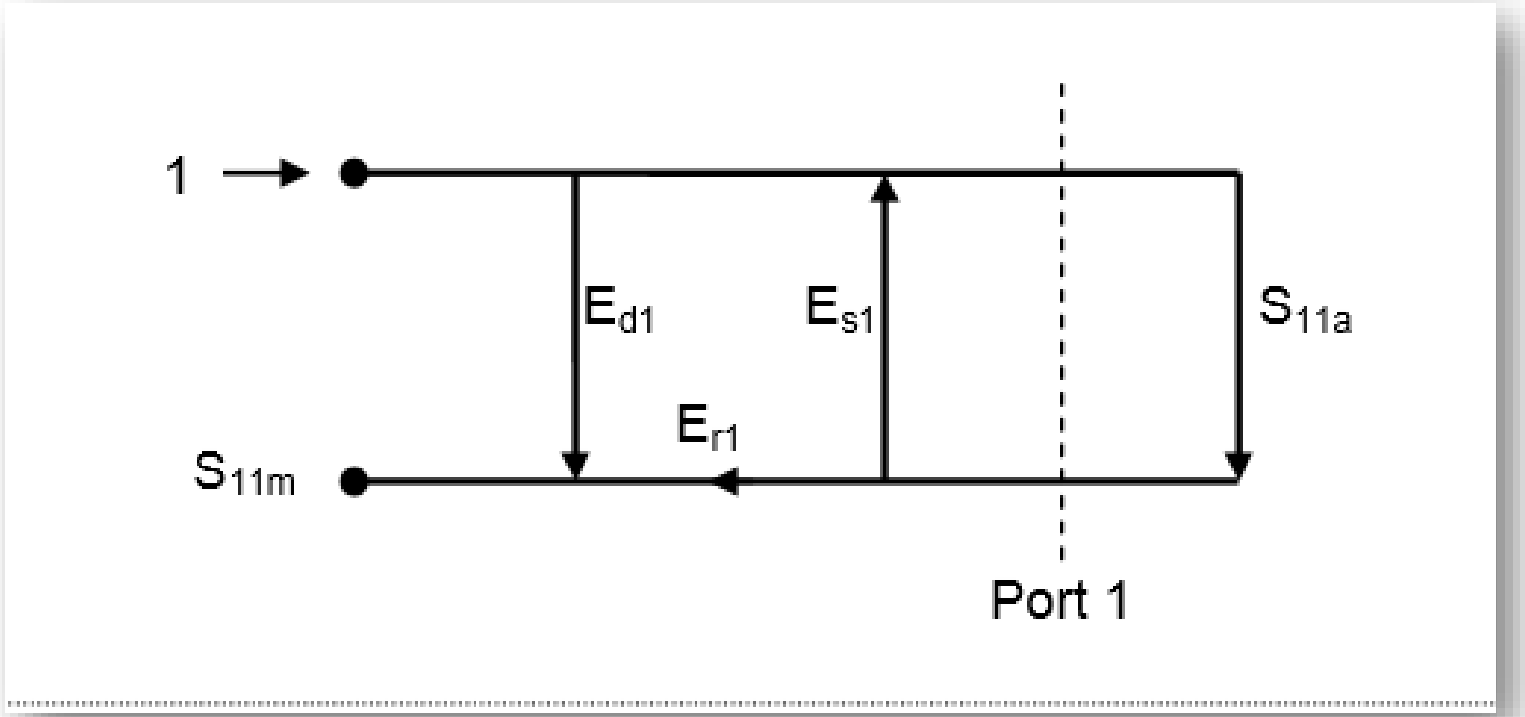
Systematic Measurement Errors



- For 2-port /2-path device, 6 forward and 6 reverse term errors
- For 2-port /1-path device, 6 forward term errors
- For 1-port device, 3-term errors

1-Port Error Model

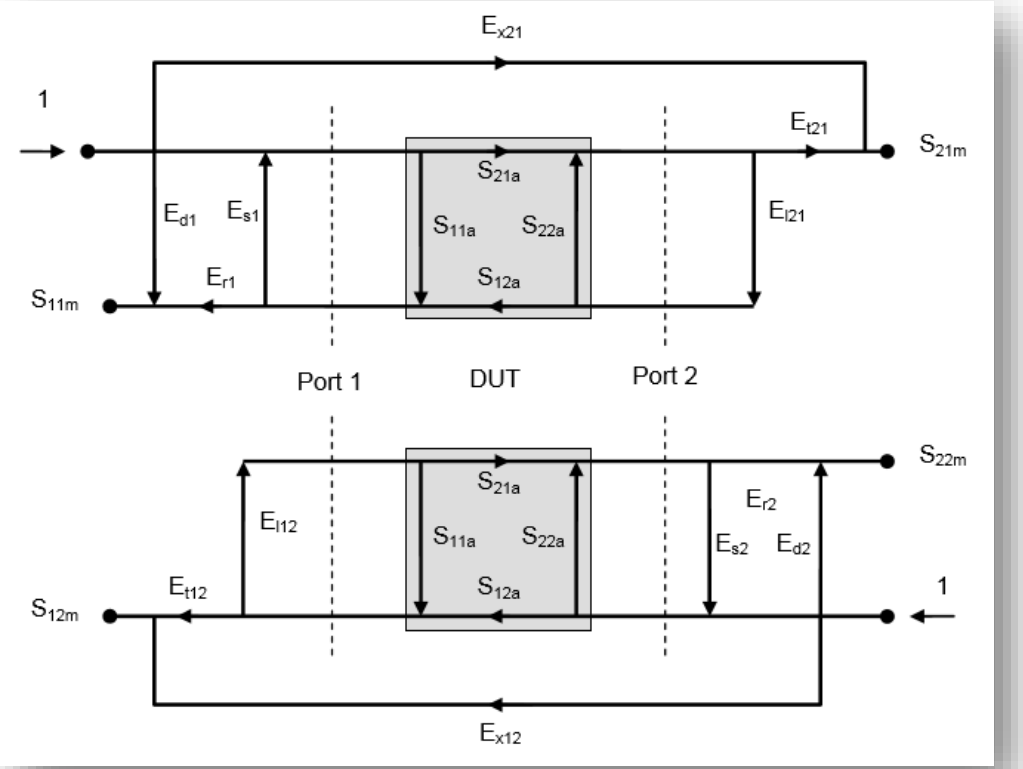
Systematic Measurement Error Models



- E_{d1} – directivity;
- E_{s1} – source match;
- E_{r1} – reflection tracking.

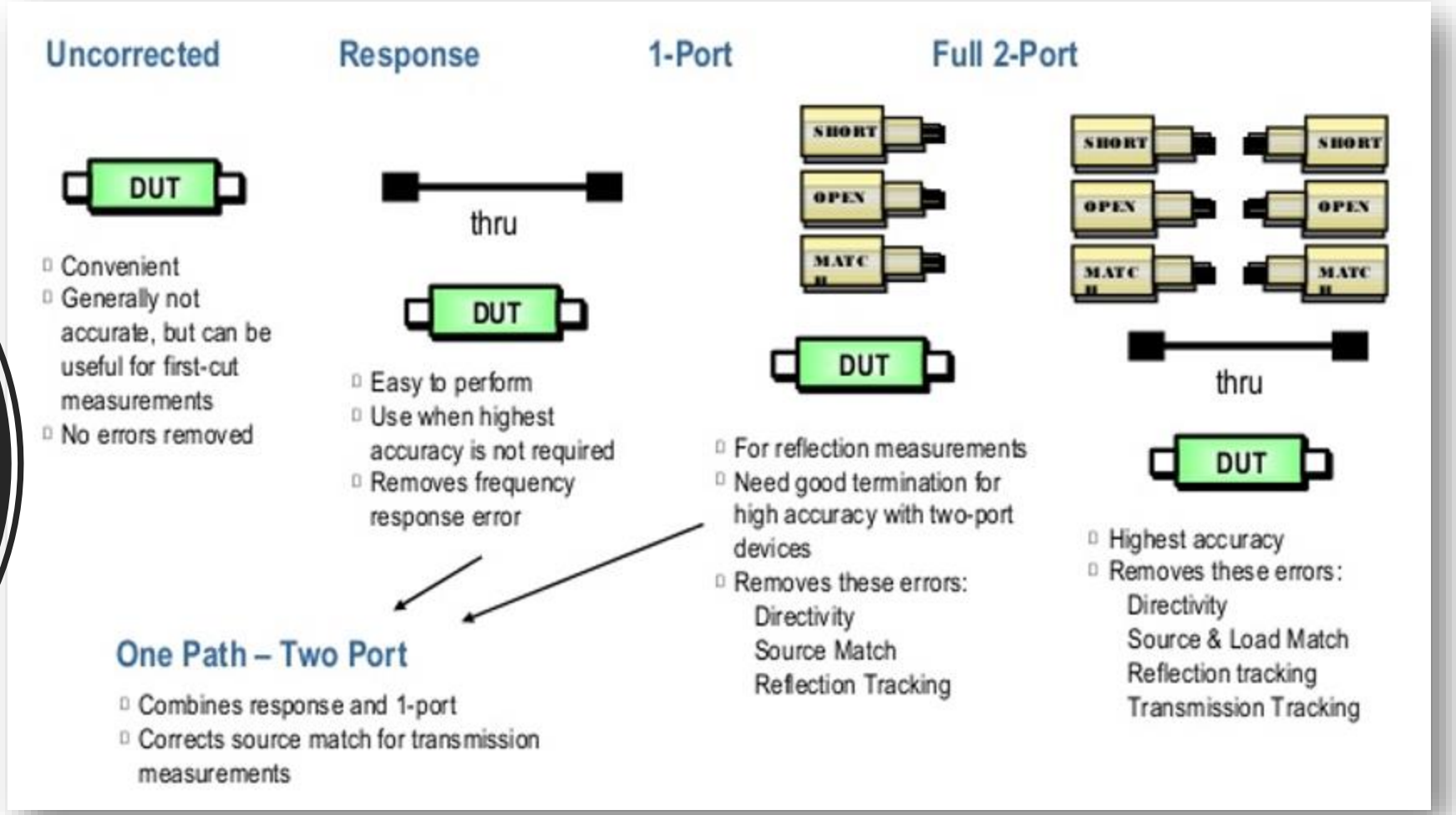
2-Port Error Model

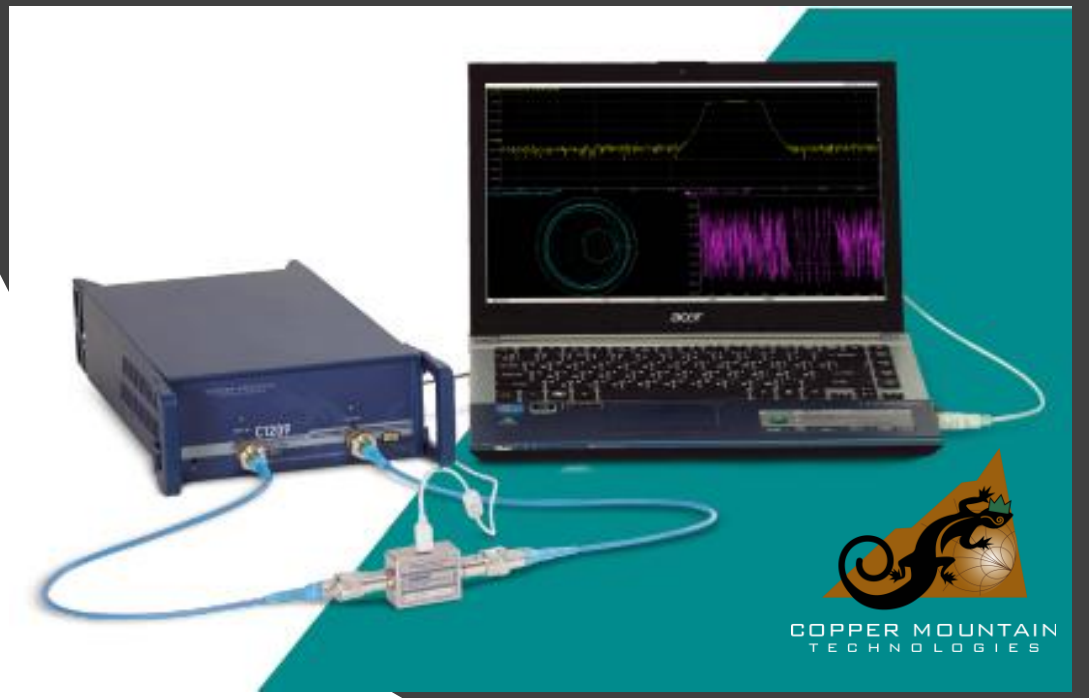
Systematic Measurement Error Models



Description	Stimulus Source	
	Port 1	Port 2
Directivity	E_{d1}	E_{d2}
Source match	E_{s1}	E_{s2},
Reflection tracking	E_{r1}	E_{r2}
Transmission tracking	E_{t1}	E_{t2}
Load match	E_{l1}	E_{l2}
Isolation	E_{x1}	E_{x2}

Systematic Measurement Error Correction or Calibration



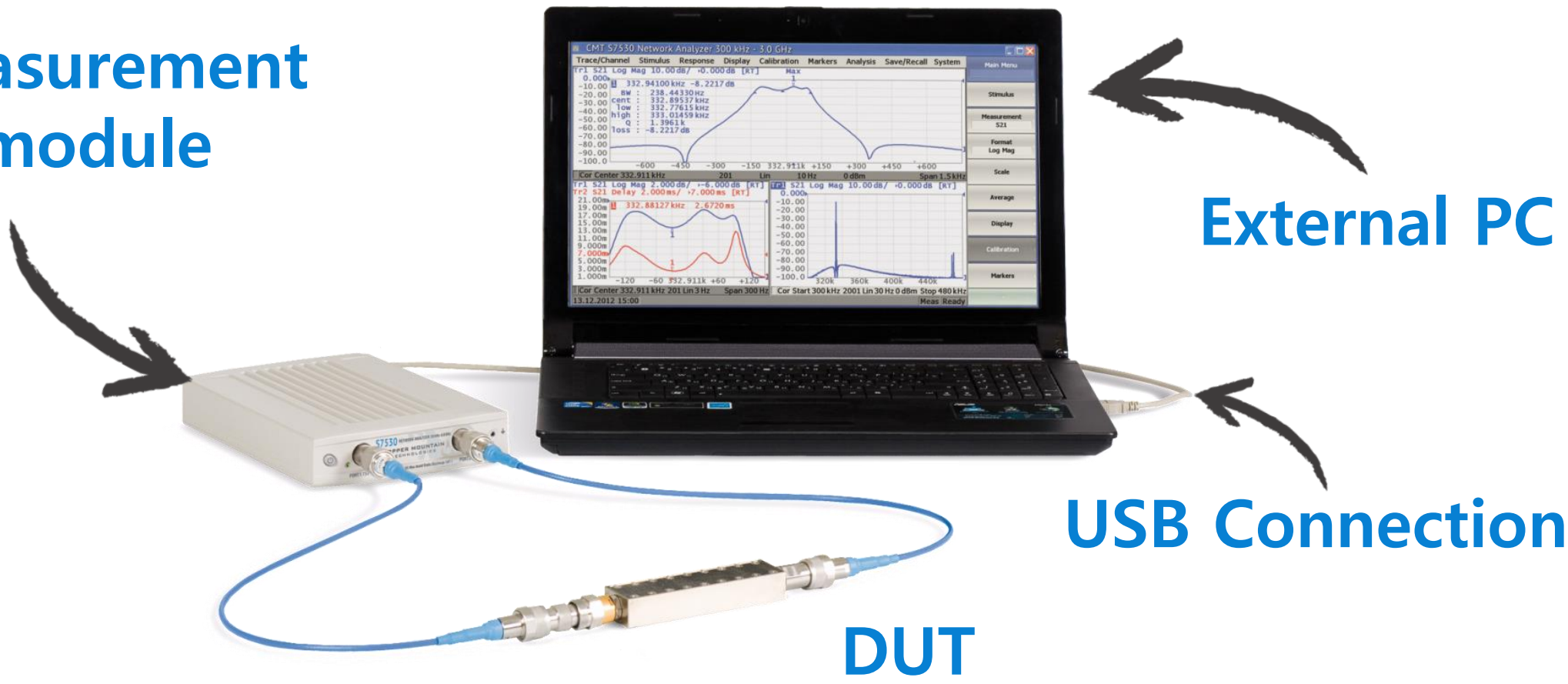


USB형 VNA의 특징과 장점

Traditional VNA

Measurement & Processing module

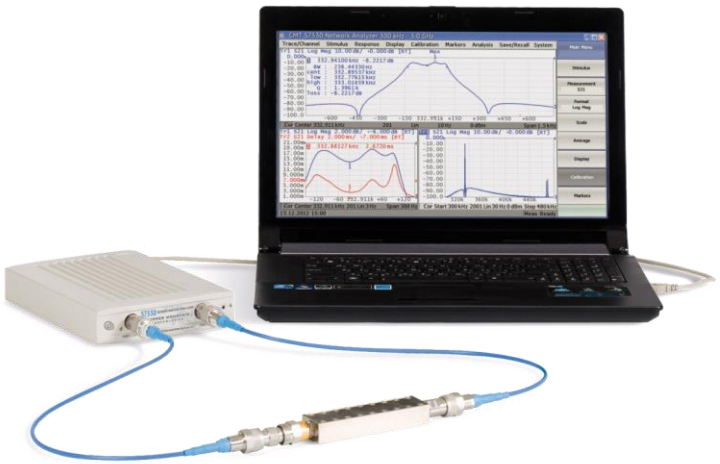
USB VNA



Advantages of USB VNA vs. Traditional VNA

- Doesn’t lock you into outdated computer hardware and OS
  - Don’t get stuck with Windows 2000 or a floppy drive
- Takes advantage of the latest advances
  - Use your modern PC instead of one spec’ed 7+ years ago
- Lower total cost of ownership
  - Due to elimination of large number of potential failure points

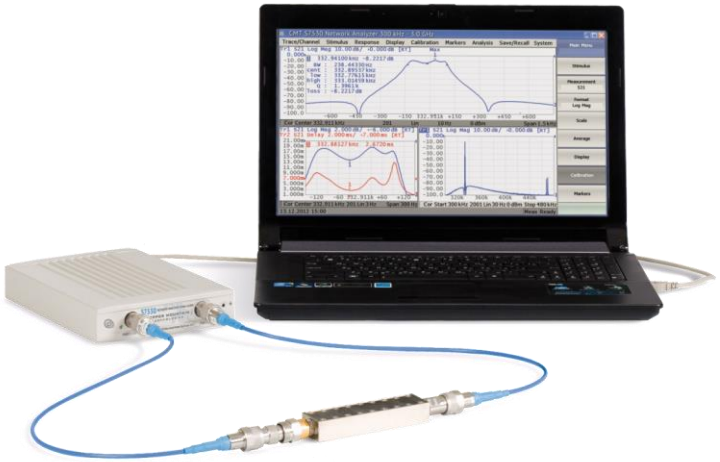
vs.

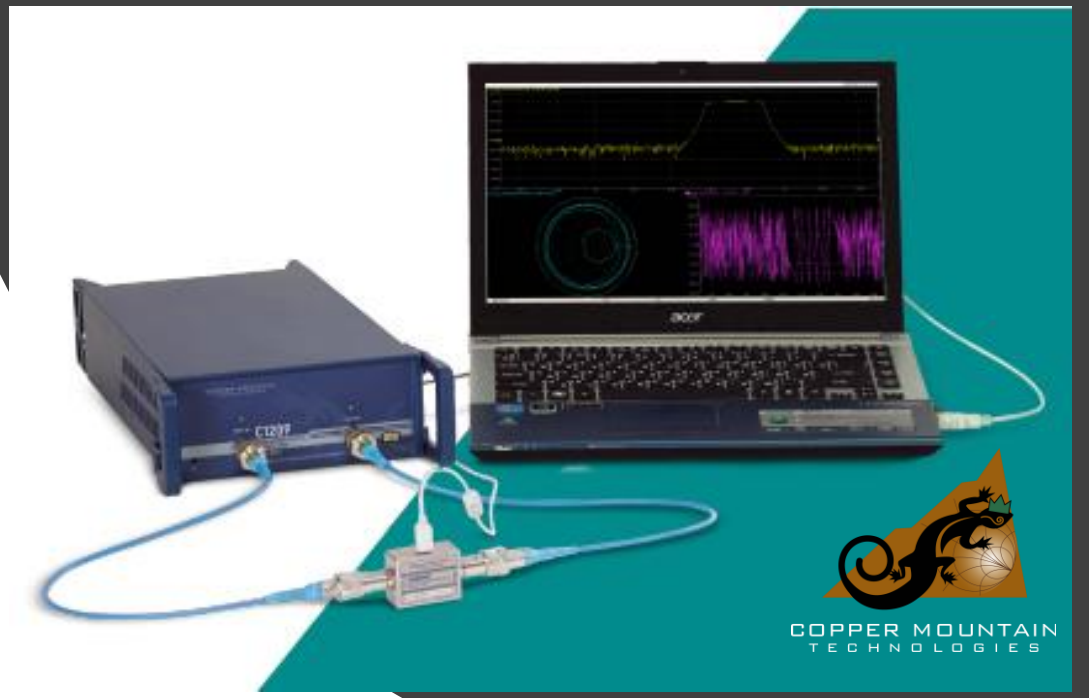


Advantages of USB VNA vs. Traditional VNA

- Travel
  - Portable size and lighter weight
  - Excellent for on-site testing
- Share
  - No user accessible non-volatile memory in the VNA
  - Results stored on your own PC
- Security
  - No need for data purging or hard drive removal in secure environments

vs.

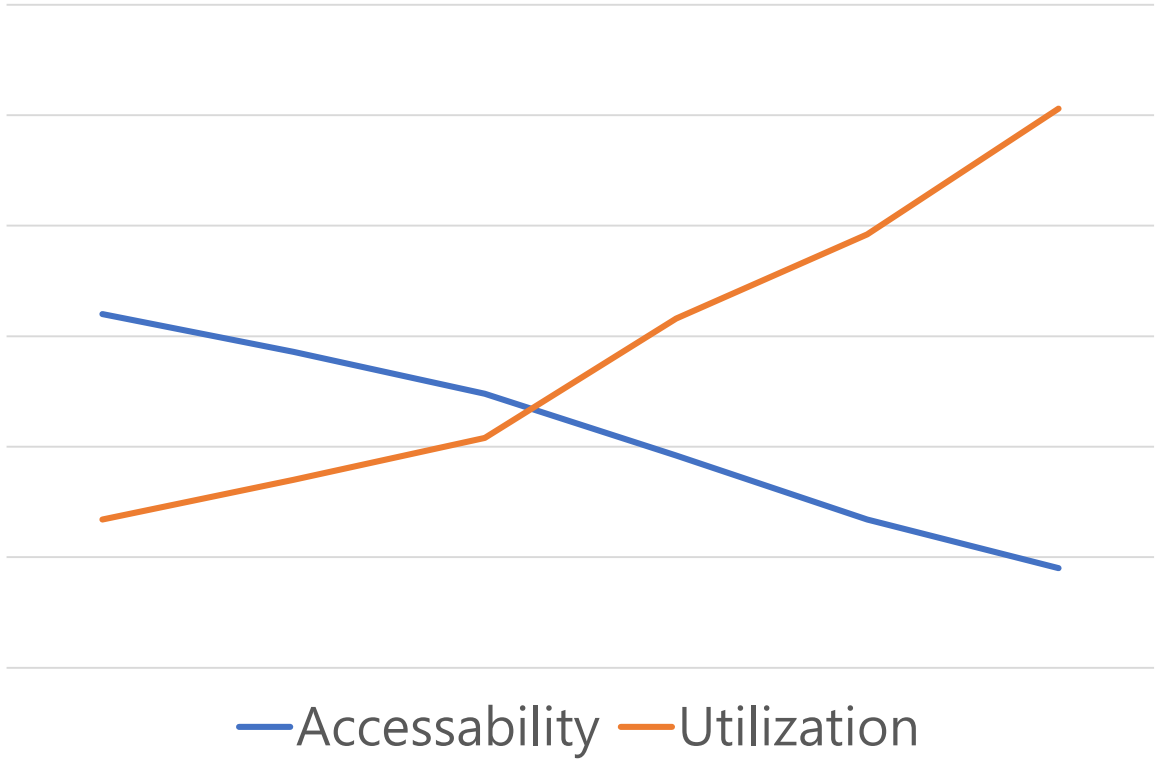




CMT사 소개

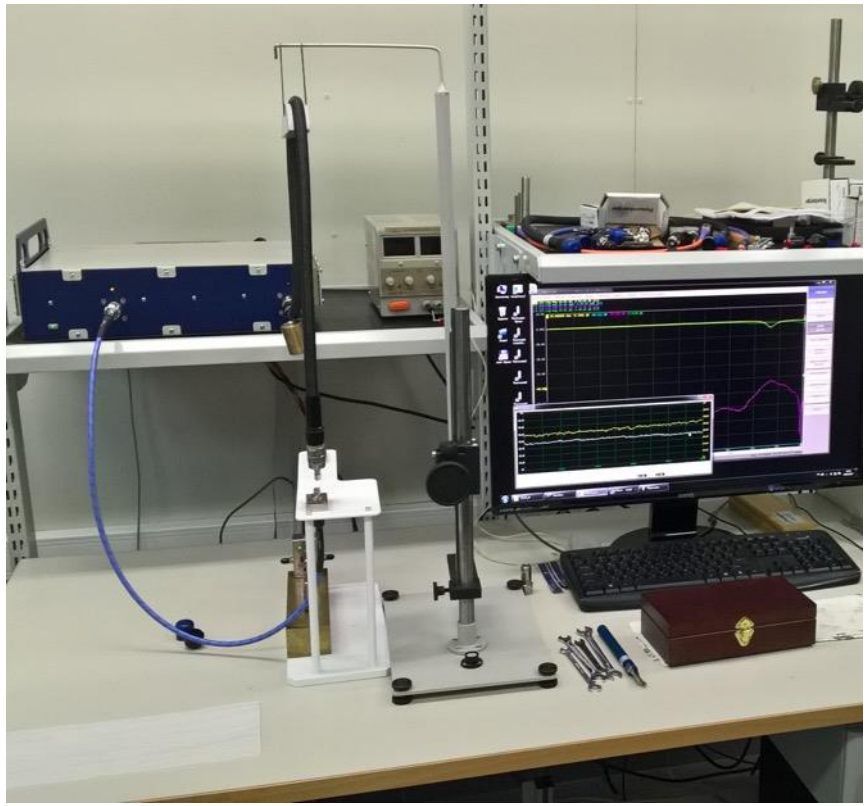
WHY WE STARTED COPPER MOUNTAIN TECHNOLOGIES

- Accessibility of VNAs decreased due to a number of factors
- Demand for VNAs that provide high-quality results increased
- Many new applications for precise VNAs emerged



COPPER MOUNTAIN™ TECHNOLOGIES

WHY OUR ENGINEERS DO WHAT THEY DO

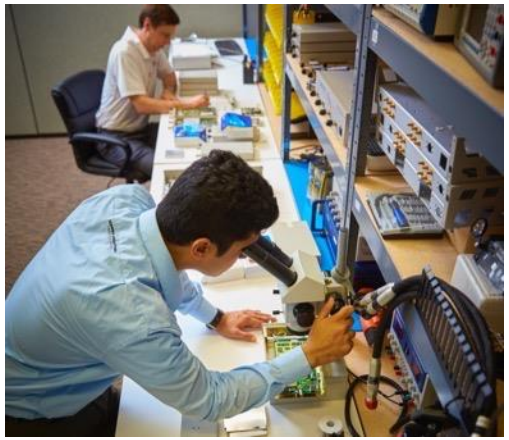


- To give RF engineers VNAs that:
  - are accessible and offer lower T otal Cost of Ownership;
  - are portable;
  - deliver precise measurements;
  - can be customized to the applic ation

COPPER MOUNTAIN™ TECHNOLOGIES

WE BUILT THE COMPANY TO DELIVER ON OUR PROMISE

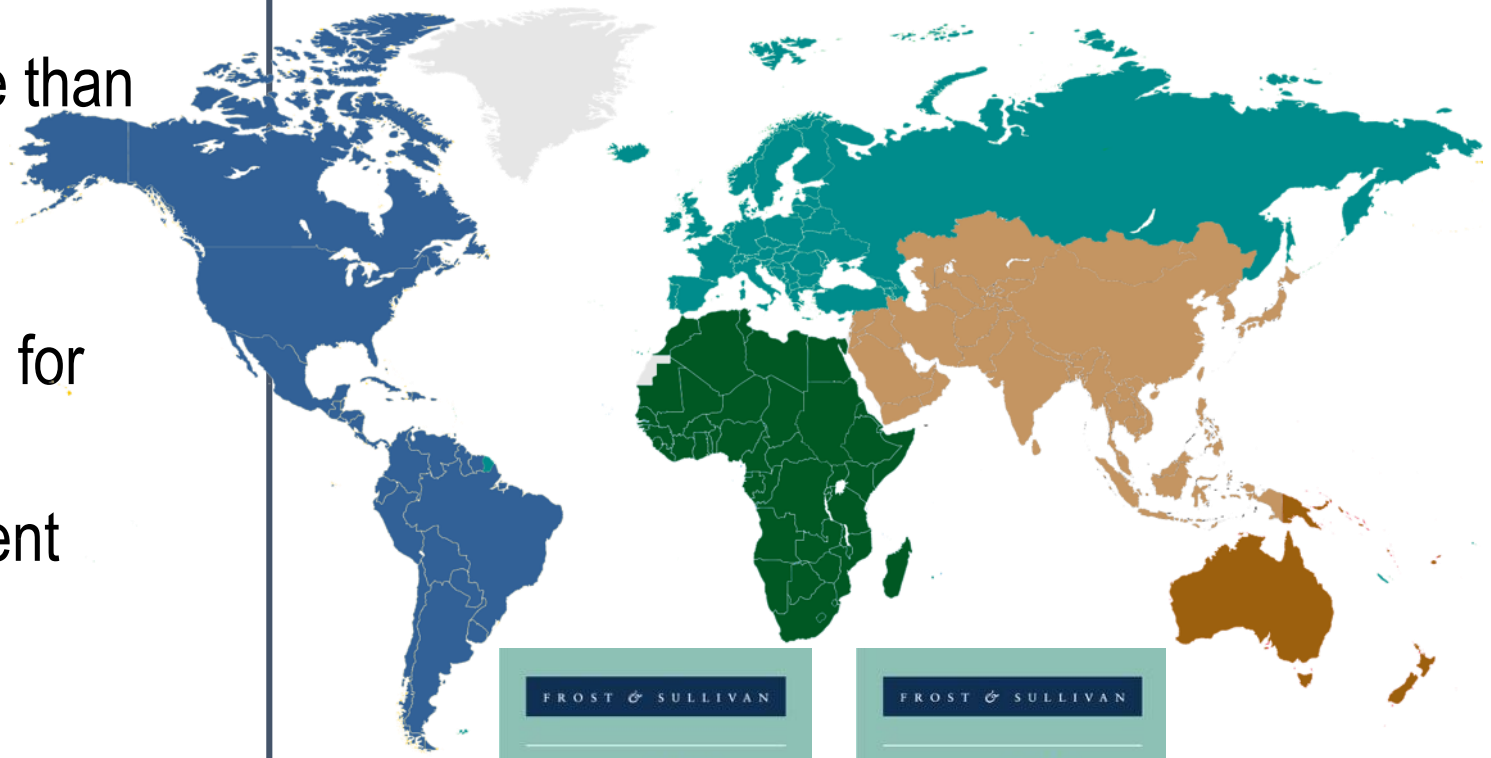
- Pioneer of metrology grade USB VNA category
- World-class metrology and engineering
- Providing **application solutions** using USB VNAs
- Based in Indianapolis, IN doing business globally
- Founded in 2011



COPPER MOUNTAIN™ TECHNOLOGIES

GLOBAL CUSTOMERS DEPEND ON CMT VNAS

- Over 1200 customers use more than 3000 VNAs around the world
- 89 reps worldwide
- Recognized by Frost & Sullivan for Leadership twice
- International industry involvement
- Industry thought leader

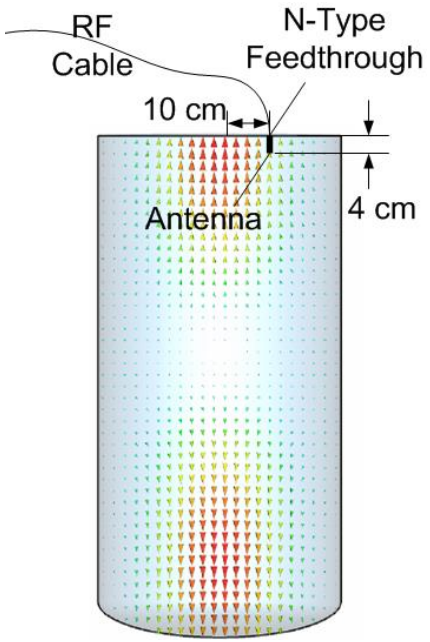


COPPER MOUNTAIN™ TECHNOLOGIES

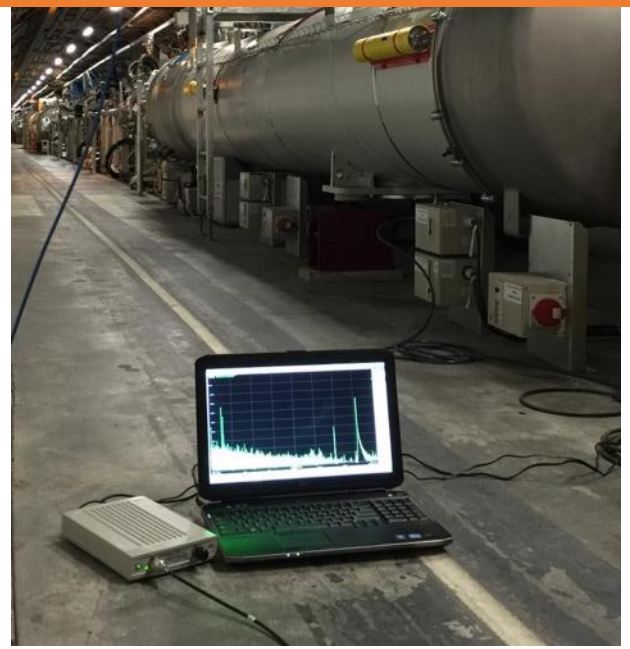
OVER 1200 CUSTOMERS AROUND THE WORLD

- Aerospace & Defense
- RF components
- Telecommunications
- Medical devices
- Higher education
- Automotive
- Cable TV

ENGINEERS ALREADY EXTENDING THEIR REACH



Gauging spacecraft fuel levels with R54



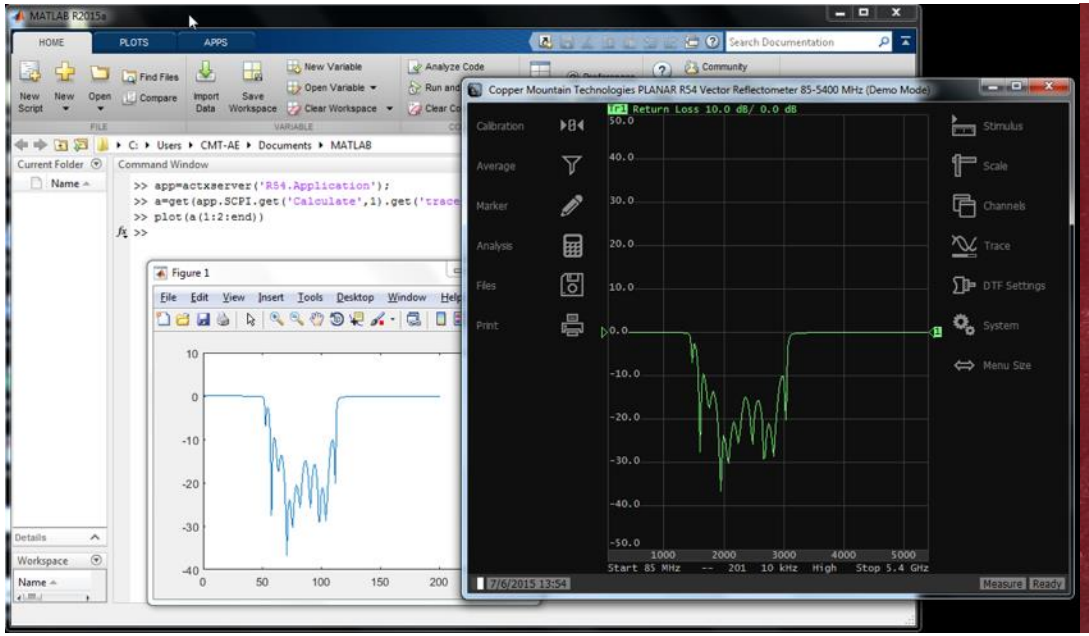
TR5048 is used in the world's largest particle accelerator

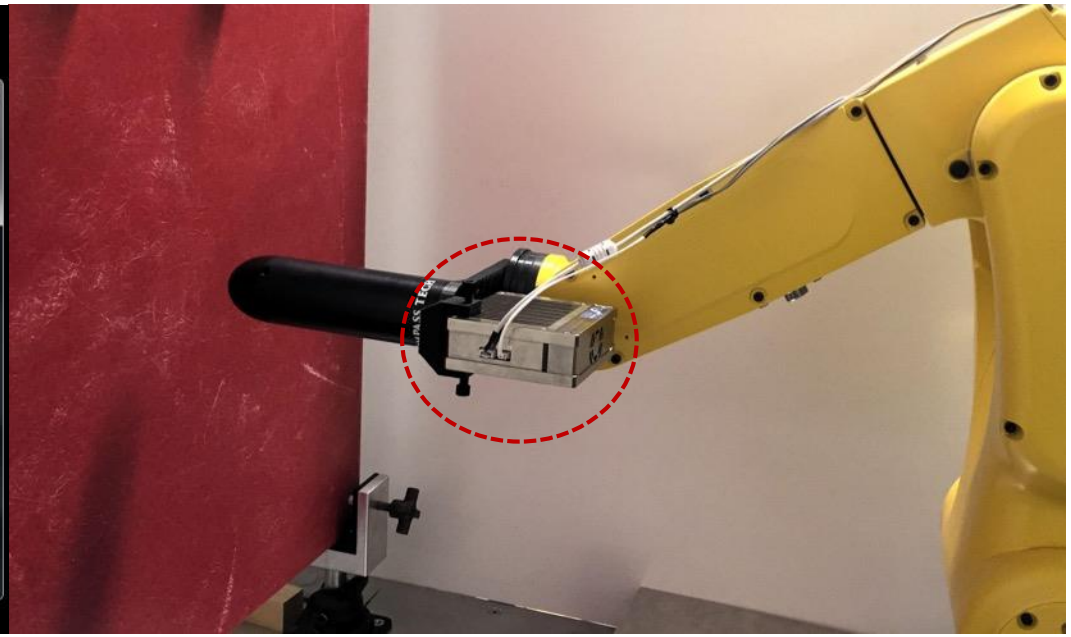
Standardized on CMT VNAs

across all facilities worldwide

Equipped a lab with 12 VNAs instead of 1

OUR USB VNAs GO WHERE NO VNA HAS GONE BEFORE

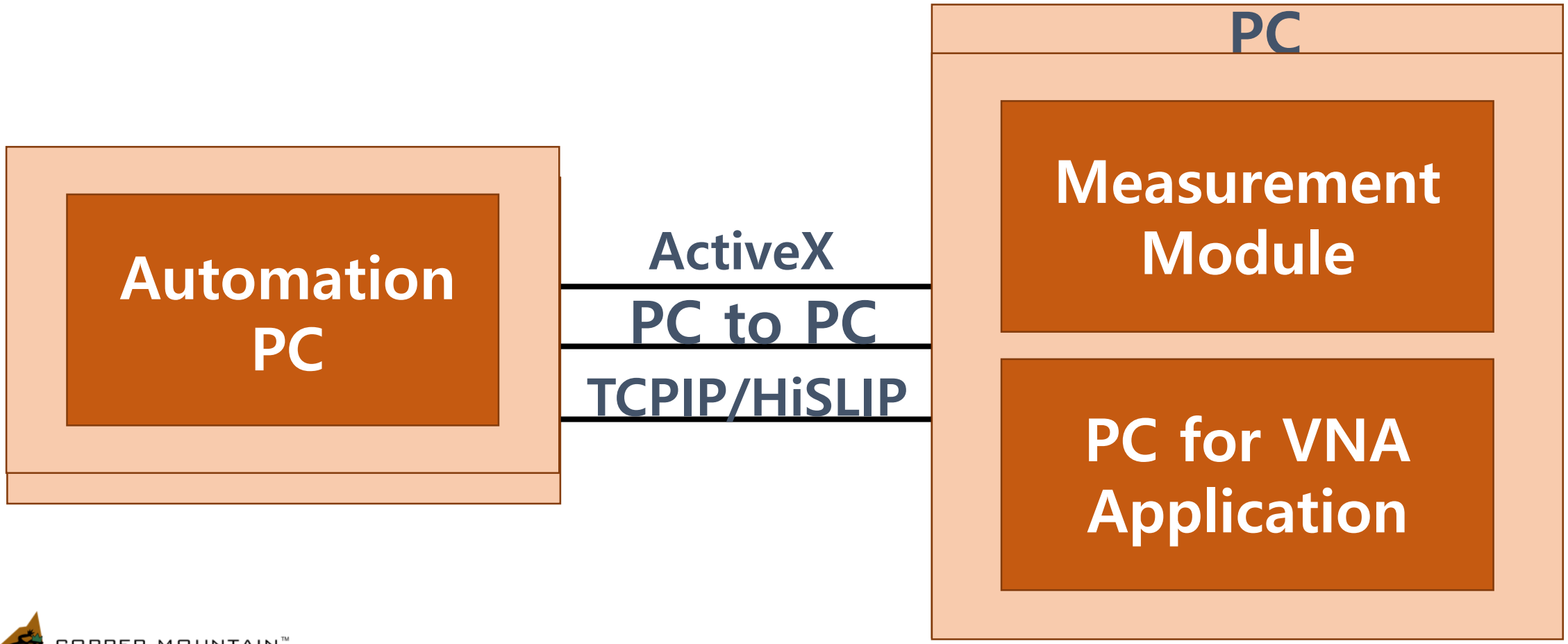




- Legacy test systems: multiple PCs, OS
- PC-driven test instruments: one PC, OS
- Form factor makes integration simple
- New VISA drivers, still SCPI commands

COPPER MOUNTAIN™ TECHNOLOGIES

OUR USB VNAS DELIVER FASTER AUTOMATION



COPPER MOUNTAIN™ TECHNOLOGIES

30+ MODELS FOR DIFFERENT APPLICATIONS

- All of the Copper Mountain Technologies USB VNAs have a 3 year warranty

1-Port VNAs (Cable & Antenna Analyzers)

Lab-grade performance in a handheld device

Frequency Range: 1 MHz to 18 GHz

Compact VNAs

Full featured lab grade performance in a compact package

Frequency Range: 9 kHz to 8.5 GHz

Cobalt VNAs

Industry-leading dynamic range and sweep speed

Frequency Range: 100 kHz to 20 GHz

CobaltFx VNAs

Cost-effective millimeter wave frequency extension system

Frequency Range: 50 GHz to 110 GHz

HOW WE ARE DIFFERENT: PRICE PERFORMANCE RATIO

	Keysight	Rhode & Schwartz	Anritsu	Tektronix	Pico	Copper Mountain Technologies
Traditional VNAs	X	X	X			
USB VNAs			1	1	1	30
Focus on metrology	X	X	X			X
Affordable price				X	X	X
Application focus						X

COPPER MOUNTAIN™ TECHNOLOGIES

OPEN TO APPLICATION-SPECIFIC CUSTOMIZATION

- We spend the time to work with you to find a solution for your problem
- Designed to be customized and deliver a high performing custom VNA solution at a competitive price

COPPER MOUNTAIN™ TECHNOLOGIES

DESIGNED FOR INTEGRATION

- Ability to integrate into test systems
- Existing application integrations with some of the following companies:

Diamond Engineering
Automated Measurement Systems

speag

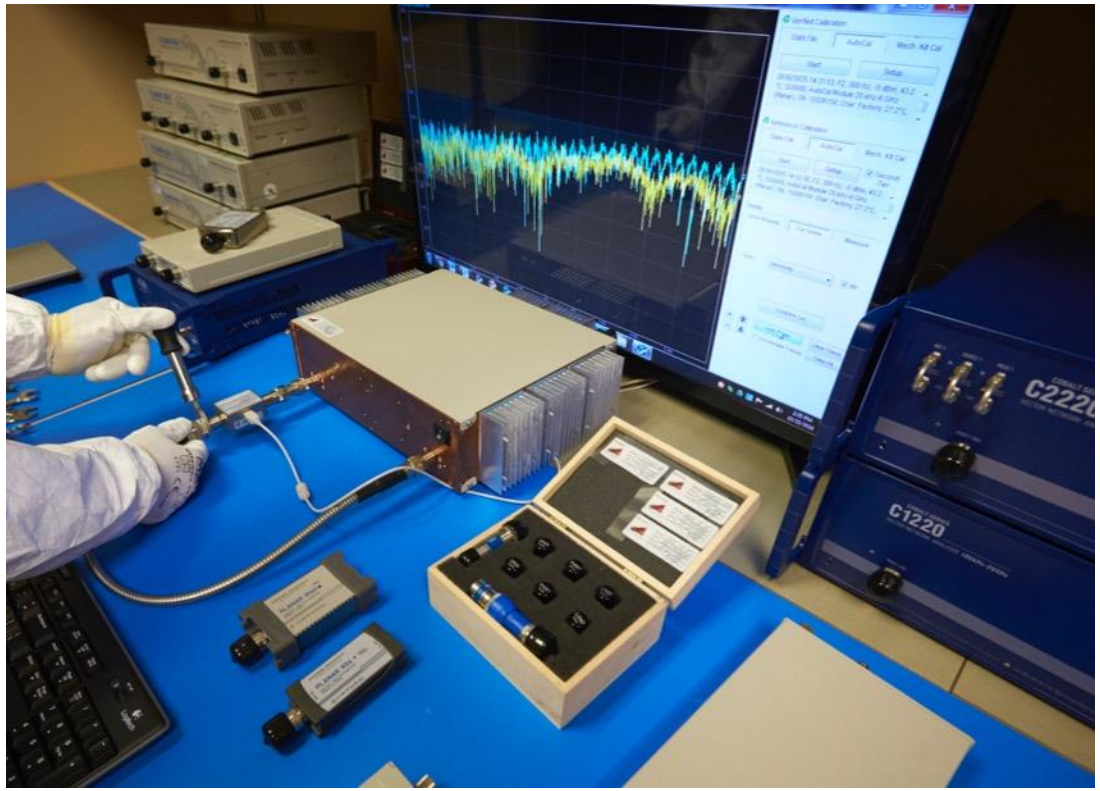
Maury Microwave

FOCUS MiCROWAVES

COPPER MOUNTAIN™ TECHNOLOGIES

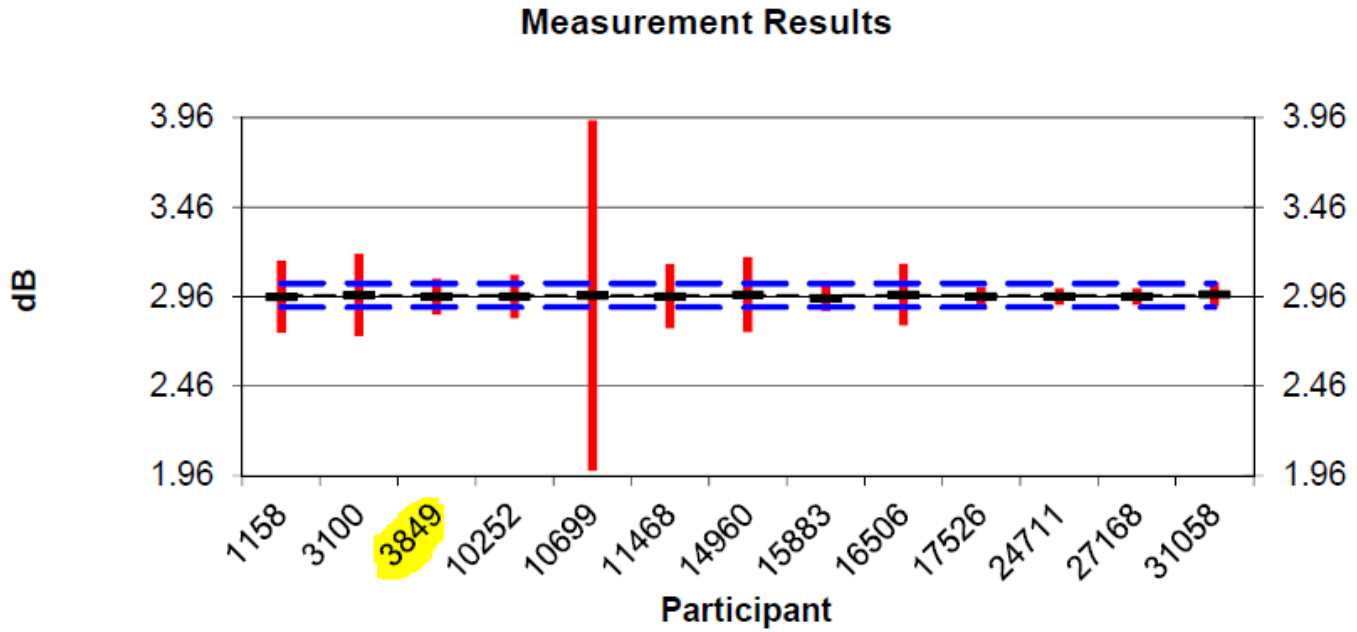
ACCREDITED CALIBRATION LAB

- Calibration laboratory accredited with ISO/IEC 17025 (2005) and meets requirements of ANSI/ NCSL Z540-1994-1
- National Institute of Standards and Technology (NIST) or international equivalent



COPPER MOUNTAIN™ TECHNOLOGIES

OUR APPROACH: METROLOGY IS KEY



COPPER MOUNTAIN™ TECHNOLOGIES

COPPER MOUNTAIN TECHNOLOGIES

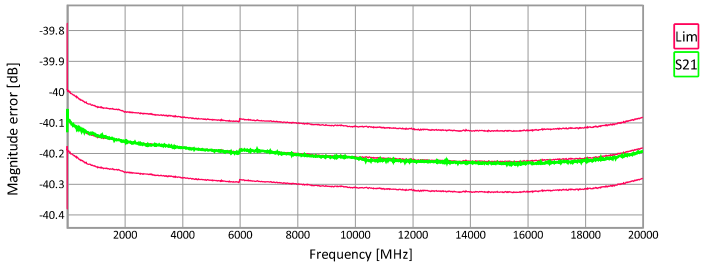
Calibration Certificate

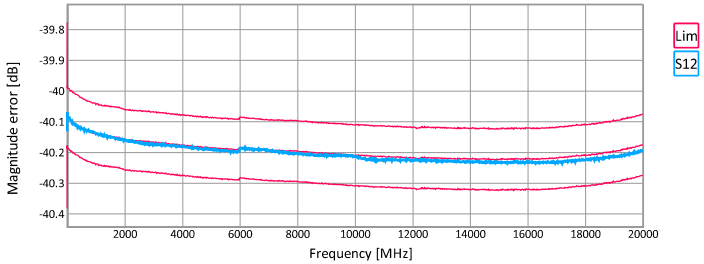
ISO/IEC 17025:2005 and ANSI/NCSL Z540.1-1994
Certificate Number: CMT-16048034-3090-0090

ilac-MRA ANAB ACCREDITED ISO/IEC 17025 ANSI/NCSL Z540-1 AC-2060

C1220 Serial Number: **16048034** Date: **25 Sept 2017** **PASS**

Transmission Coefficient Magnitude Accuracy. Attenuation 40 dB

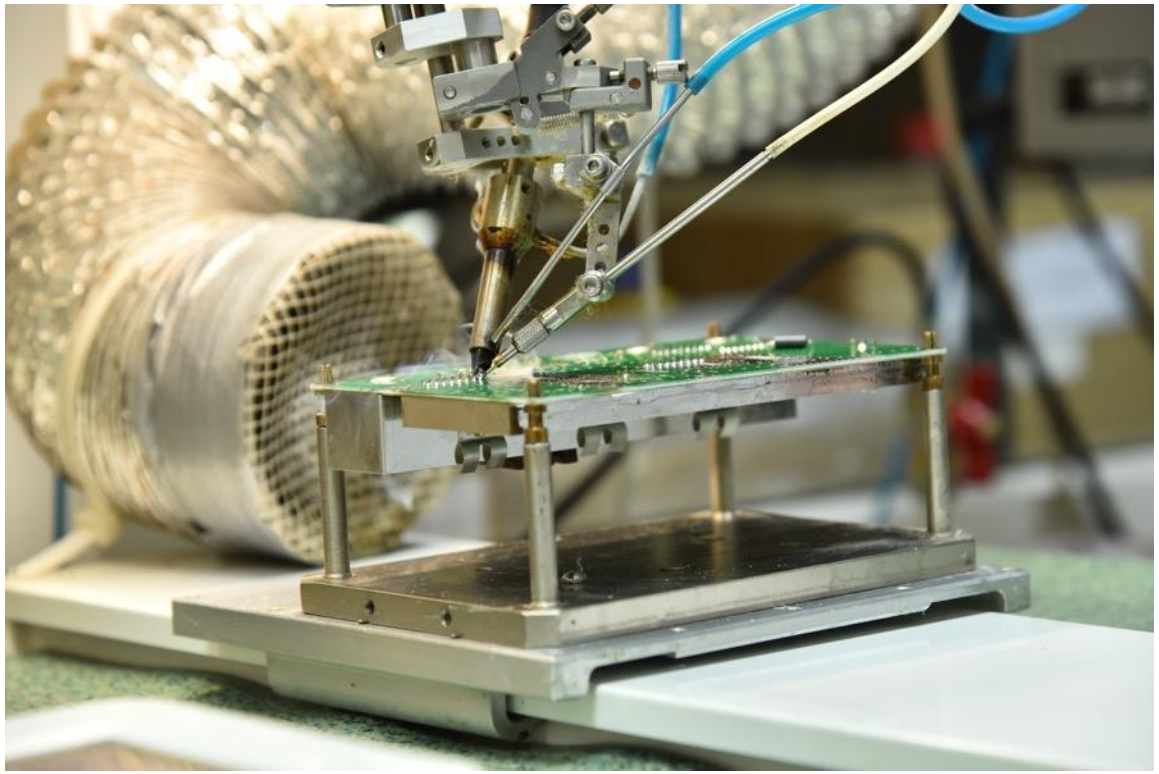




Description	Lower limit [dB]	Measured value [dB]	Upper limit [dB]	Measurement Uncertainty [dB]	Result
Transmission coefficient magnitude error:					
100 kHz to 1 MHz	-0.30	-0.05	0.30	—	PASS
1 MHz to 20 GHz	-0.10	-0.02	0.10	—	PASS

WORLD-CLASS MANUFACTURING

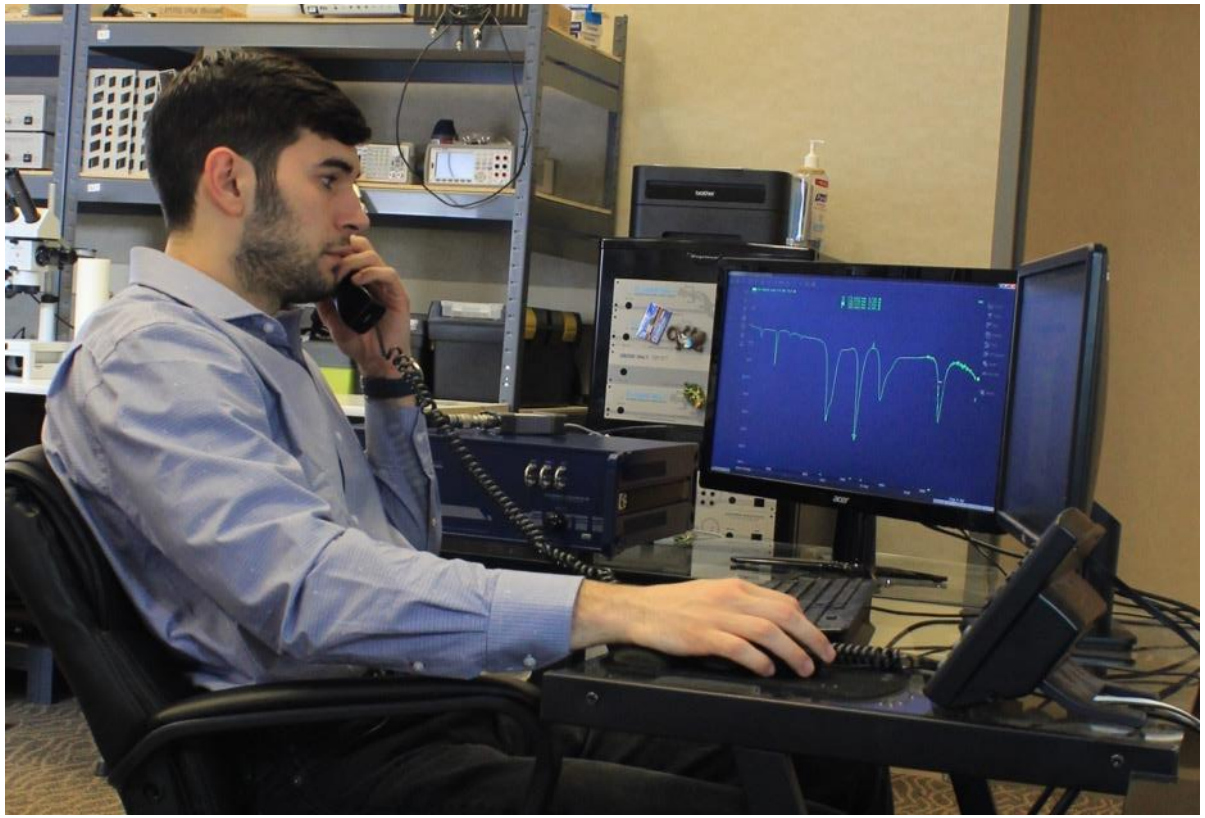
- We've partnered with Planar, which was founded by engineers with over 20 years of experience in RF and microwave, aerospace and defense technology.
- Planar is a fully ISO 9001 certified facility, fully equipped with the state -of-the-art manufacturing equipment.



COPPER MOUNTAIN™ TECHNOLOGIES

ACCESSIBLE CUSTOMER & TECHNICAL SUPPORT

- Application Engineers available for support directly
- Technical support, application-specific recommendations, and custom application development available



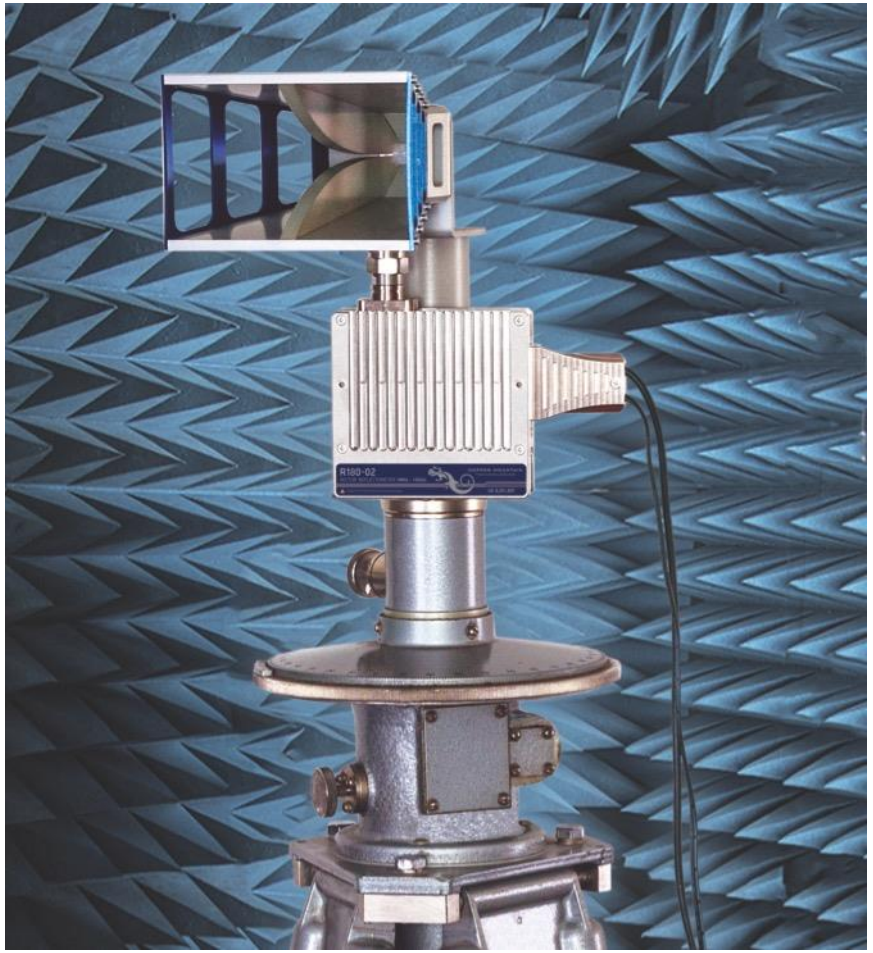
COPPER MOUNTAIN™ TECHNOLOGIES

VNAs FOR YOUR APPLICATION

COPPER MOUNTAIN™
TECHNOLOGIES

1-PORT VNAs (CABLE & ANTENNA ANALYZERS, REFLECTOMETERS)

- Lab grade performance in a handheld device.
- Solves challenges of integration, security, testing speed, ease of reporting, or space constraints.
- **US Patent 9,291,657**: Connects directly without the need for a test cable.
- All models under 1.1 lbs.
- Powered and operated via USB connection to an external PC.
- Highly dependable performance and calibration stability.



COPPER MOUNTAIN™ TECHNOLOGIES

1-PORT VNAs (CABLE & ANTENNA ANALYZERS, REFLECTOMETERS)

	R54	R60	R140	R180
Frequency Range	85 MHz to 5.4 GHz	1 MHz to 6 GHz	85 MHz to 14 GHz	1 MHz to 18 GHz
External frequency reference	No	10 MHz	32 MHz	10 MHz
External trigger	No	Input/Output	Input/Output	Input/Output
Power connector	USB mini-B	Reinforced (rugged) USB mini-B	USB mini-B	Reinforced (rugged) USB-C or +5V external
Adjustable output power	Hi/Low/Off	0.25 dB steps	Hi/Low/Off	0.05 dB steps
S21, S12 measurements	Scalar, with specialized software (available upon request)		Scalar, with specialized software (available upon request)	

☞ 1-Port VNA Products Home Page

COPPER MOUNTAIN™ TECHNOLOGIES

COMPACT VNAs – 9 kHz to 8.5 GHz

- Full featured lab grade performance in a co mpact package.
- Easy to transport and lightweight.
- 2-ports with 1 path or 2 path testing.
- Models available in 50 or 75 Ohm.
- Combines a maximum standard feature set with a size suitable for many applications.

COPPER MOUNTAIN™ TECHNOLOGIES

COMPACT VNAs

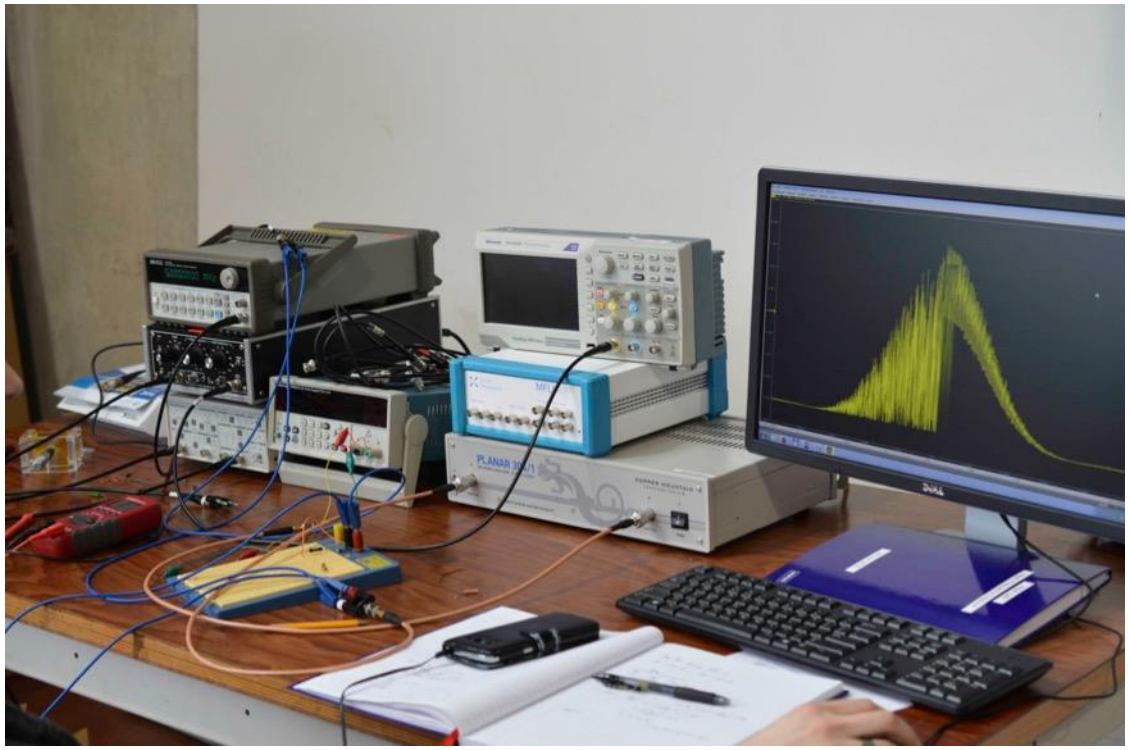
	TR1300/1	TR5048	S5048	TR7530	S7530	S5065	S5085
Frequency Range	300 kHz to 1.3 GHz	20 kHz to 4.8 GHz	20 kHz to 4.8 GHz	20 kHz to 3 GHz	20 kHz to 3 GHz	9 kHz to 6.5 GHz	9 kHz to 8.5 GHz
S-parameters	S11, S21	S11, S21	S11, S21, S12, S22	S11, S21	S11, S21, S12, S22	S11, S21, S12, S22	S11, S21, S12, S22
Port Impedance	50 Ohms	50 Ohms	50 Ohms	75 Ohms	75 Ohms	50 Ohms	50 Ohms

☞ Compact VNA Products Home Page

COPPER MOUNTAIN™ TECHNOLOGIES

PLANAR VNAs – 100 kHz to 8 GHz

- Full size instruments
- Lab quality performance in a 19-inch chassis
- 4-port configuration and direct access to receivers
- Time domain with gating, fixture simulation, frequency offset mode are standard
- Devices are ATE compatible, rack mountable, and easy to program and share between multiple users.



COPPER MOUNTAIN™ TECHNOLOGIES

PLANAR VNAs

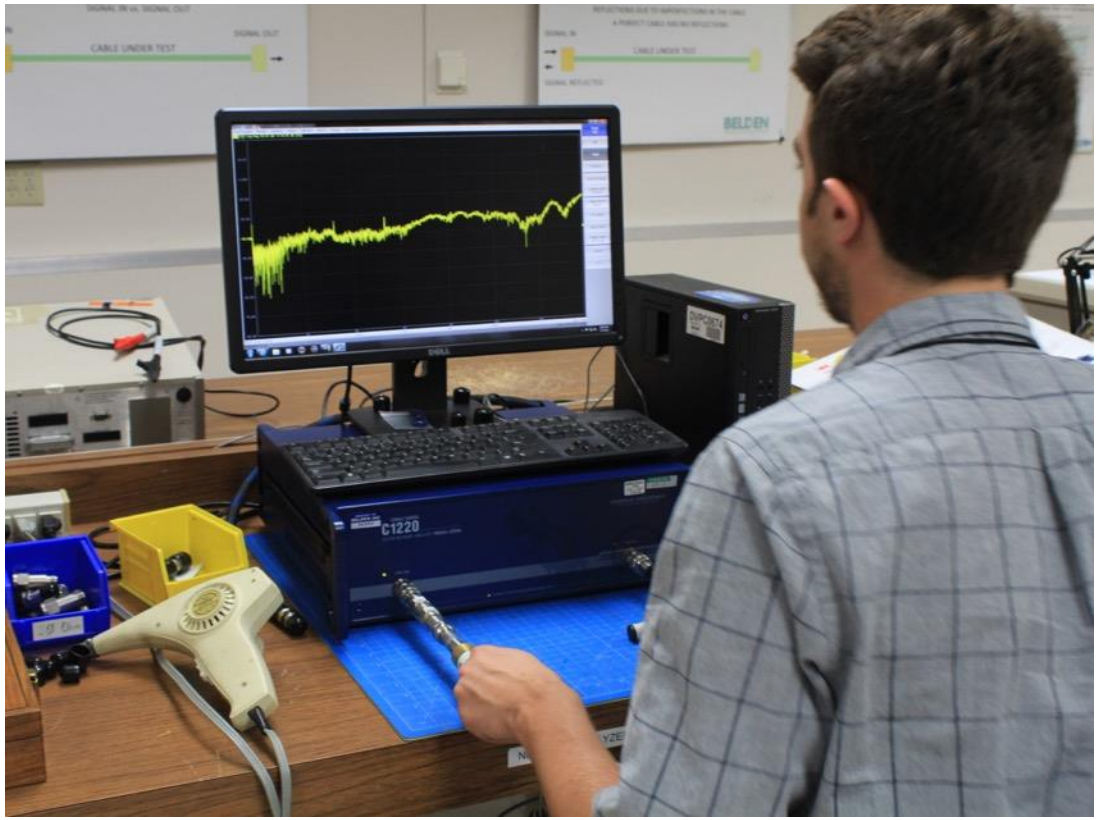
	304/1	804/1	808/1	814/1
Frequency Range	100 kHz to 3.2 GHz	100 kHz to 8 GHz	100 kHz to 8 GHz	100 kHz to 8 GHz
Number of Ports	2	2	4	2
Special Features				Direct Receiver Access

☞ Full Size VNA Products Home Page

COPPER MOUNTAIN™ TECHNOLOGIES

COBALT VNAS - 100 kHz to 20 GHz

- Industry-leading dynamic range and sweep speed :
  - 135 or 152 dB typ.* (10 Hz IF BW)
  - 10 or 12 µs*
- Ideal for fast production and applications like 5G r eal-time BTS filter tuning.
- Unmatched price-performance combination for S-parameter measurement
- The design and production of Cobalt VNAs incorp orates several innovative new manufacturing and test approaches.



COPPER MOUNTAIN™ TECHNOLOGIES

COBALT VNAs



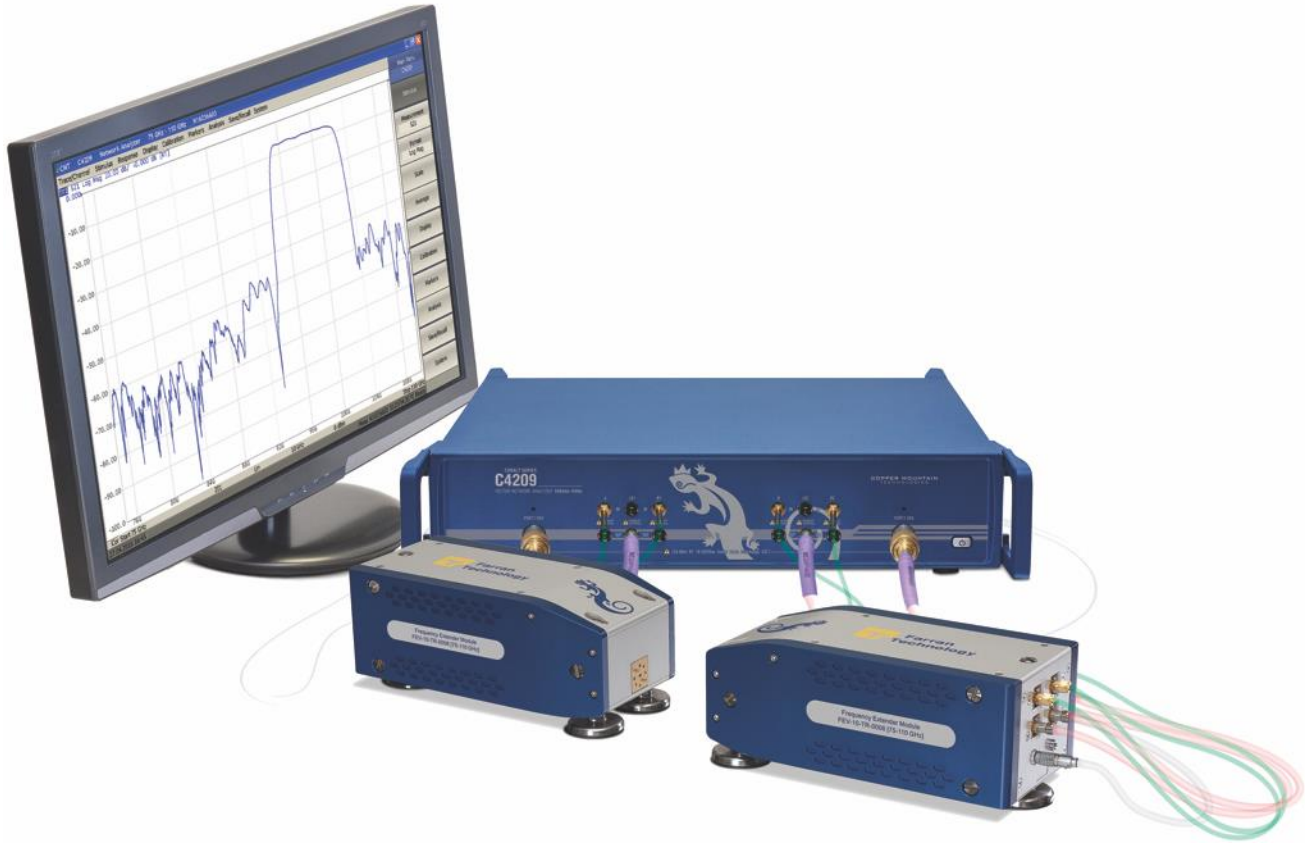

	C1209	C2209	C4209	C1409	C2409	C4409	C1220	C2220	C4220	C1420	C2420	C4420
100 kHz to 9 GHz	X	X	X	X	X	X						
100 kHz to 20 GHz							X	X	X	X	X	X
Number of Ports	2	2	2	4	4	4	2	2	2	4	4	4
Direct Receiver Access		X			X			X			X	
Frequency Extension			X			X			X			X

☞ Cobalt VNA Products Home Page

COPPER MOUNTAIN™ TECHNOLOGIES

COBALTFX VNAs: MILLIMETER WAVE FREQUENCY EXTENSION

- Cost-effective millimeter wave frequency exten sion system.
- CobaltFx is an unprecedented approach for mil limeter-wave S-parameter measurements.
- Models available in three dedicated waveguide bands, 50-75 GHz, 60-90 GHz and 75-110 GH z.
- The system features frequency extension mod ules from Farran Technology and a precision c alibration kit.



COPPER MOUNTAIN™ TECHNOLOGIES

COBALTFX PRODUCT SERIES

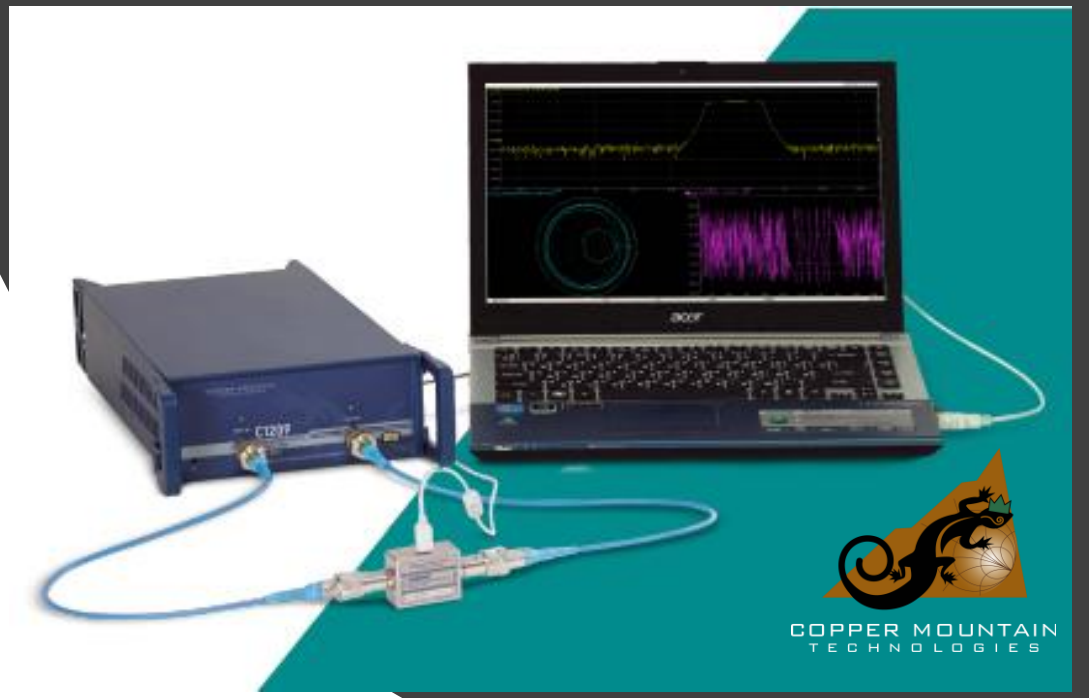
CobaltFx Compatible VNAs

C4209
C4409
C4220
C4420

	CobaltFX-15	CobaltFX-12	CobaltFX-10
System Operating Frequency	50~75GHz	60~90GHz	75~110GHz
Test Port Output Power	5dBm (Min.), 8 dBm (Typ.)	2 dBm (Min.), 5 dBm (Typ.)	0 dBm (Min.), 5 dBm (Typ.)
System Dynamic Ragne	110 dB (Min,), 120 dB (Typ.)	100 dB (Min.), 110 dB (Typ.)	100 dB (Min.), 110 dB (Typ.)

☞ CobaltFX VNA Products Home Page

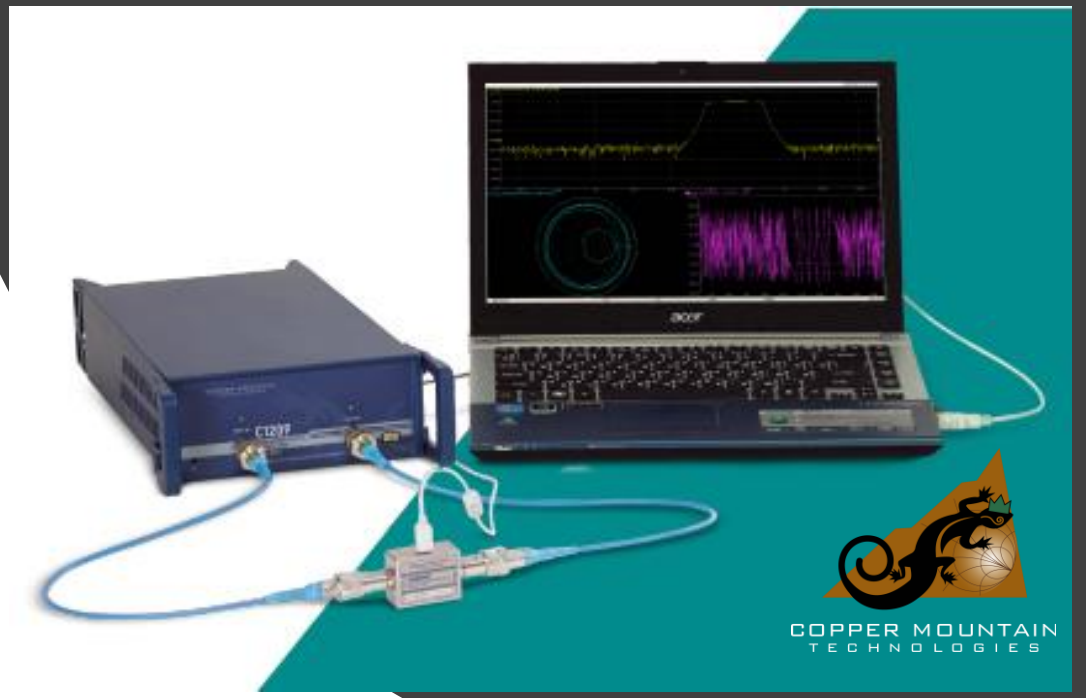
COPPER MOUNTAIN™ TECHNOLOGIES



CMT사 VNA 주요기능

PC용 GUI(Graphical User Interface)중심으로

CMT VNA GUIs (동영상)



응용사례

5G 통신용 안테나
측정 중심으로

안테나 측정사례-I

1-Port VNA를 이용한 IoT용 안테나 (LoRa) 특성 측정/검증

안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- **측정목표:**
  - ➢ LoRa Antenna의 특성(S11 Return Loss, VSWR, Phase, Smith Chart) 검증
  - ➢ 측정 환경: Open space
- **피측정체:** Taoglas사 433MHz ISM Band Terminal Antenna (모델명: TI.10.0112)
  - **특징**

✓ Omni-directional
✓ Peak gain of 0dBi
✓ SMA(M)RA Plug Connector
✓ Low Profile and Robust Handling
✓ 44.8mm Antenna Length
✓ IP65
✓ RoHS Compliant

  - **응용분야**

1. Connected Industry
2. Smart City
3. Smart Energy
4. Connected Car
5. Other
6. Smart Agriculture
7. Connected Building[3]
8. Connected Health
9. Smart Retail
10. Smart Supply Chain

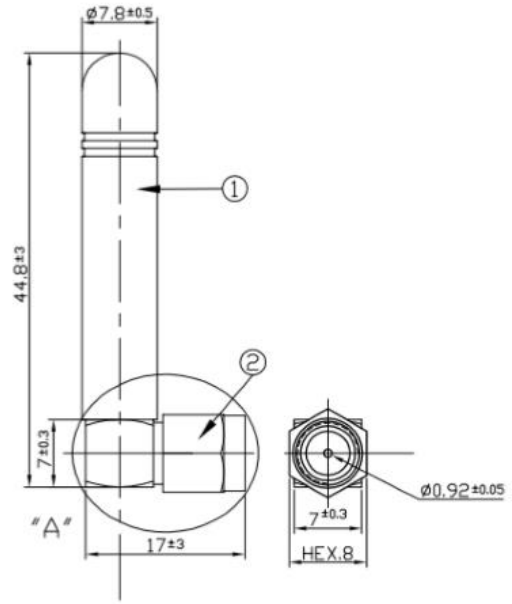
안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

• 피측정체(계속):

▪ 물리적 크기



	Name	Material	Finish	Quantity
①	Antenna Cover	TPU	Black	1
②	SMA(M)RA	Brass	Gold	1

▪ 전기적 특성

Parameter	Specification
Applications	433MHz ISM Band
Frequency	433.05~434.79MHz
Peak Gain	0dBi
Return Loss	-20dB
Impedance	50 Ohms
Radiation Pattern	Omni-directional
Polarization	Linear
VSWR	≤1.5:1
Power handling	5 W
Housing	TPE
Connector	SMA(M)RA Plug
Operation Temperature	-40°C to + 85°C
Storage Temperature	-40°C to + 105°C

안테나 측정사례-I

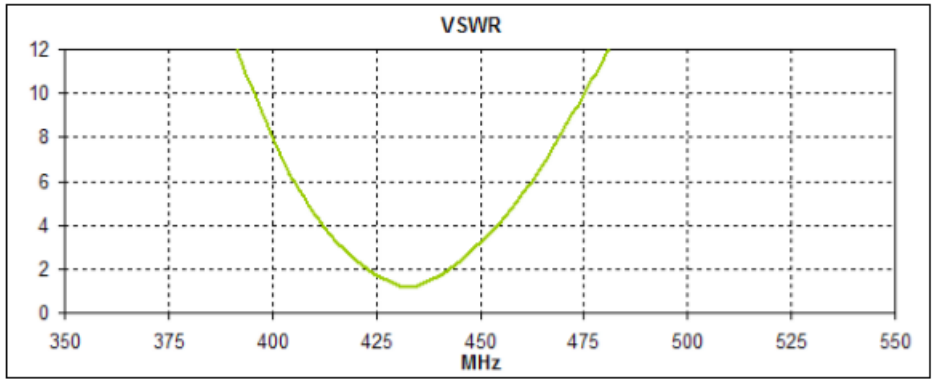
IoT용 안테나

(LoRa) 측정/검증

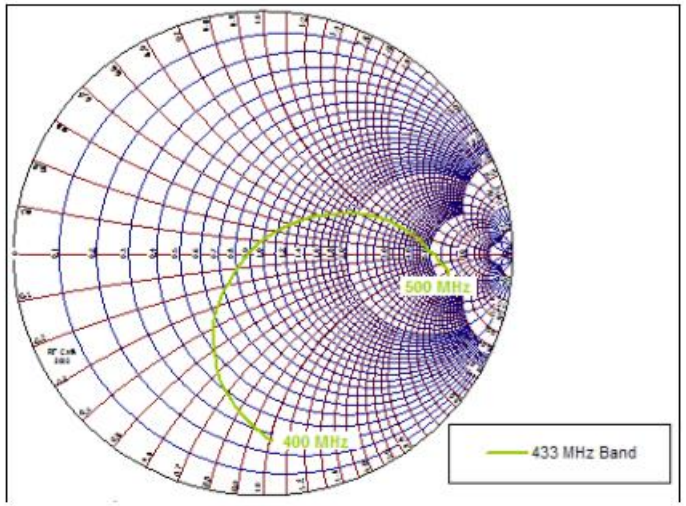
- **피측정체(계속):**
  - **Antenna Parameter사양**

1 Return Loss Data

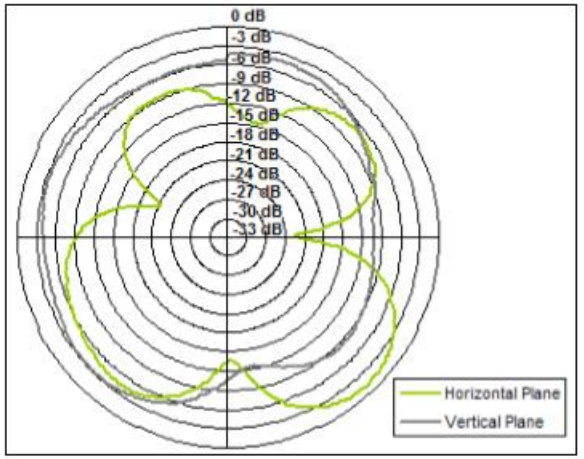
2 VSWR Data



3 Smith Chart Data



4 Radiation Pattern



안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- **측정기 주요 기능 및 사양:**
  - 모델명: **R60**
    - Frequency range: 1.0 MHz-6.0 GHz
    - Number of ports: 1 (N-type, male)
    - Dynamic Range: 109 dB typ. @100Hz IF BW
    - Measurement Bandwidth: 10Hz to 100kHz
    - Measurement time per point: 100 μs min typ.
    - Up to 100,001 measurement points per sweep
    - Effective directivity: 46dB
    - Measured parameters: S_{11} Log magnitude, DTF, Smith, and more

☞ R60 Product Home Page

안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

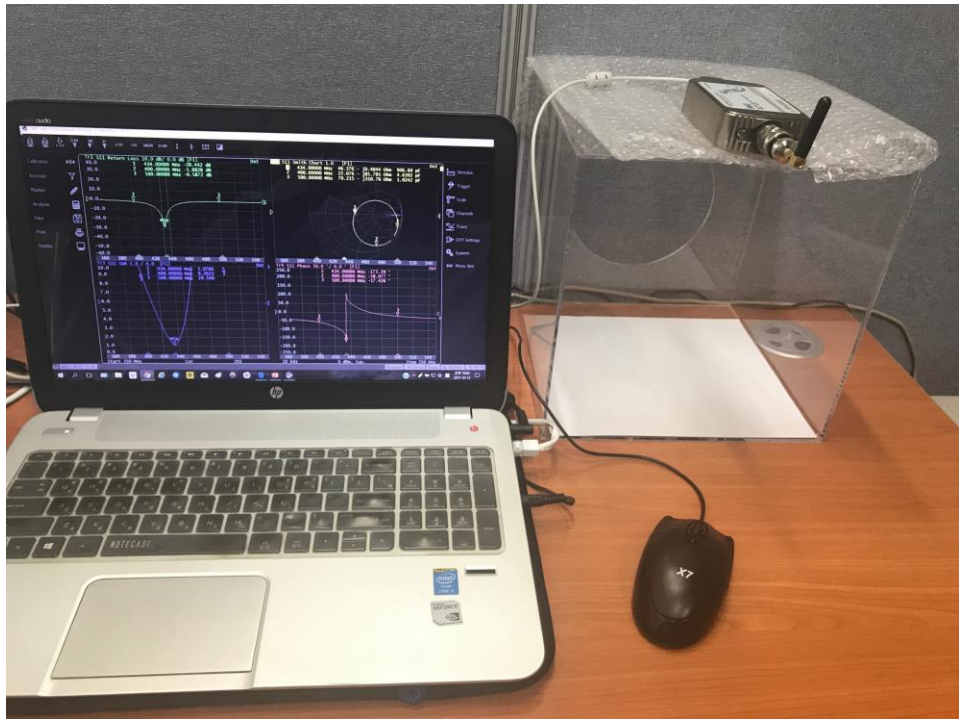
- **측정구성:**
  - 1 set x R60
  - 1 set x VNA GUI Software (RVNA), PC에 설치
  - Adapters
    - 1 ea x N-Type (female) to SMA (female)
  - 1 set x Calibration Kit, SMA-J, DC to 6GHz, Load<-32dB, VSWR:1.05
  - 1 set x PC
  - 1 ea x LoRa Antenna

안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- **측정 Set-up:**
  - **측정주파수 범위:** 350MHz to 500MHz
  - **측정포인트 개수:** 201개
  - **IF Bandwidth:** 10kHz
  - **Output Power:** 0 dBm
  - **측정파라미터:** S11 Return Loss, SWR, Phase, Smith Chart
  - **Calibration:** Full 1-Port Calibration (Open, Short, Load)



안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

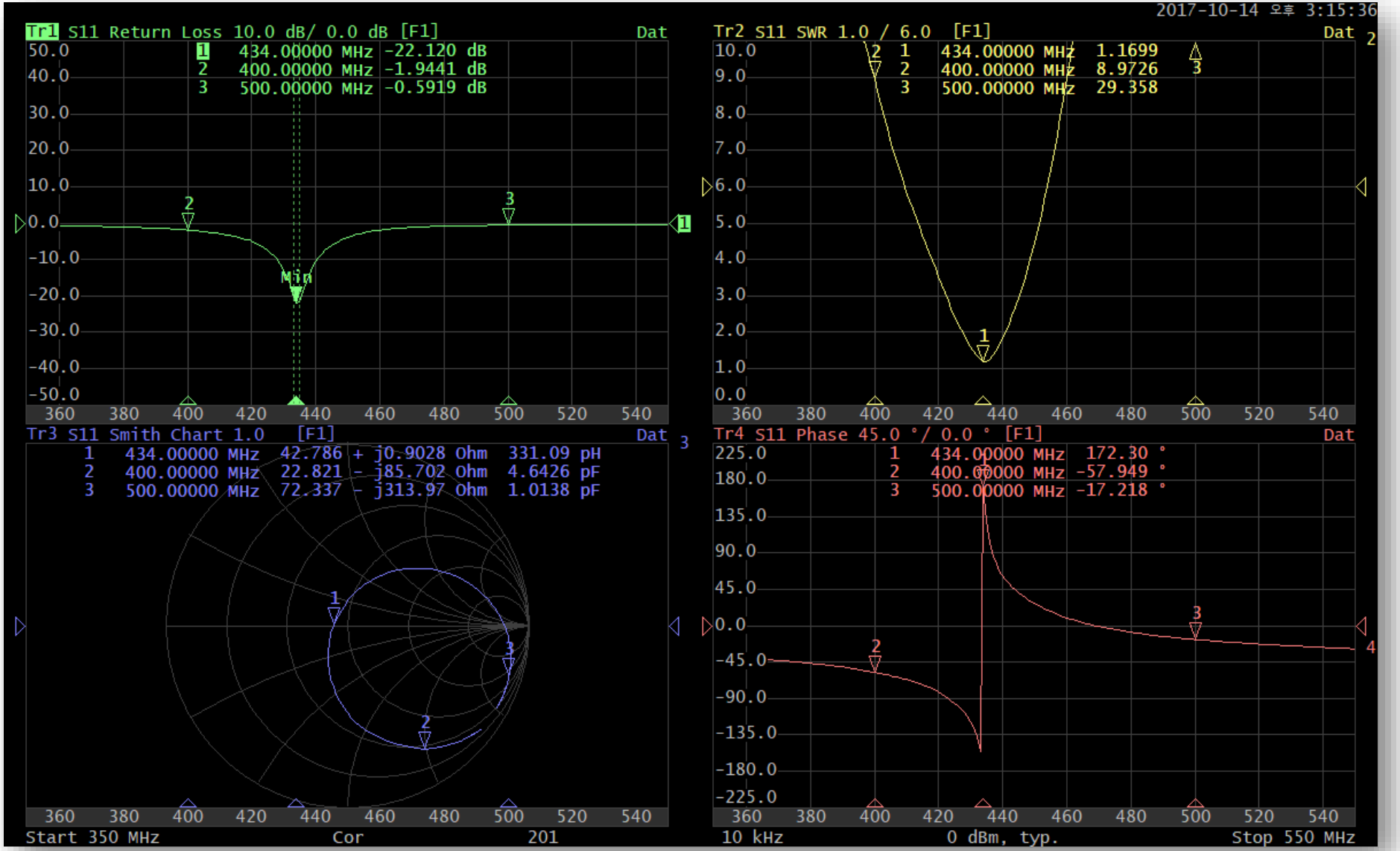
- **측정 동영상:**

안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- **측정결과: All Trace Data (S11 Return Loss, SWR, Smith Chart, Phase)**

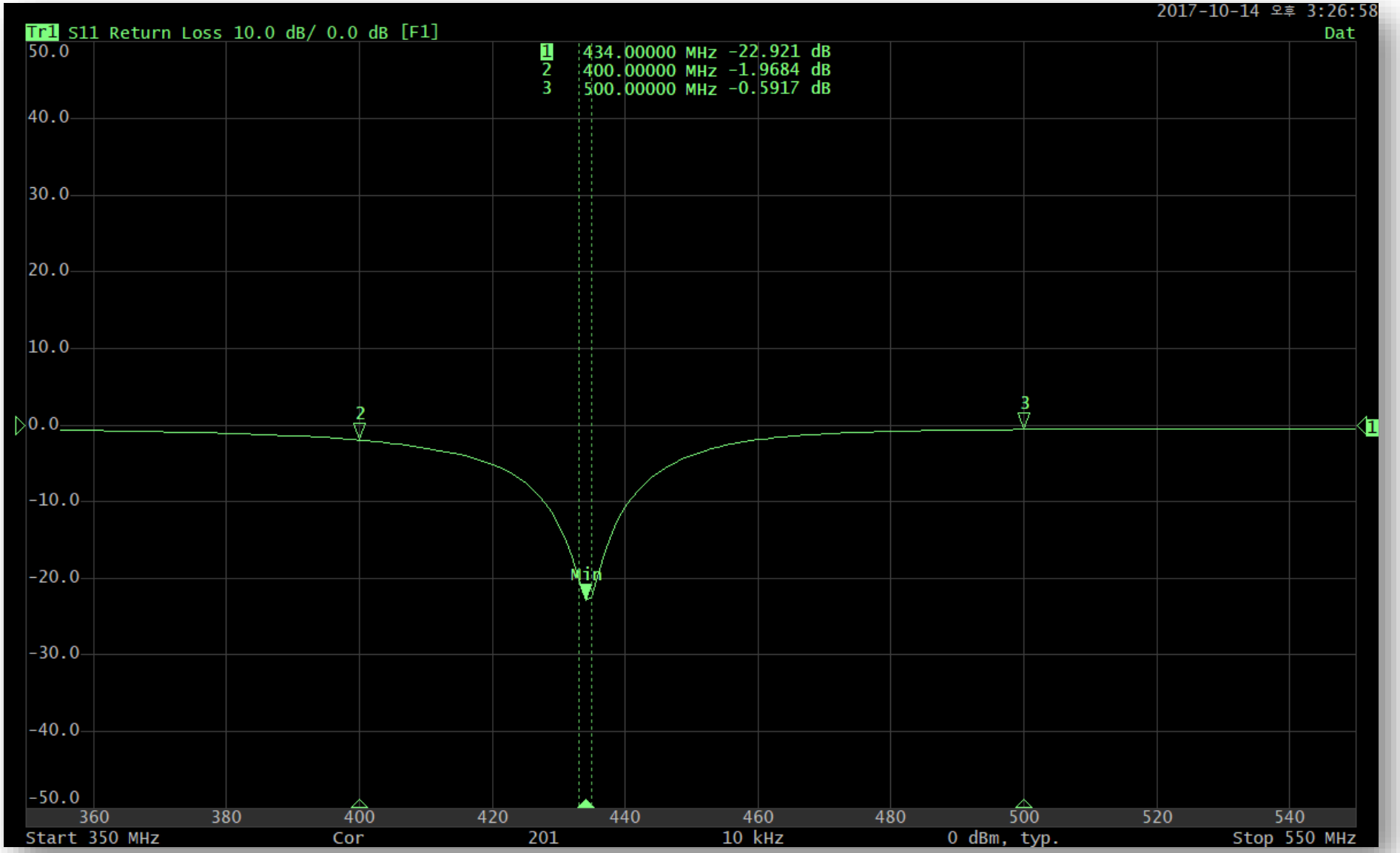


안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- 측정결과: S11 Return Loss

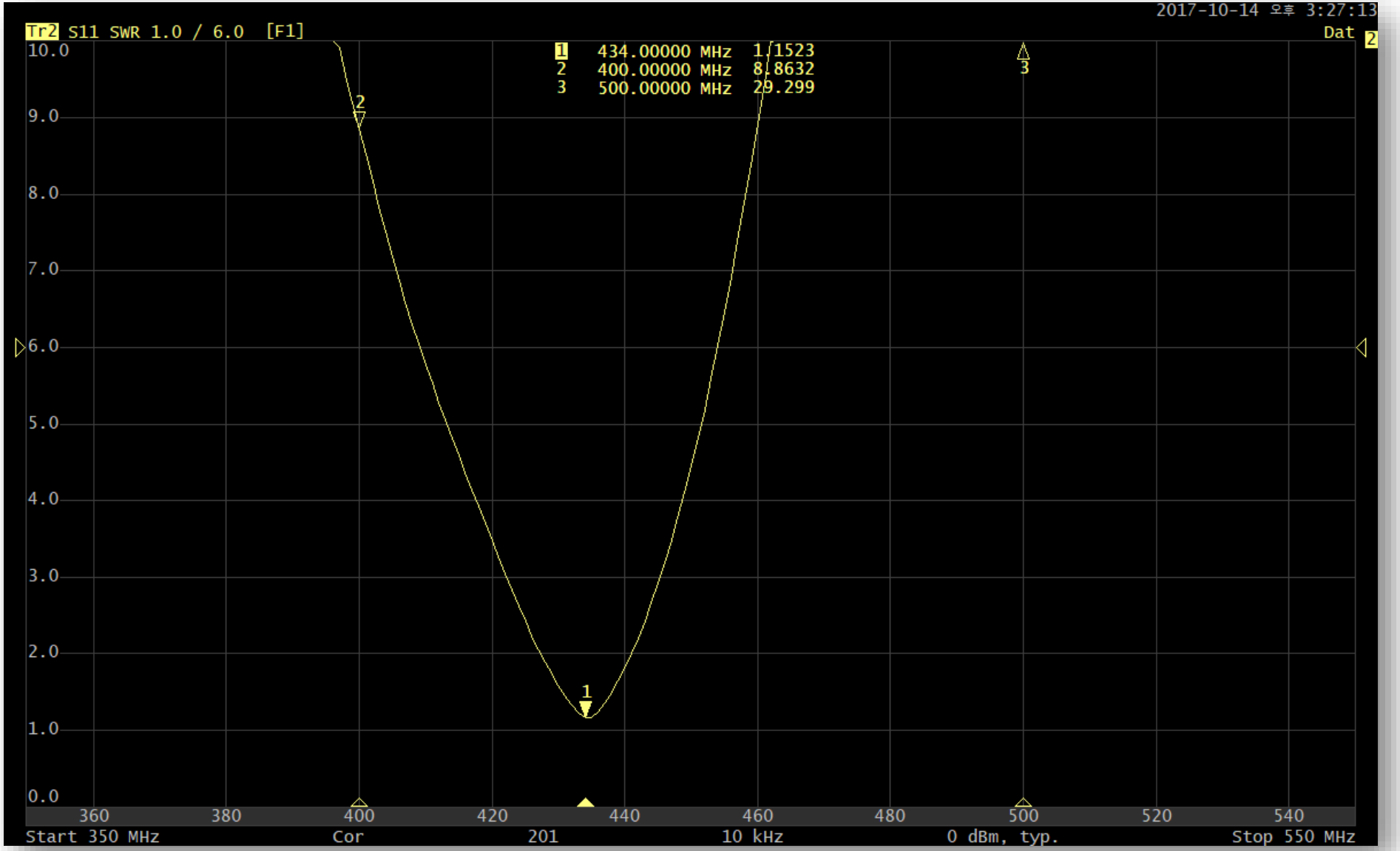


안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- 측정결과: S11 SWR

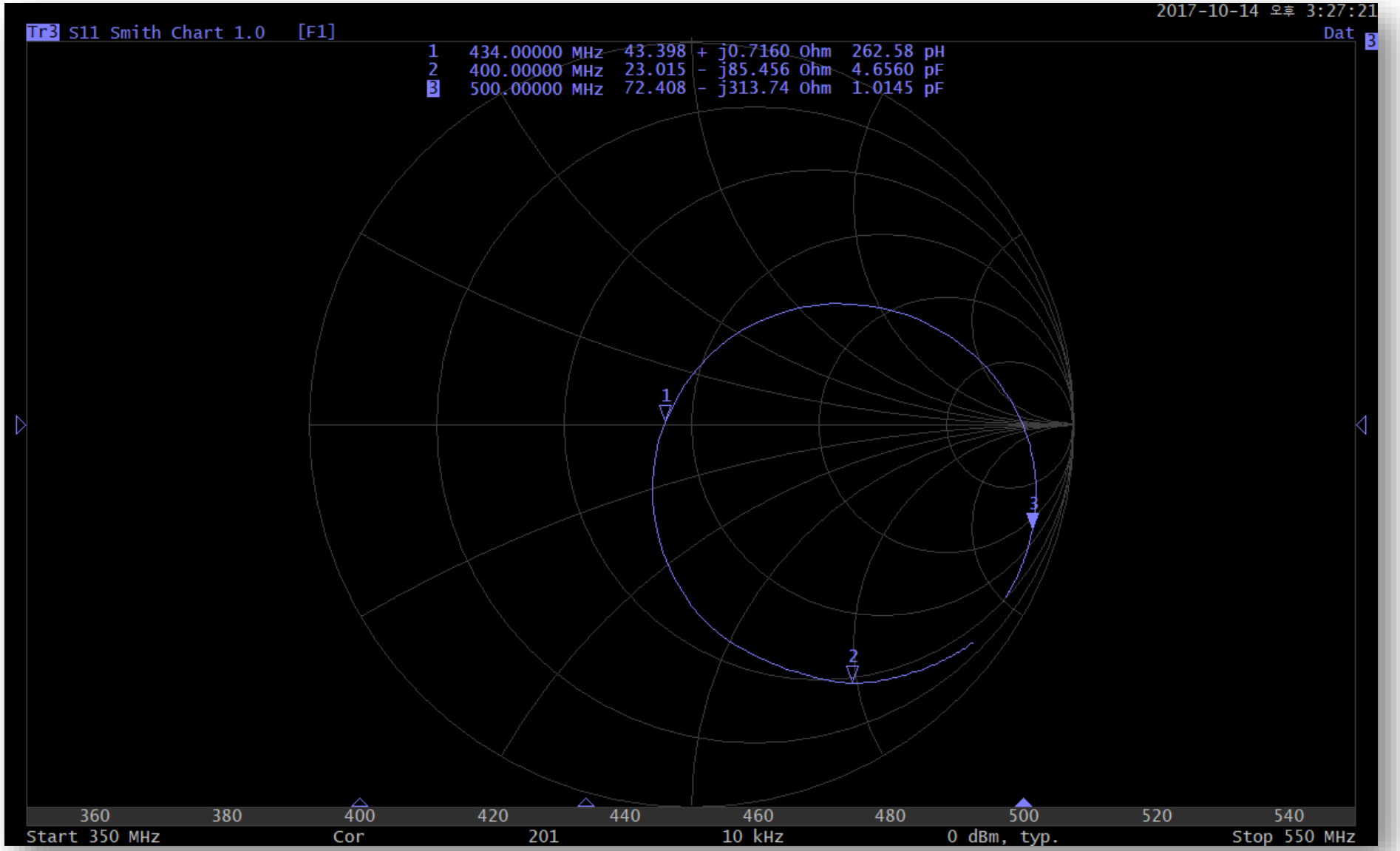


안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- 측정결과: S11 Smith Chart

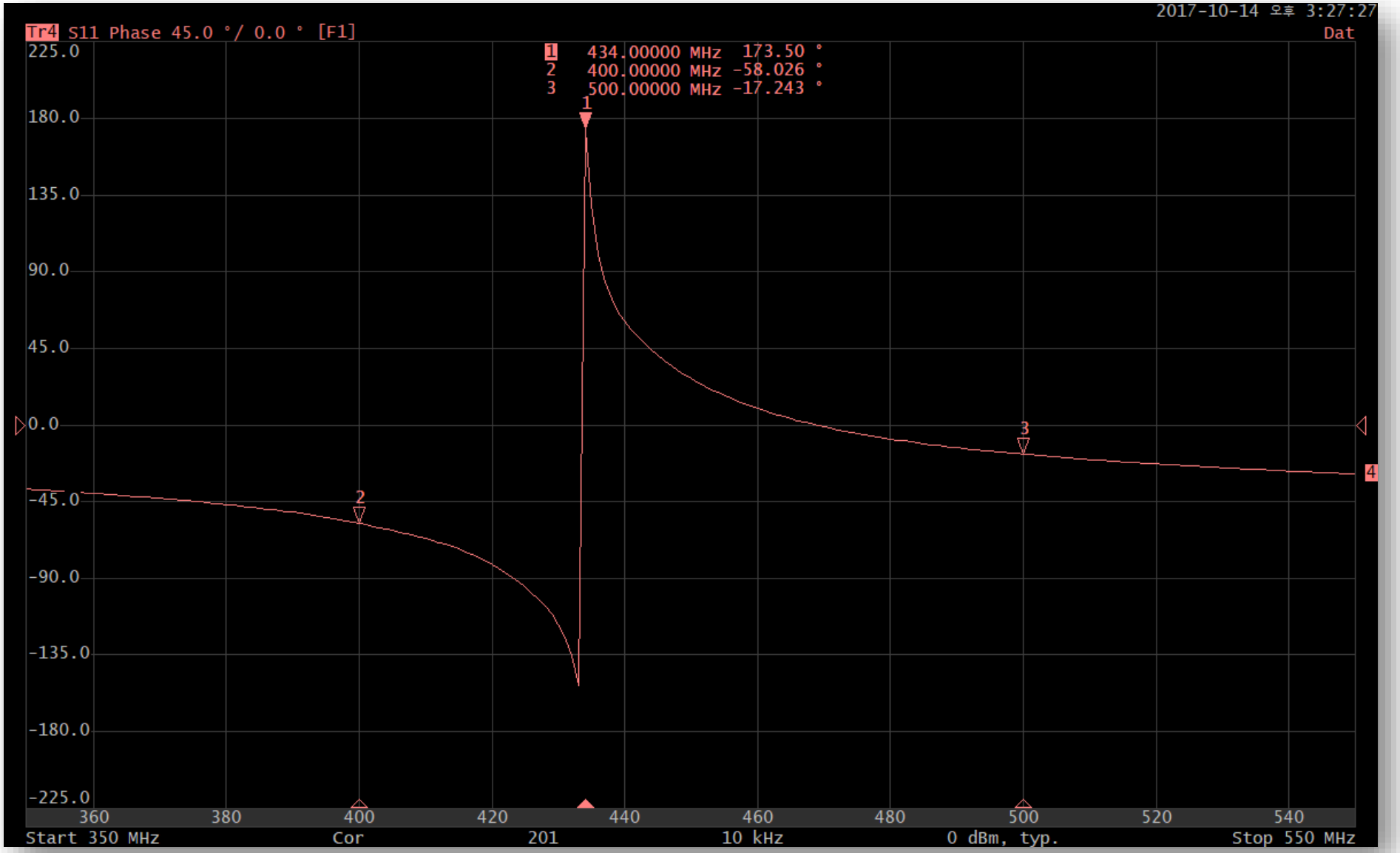


안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- 측정결과: S11 Phase



안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- 측정결과: CSV format for S11 Return Loss

	A	B	C	D	E	F	G	H	I	J	K
1	3.50E+08	-6.12E-01	0.00E+00								
2	3.51E+08	-6.22E-01	0.00E+00								
3	3.52E+08	-6.32E-01	0.00E+00								
4	3.53E+08	-6.44E-01	0.00E+00								
5	3.54E+08	-6.50E-01	0.00E+00								
6	3.55E+08	-6.60E-01	0.00E+00								
7	3.56E+08	-6.71E-01	0.00E+00								
8	3.57E+08	-6.79E-01	0.00E+00								
9	3.58E+08	-6.89E-01	0.00E+00								
10	3.59E+08	-7.01E-01	0.00E+00								
11	3.60E+08	-7.08E-01	0.00E+00								
12	3.61E+08	-7.22E-01	0.00E+00								
13	3.62E+08	-7.32E-01	0.00E+00								
14	3.63E+08	-7.46E-01	0.00E+00								
15	3.64E+08	-7.55E-01	0.00E+00								
16	3.65E+08	-7.67E-01	0.00E+00								
17	3.66E+08	-7.79E-01	0.00E+00								
18	3.67E+08	-7.95E-01	0.00E+00								
19	3.68E+08	-8.11E-01	0.00E+00								
20	3.69E+08	-8.23E-01	0.00E+00								
21	3.70E+08	-8.44E-01	0.00E+00								
22	3.71E+08	-8.58E-01	0.00E+00								
23	3.72E+08	-8.79E-01	0.00E+00								

LoRa antenna test_tr1 data

안테나 측정사례-I

IoT용 안테나

(LoRa) 측정/검증

- **측정결과: Touchstone files**

```
! COPPER MOUNTAIN TECHNOLOGIES, R60, 0020417, 17.3.2/3.0
! Date: 2017-10-14 오후 3:13:19
! Data: Format [Calibration Info]
! Frequency                S11: Re/Im F1
# HZ S RI R 50
3.50000000E+08   7.36656055E-01 -5.70979848E-01
3.51000000E+08   7.33508879E-01 -5.73868544E-01
3.52000000E+08   7.30202672E-01 -5.75959232E-01
3.53000000E+08   7.26731462E-01 -5.78073952E-01
3.54000000E+08   7.23674752E-01 -5.80866813E-01
3.55000000E+08   7.20014139E-01 -5.83487269E-01
3.56000000E+08   7.16341399E-01 -5.86052922E-01
3.57000000E+08   7.12847825E-01 -5.88579583E-01
3.58000000E+08   7.08982584E-01 -5.90779954E-01
3.59000000E+08   7.04998326E-01 -5.93044538E-01
3.60000000E+08   7.01158806E-01 -5.95237629E-01
3.61000000E+08   6.96844372E-01 -5.97310941E-01
3.62000000E+08   6.92925197E-01 -5.99648981E-01
3.63000000E+08   6.88783574E-01 -6.01932547E-01
3.64000000E+08   6.84718945E-01 -6.04402030E-01
3.65000000E+08   6.80715622E-01 -6.06931973E-01
3.66000000E+08   6.75954139E-01 -6.09106812E-01
3.67000000E+08   6.71508696E-01 -6.11833226E-01
3.68000000E+08   6.67088530E-01 -6.13961747E-01
3.69000000E+08   6.62388699E-01 -6.16406579E-01
3.70000000E+08   6.57712123E-01 -6.18424414E-01
3.71000000E+08   6.53019750E-01 -6.20982616E-01
3.72000000E+08   6.48119263E-01 -6.23239304E-01
3.73000000E+08   6.43240343E-01 -6.25919003E-01
3.74000000E+08   6.38266994E-01 -6.28488231E-01
3.75000000E+08   6.32458617E-01 -6.31004679E-01
3.76000000E+08   6.27228529E-01 -6.33798082E-01
3.77000000E+08   6.21299510E-01 -6.36549469E-01
3.78000000E+08   6.14603966E-01 -6.38706447E-01
3.79000000E+08   6.08416439E-01 -6.40898411E-01
3.80000000E+08   6.01511361E-01 -6.43399630E-01
```

```
! COPPER MOUNTAIN TECHNOLOGIES, R60, 0020417, 17.3.2/3.0
! Date: 2017-10-14 오후 4:22:56
! Data: Format [Calibration Info]
! Frequency                S11: Mag/Ang F1
# HZ S MA R 50
3.50000000E+08   9.32366340E-01 -3.74975675E+01
3.51000000E+08   9.31298564E-01 -3.77148537E+01
3.52000000E+08   9.30159800E-01 -3.79329170E+01
3.53000000E+08   9.28963319E-01 -3.81812901E+01
3.54000000E+08   9.28110413E-01 -3.84304928E+01
3.55000000E+08   9.26956186E-01 -3.86640341E+01
3.56000000E+08   9.26025325E-01 -3.89196291E+01
3.57000000E+08   9.25151506E-01 -3.91705095E+01
3.58000000E+08   9.23993680E-01 -3.94142148E+01
3.59000000E+08   9.22495030E-01 -3.96720420E+01
3.60000000E+08   9.21840971E-01 -3.99421956E+01
3.61000000E+08   9.20550666E-01 -4.02024652E+01
3.62000000E+08   9.19540867E-01 -4.04769977E+01
3.63000000E+08   9.17770266E-01 -4.07644294E+01
3.64000000E+08   9.16300166E-01 -4.10491095E+01
3.65000000E+08   9.15223431E-01 -4.13330267E+01
3.66000000E+08   9.13710120E-01 -4.16505167E+01
3.67000000E+08   9.12317140E-01 -4.19660246E+01
3.68000000E+08   9.10704992E-01 -4.22387848E+01
3.69000000E+08   9.09344379E-01 -4.25879466E+01
3.70000000E+08   9.07850512E-01 -4.29223674E+01
3.71000000E+08   9.05856987E-01 -4.32407307E+01
3.72000000E+08   9.03722646E-01 -4.35886434E+01
3.73000000E+08   9.01680749E-01 -4.39424485E+01
3.74000000E+08   8.99487835E-01 -4.42795905E+01
3.75000000E+08   8.96969641E-01 -4.46452679E+01
3.76000000E+08   8.95069398E-01 -4.49802077E+01
3.77000000E+08   8.93115881E-01 -4.53384283E+01
3.78000000E+08   8.90438107E-01 -4.57102807E+01
3.79000000E+08   8.87977705E-01 -4.60578763E+01
3.80000000E+08   8.85379375E-01 -4.64754767E+01
```

```
! COPPER MOUNTAIN TECHNOLOGIES, R60, 0020417, 17.3.2/3.0
! Date: 2017-10-14 오후 4:23:20
! Data: Format [Calibration Info]
! Frequency                S11: dB/Ang F1
# HZ S DB R 50
3.50000000E+08  -6.10393826E-01 -3.75004642E+01
3.51000000E+08  -6.17602604E-01 -3.77296407E+01
3.52000000E+08  -6.28854509E-01 -3.79530503E+01
3.53000000E+08  -6.41255460E-01 -3.82040230E+01
3.54000000E+08  -6.46241829E-01 -3.84189492E+01
3.55000000E+08  -6.58226802E-01 -3.86687434E+01
3.56000000E+08  -6.66938760E-01 -3.89264206E+01
3.57000000E+08  -6.77042659E-01 -3.91662563E+01
3.58000000E+08  -6.86159682E-01 -3.94146749E+01
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3.60000000E+08  -7.06525822E-01 -3.99404643E+01
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3.64000000E+08  -7.58485481E-01 -4.10372913E+01
3.65000000E+08  -7.68092473E-01 -4.13278697E+01
3.66000000E+08  -7.82953730E-01 -4.16501711E+01
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3.72000000E+08  -8.80375146E-01 -4.35840782E+01
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3.79000000E+08  -1.02957190E+00 -4.60686051E+01
3.80000000E+08  -1.05517653E+00 -4.64969573E+01
```

안테나
측정사례-I

IoT용 안테나

(LoRa) 측정/검증

결과 요약

- 경제적인 1-Port VNA를 이용하여 IoT용 안테나(ex. LoRa)의 S11 Parameter들을 간단히 측정/검증할 수 있음.
- 단, 안테나 성능 검증에 영향을 끼칠 수 있는 외부의 요인들을 최소화하기 위해서 Anechoic Chamber내에서 측정/검증하기를 권장함.

안테나 측정사례-II

mmWave 측정시스템을 이용한 E-band Horn Antenna측정

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **목표:** mmWave Horn Antenna (E-band) Measurements
- **피시험체:**

SAR-2013-12-S2

WR-12 Pyramidal Horn Antenna, 20 dBi Gain

Description:

Model SAR-2013-12-S2 is an E-band pyramidal horn antenna that operates from 60 GHz to 90 GHz. The antenna offers 20 dBi nominal gain and a typical half power beamwidth of 14 degrees on the E-plane and 15 degrees on the H-plane. The antenna supports linear polarized waveforms. The input of this antenna is a WR-12 waveguide with UG-387/U flange.

Features:

- Rectangular Waveguide Interface
- Precisely Machined and Gold Plated
- Linear Polarization
- High Return Loss

Applications:

- Antenna Ranges
- Antenna Gain Measurements
- System Setups

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

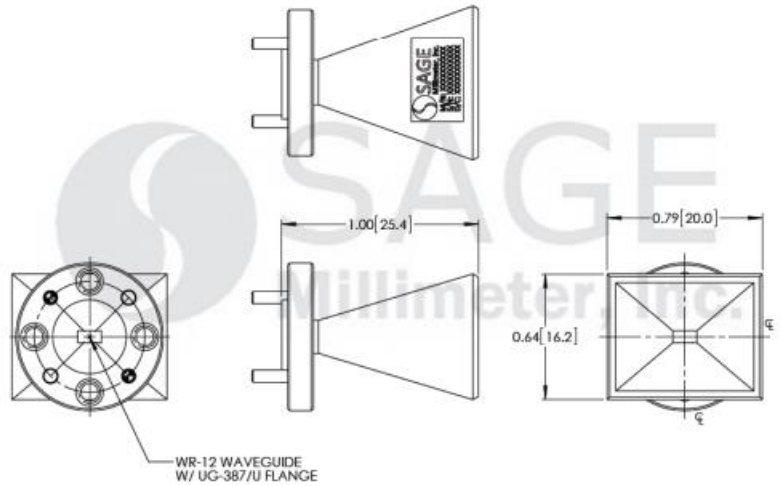
- **피시험체:**

Electrical Specifications:

Parameter	Minimum	Typical	Maximum
Frequency	60 GHz		90 GHz
Gain	18.5 dBi	20 dBi	21 dBi
Polarization		Linear	
3 dB Beamwidth, E-Plane		14°	
3 dB Beamwidth, H-Plane		15°	
Side Lobes, E-Plane		14 dB	
Side Lobes, H-Plane		30 dB	
VSWR		1.15:1	

Mechanical Specifications:

Item	Specification
Antenna Port	WR-12 Waveguide
Flange Type	UG-387/U Flange
Size	1.00" (L) X 0.79" (W) X 0.64"(H)
Material	Brass
Finish	Gold Plated
Weight	0.6 Oz
Outline	AR-E1

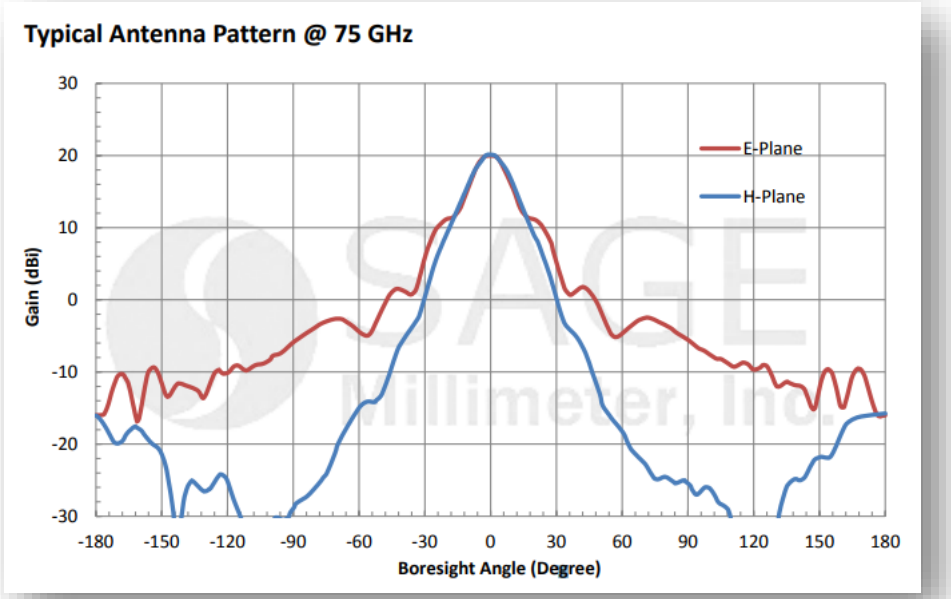


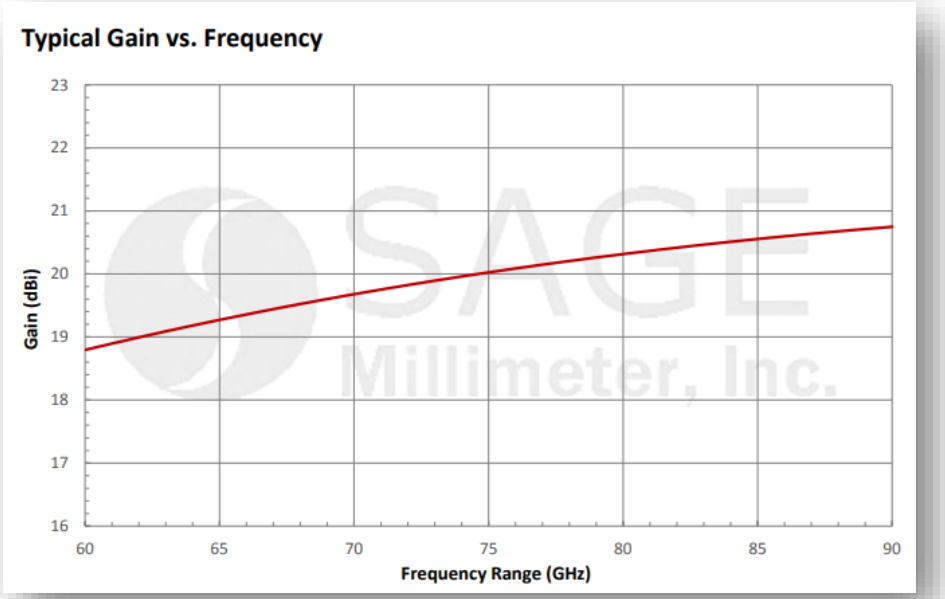
안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **피시험체:**





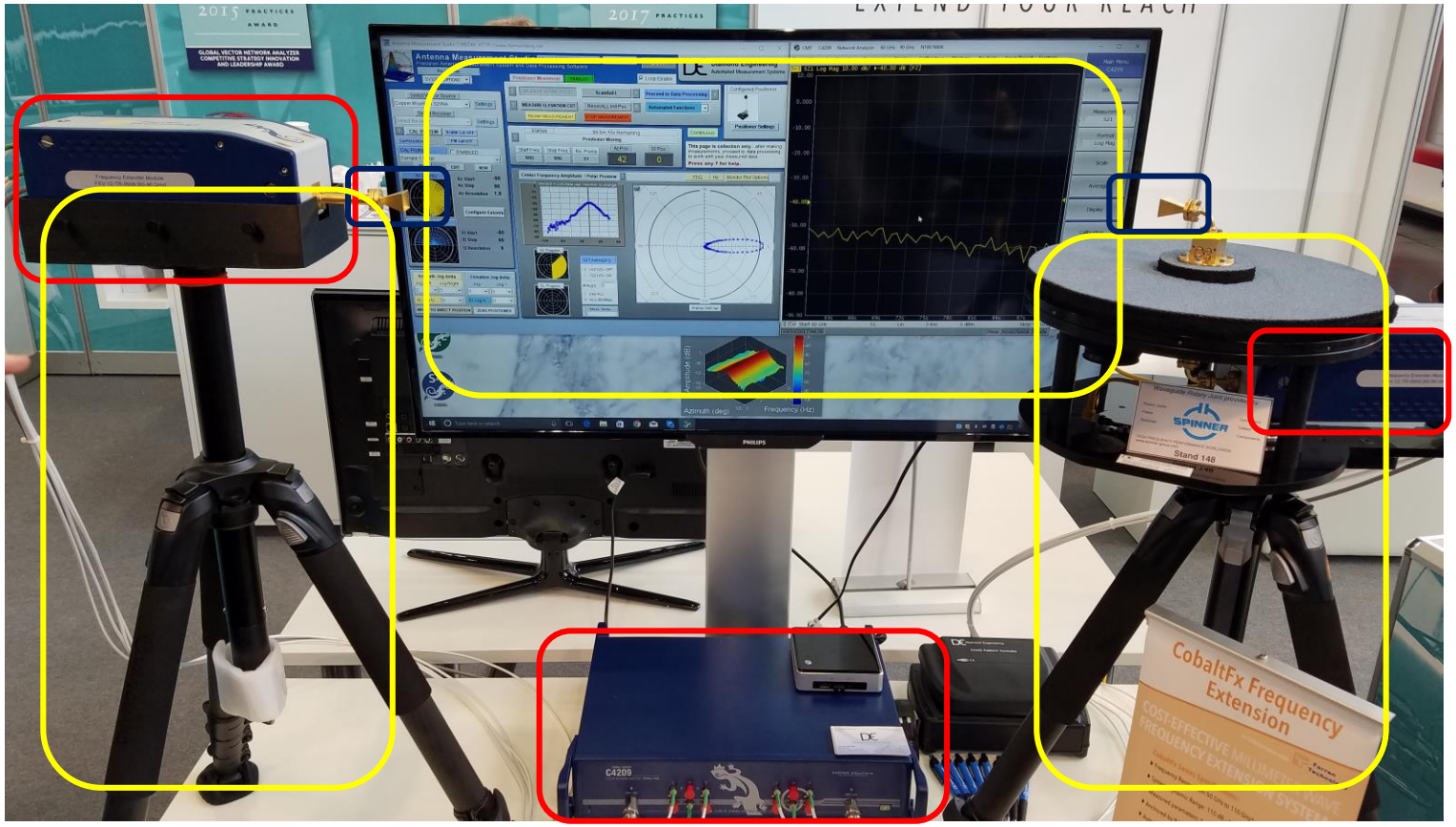
안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

• 측정환경 및 시스템 구성: Open space @ EuMW2017

Diamond Engineering
Automated Measurement Systems



- **Measurement Freq** :60~90 GHz
- **IF Bandwidth:** 3kHz
- **Measurement Point:** 51
- **VNA Output Power:** 0 dBm
- **Horn Antenna Gain**: 20 dBi
- **Antenna Path Loss:** -65dB @1m
- **Measures:**
  - ✓ S-parameters
  - ✓ Directivity
  - ✓ Beam width
  - ✓ Front to Back
  - ✓ Axial Ratio
  - ✓ Efficiency
  - ✓ TRP/TIS
  - ✓ etc.

Copper Mountain Technologies
CobaltFX-12 E-band mmWave VNA

DAMS
Antenna Measurement System

AUT (Horn antennas)

- video clip: https://youtu.be/QLc909RmNUI

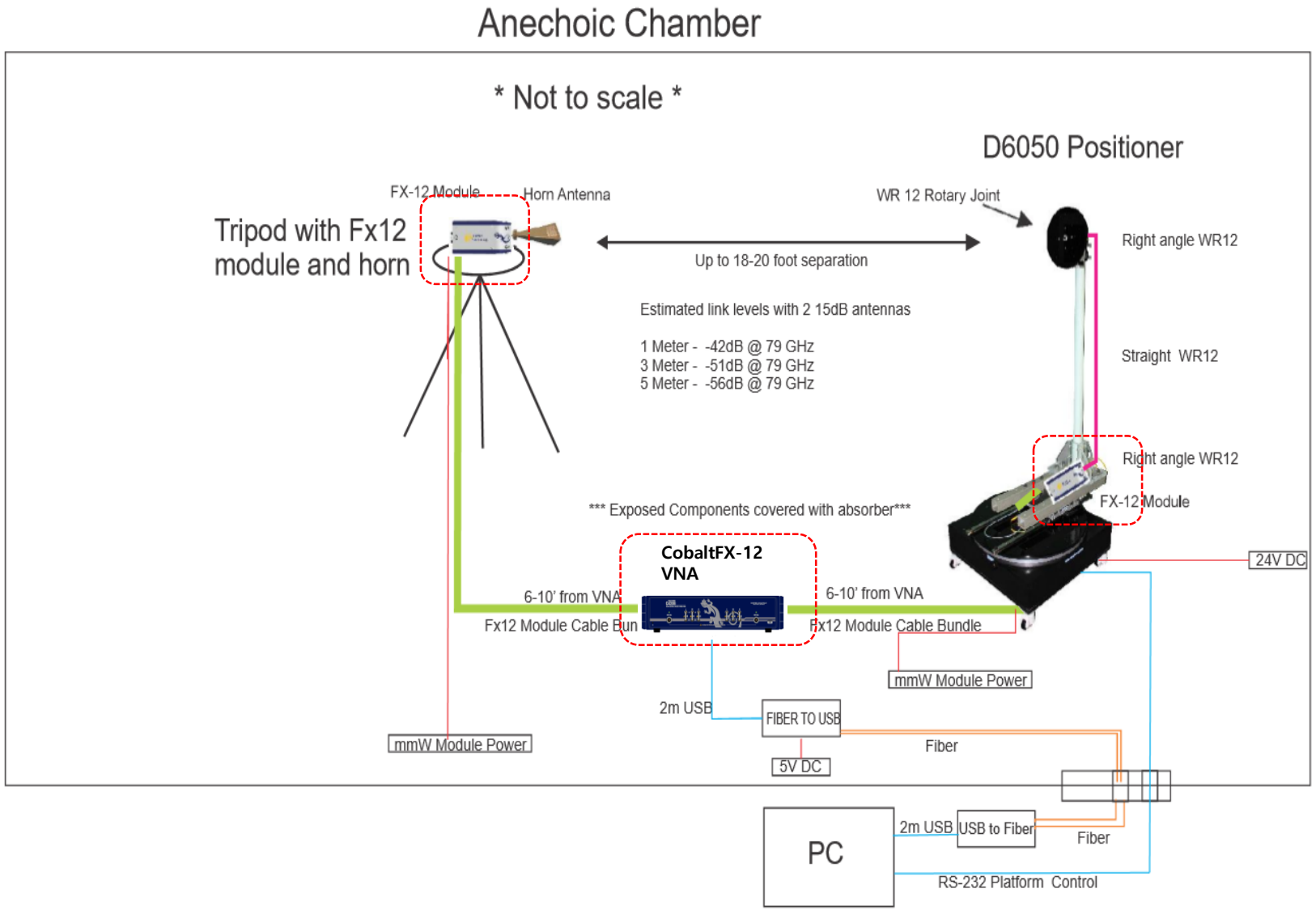
안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

• 측정시스템 구성 @ Anechoic Chamber

Diamond Engineering
Automated Measurement Systems



Test Equipment

DAMS D6050 Antenna Measurement System with custom mounting options for Cobalt Fx12 Module

Copper Mountain Cobalt FX-12 E-Band VNA with 4.5m extended cables

Optional pre-configured PC

Waveguide Parts

2x Right Angle WR-12 Waveguide
1x Straight Waveguide Section
1x Waveguide Rotary Joint
2x Waveguide Antennas

Other Accessories

4 Port USB - Fiber Extender
Dual LC Fiber Cable (inside)
Dual LC Fiber Cable (outside)
2 x USB Cables
2x DB9-RS232 Cable
Panel Adapters for Serial/Fiber
Tripod for Reference Antenna
Misc Absorber

Fixture for mounting Fx12 module to tripod

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - **CMT CobaltFX-12 mmWave VNA System**
    - **System구성** = VNA + Frequency Extension Module + RF/IF/DC cables + Cal Kit (Waveguide)

    - **VNA:** 9GHz (C4209, C4409) or 20GHz (C4220, C4420) 중 택일

	C4209	C4409	C4220	C4420
				
Frequency Range (Dynamic Range)	100 kHz to 9 GHz (162 dB @1Hz IF)		100 kHz to 20 GHz (145 dB @1Hz IF)	
Time per point(typ.)	10 µsec		12 µsec	

- **System Key Specifications**

	Unit	Min	Typ	Max
System Operating Frequency	GHz	60		90
Test Port Output Power	dBm	+2	+5	
System Dynamic Range (2)	dB	100	110	
RF Input Frequency	GHz	5		7.5
RF Input Power	dBm		0	
LO Input Frequency	GHz	5		7.5
LO Input Power	dBm		0	
IF Output Frequency	MHz		7.5	
Test Port Interface	-	WR-12 IEEE 1785-2a compatible with UG-387/U		

- **Waveguide Cal Kit Specifications**

Specification	FEK-12-0006			
	Unit	Min	Typ	Max
Operating Frequency Range	GHz	60		90
Waveguide Designation		WR-12, WG-26		
Flange Type		IEEE 1785-2a (Precision style)		
Cut Off Frequency	GHz	48.3692		
Fixed Load VSWR		<1.04:1		
Flush Short Flatness	mm	<0.012		

안테나 측정사례-II

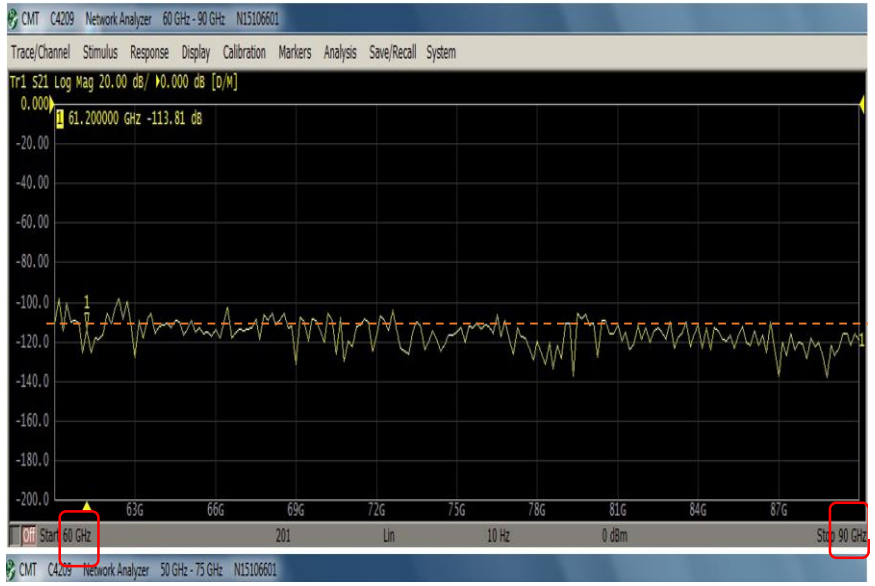
mmWave용 안테나

(Horn) 측정/검증

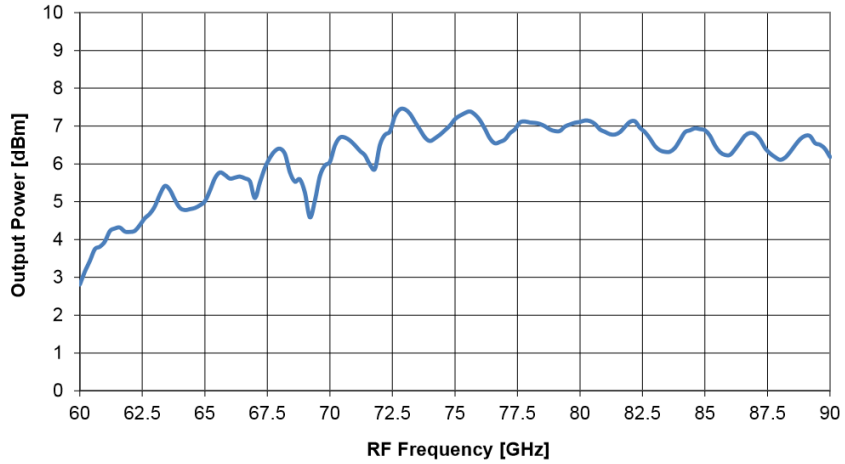
- **제품 세부내용:**
  - ➢ **CMT CobaltFX-12 mmWave VNA System**

  - ▪ **Measurement Capabilities**
    - ✓ **Measured Parameters:** S-parameters
    - ✓ **Data Display Formats:** log/lin magnitude, phase, group delay, SWR, smith chart, etc.
    - ✓ **Advanced Analysis:** mixer/converter measurement, time domain gating, embedding/de-embedding, limit testing, MCM (Matching Circuit Modeling) etc.
    - ✓ **Measurement Automation:** COM/DCOM compatible, LabView compatible

▪ **System Dynamic Range (typ.)**



▪ **Output Power vs. Frequency**

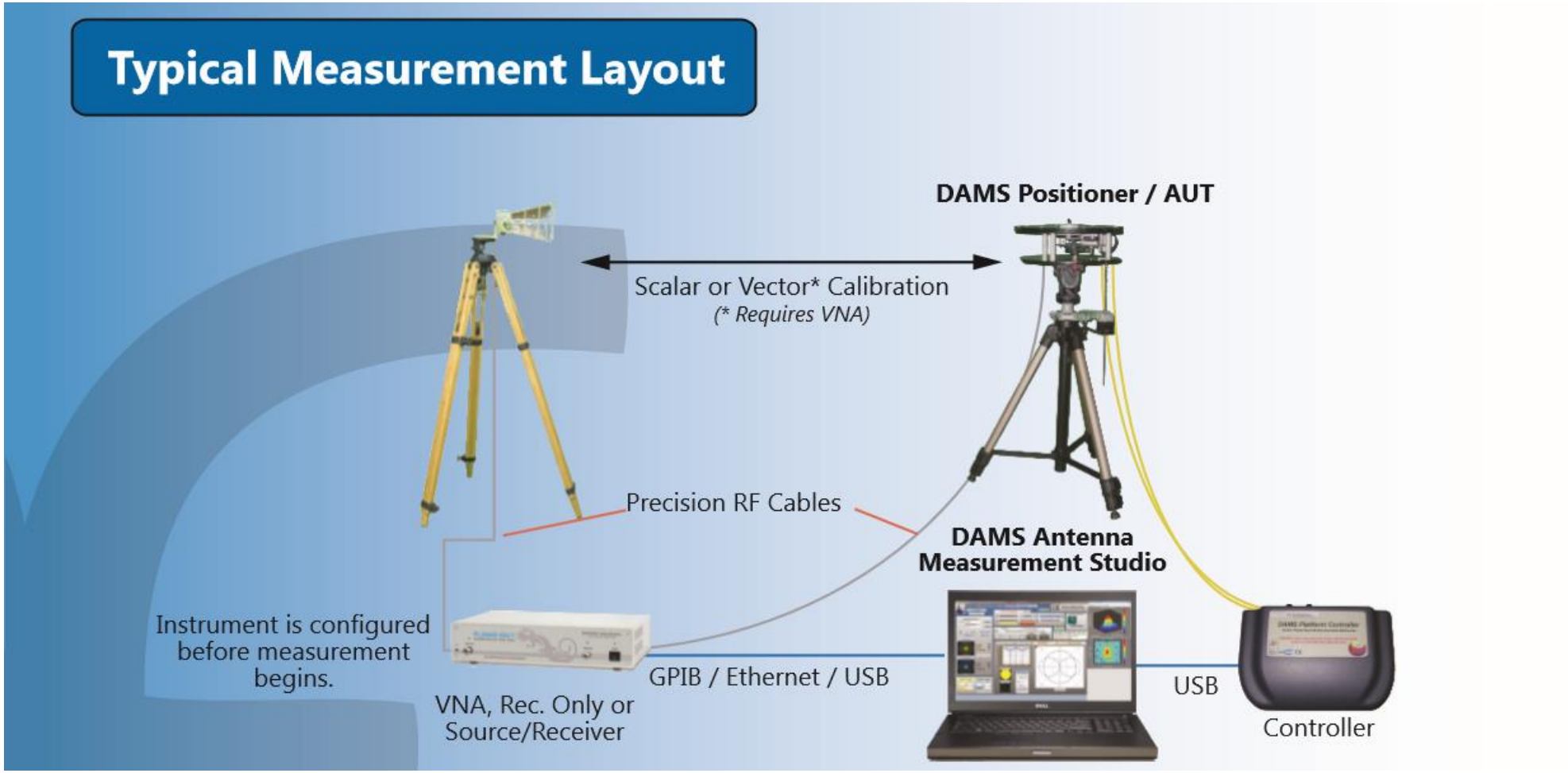


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - **DAMS (Diamond Engineering Antenna Measurement System)**



☞ DAMS Antenna Measurement System Product Home Page

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
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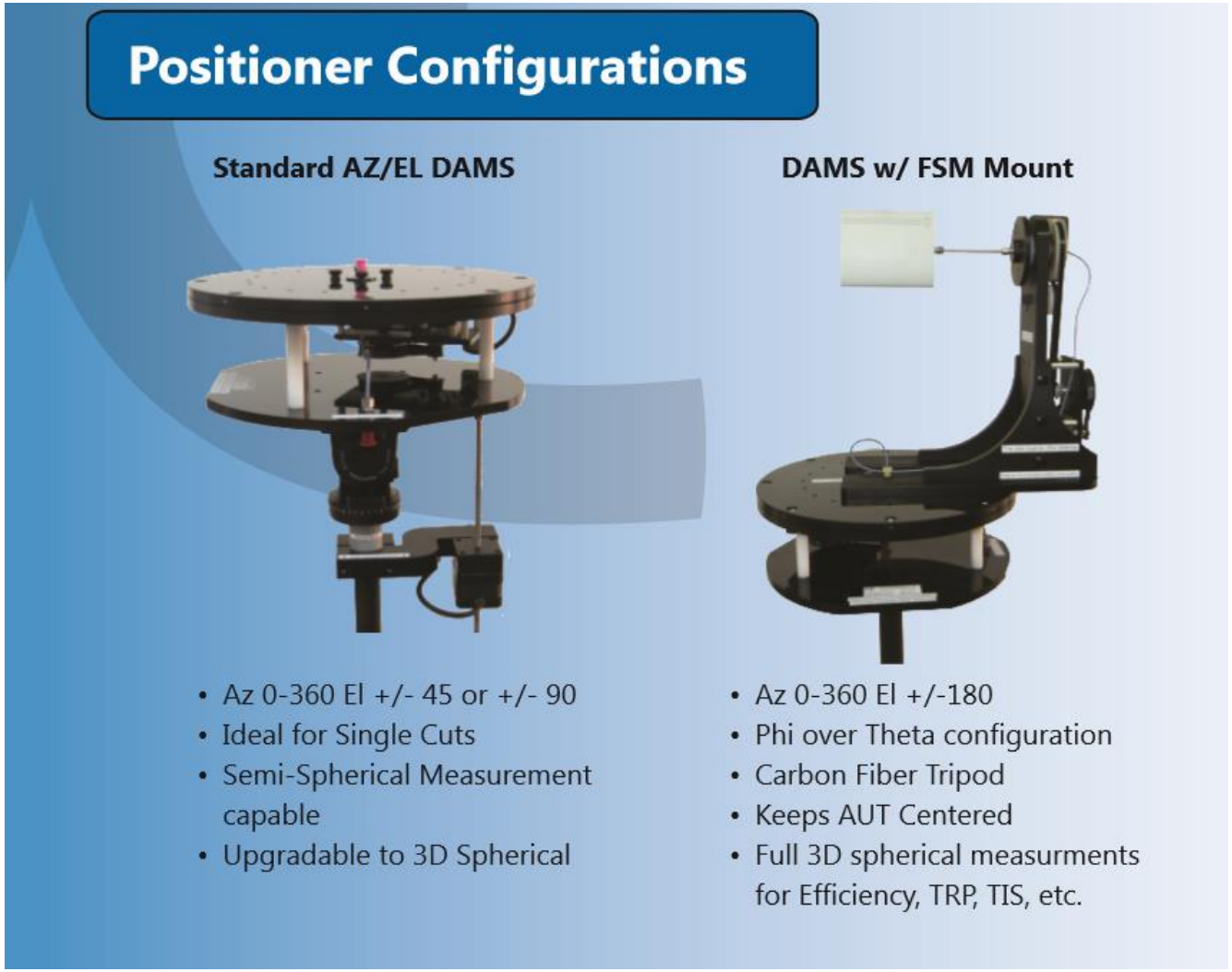


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - **DAMS (Diamond Engineering Antenna Measurement System)**

D6050 Multi-Axis Positioner NEW!

Positioner Features:

- Configurable up to 50 GHz coax and 110GHz WR10 Waveguide
- Adjustable Z axis for precision AUT Centering
- High Resolution
  .025 Deg - Theta / Turntable, .025 Deg - Phi/Roll
- Weight Capacity - Turntable-150 Lb, Phi/Roll-25 Lb
- Low-noise coaxial rotary joints.
- Precision Stepper motors
- Upgradable to 4-5 Axis for automated phase measurements
- Includes 2 x 15' RF Cables
- 24" Diameter turnable plate , 10" Diameter roll plate
- Casters for portability
- 3 year parts & labor warranty

Available Models and Options:

- D6050-6 DC–6 GHz
- D6050-18 DC-18 GHz
- D6050-40 DC-40 GHz
- D6050-50 DC–50 GHz
- D6050-mmW-CFX - Compatible with Copper Mountain CobaltFX mmW VNA
- OPT 3A Automated Z axis -
- OPT 4A Automated Z and X axis with pseudo Y axis

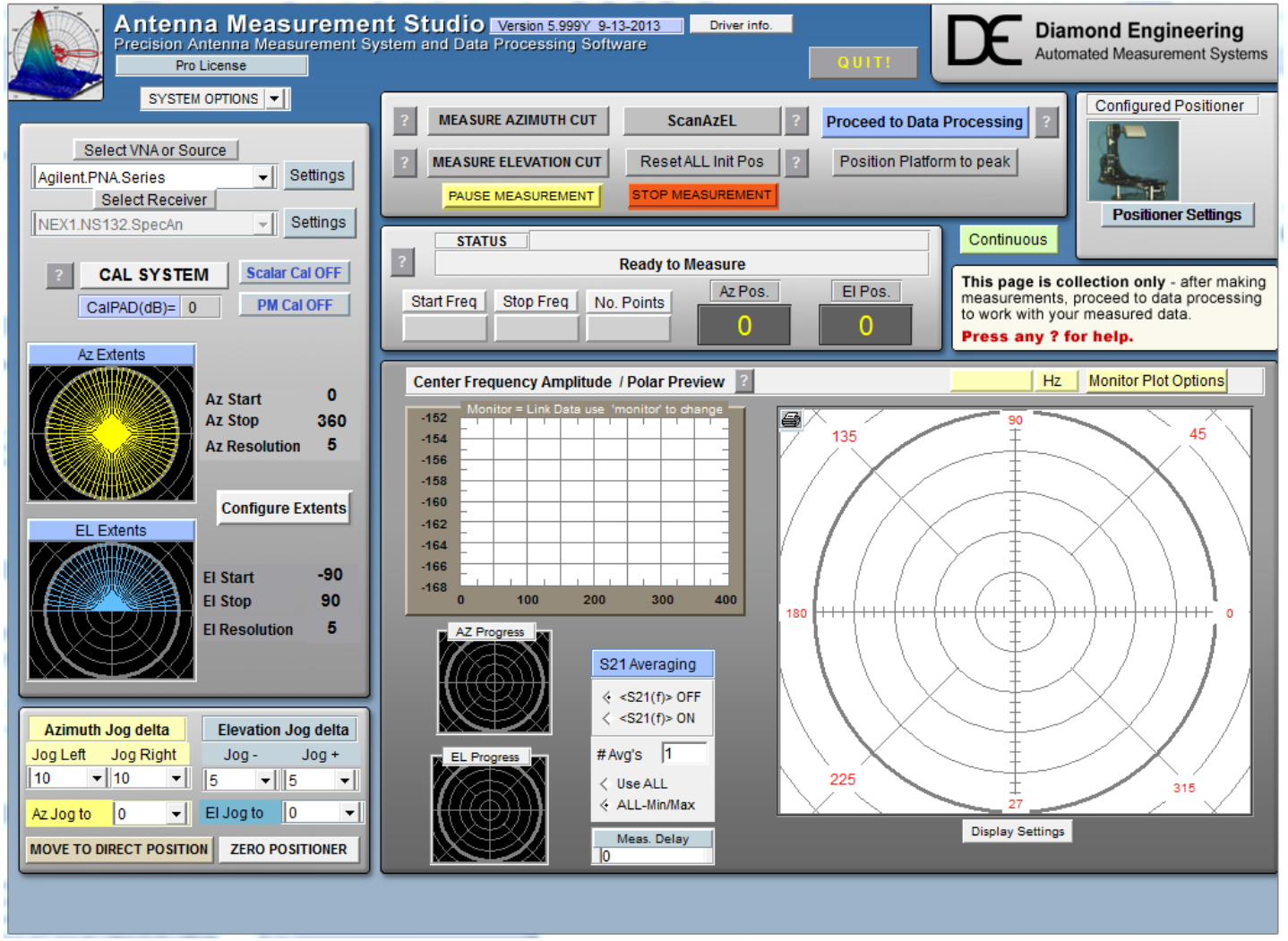
Supports most GPIB and Ethernet enabled instruments

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - ➢ **DAMS (Diamond Engineering Antenna Measurement System)**

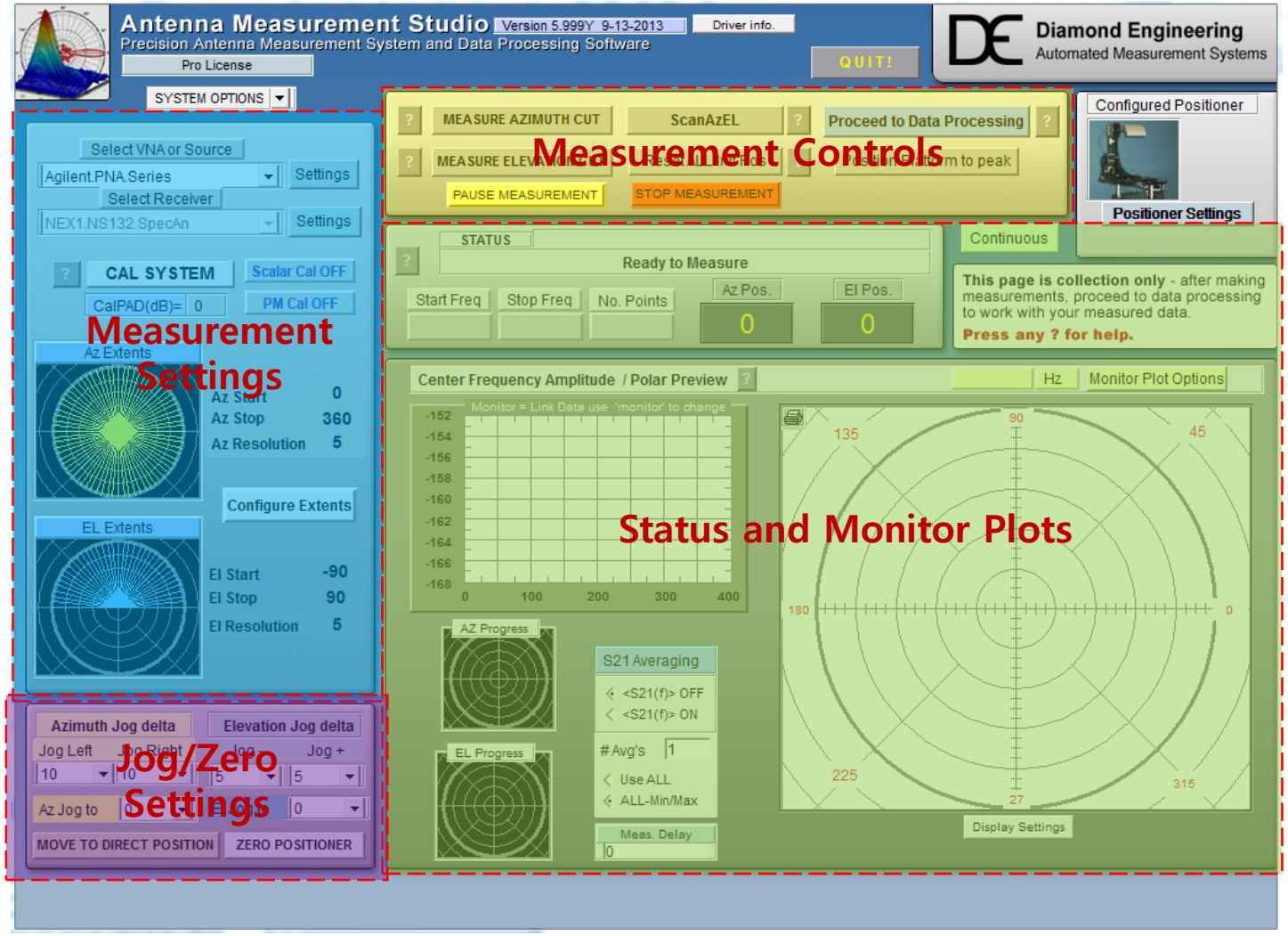


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - ➢ **DAMS (Diamond Engineering Antenna Measurement System)**



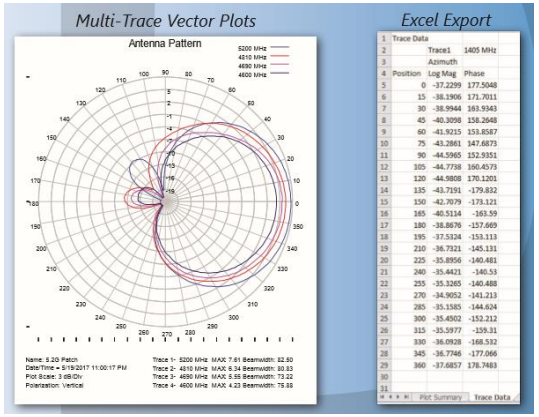
안테나 측정사례-II

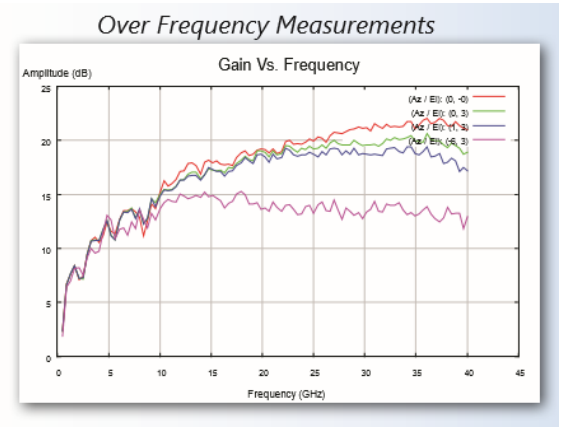
mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - ➢ **DAMS (Diamond Engineering Antenna Measurement System)**

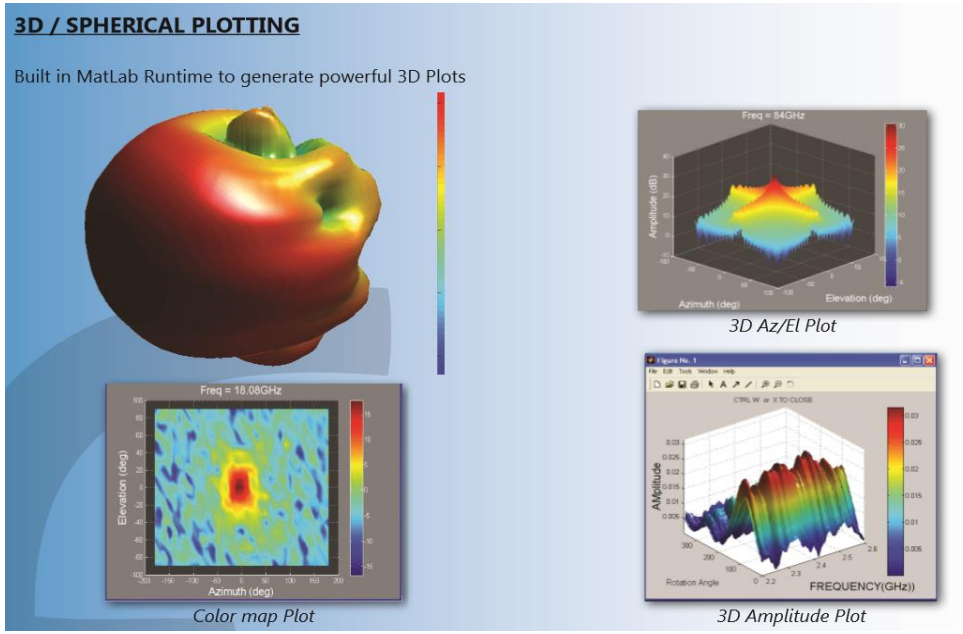
Diamond Engineering
Automated Measurement Systems





Standard Features:

- One-touch antenna profiling
- Multiple S-parameters (S21, S11, etc.)
- Multiple trace plots
- Basic 3D plots
- Reference antenna import feature
- Data Export / Import function
- Exportable vector plots
- Over frequency measurements
- Various calibration methods
- Fully configurable positioner settings
- Extensive plotting features
- Data set manipulation



JWILL TECHNOLOGY
Innovating Test Automation

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **제품 세부내용:**
  - ➢ **DAMS (Diamond Engineering Antenna Measurement System)**

Diamond Engineering
Automated Measurement Systems

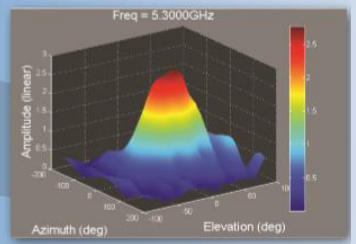
Advanced Processing Modules:

- Efficiency / TRP Calculation
- RCS Calculation
- Phase Center
- TIS (Total Isotropic Sensitivity)
- Advanced spherical 3D plots
- Exclusive data set calculator

GAIN CALCULATION FEATURES

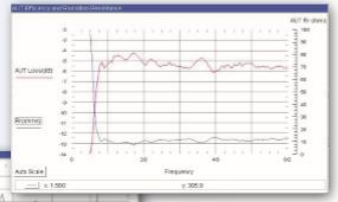
Modules:

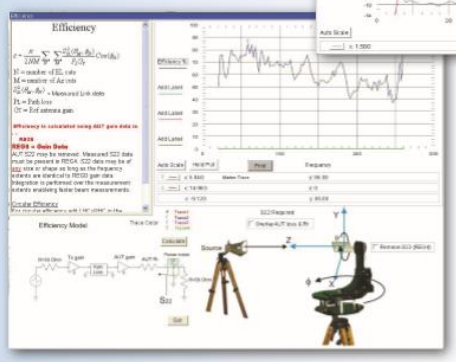
- Linear gain transfer
- Circular gain via linear H-V
- Gain Substitution
- Total power factor
- 3 point method



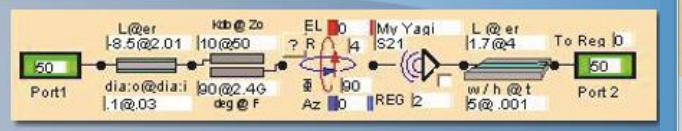
ANTENNA EFFICIENCY

- Total Efficiency
- Material Loss
- Radiation Resistance

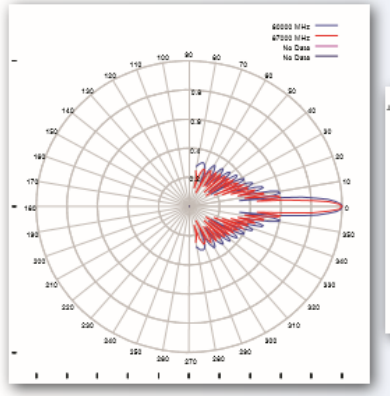


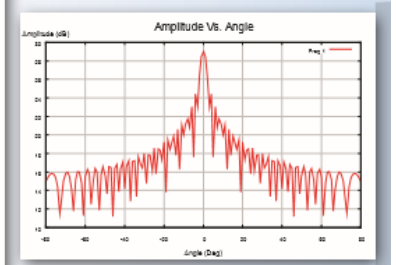


ANTENNA NETWORK SIMULATOR



RCS MEASUREMENT MODULE





New Features for 2017 / 2018

- Calibration Profiles with automatic gain calculation
- TIS (Total Isotropic Sensitivity) measurement
- Phase center measurement
- MSI / Planet export for site planning software
- Compatible with Windows 7, 8, and 10

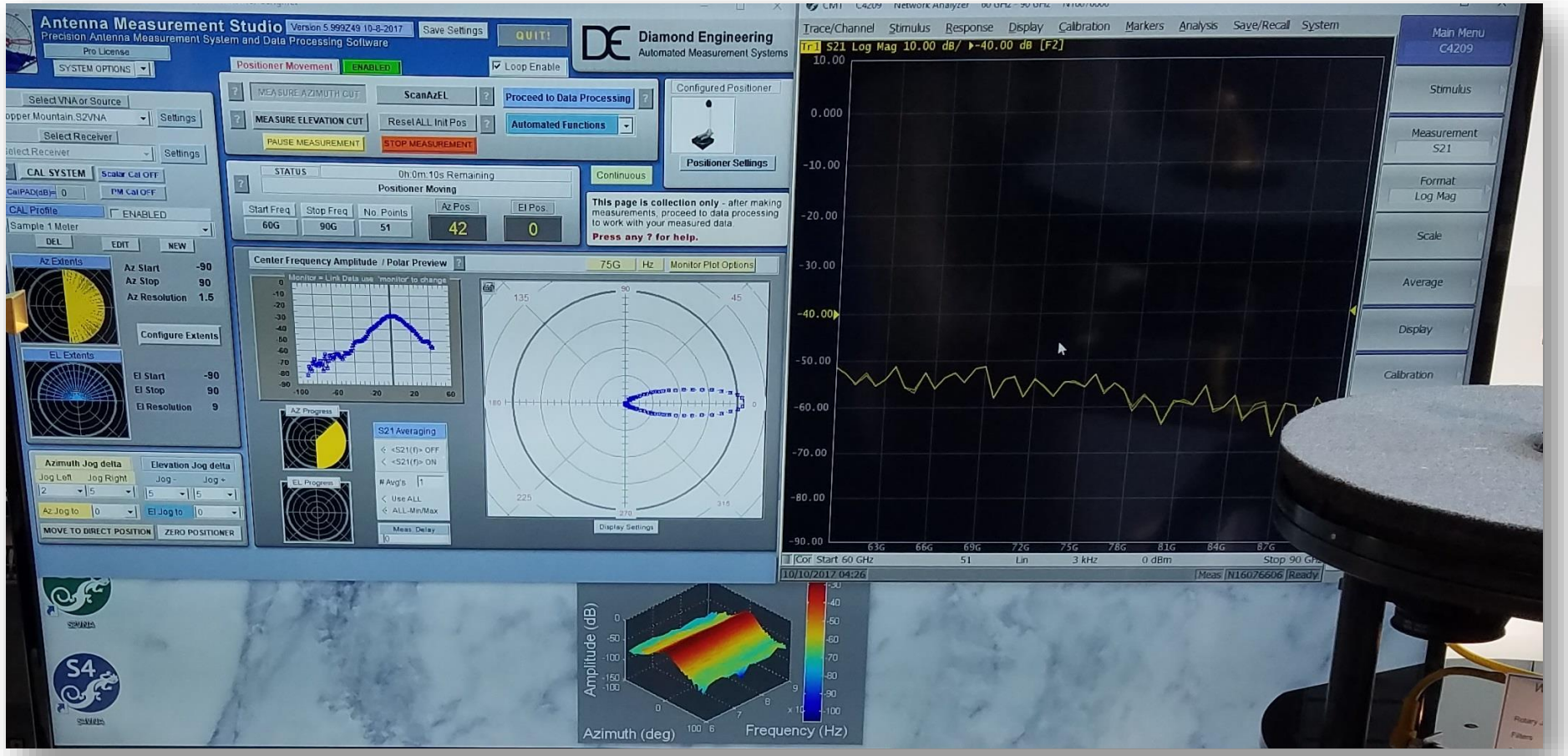
JWILL TECHNOLOGY
Innovating Test Automation

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- 측정 결과: 통합 측정화면

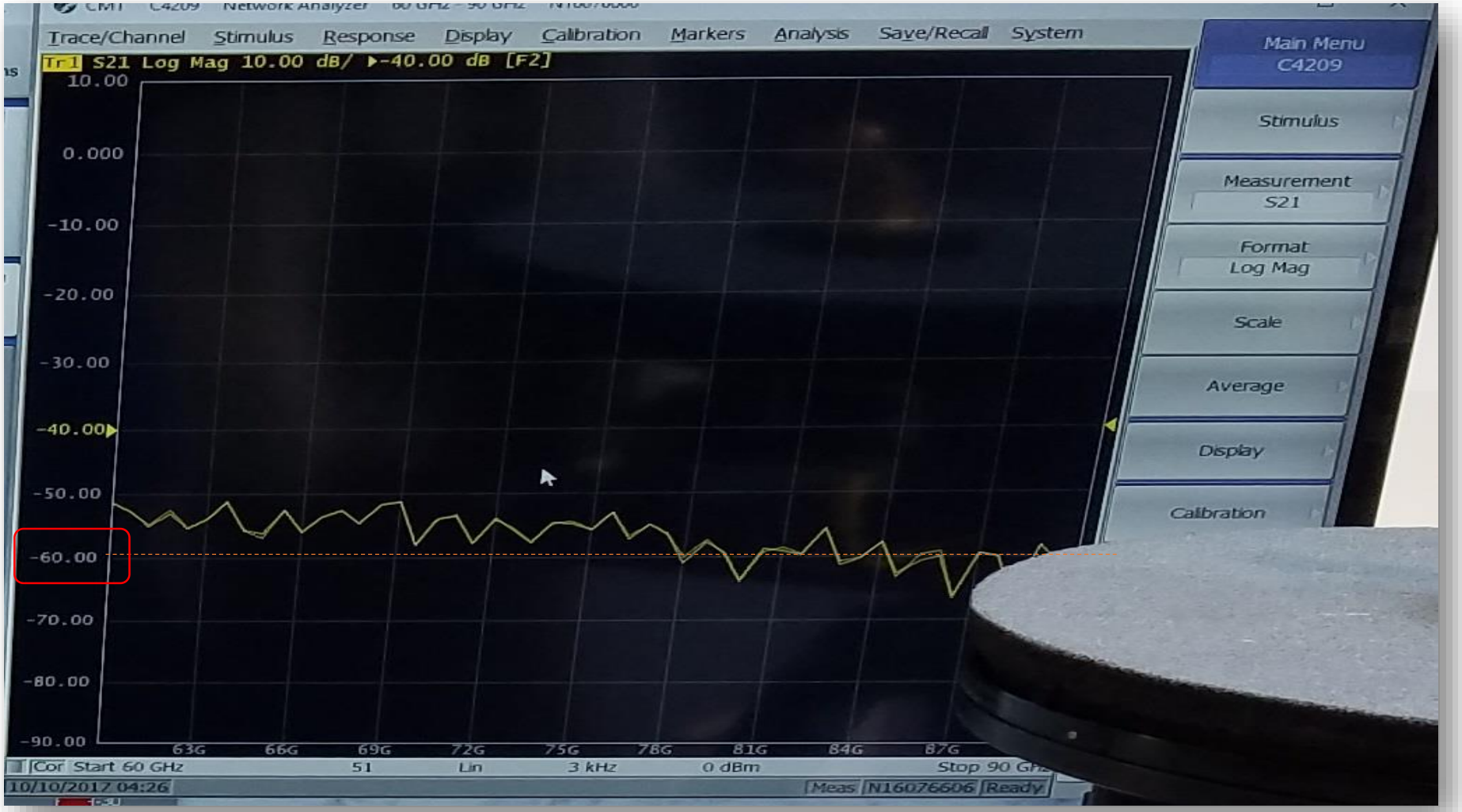


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **측정 결과: S21 Log Magnitude**

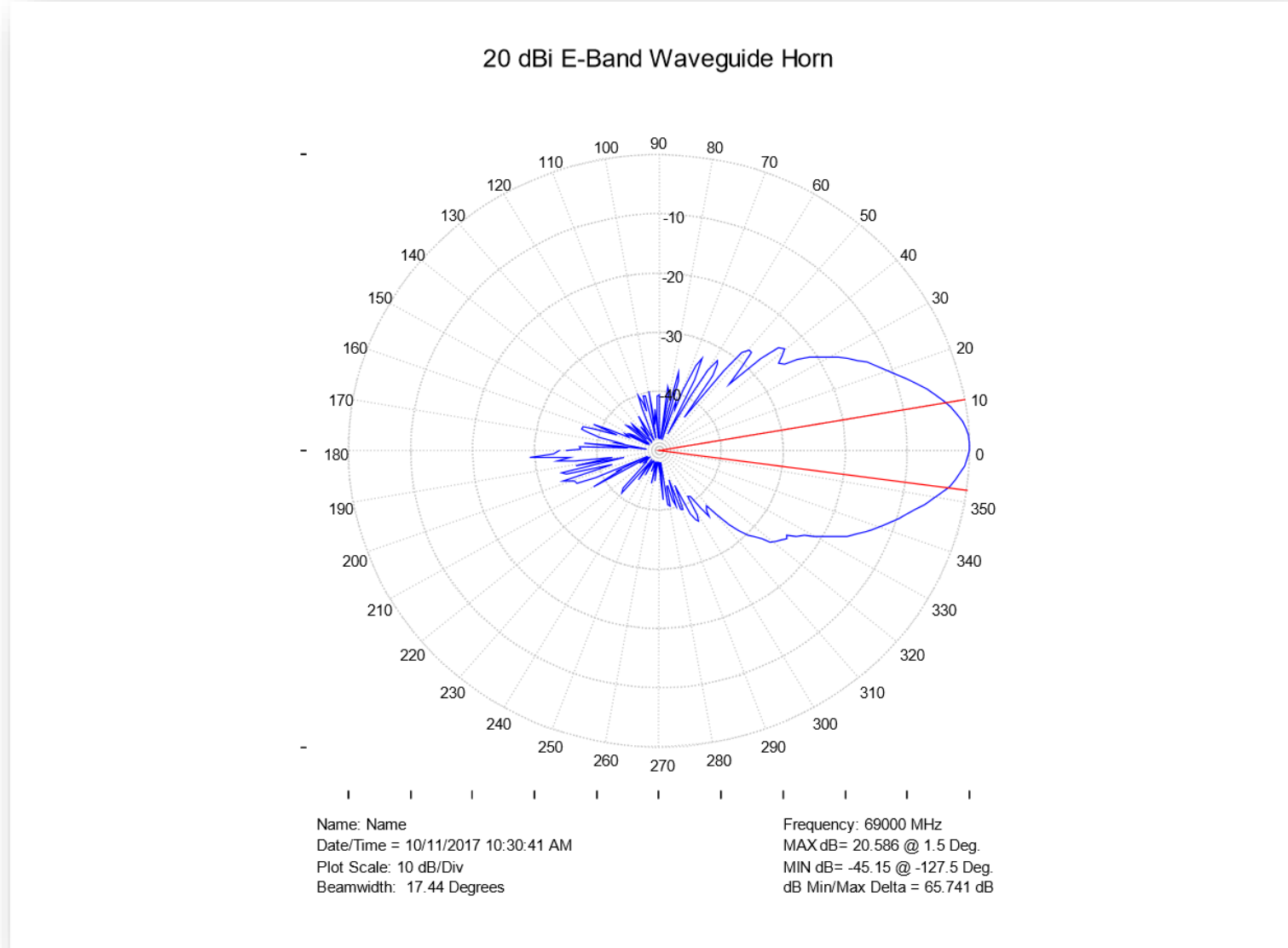


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

• 측정 결과: Antenna Radiation Pattern @

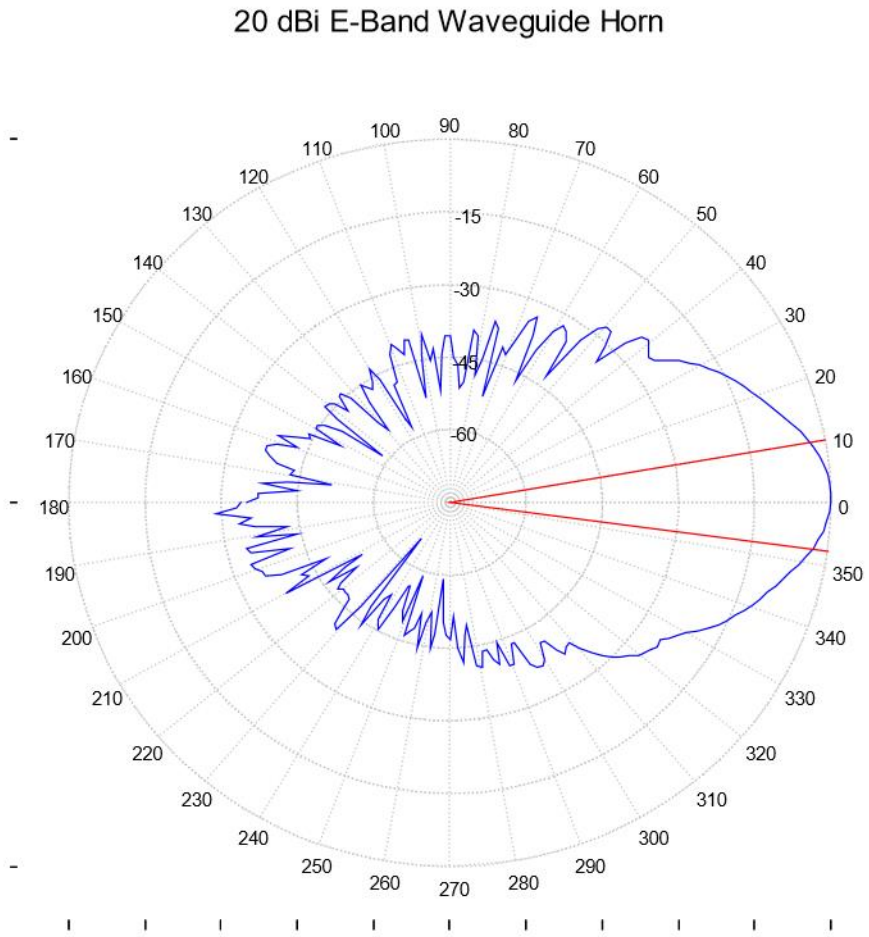


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- 측정 결과: Antenna Radiation Pattern @

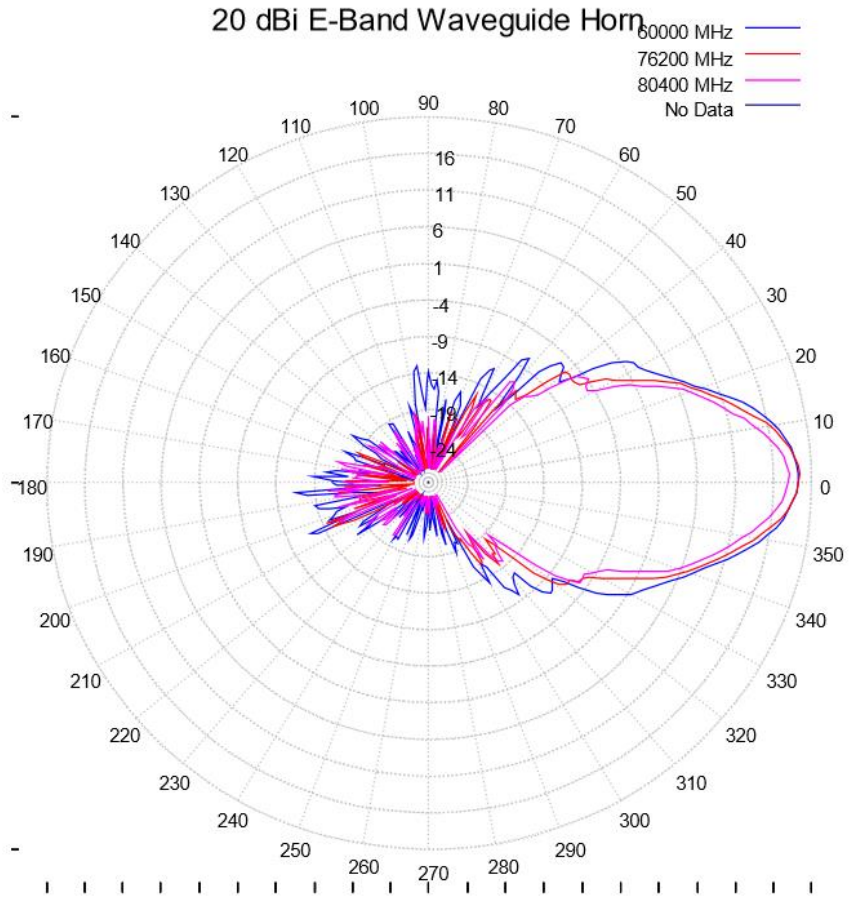


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- 측정 결과: Antenna Radiation Pattern @



Name: Multi-Trace.
Date/Time = 10/11/2017 10:44:34 AM
Plot Scale: 5 dB/Div
Polarization: Horizontal

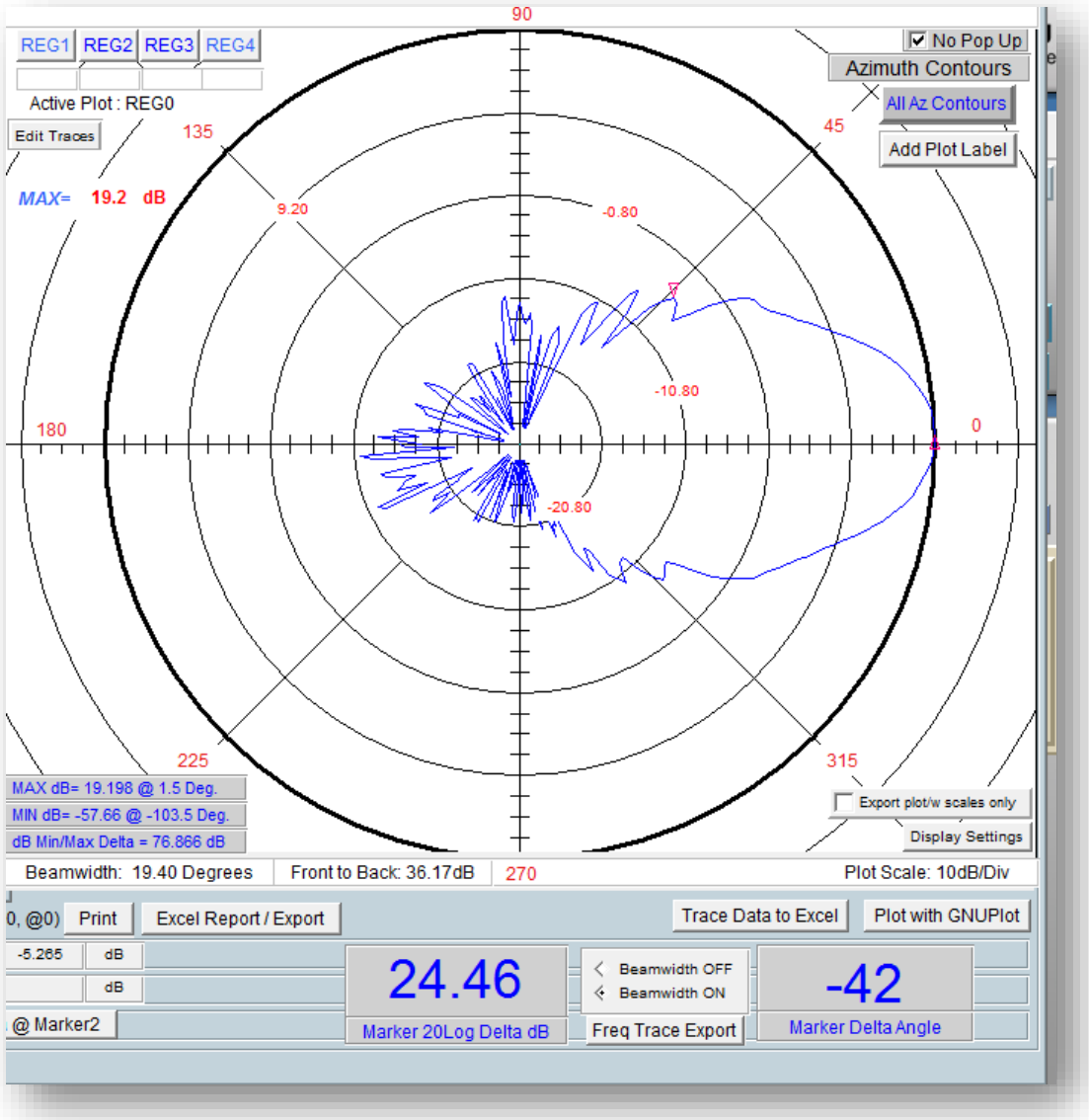
Trace 1- 60000 MHz MAX: 19.20 Beamwidth: 19.41
Trace 2- 76200 MHz MAX: 19.33 Beamwidth: 16.89
Trace 3- 80400 MHz MAX: 18.01 Beamwidth: 16.16
Trace 4- 0 MHz MAX: 0.00 Beamwidth: 0.00

안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- 측정 결과: Marker Sidelobe

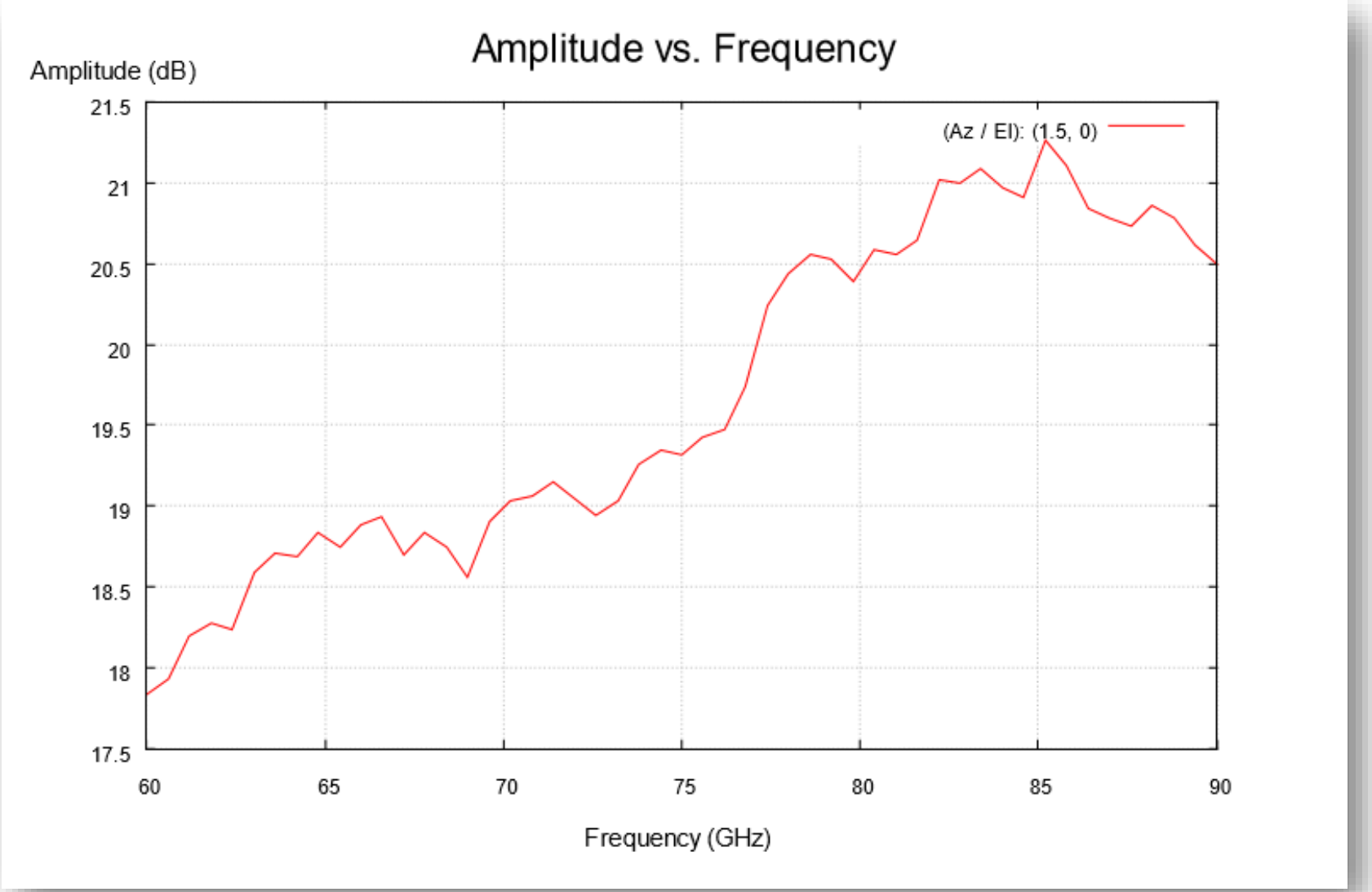


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **측정 결과: Antenna Gain (Amplitude) vs. Frequency**

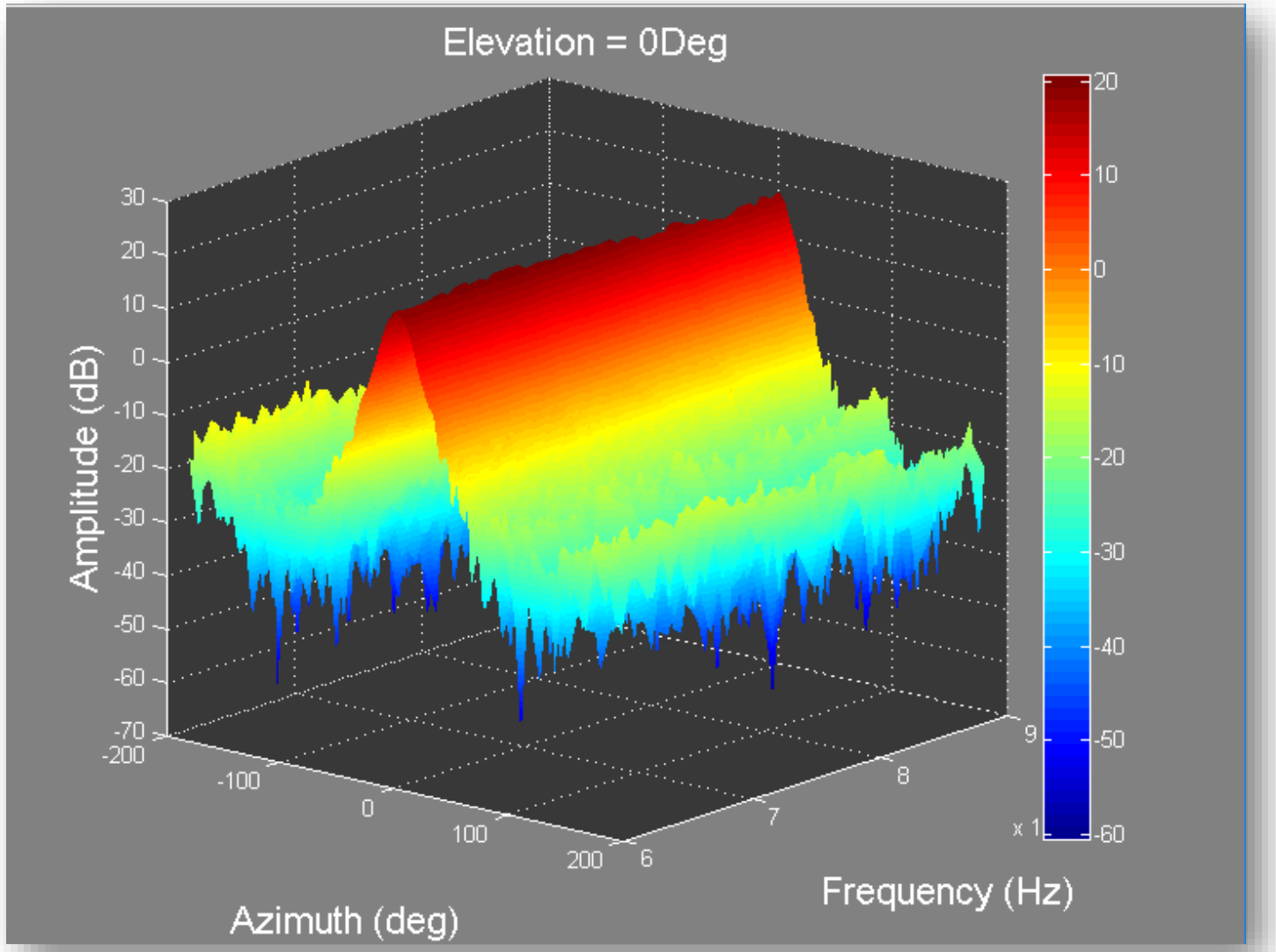


안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

- **측정 결과: 3D Amplitude Plot**



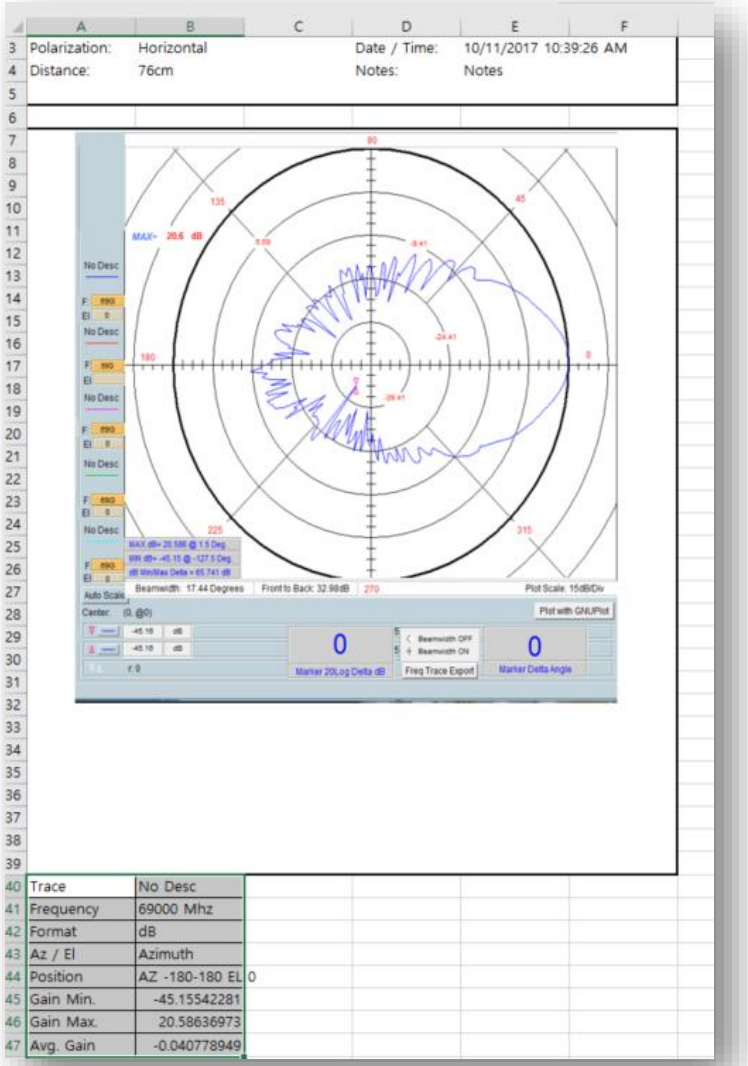
안테나 측정사례-II

mmWave용 안테나

(Horn) 측정/검증

• 측정 결과: Excel Report

Plot Summary



Polarization:	Horizontal	Date / Time: 10/11/2017 10:39:26 AM
Distance:	76cm	Notes: Notes

Trace	No Desc
Frequency	69000 Mhz
Format	dB
Az / El	Azimuth
Position	AZ -180-180 EL 0
Gain Min.	-45.15542281
Gain Max.	20.58636973
Avg. Gain	-0.040778949

Trace Data

	A	B	C	D
1	Trace Data			
2		Trace1		
3		Azimuth		
4	Position	dBi	Phase	
5	-180	-13.3983	46.3351	
6	-178.5	-12.3927	60.81661	
7	-177	-8.52628	28.18746	
8	-175.5	-15.0776	-19.2046	
9	-174	-12.8692	34.79819	
10	-172.5	-15.7936	29.7873	
11	-171	-21.8673	2.868746	
12	-169.5	-15.7574	121.5553	
13	-168	-23.7112	-176.818	
14	-166.5	-13.329	-174.046	
15	-165	-13.9916	-169.073	
16	-163.5	-21.5311	-110.155	
17	-162	-13.1398	-78.1955	
18	-160.5	-13.96	-77.8933	
19	-159	-14.8966	-57.0783	
20	-157.5	-15.1011	-144.23	
21	-156	-18.2469	-11.9684	
22	-154.5	-27.3355	-166.784	
23	-153	-21.7427	179.8021	
24	-151.5	-22.6958	-165.186	
25	-150	-17.1872	-118.61	

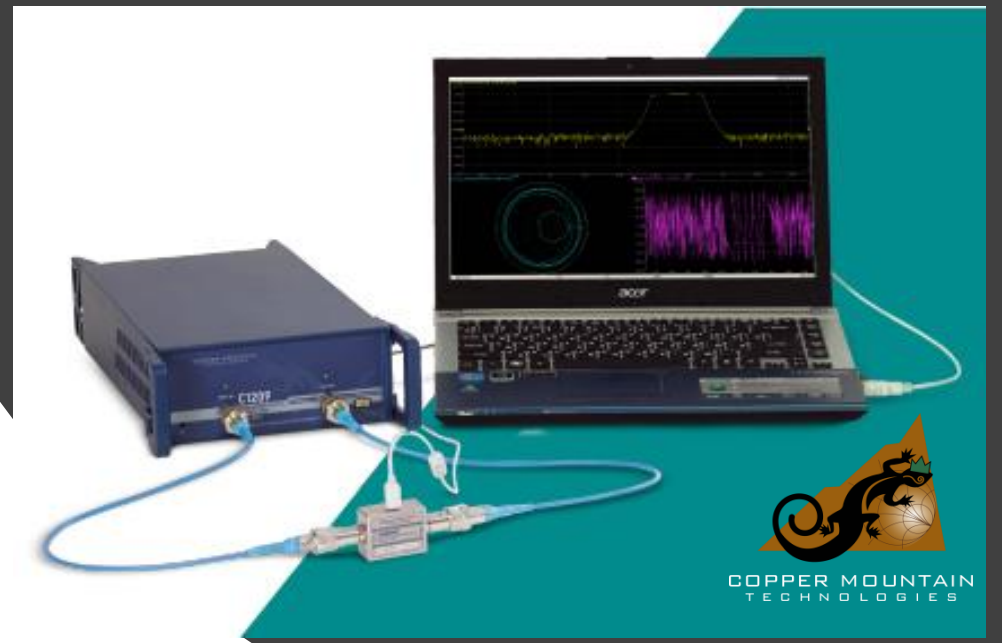
안테나
측정사례-II

mmWave용 안테나

(Horn) 측정/검증

결과 요약

- 경제적이고 가성비가 우수한 CobaltFX-12 USB VNA를 통합한 DAMS 안테나 측정시스템으로 E-band대역 Gain Horn안테나의 특성을 충분히 다각적으로 분석할 수 있었음.
- 안테나 성능 검증에 영향을 끼칠 수 있는 외부의 요인들을 최소화하여 보다 정밀하게 측정하기 위해서 Anechoic Chamber내에서 측정/검증하기를 권장함.



웨비나 결론

웨비나 목적과 대상

목적

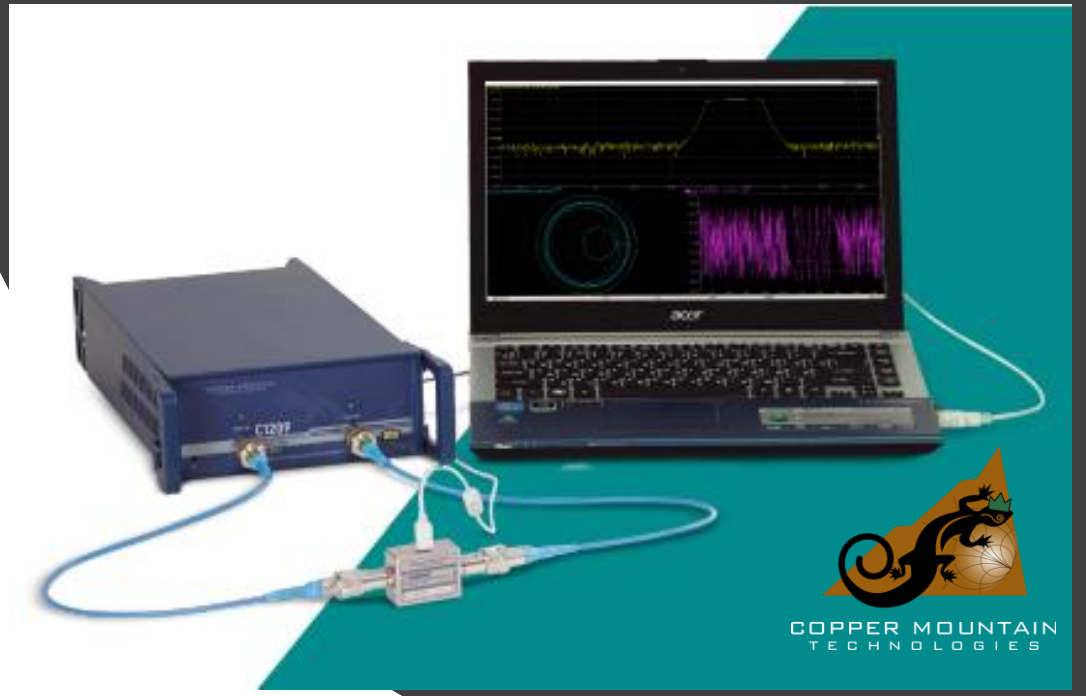
- 일체형 VNA대비 훨씬 작고, 가벼워 설치 공간의 활용성이나 휴대성이 탁월하며, 총소유비용(Total Cost of Ownership) 또한 저렴하여 가성비가 뛰어난 Copper Mountain Technology사의 USB VNA를 소개, 고객에게 더 큰 편익을 드리기 위함.

대상

- RF / Microwave 전자 응용 부품/모듈/시스템 연구소, 혹은 산업체의 연구/개발/생산/서비스 엔지니어
- RF / Microwave 전자 응용 테스트 시스템 개발/제조업체
- RF / Microwave 전자 교육기관
- 기타 USB VNA에 대해 관심있으신 분

- **Contact**
  - **주소**: 경기도 성남시 분당구 황새울로 200번길 36, 616 (수내동, 동부루트빌딩)
  - 대표번호 : 070-4401-4628
  - 팩스: 031-601-8058
  - E-mail: sales@jwill.co.kr
  - 홈페이지: www.jwill.co.kr

감사합니다!

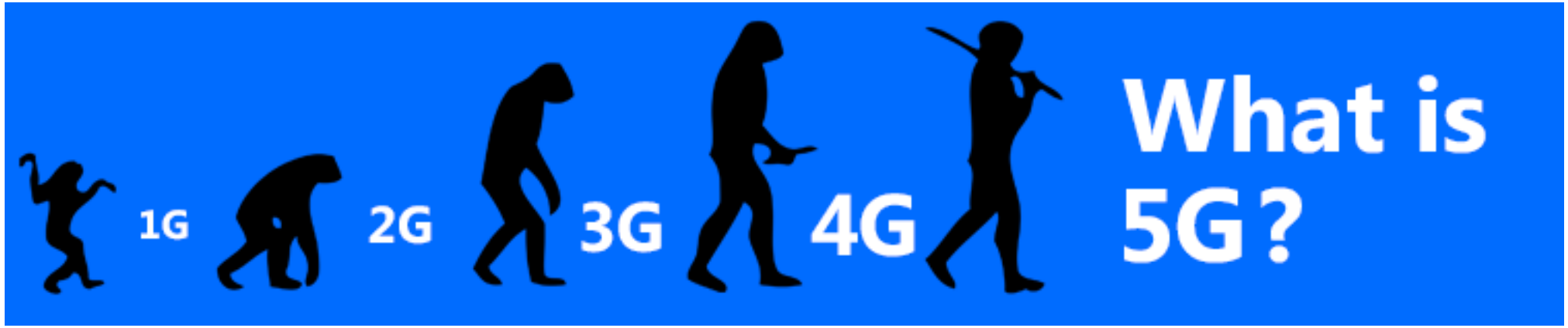


참고자료

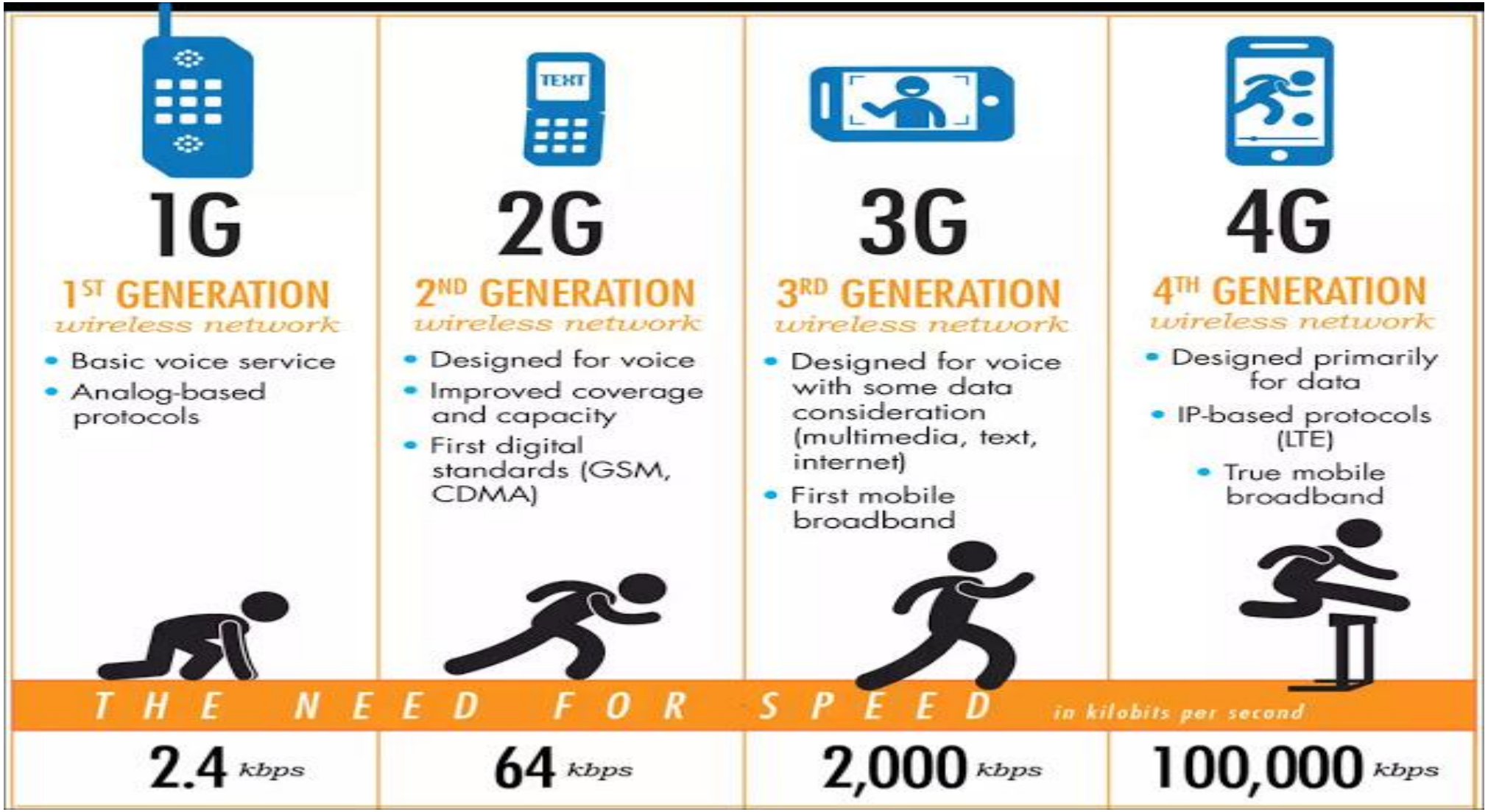
5G 시장 및 기술동향

IoT, WiGig, mmWave

5G시장 및 기술동향

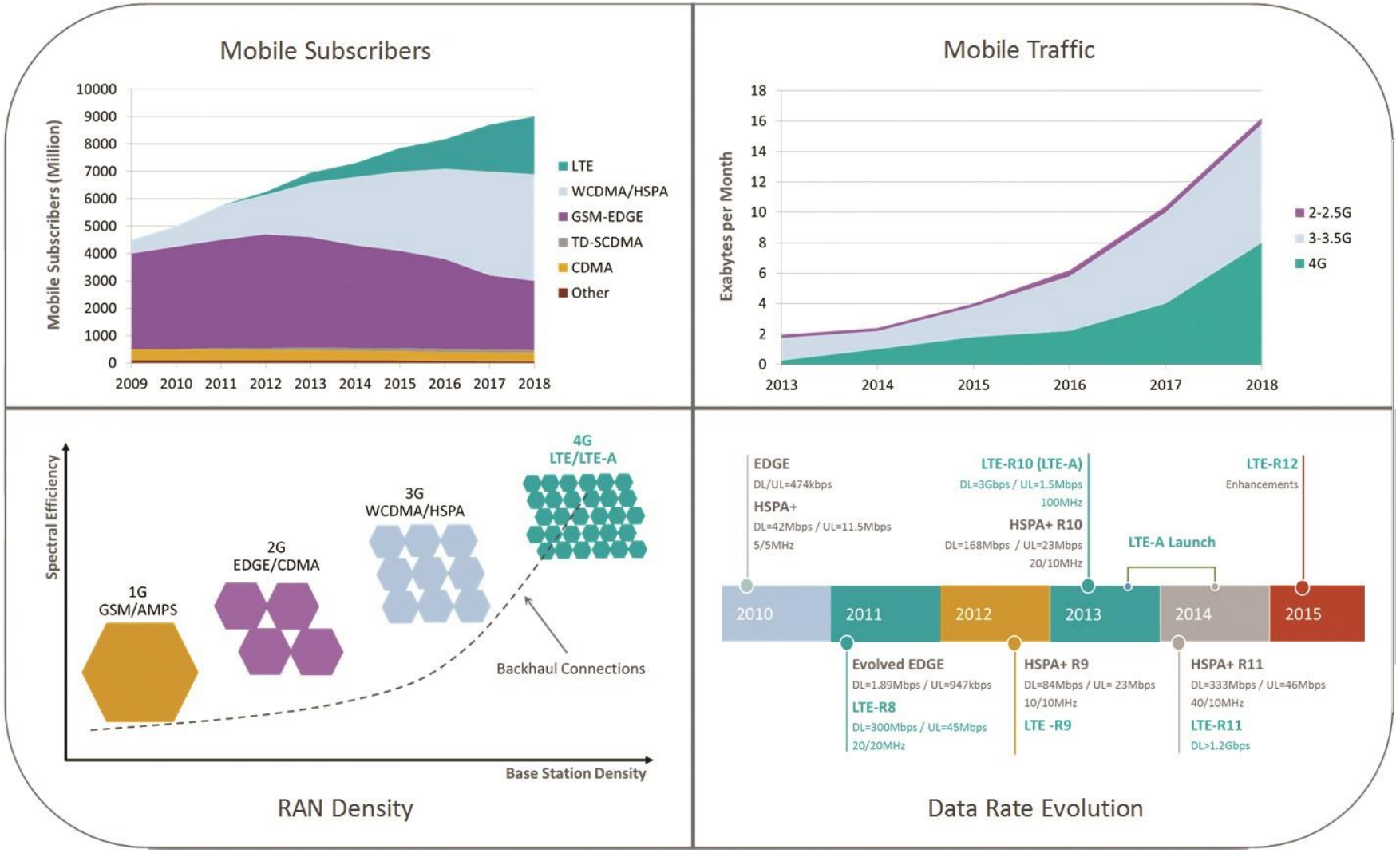


5G시장 및 기술동향


1G
1ST GENERATION
wireless network
• Basic voice service
• Analog-based protocols
2G
2ND GENERATION
wireless network
• Designed for voice
• Improved coverage and capacity
• First digital standards (GSM, CDMA)
3G
3RD GENERATION
wireless network
• Designed for voice with some data consideration (multimedia, text, internet)
• First mobile broadband
4G
4TH GENERATION
wireless network
• Designed primarily for data
• IP-based protocols (LTE)
• True mobile broadband
THE NEED FOR SPEED
in kilobits per second
2.4 kbps
64 kbps
2,000 kbps
100,000 kbps

5G시장 및 기술동향

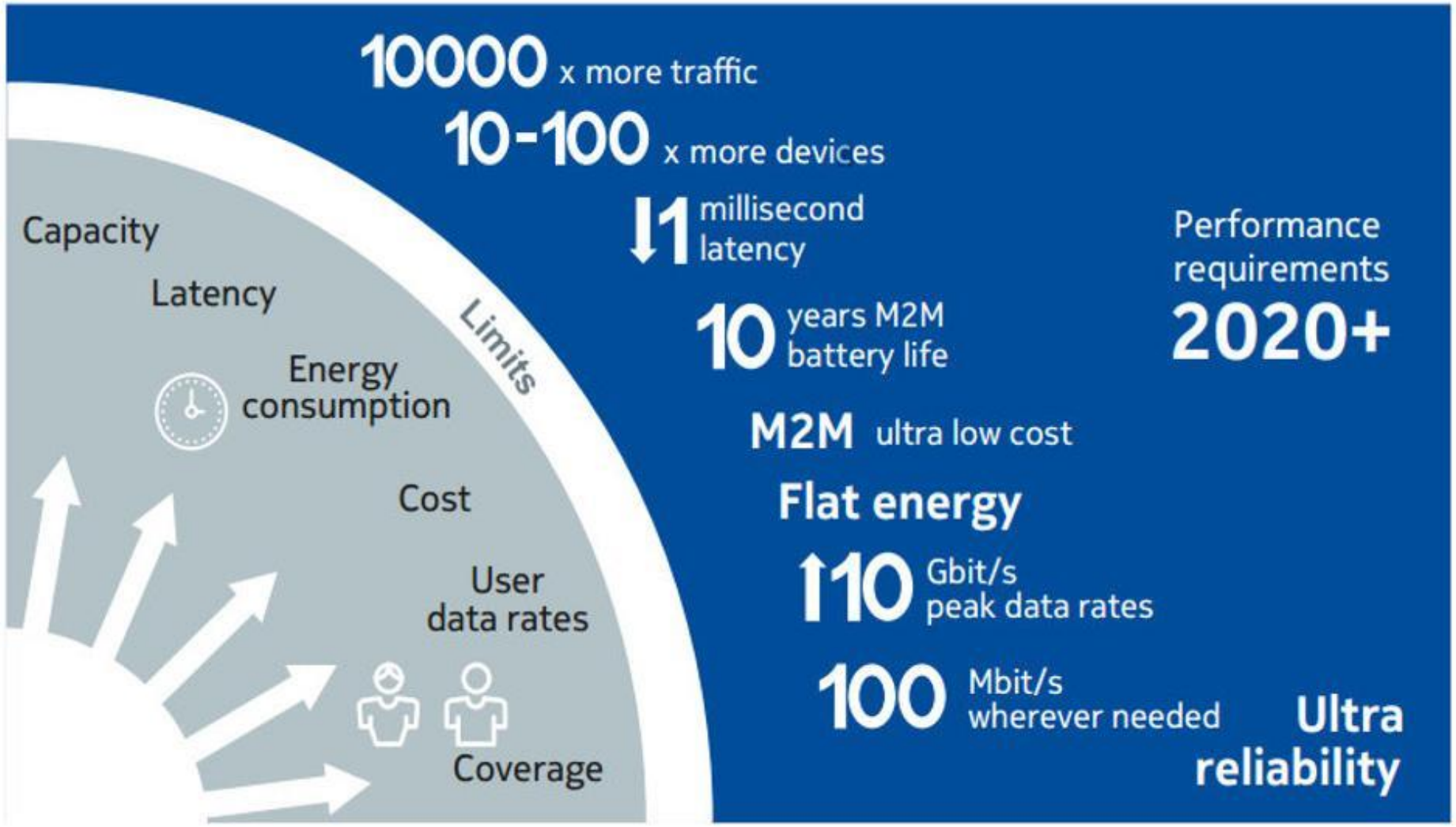
Market Drivers for 5G



Source: Microwaves & RF (Sep 17,2015)

5G시장 및 기술동향

The Essentials in 5G



Source: Courtesy of Nokia (CES2016)

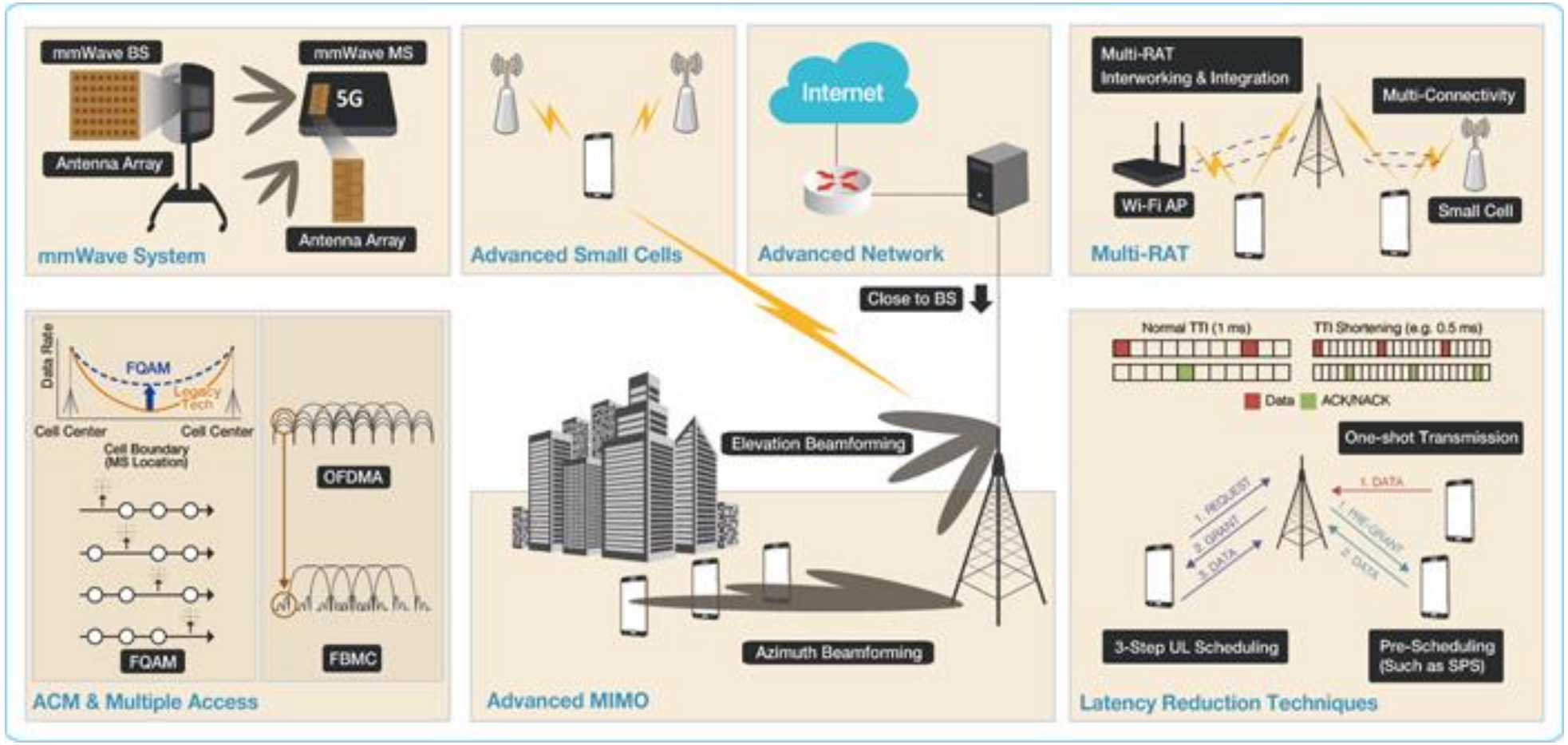
5G시장 및 기술동향

Key Usages in 5G

Source: European Commission

5G Key Enabling Technologies

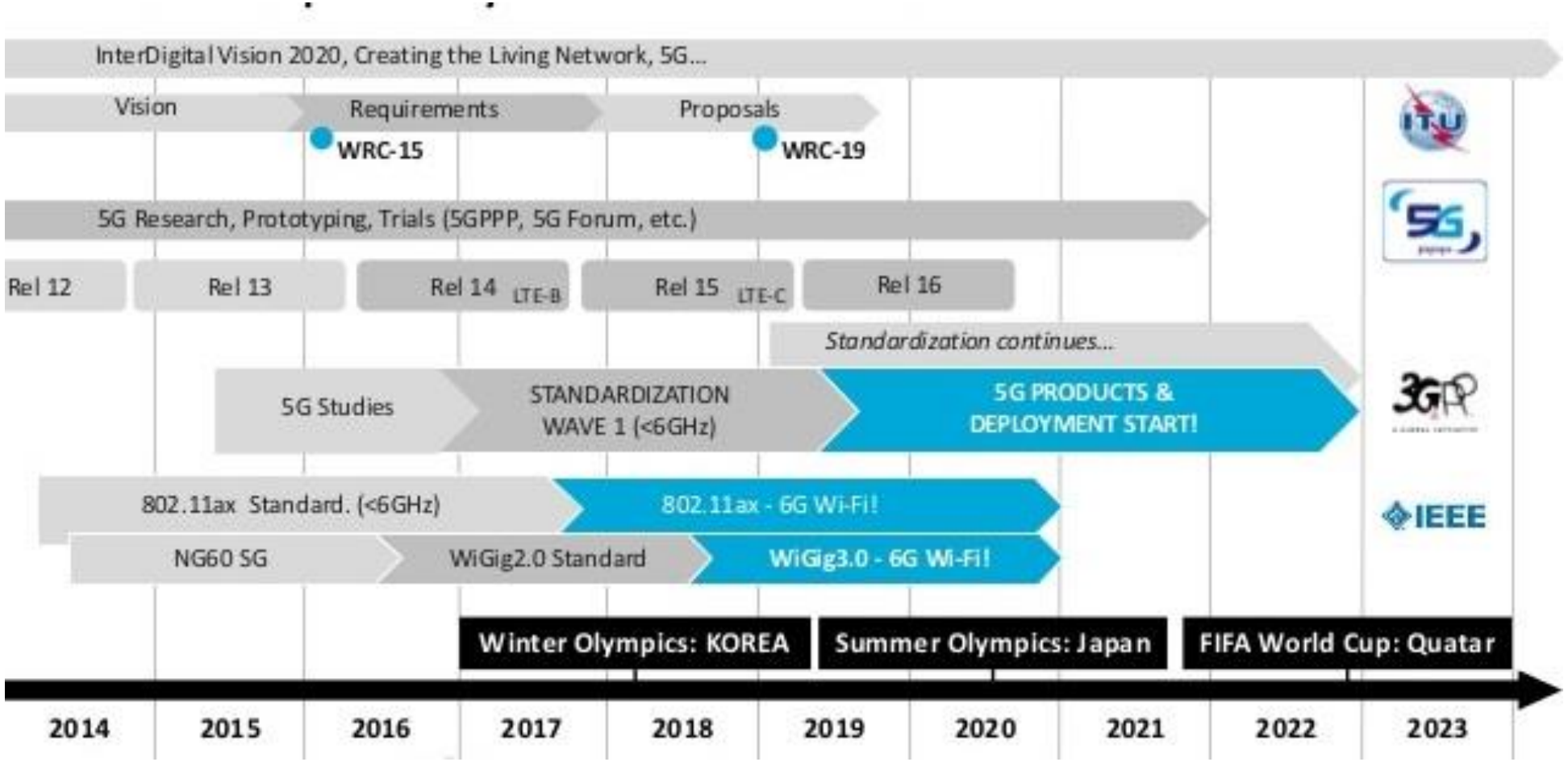
5G시장 및 기술동향



Source: Samsung Developers (developer.samsung.com/tech-insights/5G/5g-key-enabling-technologies)

5G Roadmap

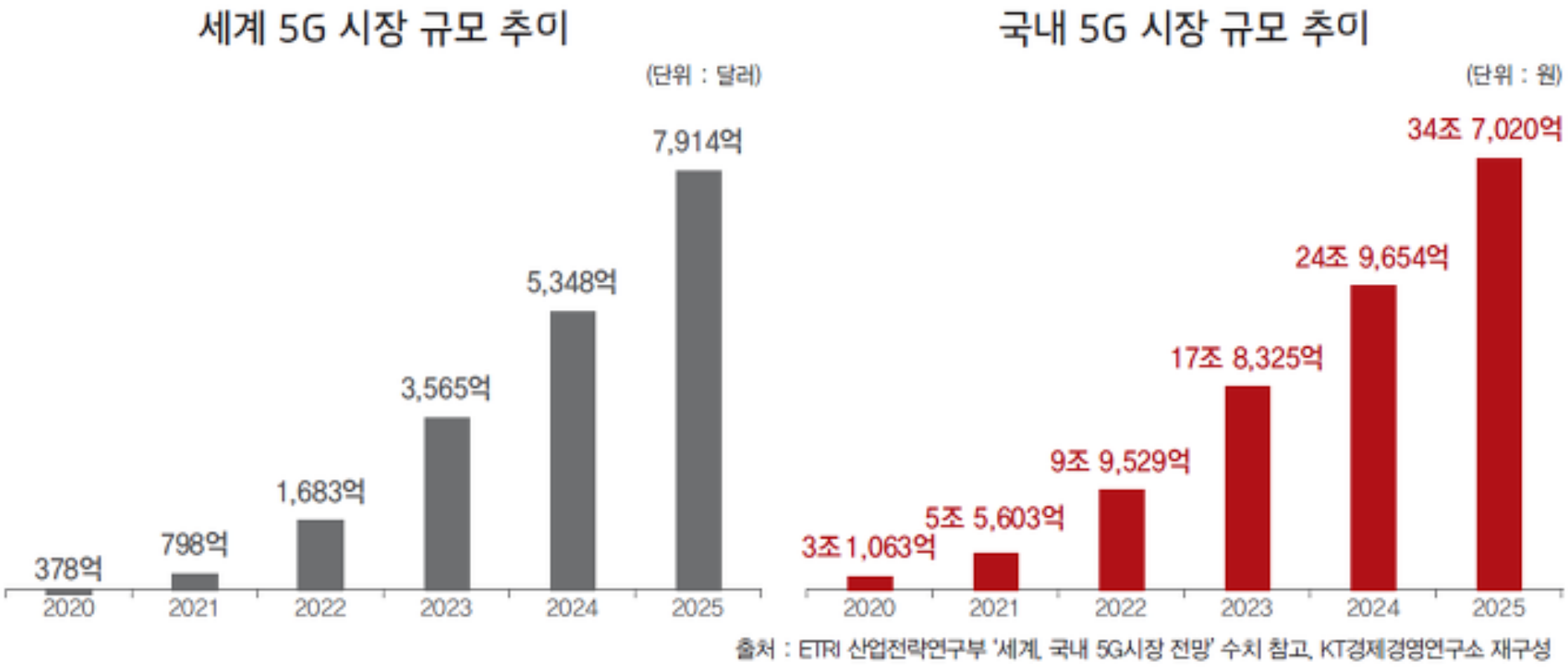
5G시장 및 기술동향



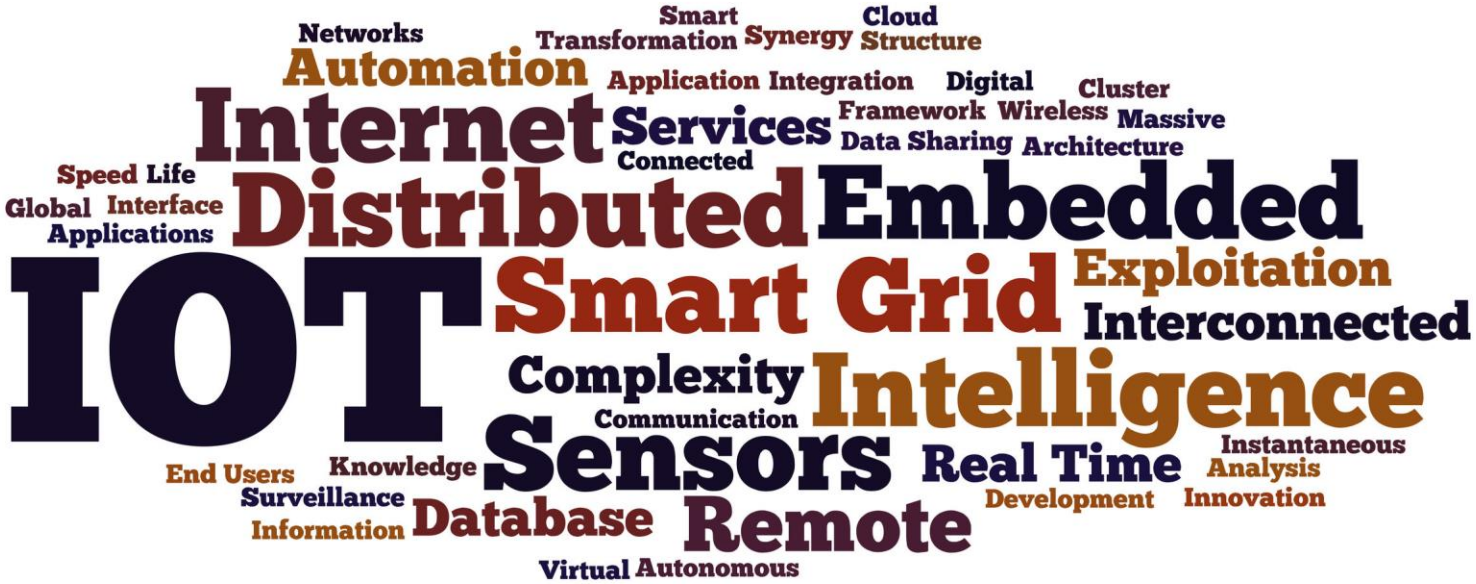
Source: InterDigital, MWC2015

5G시장 및 기술동향

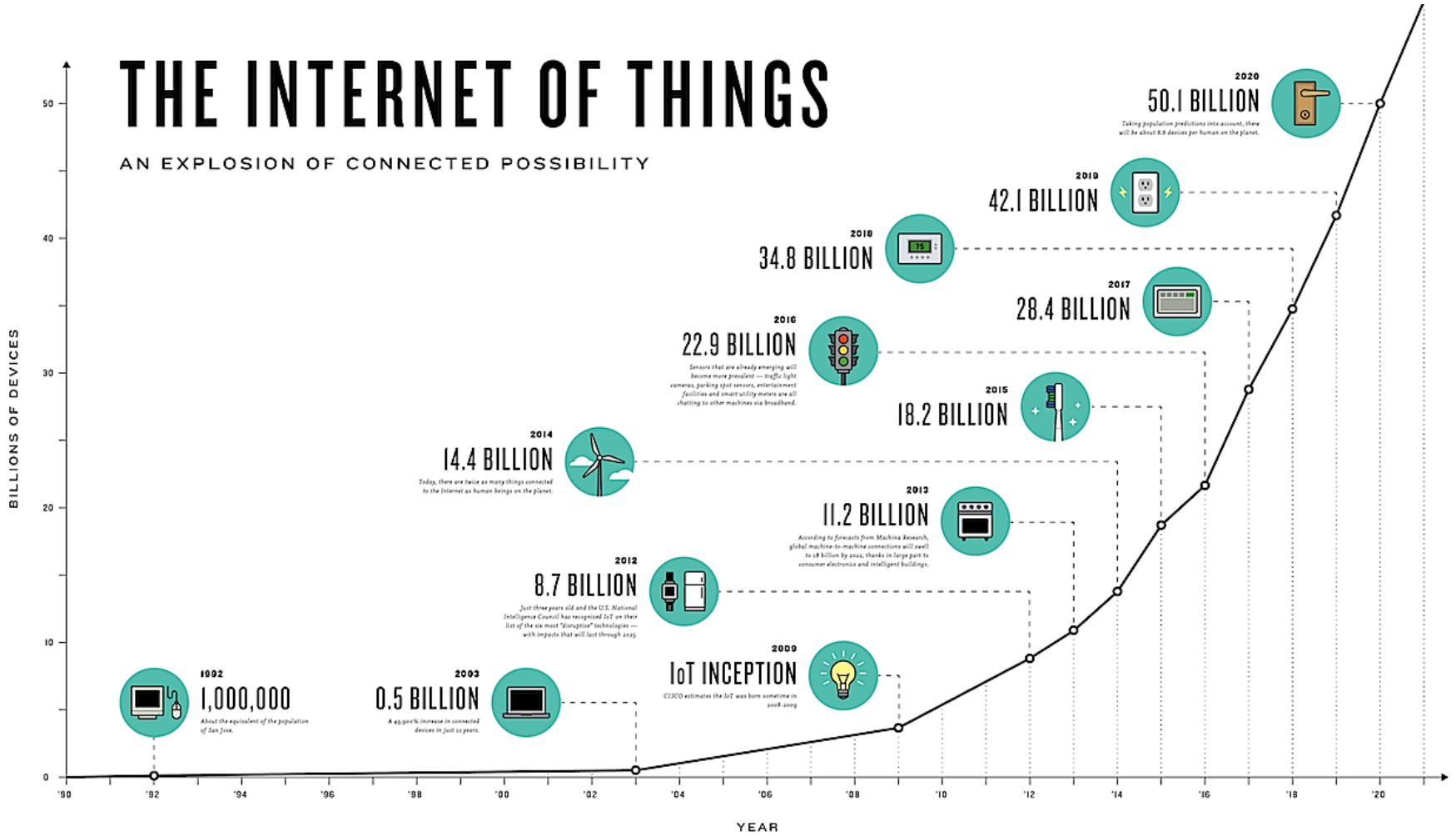
5G 시장 전망



5G시장 및 기술동향


Networks
Smart
Transformation
Synergy
Cloud
Structure
Automation
Application
Integration
Digital
Cluster
Internet
Services
Framework
Wireless
Massive
Data Sharing
Architecture
Connected
Speed
Life
Global
Interface
Applications
Distributed
Embedded
IOT
Smart Grid
Exploitation
Interconnected
Complexity
Intelligence
Communication
Sensors
Real Time
Instantaneous
Analysis
End Users
Knowledge
Surveillance
Development
Innovation
Information
Database
Remote
Virtual
Autonomous

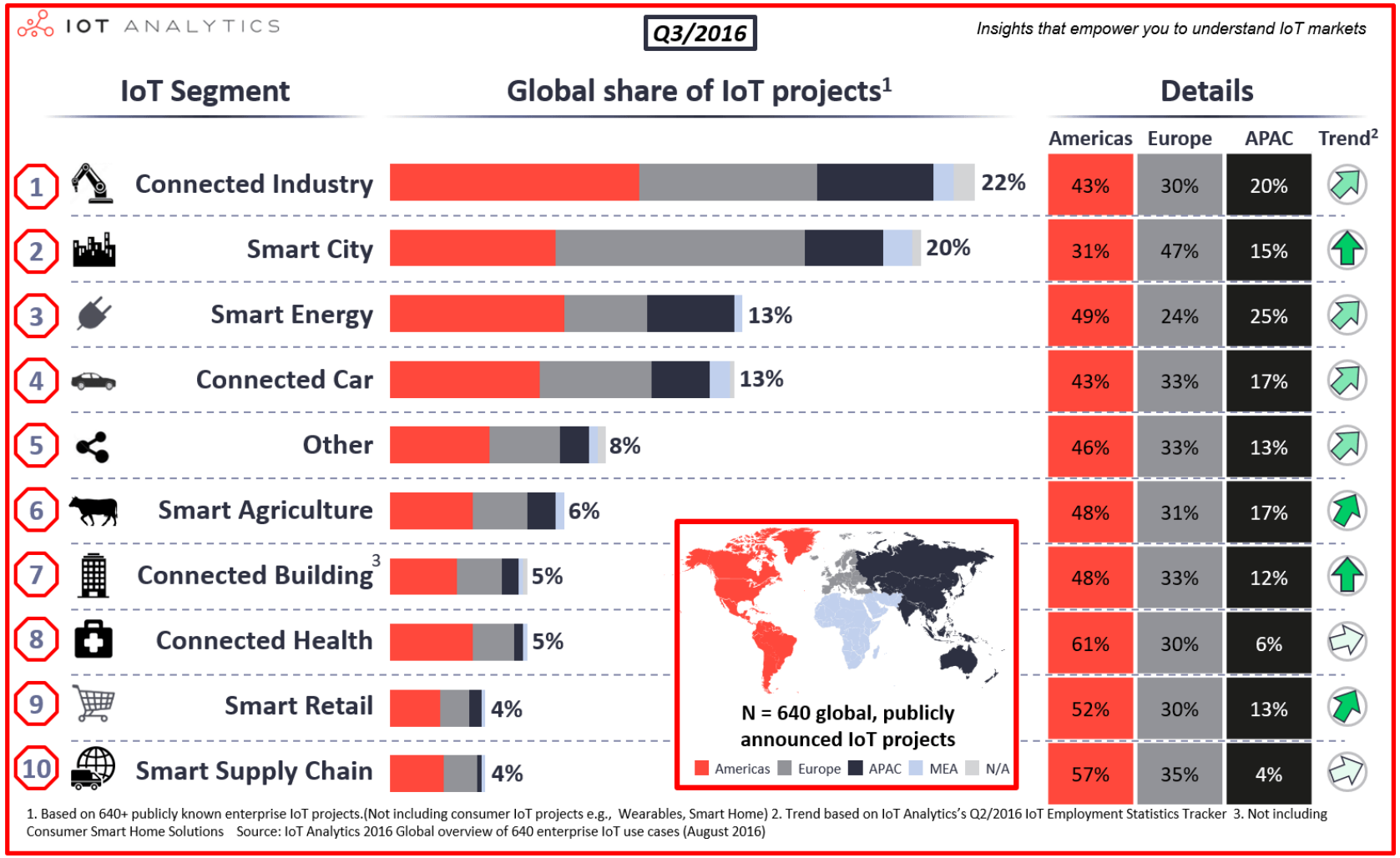
5G시장 및 기술동향



Source: Misumi Mech Lab

5G시장 및 기술동향

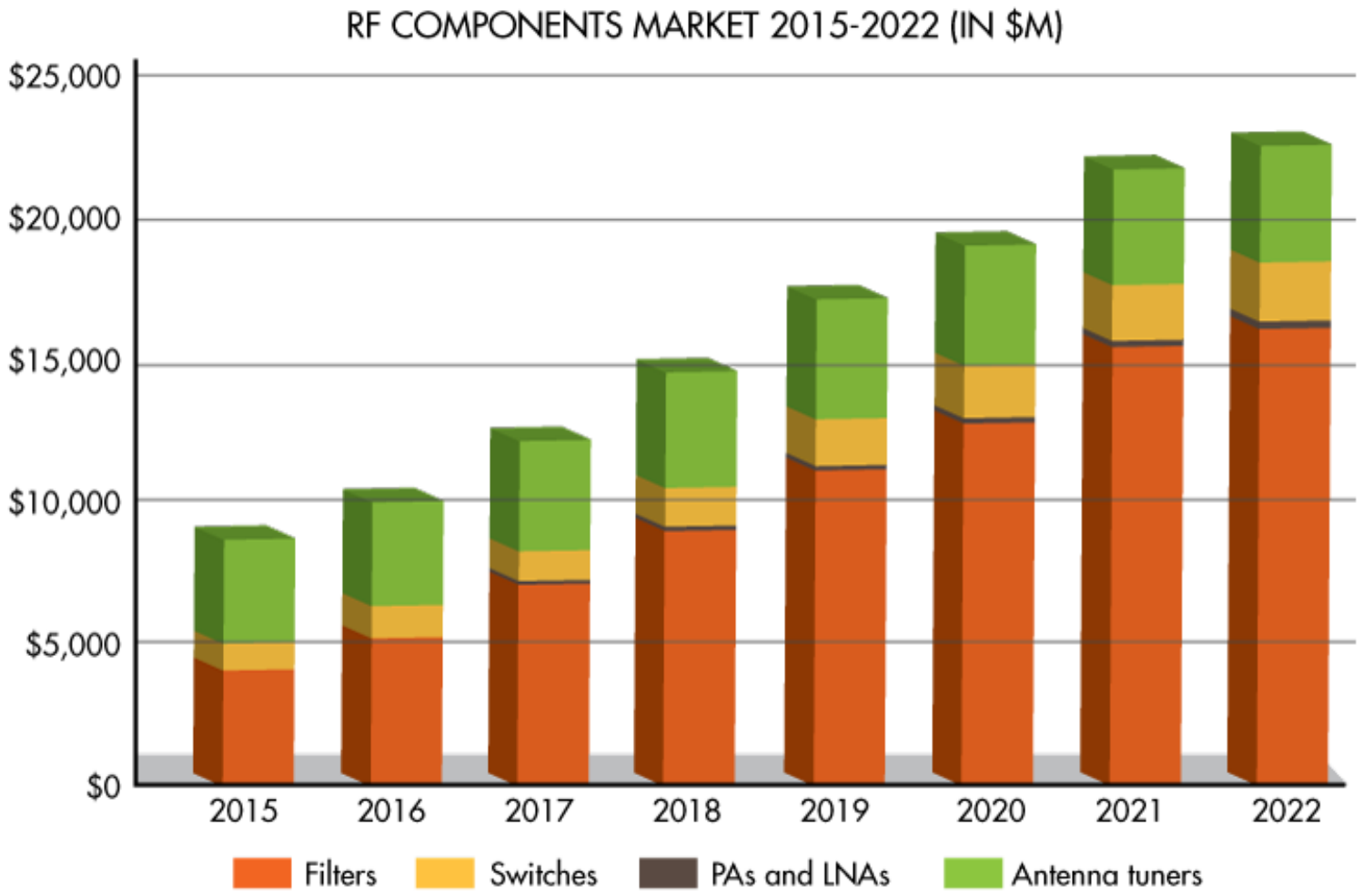
IoT 시장 전망



Source: IoT Analytics

5G시장 및 기술동향

IoT용 RF부품 시장 전망



Source: Microwave & RF

IoT 기반 기술들

주 체	기존			저전력 장거리통신		LTE-MTC	
	Wi-Fi	Zigbee	Bluetooth	SigFox	LoRa WAN	LTE-M/ NB-LTE-M	NB-IoT
통신범위	20~100m	10~100m	10m	13Km 이내	11Km 이내	11Km 이내	15Km 이내
주파수	2.4GHz, 5GHz	868, 900 ~928MHz, 2.4GHz	2.4GHz	8~900MHz (비면허 대역)	8~900MHz (비면허 대역)	1.4MHz/ 200KHz	200KHz
전송속도	2~54Mbps	250Kbps	1~2.1Mbps	100bps	10Kbps	1~2Mbps	200Kbps
전력소비/ 배터리수명	50~200mW	평균15mW 이하	1~30mW	약 10년	약 10년	약 10년	약 10년
표준화	IEEE 802.11b,g	IEEE 802.15.4 포함	IEEE 802.15.1	비표준	비표준	3GPP Release 12	3GPP Release 13

* 자료참조 : 소프트웨어정책연구소, 사물인터넷의 특징과 기반기술동향, 2016. (IEEE 802.11, 802.15.4 표준, 3GPP Release, SSR Analysis)

IoT 기반 기술들

주 체	기존			저전력 장거리통신		LTE-MTC	
	Wi-Fi	Zigbee	Bluetooth	SigFox	LoRa WAN	LTE-M/ NB-LTE-M	NB-IoT
통신범위	20~100m	10~100m	10m	13Km 이내	11Km 이내	11Km 이내	15Km 이내
주파수	2.4GHz, 5GHz	868, 900 ~928MHz, 2.4GHz	2.4GHz	8~900MHz (비면허 대역)	8~900MHz (비면허 대역)	1.4MHz/ 200KHz	200KHz
전송속도	2~54Mbps	250Kbps	1~2.1Mbps	100bps	10Kbps	1~2Mbps	200Kbps
전력소비/ 배터리수명	50~200mW	평균15mW 이하	1~30mW	약 10년	약 10년	약 10년	약 10년
표준화	IEEE 802.11b,g	IEEE 802.15.4 포함	IEEE 802.15.1	비표준	비표준	3GPP Release 12	3GPP Release 13

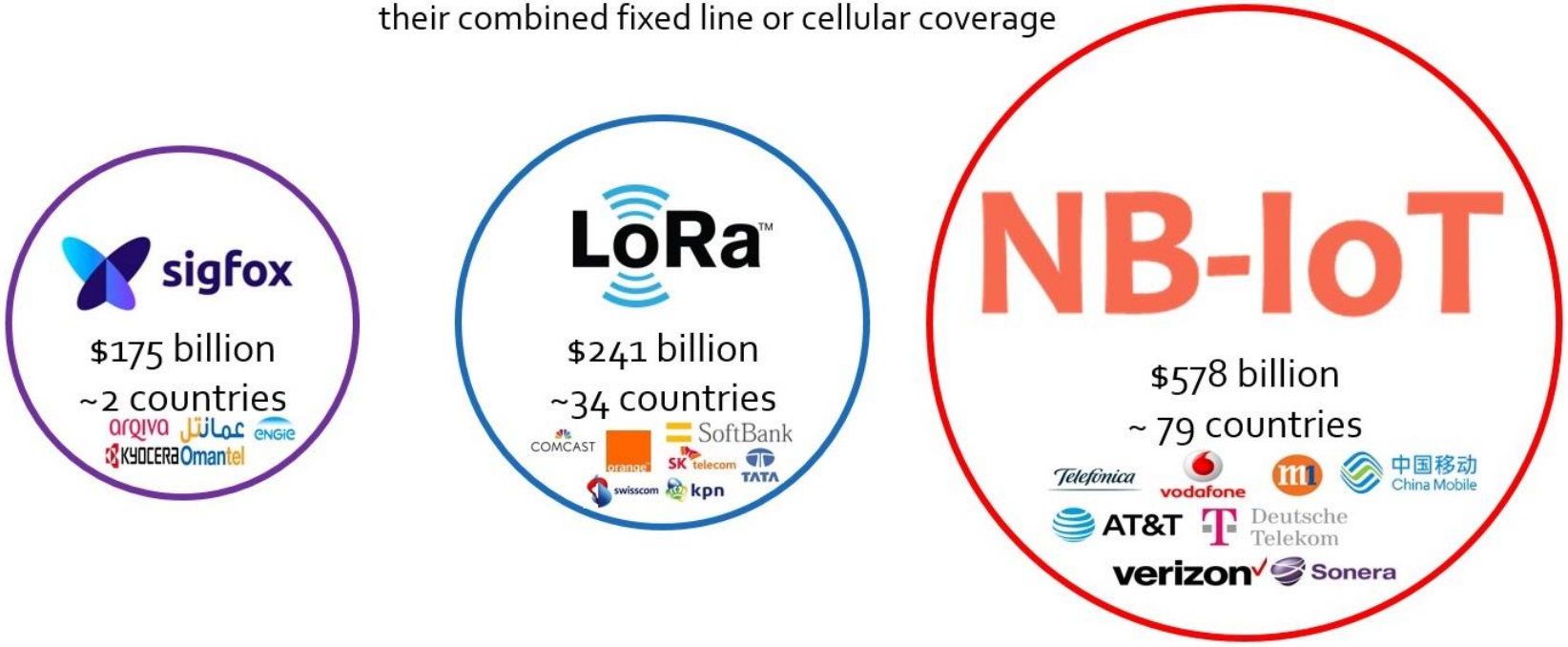
* 자료참조 : 소프트웨어정책연구소, 사물인터넷의 특징과 기반기술동향, 2016. (IEEE 802.11, 802.15.4 표준, 3GPP Release, SSR Analysis)

5G시장 및 기술동향

NB-IoT vs. LoRa

By 2022, NB-IoT will be the winner due to the ability of its MNOs to deliver reliability and coverage

Combined FY 2016 revenues of public MNO partners, and their combined fixed line or cellular coverage



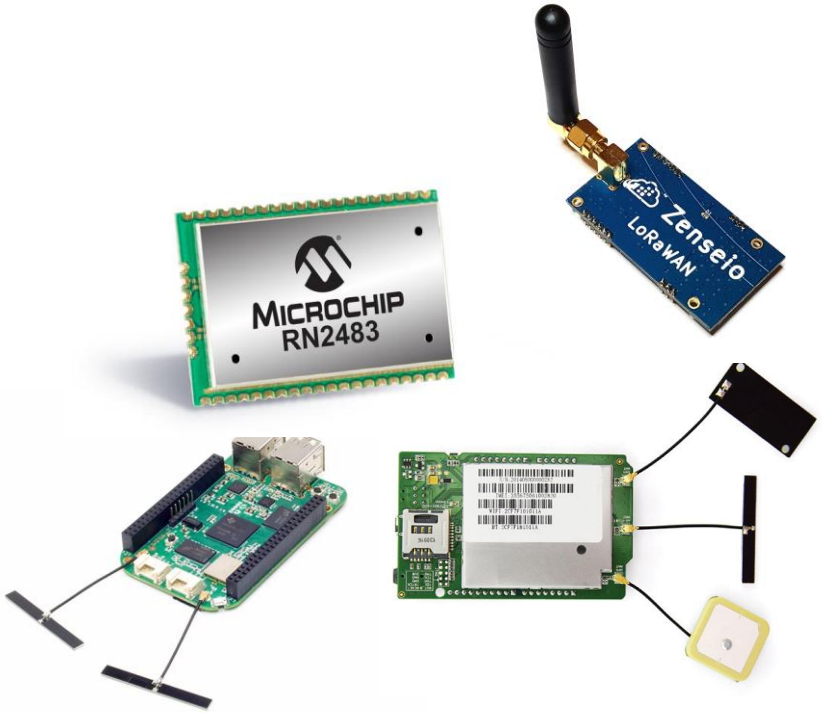
Source: Lux Research, Apr 27, 2017

5G시장 및 기술동향

IoT RF Modules & Antennas

NB-IoT

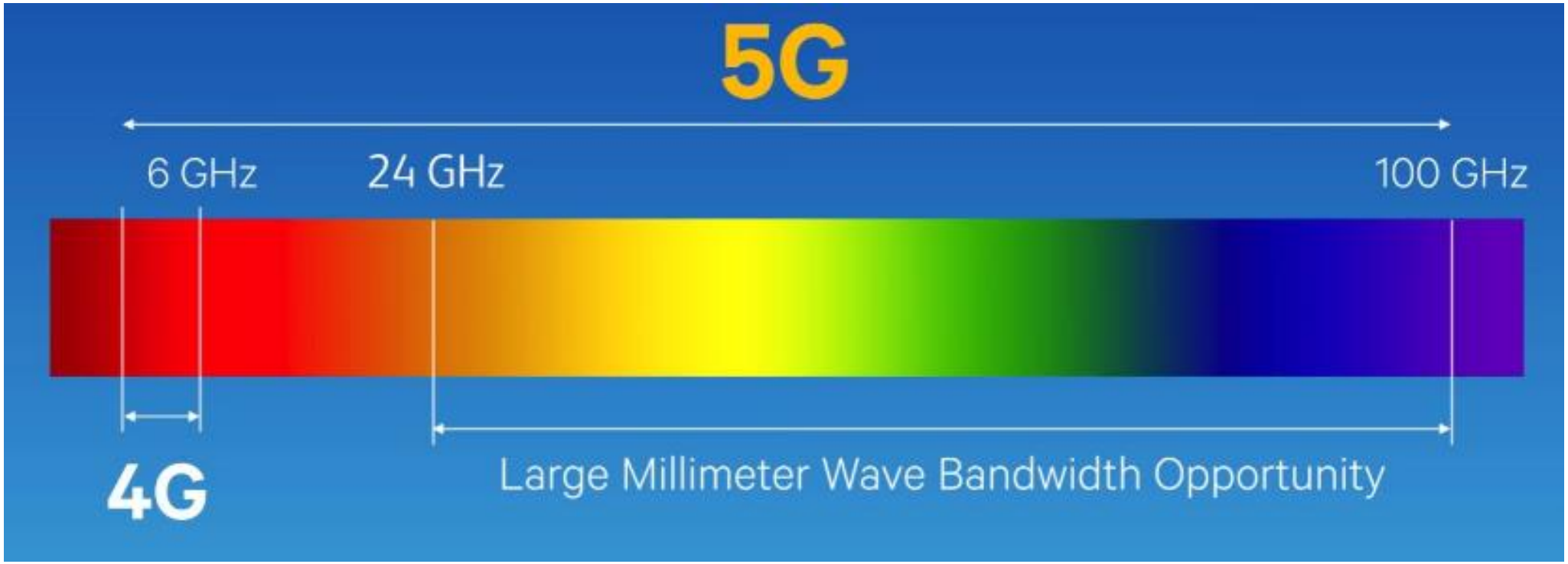
LoRa



5G시장 및 기술동향

5G시장 및 기술동향

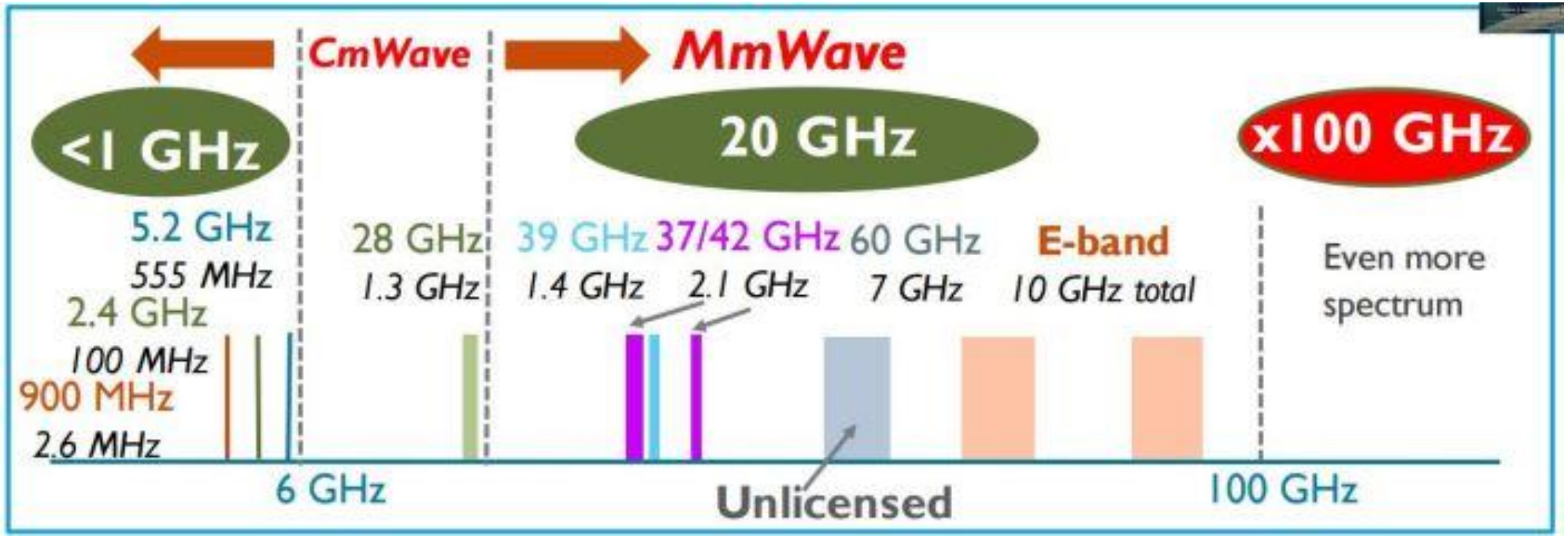
mmWave(밀리미터파) 주파수 대역



Source: RCR Wireless News, Aug 15, 2016

5G시장 및 기술동향

mmWave(밀리미터파) 주파수 대역



* Possible frequency band allocation: 24-33GHz, 37-50GHz, 66-76GHz, 81-86GHz)

Source: The University of Texas at Austin

5G시장 및 기술동향

Why mmWave?

- Higher channel bandwidth & data rate (>10Gbps)
- High antenna efficiency (small size, higher gain)
- Higher spectrum efficiency (massive MIMO, spatial multiplexing for multi-users)
- Interference mitigation (narrow antenna beam, beam steering)
- Better cell edge coverage (small cells, directed beam)

Source: The University of Texas at Austin

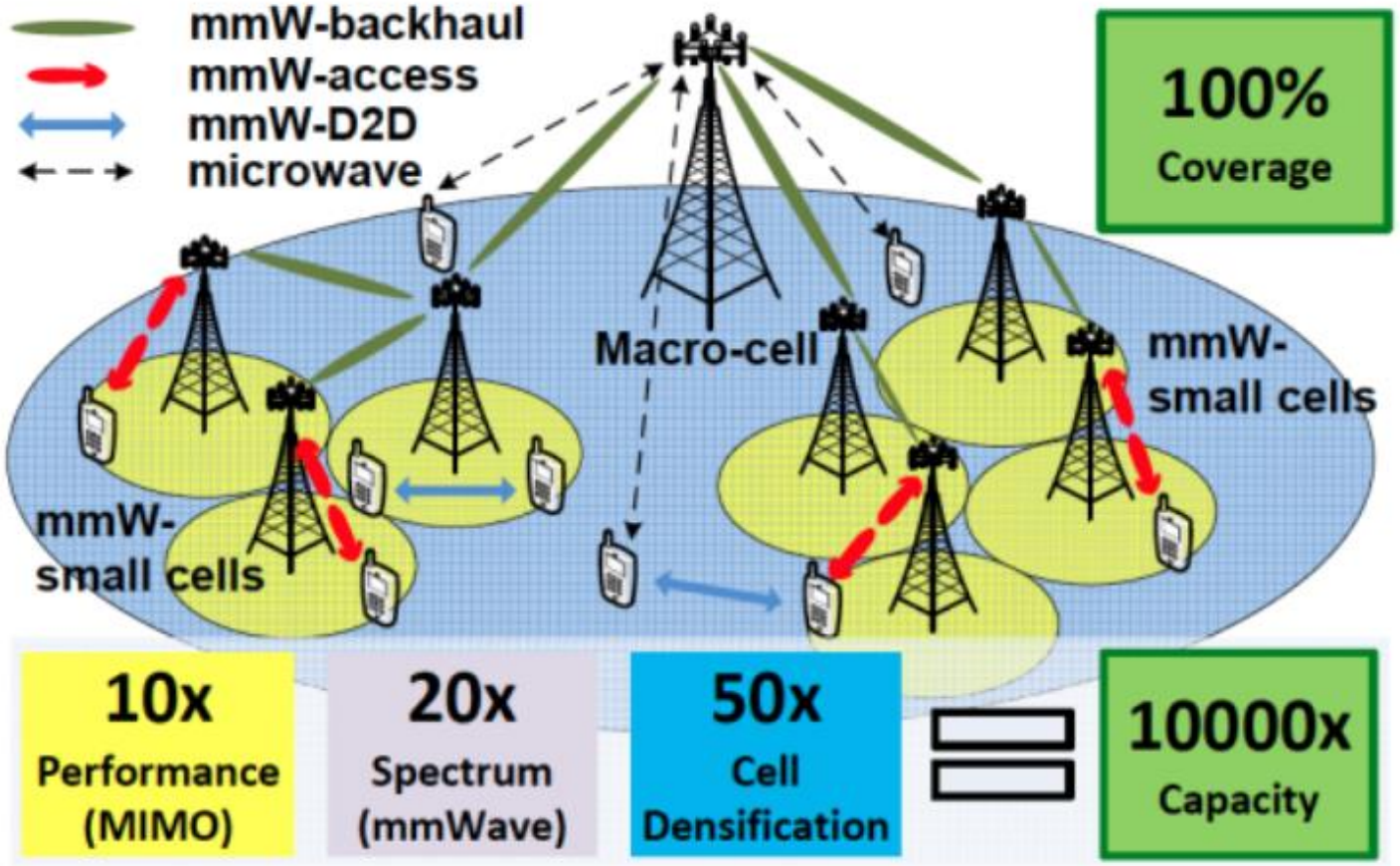
Key mmWave Applications

- Wireless Communications
- WLAN/WPAN
- Automotive Radars

Source: The University of Texas at Austin

5G시장 및 기술동향

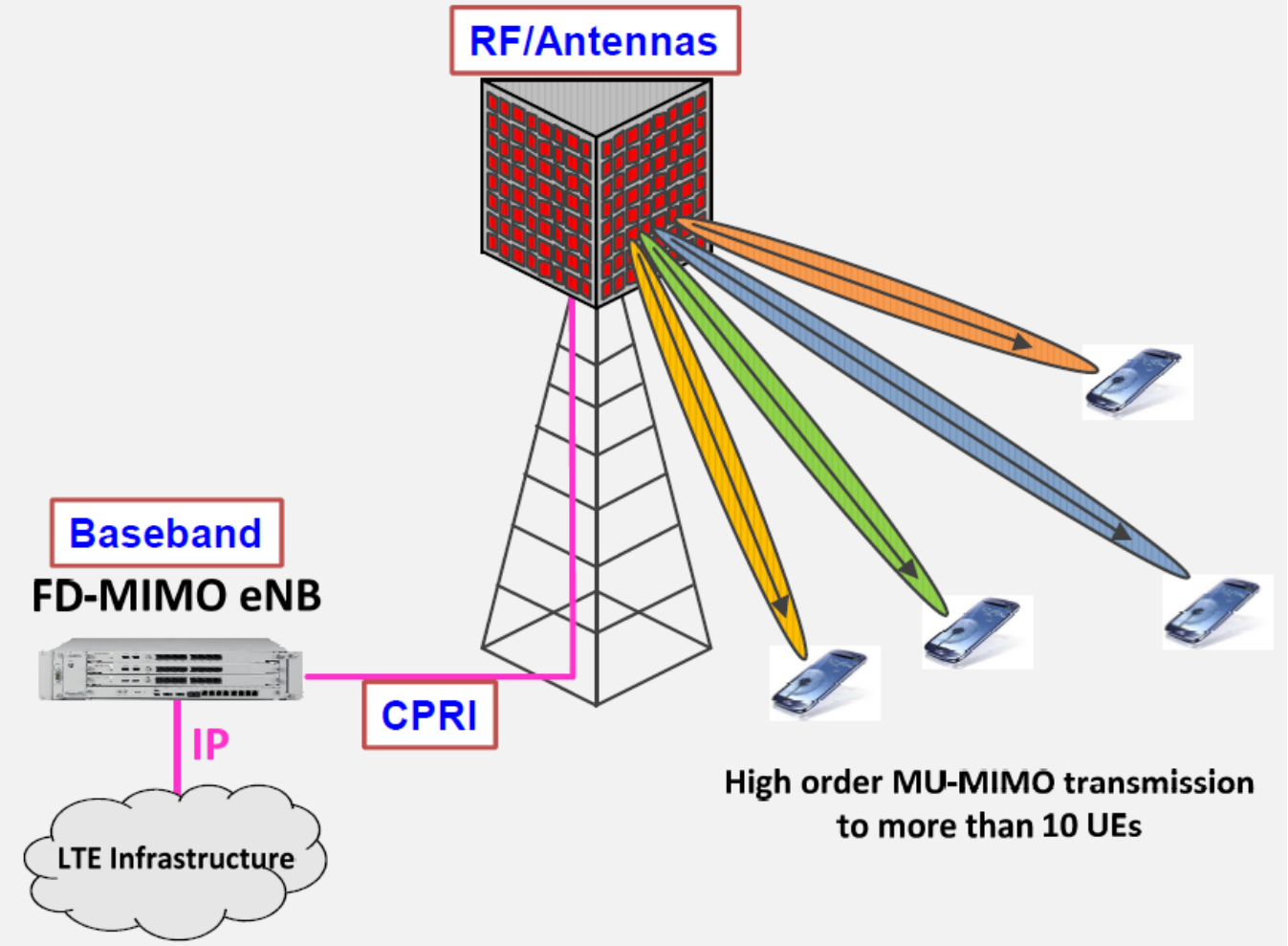
Wireless Communications



Source: The University of Texas at Austin

5G시장 및 기술동향

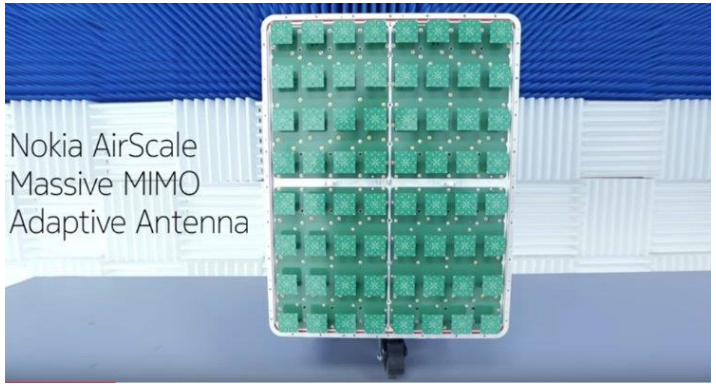
Massive MIMO



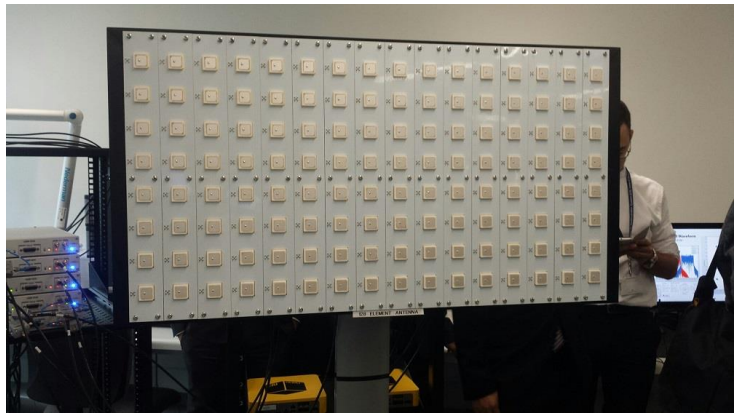
Source: Samgsung Electronics

5G시장 및 기술동향

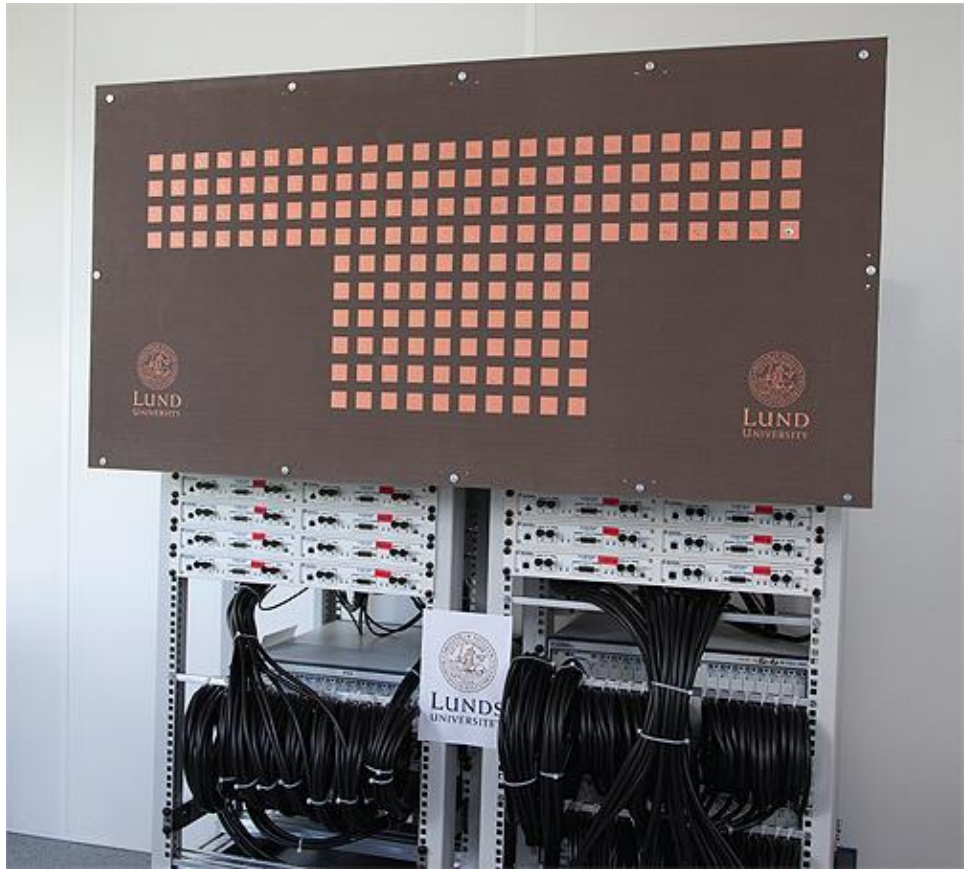
Massive MIMO Antenna Prototypes



64x64 antenna array by Nokia & Mistubishi



128 element antenna array by 5GIC, UK



128 element antenna array by Lunds Univ.,Sweden

mmWave for WLAN/WPAN

MmWave for WLAN/WPAN

Standard	Bandwidth	Rates	Approval Date
WirelessHD	2.16 GHz	3.807 Gbps	Jan. 2008
IEEE 802.11ad	2.16 GHz	6.76 Gbps	Dec. 2012

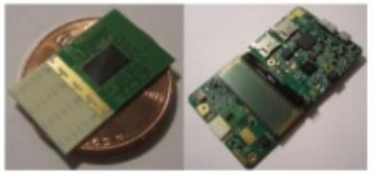
- Standards developed @ unlicensed 60 GHz band
  - WirelessHD: Targeting HD video streaming
  - IEEE 802.11ad: Targeting Gbps WLAN
- Compliant products already available
  - Dell Alienware laptops, Epson projectors, etc.
  - 11ad Chipset available from Wilocity, Tensorcom, Nitero
- Extension of 802.11ad is underway (>20 Gbps)*

* http://www.ieee802.org/11/Reports/ng60_update.htm


Dell Laptop**


Epson projector**

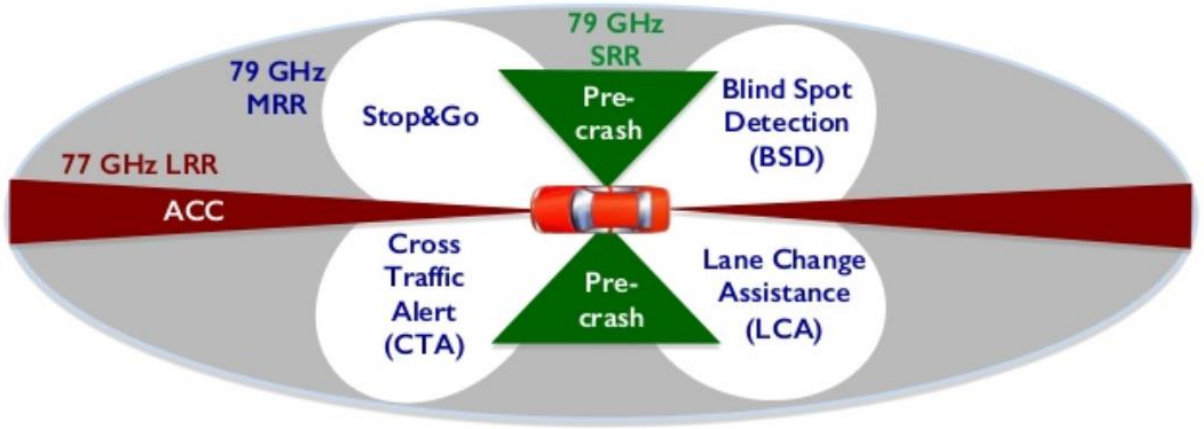

Wilocity's chipset***


Tensorcom's chipset***

Source: The University of Texas at Austin

Automotive Radars

MmWave for automotive radar



Type	LRR	MRR	SRR
Frequency band (GHz)	76-77	77-81	77-81
Bandwidth (GHz)	0.6	0.6	4
Range (m)	10-250	1-100	0.15-30
Distance accuracy	0.1	0.1	0.02

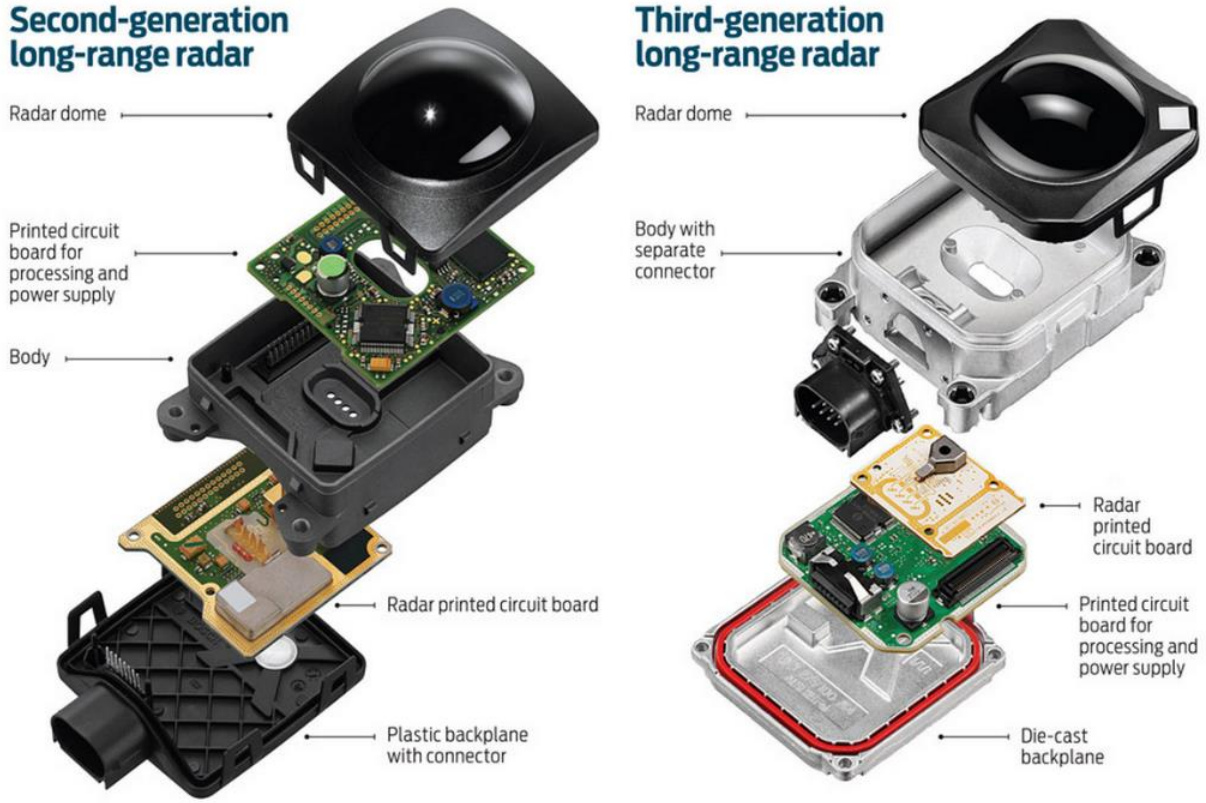
- Long range radar (LRR) is used for automatic cruise control (ACC)
- Medium range radar (MRR) supports CTA, LCA, stop&go and BSD
- Short range radar (SRR) is used for parking aid and precrash applications

Source: The University of Texas at Austin

5G시장 및 기술동향

Automotive Radar Sensors

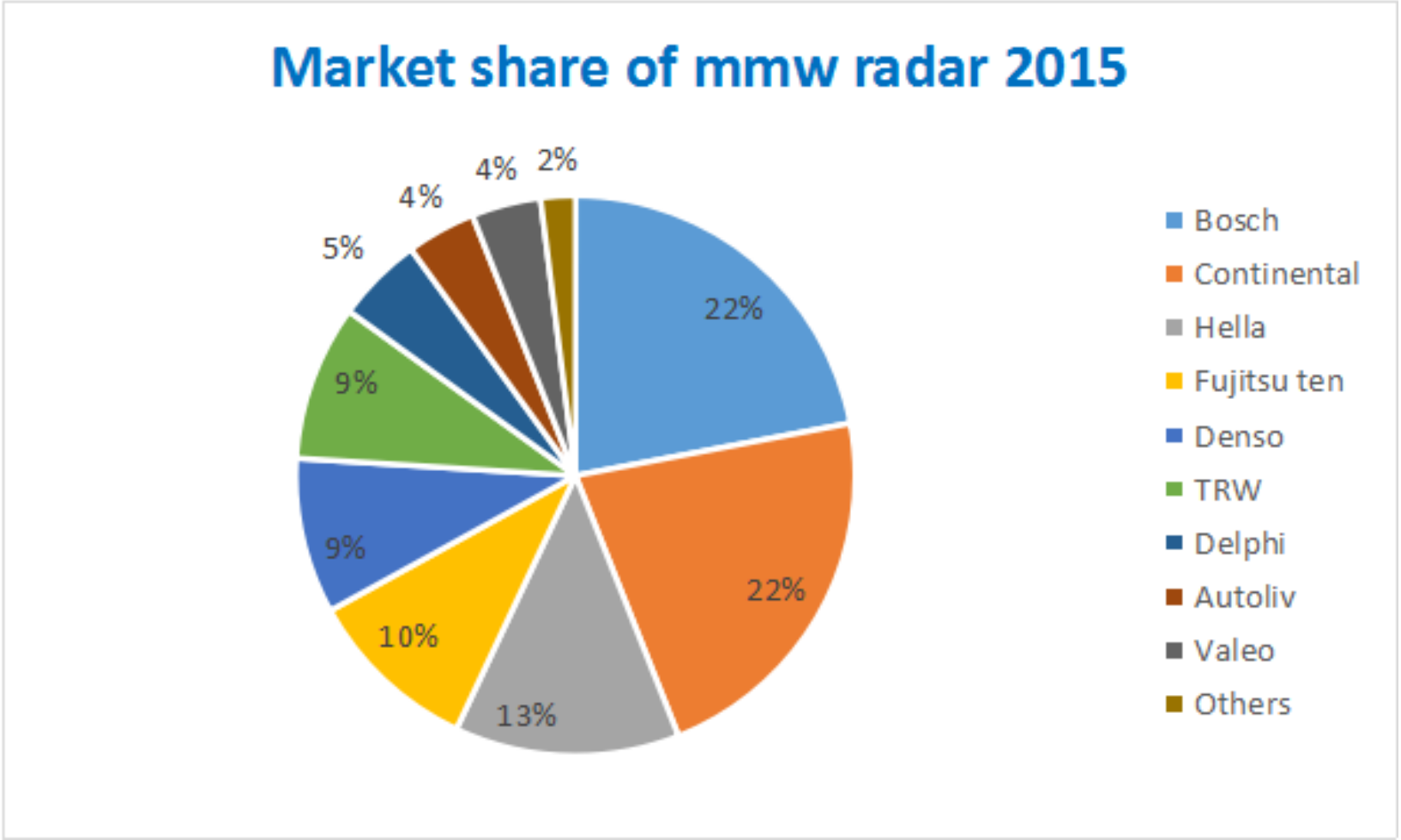
EVOLUTION OF A RADAR Bosch's latest long-range system greatly simplifies the radar's printed circuit board. Instead of a handful of gallium arsenide chips to generate, amplify, and detect the 77-gigahertz microwaves, the system uses just one or two (as shown) of Infineon's silicon germanium chips.



Source: Bosch

5G시장 및 기술동향

Automotive Radar Market Share



Source: Vehicle Trend