BHW TECHNOLOGIES

RF Chips & Beyond

Advanced RF IC, Front-End Module, RF Active integrated Antenna (RFAiA™) and Wireless Sub-System Solutions

BHW AppNote #006

Low-Noise High-IIP3 LNB Architecture Using Cascade of BHWL160 for Multi-Band High-Precision GNSS

Rev. 2.3

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Background: Dual-Band is Next Mainstream for GNSS

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Dual-Band Precision GNSS Market Moving from Insignificant to Billions in Less Than Five Years

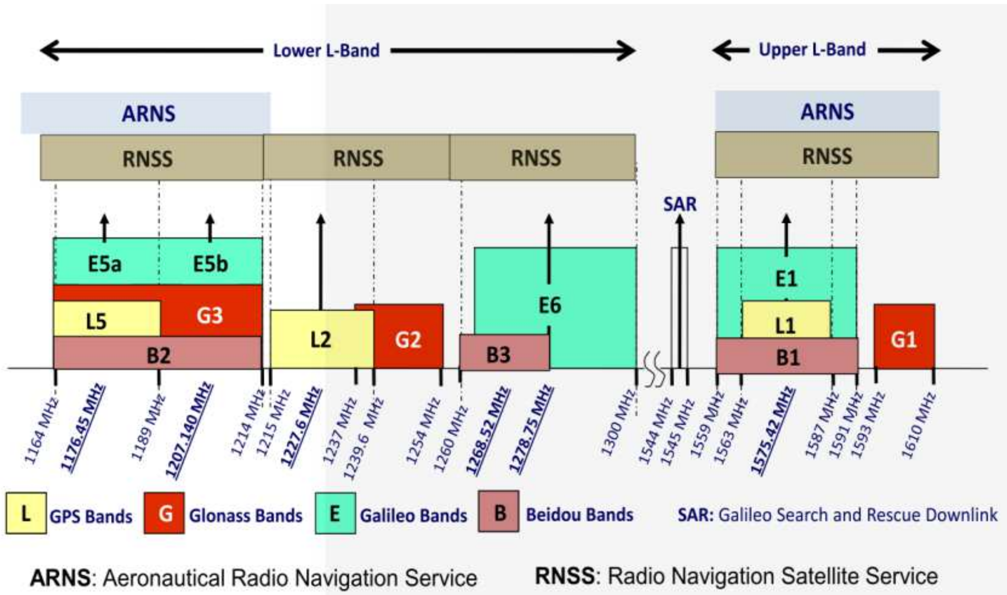
Oyster Bay, New York - 06 Dec 2018

After many years of development at the fringe of the Global Navigation Satellite System (GNSS) industry, dual-frequency GNSS devices are finally ready to hit the mass market and will account for more than a billion chipset shipments in 2023, according to a new market data report by **ABI Research**, a market-foresight advisory firm providing strategic guidance on the most compelling transformative technologies. The report finds that the bulk of this growth will come from the adoption in the smartphone market with consumers hungry for better location accuracy.

Dual-band GNSS can mitigate the so-called multipath interference effects which are especially present in areas with a high density of buildings, like urban canyons, and deliver significantly higher accuracy than single-frequency devices. However, there have been several obstacles preventing widespread adoption of dual-band GNSS until now, including insufficient satellite coverage of a second band, which could be L2 or L5/E5, high chipset prices, and challenges in fitting these integrated circuits and related antennas into small devices such as smartphones.

Technical Challenges for Dual/Multi-Band All-Constellation GNSS:

- ➢New Dual/Multi/Wide-Band Antenna
- ➢LNA with Low NF and Sufficient Gain over Wide Frequency Band 1165-1610MHz
- ➢Resistant to RF Interference (Anti-Jamming & Anti-Spoofing)
- ➢System Implementation and Optimization
- ➢Best-Class Performance at Lowest BOM Cost

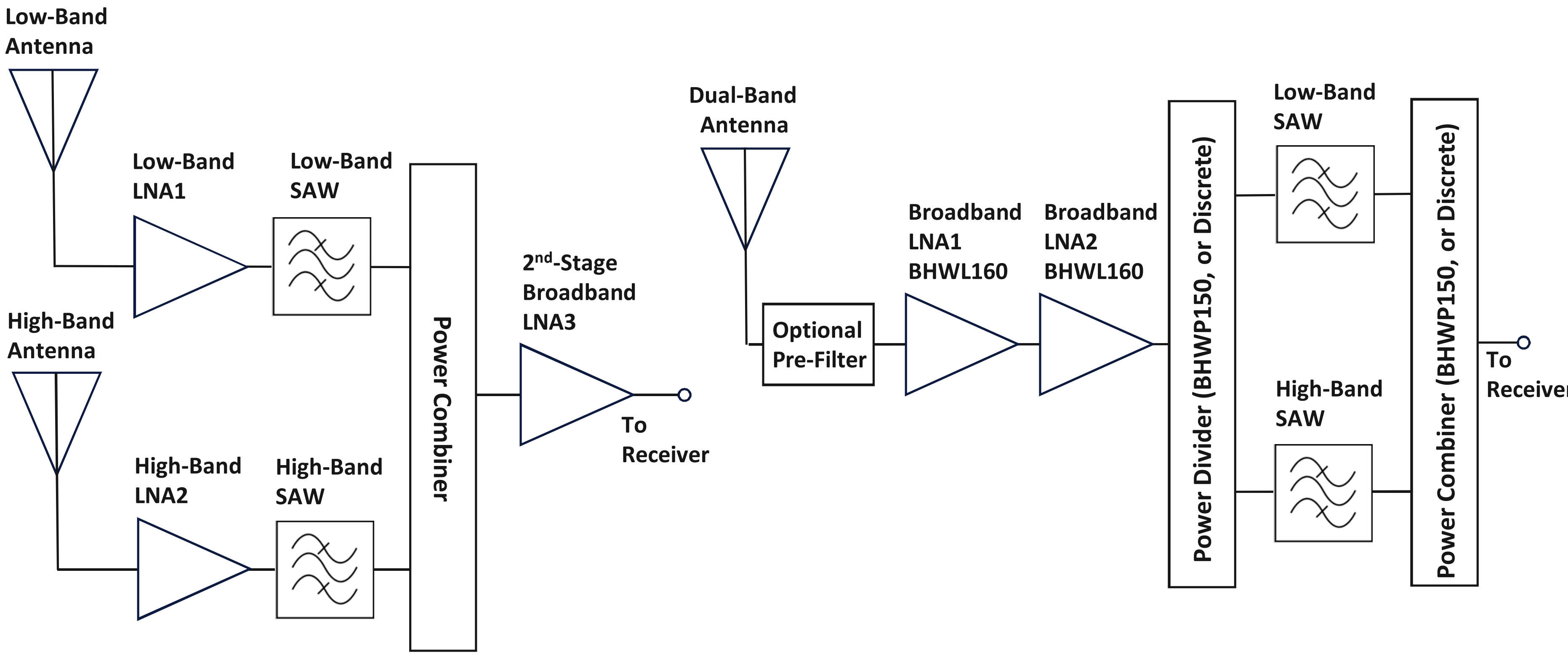


This AppNote describes design and test results of cascading two BHWL160 wideband GNSS LNAs to provide low-noise, high-IIP3 performance for all-band all-constellation GNSS active antennas and modules with best-class positioning accuracy and anti-RFI capability.

LNB Topologies for Dual-Band GNSS

Conventional Topology A
Dual-Antenna/Dual-LNA

BHW Proposal Topology B
Single-Antenna/Broadband-LNA

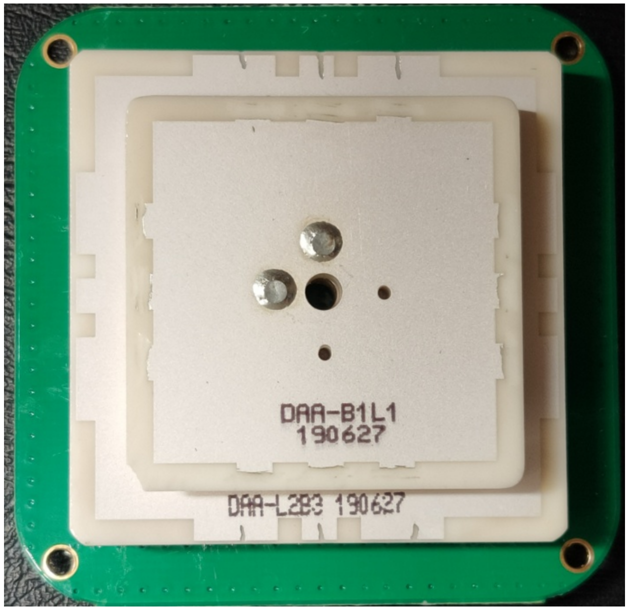


Notes:

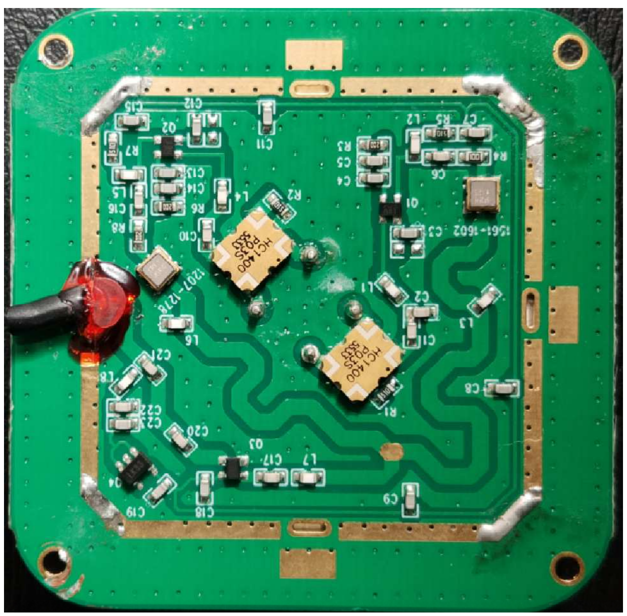
- Most current dual-band GNSS designs use Topology A, based on separate antennas and LNAs for low and high band
- Dual/Multi-Band GNSS receiver with broadband antenna and LNA (Topology B) has huge size and cost advantages over dual-antenna/ dual-LNA based topology
- Full-band all-constellation LNAs with state-of-art RF performance are available today, such as BHWL160/BHWL161
- Concerns over potential interference/desensitization for broadband design is address by high input P1dB/IIP3 of the LNA
- Topology B takes full advantage of BHWL160’s broadband, low-NF, moderate gain and outstanding IIP3 to enable multi-band GNSS LNBs (Low Noise Block) with best system NF and IIP3 at minimal device count, power, and BOM cost
- An optional double-notch pre-filter can be added between the antenna and LNA to further improve anti-jamming capability of the GNSS system significantly, while causing only very minor degradation in C/N0 and TTFF from cold start

Example of Conventional Dual-Band GNSS Front-End

Top



Bottom



Upper Antenna (L1/B1)
-Size: 33.5x33.5x4mm
Lower Antenna (L2/B3)
-Size: 43x43x6.4mm
PCB
-Size: 55x55x0.83mm

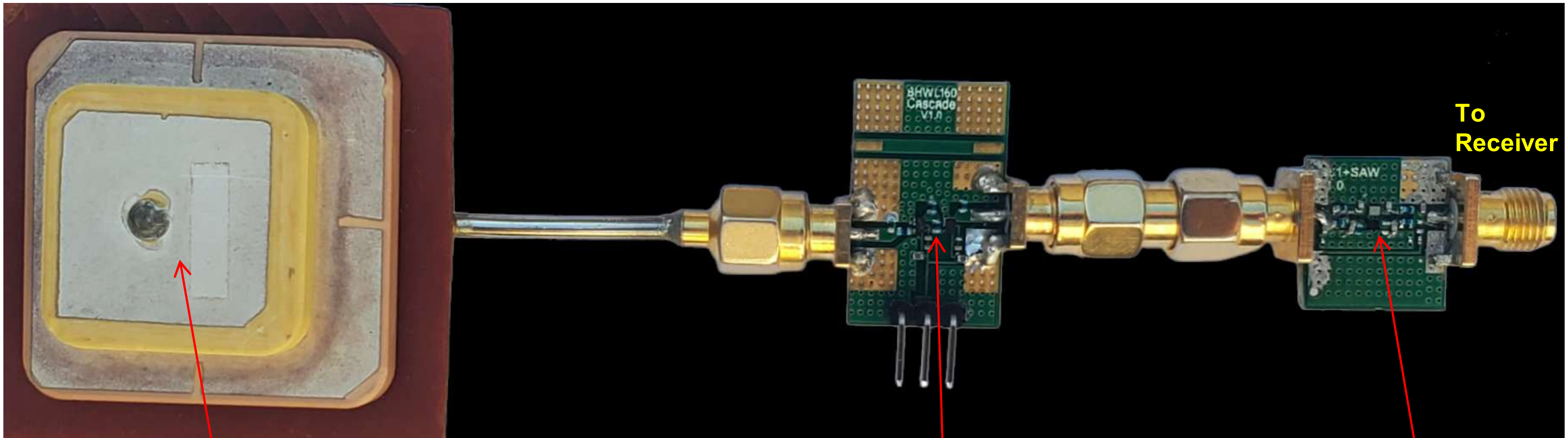
1st LNA
-Q1: Infineon BFP640
-12 Components between Hybrid and SAW
2nd LNA
-Q2: Infineon BFP640
-11 Components between Hybrid and SAW
3rd Amplifier
-Q3: Unknown P/N
-9 Components
Hybrid
-P/N: Yantel HC1400P03S
-Size: 6.35*5.08mm

Comments:

1) **Dual-channel design with separate antennas and LNAs for low and high band**
2) **Two-Stage LNA topology to meet total gain budget for a typical active GNSS antenna/module**
3) **Very complicated design with too many components, due to the use of discrete transistors for LNAs**

BHW Proposal of Dual-Band GNSS Front-End

Breadboard for Proof-of-Concept Test



Single-Feed
Dual-Band Antenna

BHWL160
LNA Cascade

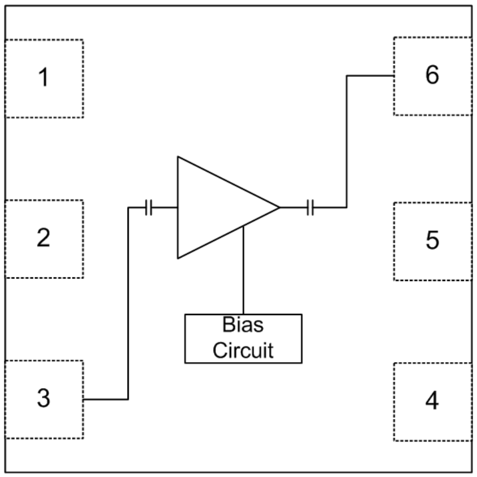
Low/High-Band SAWs
& Discrete Power
Splitter/Combiner

Features & Advantages:

- Simplest implementation of dual-band all-constellation GNSS receiver front-end in the industry
- Single-feed dual-band antenna eliminates the need of bulking and expensive passive components such as 90 degree hybrids
- Cascade of two BHWL160 provides ~30dB gain across 1176-1610MHz and industry's lowest system noise figure
- High gain of BHWL160 cascade relaxes greatly post-LNA RF designs, allowing the use of inexpensive SAW filters and power splitter/combiner
- Post-LNA design can alternatively use dual-band SAW filters with integrated diplexers to reduce PCB foot print
- The proposed receiver architecture has demonstrated maximum C/N0 of 49~53dB simultaneously in multiple GNSS bands including L1, B1, L5, B2, E1 and E5 (see Pages 23, 24, 30, 33 for test results)

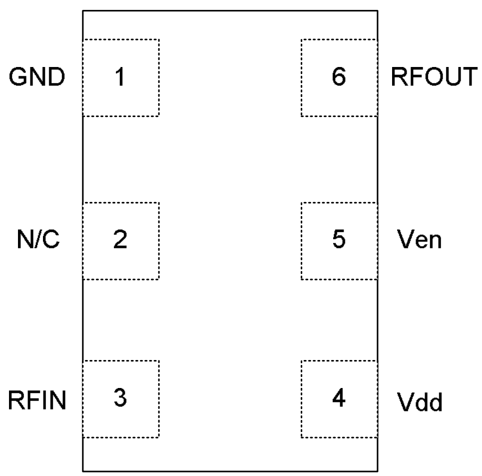
BHWL160 Wideband GaAs Low Noise Amplifier

Functional Block Diagram



Package Pin-Out

(Top "See-Through" View)



DFN-6L 1.45x1.0x0.55mm

Product Overview:

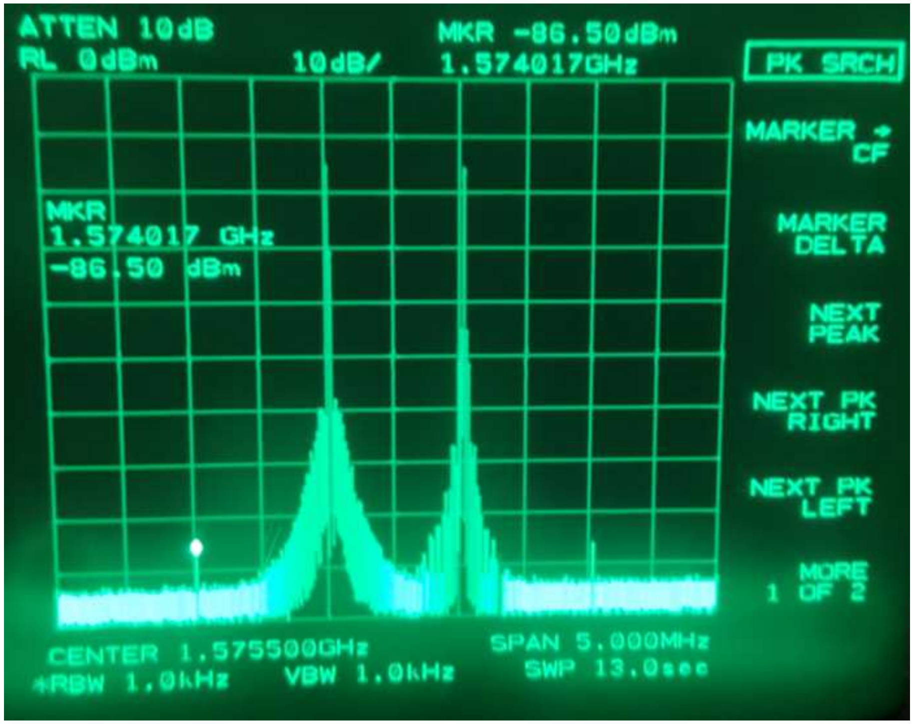
- Advanced GaAs E/D-pHEMT Process
- Triple-Frequency Operation for All Major GNSS
- Low Noise Figure over Broadband:
  ~0.5dB(High-Band); ~0.7dB(Full-Band)
- Power Gain: 15/16dB (High/Low-Band)
- High Input P1dB: -6dBm at 1575MHz
- Industry-Leading In-Band/OOB IIP3 & IIP2
- Low Current: 6mA at 3.3V
- Adjustable Current: 1.5~7mA at 1.2~3.6V
- ESD at All I/O Ports: 1kV HBM, >2KV CDM
- Ultra-Small 1.45x1.0mm DFN-6L Package

Applications:

- GNSS for Smartphones, Smart Watches, Wearables
- GNSS for PNDs, UAVs and Drones
- GNSS for Vehicles, ADS Systems
- GNSS for Shared Rides, Asset Tracking
- Active GNSS Antennas & Modules
- UHF 600/700/868/915MHz Products
- 2.4GHz BLE AoA/AoD Systems
- 2.4GHz Remote Controls
- Other Generic Radios from Sub-GHz to 2.5GHz

BHWL160 In-Band and Out-of-Band IIP3

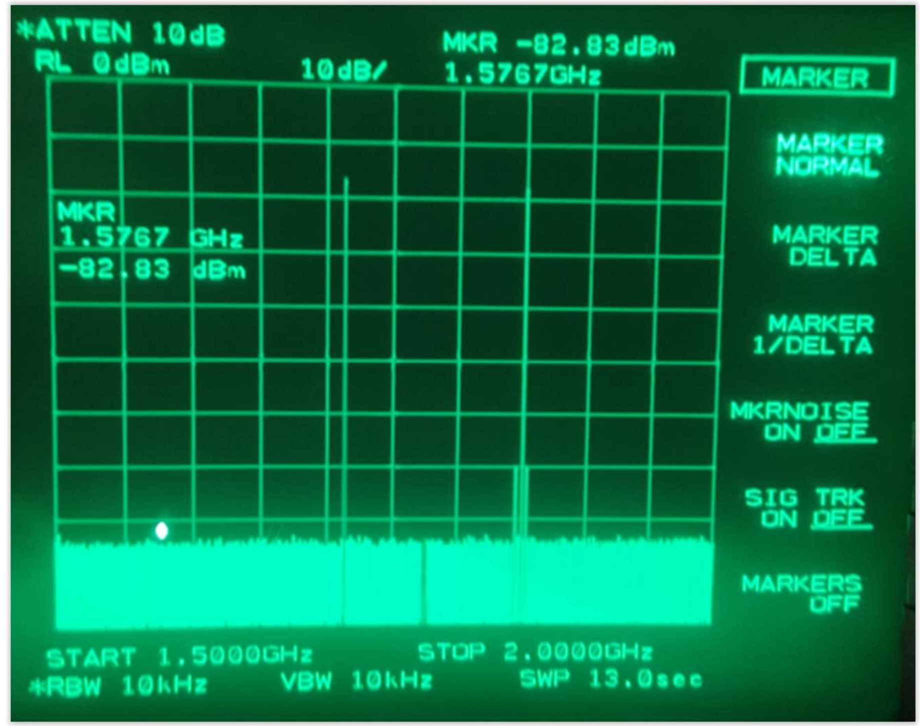
In-Band IIP3



In-Band IIP3 = +5.7dBm

f1=-30dBm@1575MHz
f2=-30dBm@1576MHz
Vdd=Ven=3.3V
Note: Side-bands near f1/f2 are due to non-ideal source signal and unrelated to intermodulation of the LNA itself.

Out-of-Band IIP3

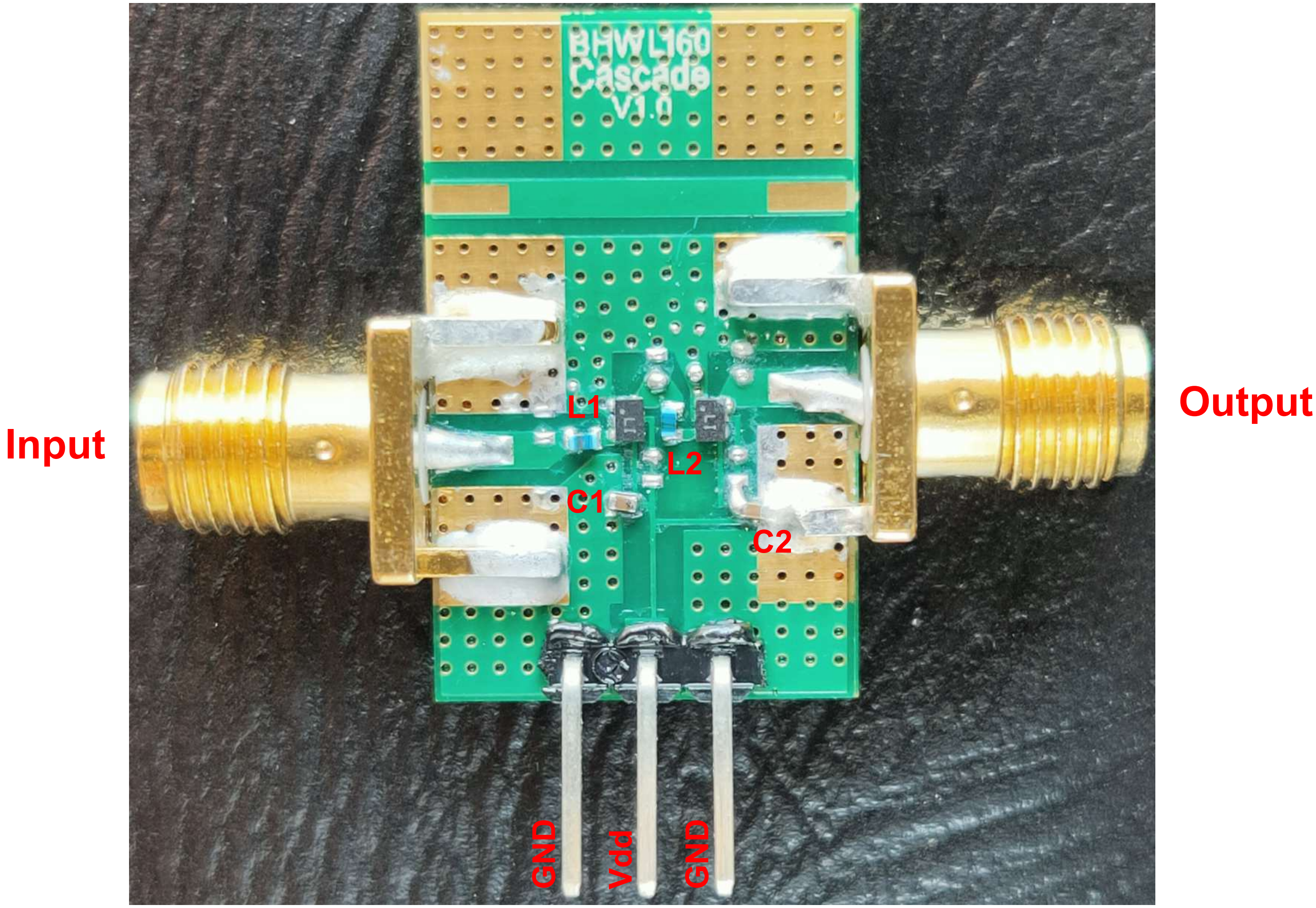


Out-of-Band IIP3 = +4.3dBm

f1=-30dBm@1712.71MHz
f2=-30dBm@1850MHz
TOI=1575.42MHz
Vdd=Ven=3.3V
Note: Side-bands near f2 are due to non-ideal source signal and unrelated to intermodulation of the LNA itself.

Most existing GNSS LNAs have IIP3 below 0dBm. The exceptionally high IIP3 of BHWL160, along with other features including low NF, moderate gain, and fullband coverage makes it possible to design dual-band GNSS systems with the least system complexity, reduced active device and passive component counts, smaller PCB size, lower current consumption and BOM cost, while delivering top-class performance simultaneously, for the first time in the industry

BHWL160 Cascade EVB for High-Band

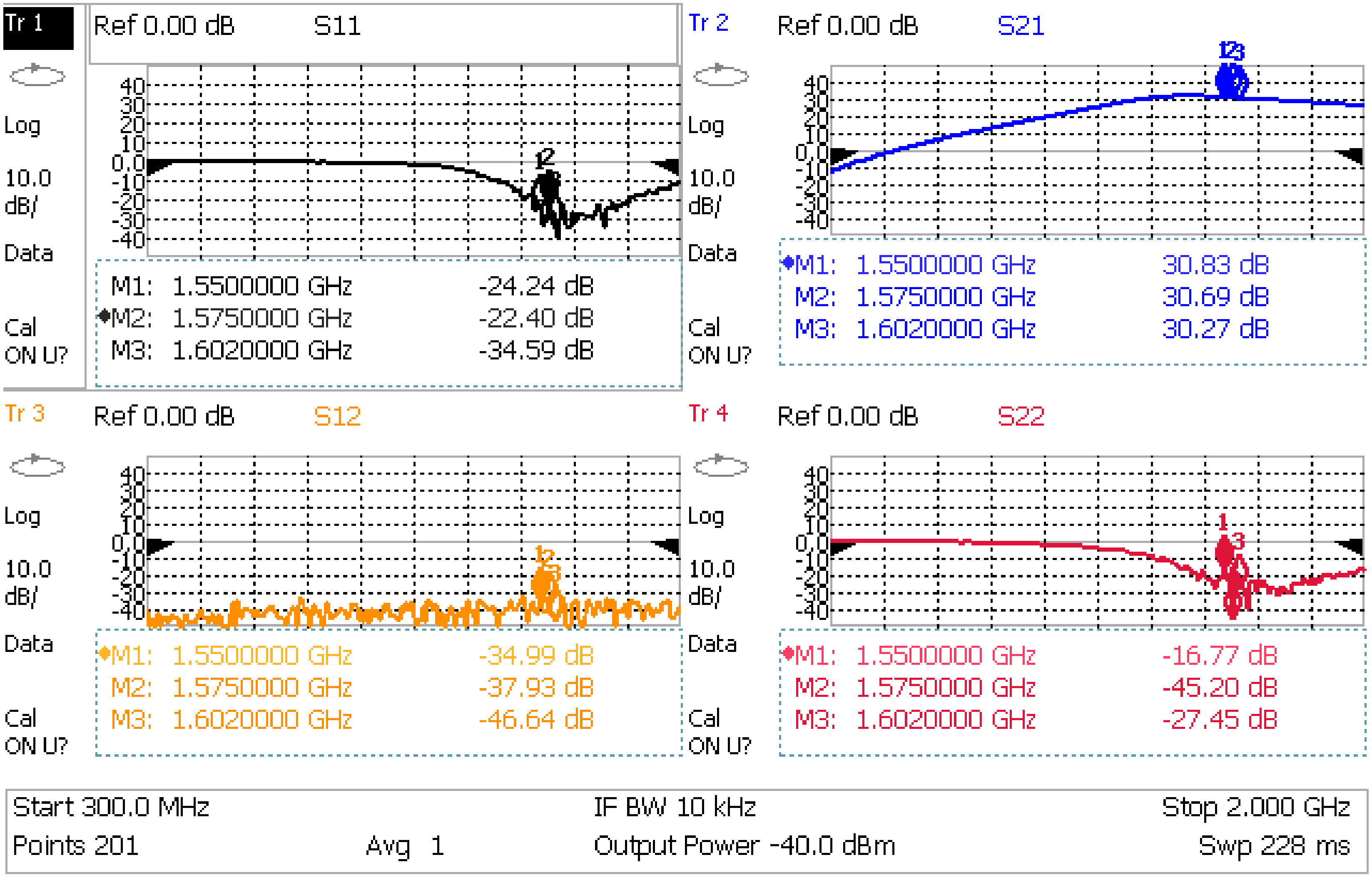


Notes:

- BOM for High-Band GNSS (1550-1610MHz): L1=L2=9.1nH (Murata LQW15A Recommended), C1=C2=1uF.
- Optional resistors can be added to control line to reduce current for specific applications. See BHWL160 AppNote for details.
- Nominal bias: Vdd=Ven=3.3V, Idq~15mA total for the two LNAs.

BHWL160 Cascade for High-Band: S-Parameters

Typical Small-Signal S-Parameters at Vdd=Ven=3.3



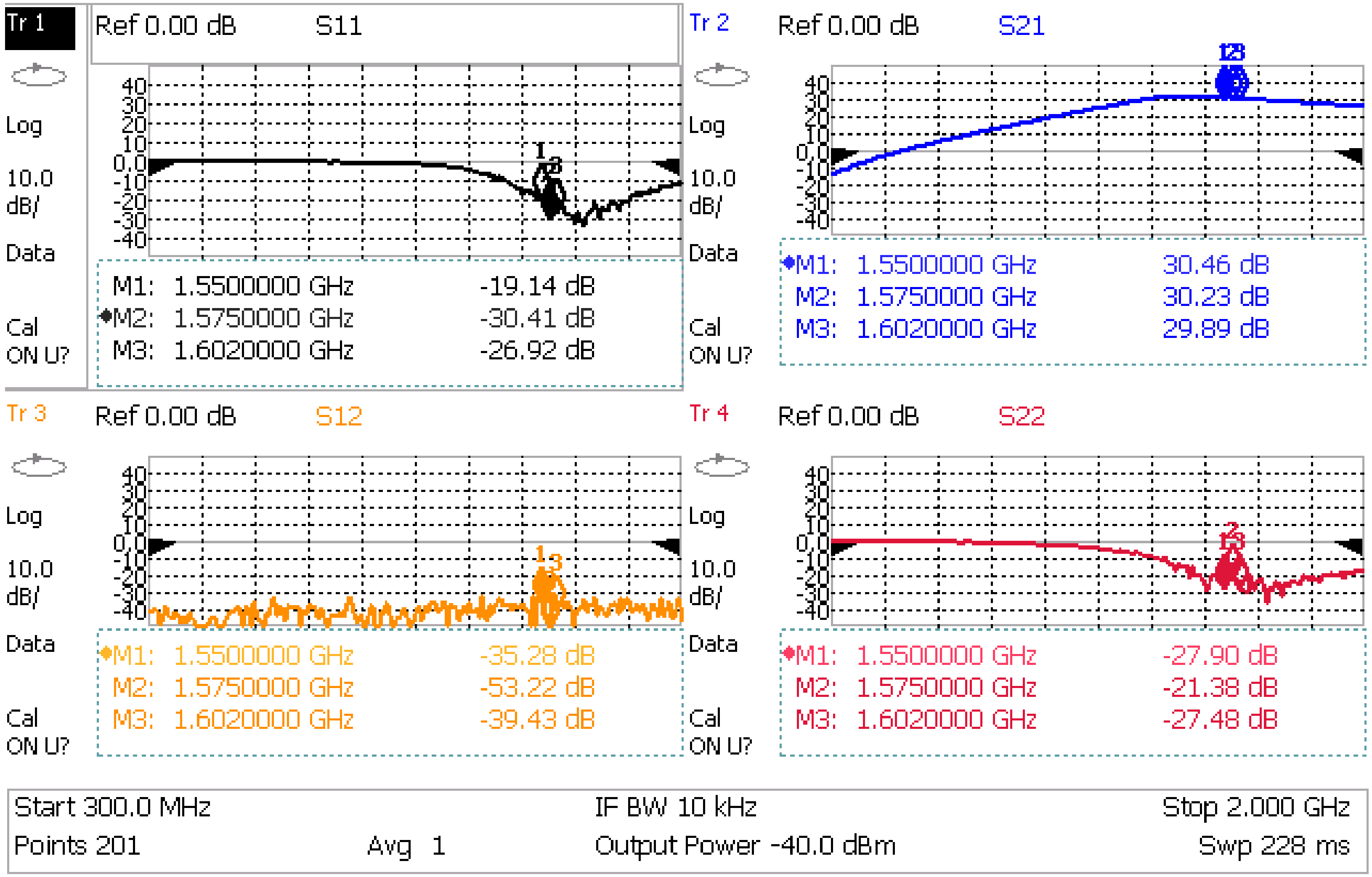
Notes:

-L1=L2=9.1nH, C1=C2=1uF, Vdd=Ven=3.3V, Idq~15mA

-Measured S21 includes EVB trace and SMA connector losses (~0.2dB)

BHWL160 Cascade for High-Band: S-Parameters

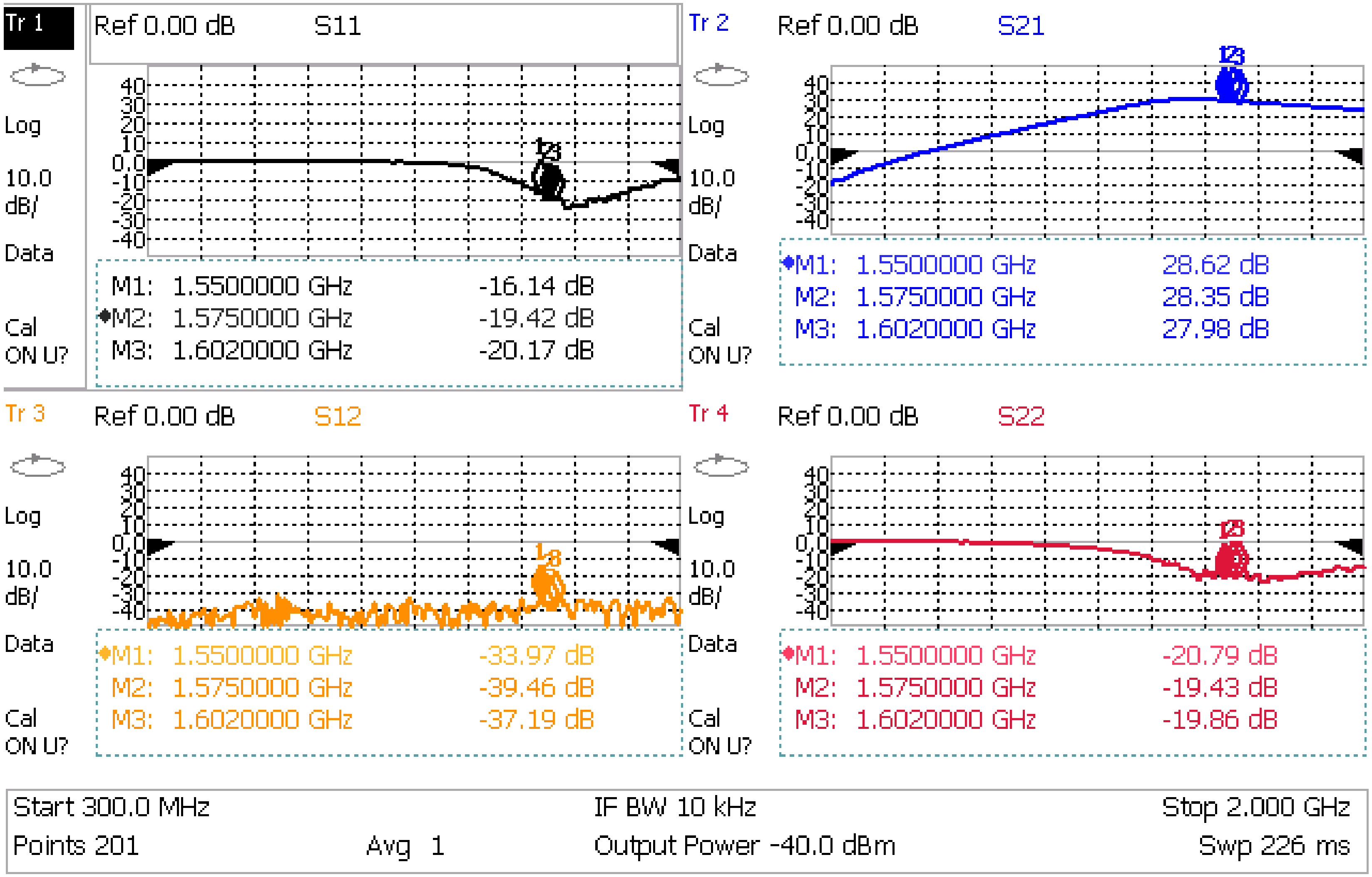
Typical Small-Signal S-Parameters at Vdd=Ven=2.8V



Notes:
-L1=L2=9.1nH, C1=C2=1uF, Vdd=Ven=2.8V, Idq~13mA
-Measured S21 includes EVB trace and SMA connector losses (~0.2dB)

BHWL160 Cascade for High-Band: S-Parameters

Typical Small-Signal S-Parameters at Vdd=Ven=1.8V

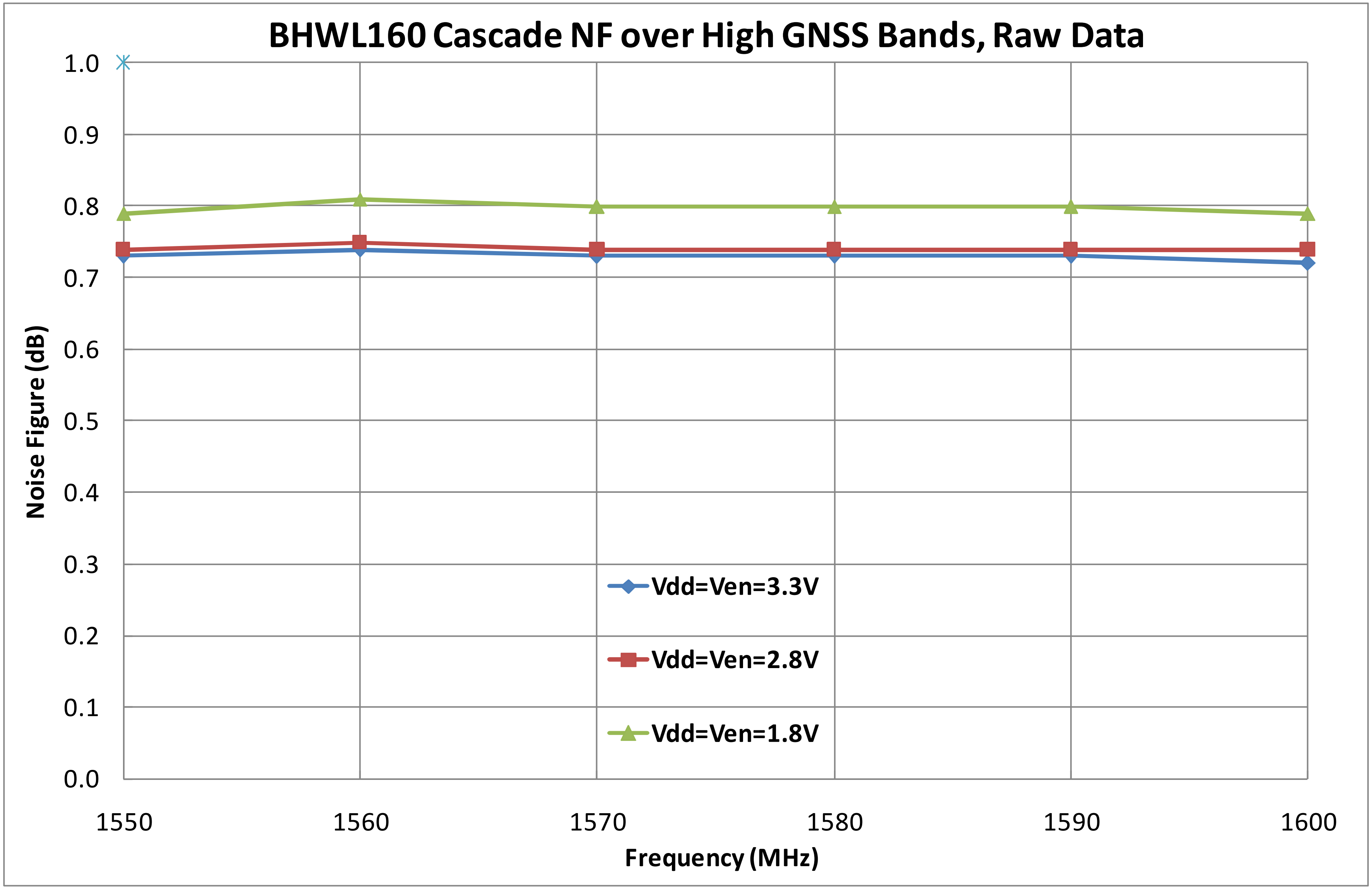


Notes:

-L1=L2=9.1nH, C1=C2=1uF, Vdd=Ven=1.8V, Idq~7mA

-Measured S21 includes EVB trace and SMA connector losses (~0.2dB)

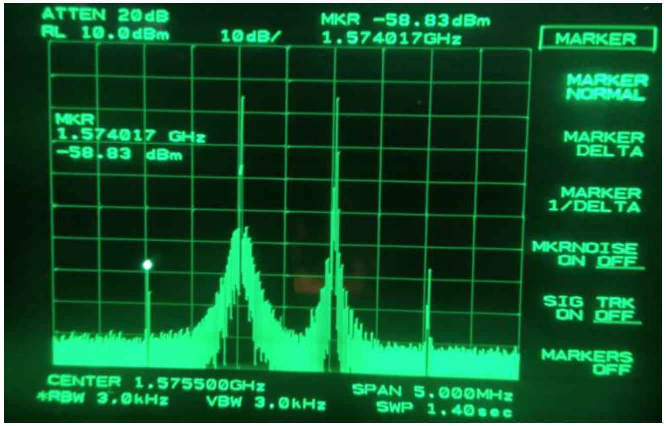
BHWL160 Cascade for High-Band: Noise Figure

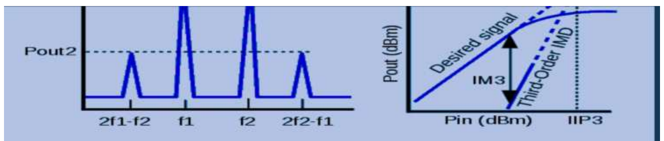


- **Measured data included EVB feedline and SMA connector losses. Actual system NF should be ~0.05dB lower**
- **Tested at Ambient Temperature Ta~26^{o}C. Expected Slightly Lower NF at Standard Ta=16.85^{o}C (290K) for NF Measurement.**

BHWL160 Cascade for High-Band: IIP3 Benchmark

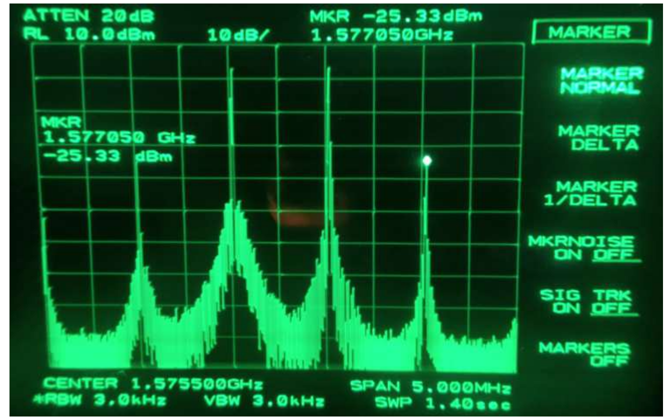
BHWL160 Cascade IIP3

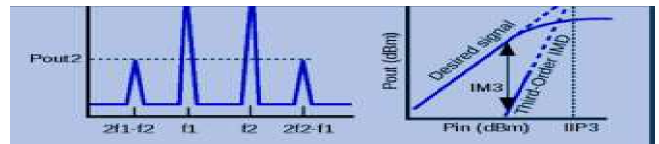




Pout1	-5	dBm
Pout2	-58.83	dBm
Gain	30.9	dB
NF	.7	dB
Bandwidth	10	kHz
Temperature	20	°C
IIP3	-8.98	dBm
OIP3	21.92	dBm
IM3	53.83	dBc
Min. discer. Input Signal	-133.24	dBm
Max. spur free Input Signal	-50.4	dBm
Spur free dynamic range	82.84	dB

MAX2659 Cascade IIP3



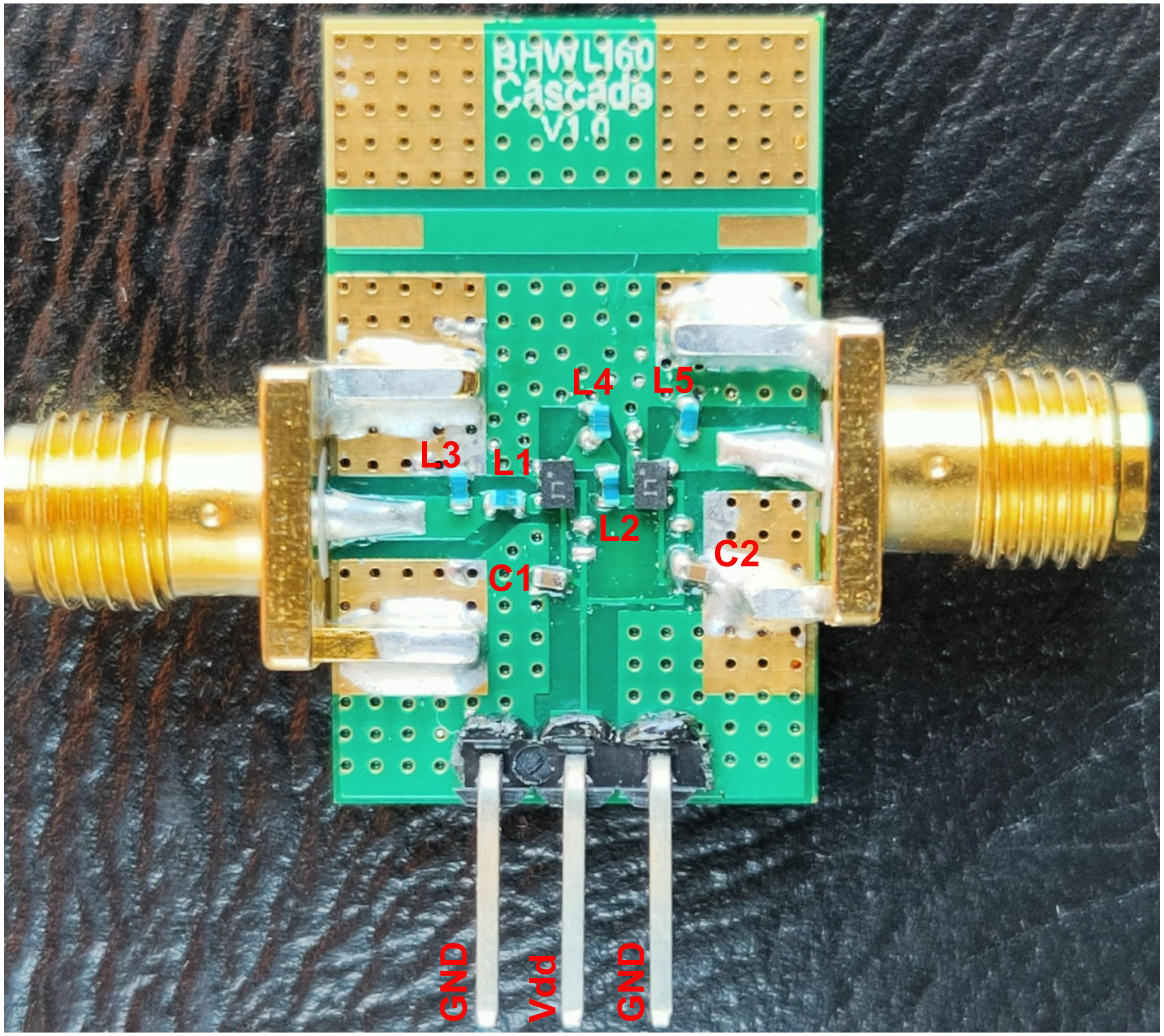


Pout1	3.33	dBm
Pout2	-25.33	dBm
Gain	38.9	dB
NF	.8	dB
Bandwidth	10	kHz
Temperature	20	°C
IIP3	-21.24	dBm
OIP3	17.66	dBm
IM3	28.66	dBc
Min. discer. Input Signal	-133.14	dBm
Max. spur free Input Signal	-58.54	dBm
Spur free dynamic range	74.6	dB

Notes:

- All LNAs were biased at Vdd=Ven=3.3V
- Two-Tone test conditions: f1=-35dBm at 1575MHz, f2=-35dBm at 1576MHz
- Side-bands near f1 and f2 are due to non-ideal source signal and unrelated to IMD of the LNA itself
- BHWL160 cascade (31dB gain) has a robust IIP3 of -9dBm, around 12dB higher than the same cascade of two MAX2659 LNAs
- BHWL160 cascade has Spur Free Dynamic Range of 82.8dB, around 8dB higher than the same cascade of two MAX2659 LNAs

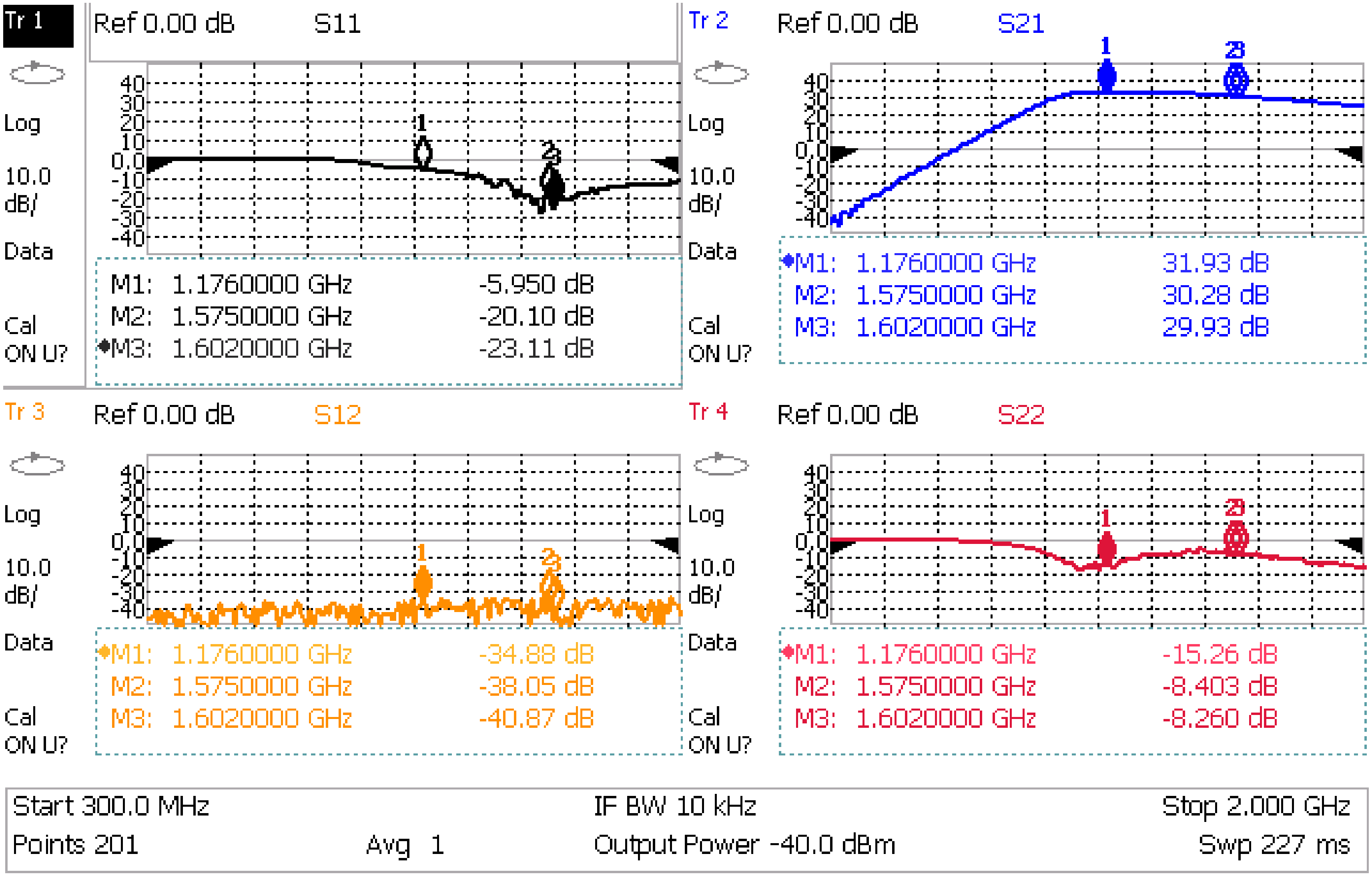
BHWL160 Cascade EVB for Full-Band GNSS



Nominal BOM for Full-Band GNSS (1165-1610MHz):

- L1=L2=7.5nH, L3=10nH, L4=3.9nH, L5=10nH (Murata LQW15A Recommended), C1=C2=1uF
- Inductor values may need minor adjustment to achieve optimal performance on customer's specific PCB
- Optional resistors can be added to control line to reduce current for specific applications. See BHWL160 AppNote for details.
- Nominal bias: Vdd=Ven=3.3V, Idq~15mA total for the two LNAs.

BHWL160 Cascade for Full-Band GNSS : S-Parameters



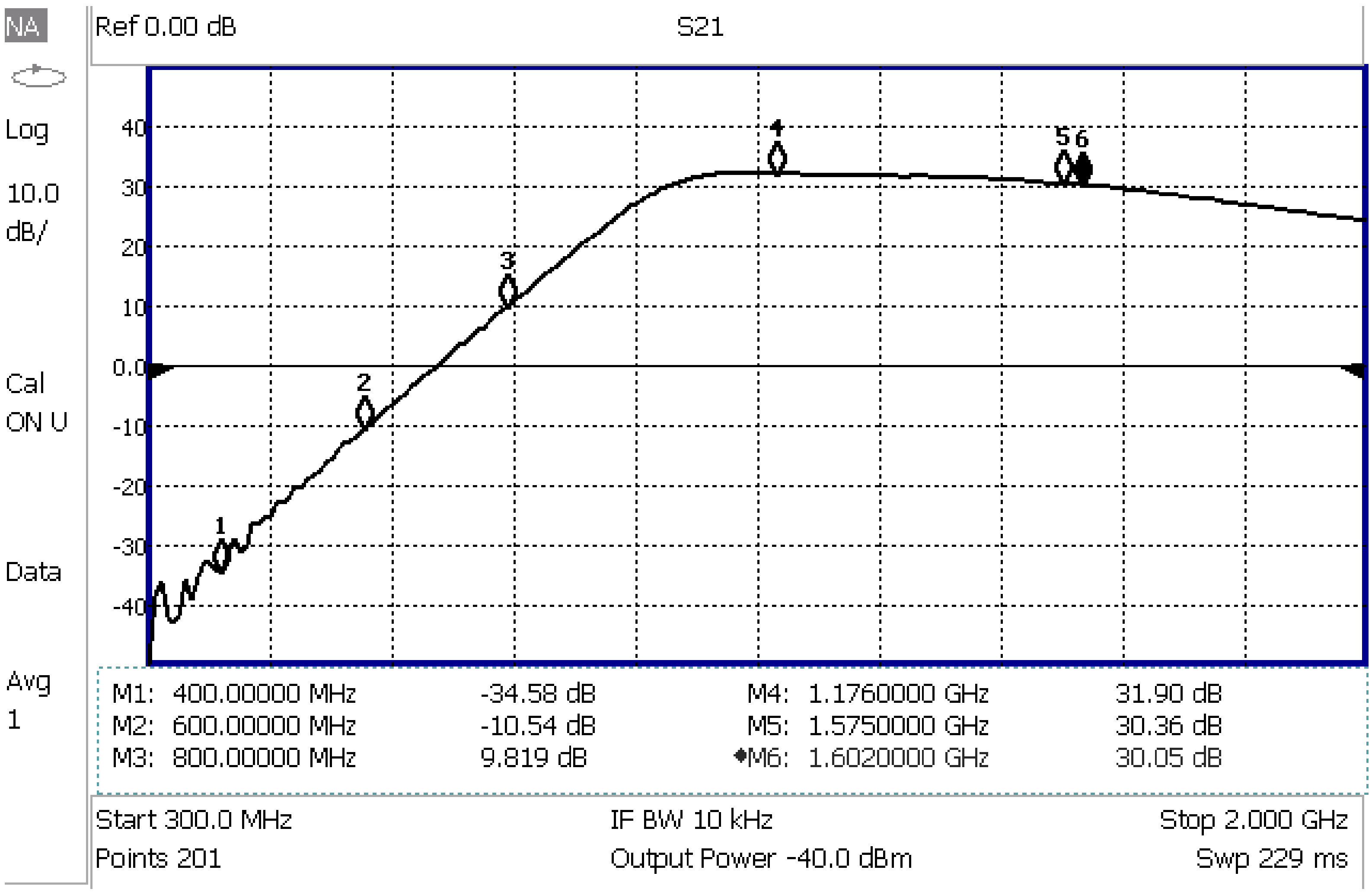
Notes:

-DC Bias: Vdd=Ven=3.3V, Idq~15mA total

-Measured S21 includes EVB trace and SMA connector losses (~0.2dB)

BHWL160 Cascade for Full-Band GNSS : S-Parameters

Broadband S21 with Enhanced Rejection of UHF-Band RF Interference



Notes:
-DC Bias: Vdd=Ven=3.3V, Idq~15mA total
-Measured S21 includes EVB trace and SMA connector losses (~0.2dB)

BHWL160 Cascade: Full-Band BOM & Test Data

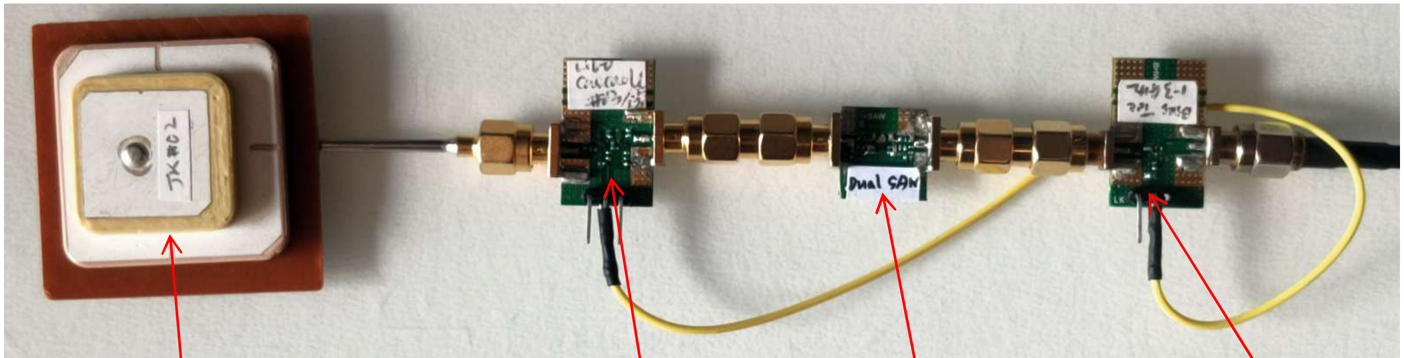
Measured Noise Figure of BHWL160 Cascade over Full GNSS Bands

(Raw Data including SMA and Feedline Losses, Vdd=3.3V, Idq~15mA Total)

- **Measured data included EVB feedline and SMA connector losses. Actual system NF should be ~0.05dB lower**
- **Tested at Ambient Temperature Ta~26°C. Expected Slightly Lower NF at Standard Ta=16.85°C (290K) for NF Measurement.**

Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

Without Double-Notch Pre-Filter



SMA Cable
To Receiver
（HD8040D）

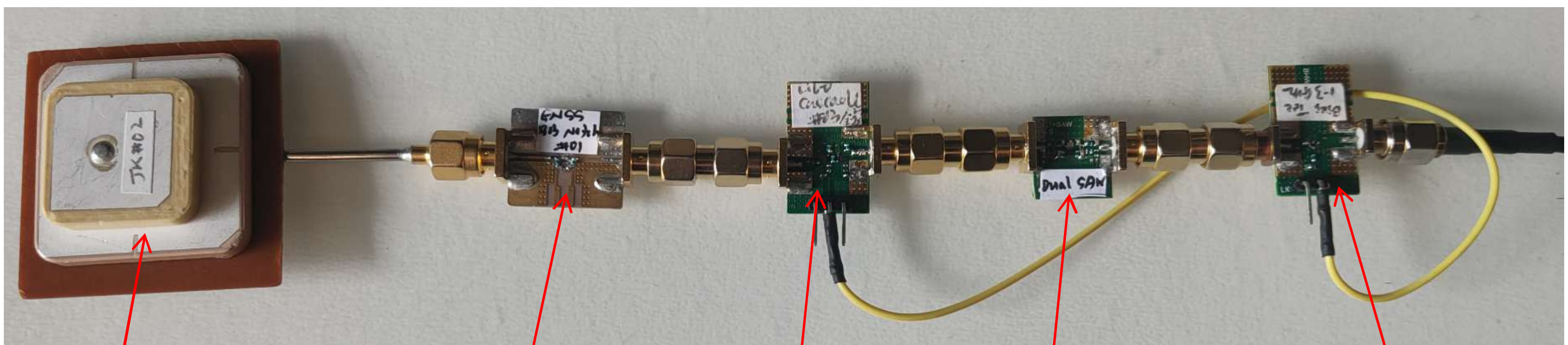
Dual-Band Antenna
Jiakang Electronics
DADA1176R-1568R3540E-2540AZDZ3-T

BHWL160
Cascade

Dual-SAW with
Power Splitter/Combiner

Bias-T for DC Feed
Vdd Range: 1.8~3.6V
(3.13V for this test)

With Double-Notch Pre-Filter



SMA Cable
To Receiver
（HD8040D）

Dual-Band Antenna
Jiakang Electronics
DADA1176R-1568R3540E-2540AZDZ3-T

Double-Notch
Pre-Filter

BHWL160
Cascade

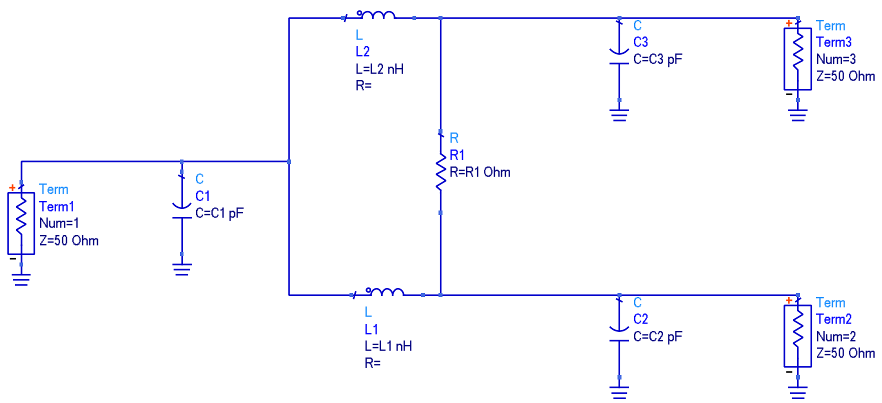
Dual-SAW with
Power Splitter/Combiner

Bias-T for DC Feed
Vdd Range: 1.8~3.6V
(3.13V for this test)

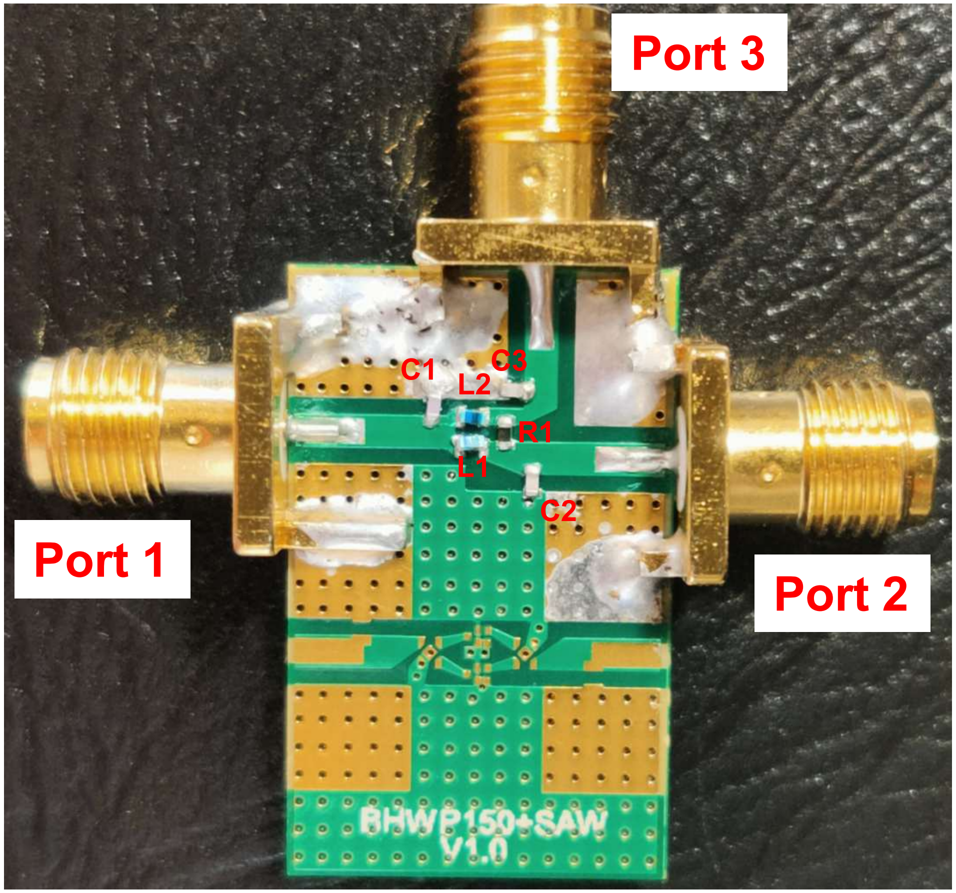
Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

GNSS Full-Band Power Splitter & Combiner

Circuit Schematic



Evaluation Board

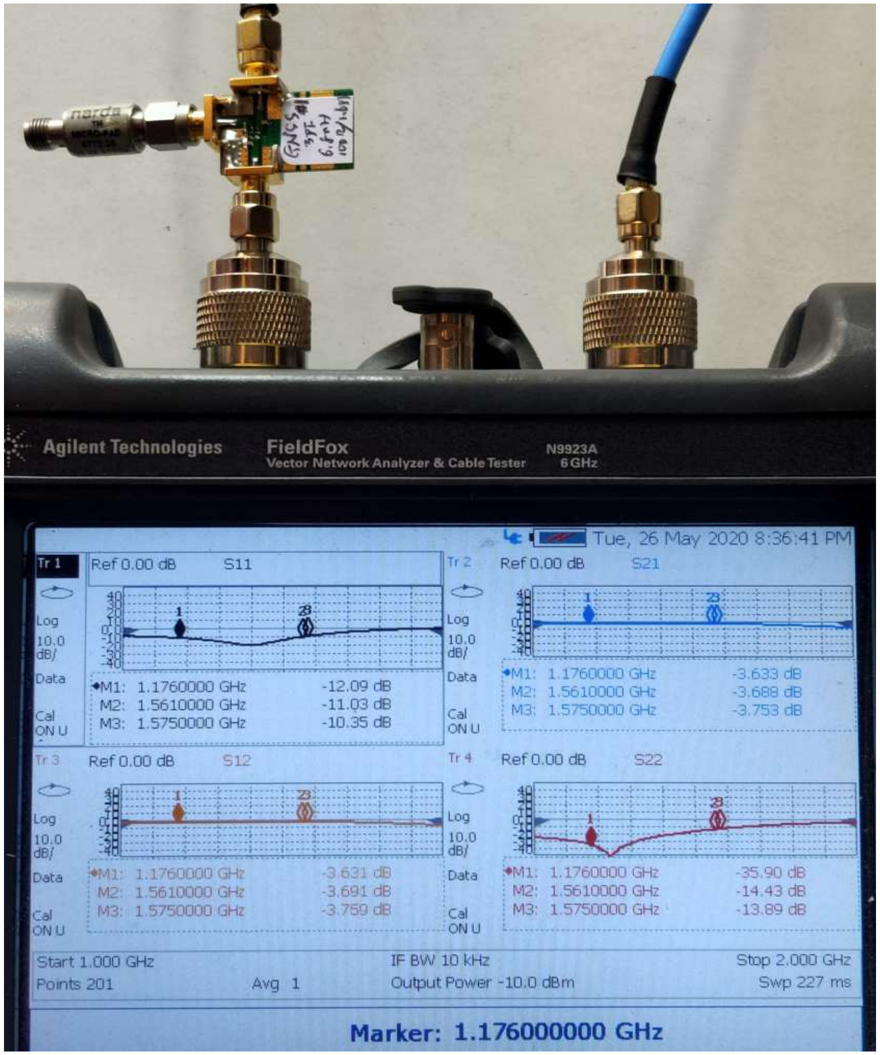


Recommended BOM:
C1=3F, C2=C3=1.6pF, R1=100 Ohm, L1=L2=6.8nH (Murata LQW15A Series Recommended)

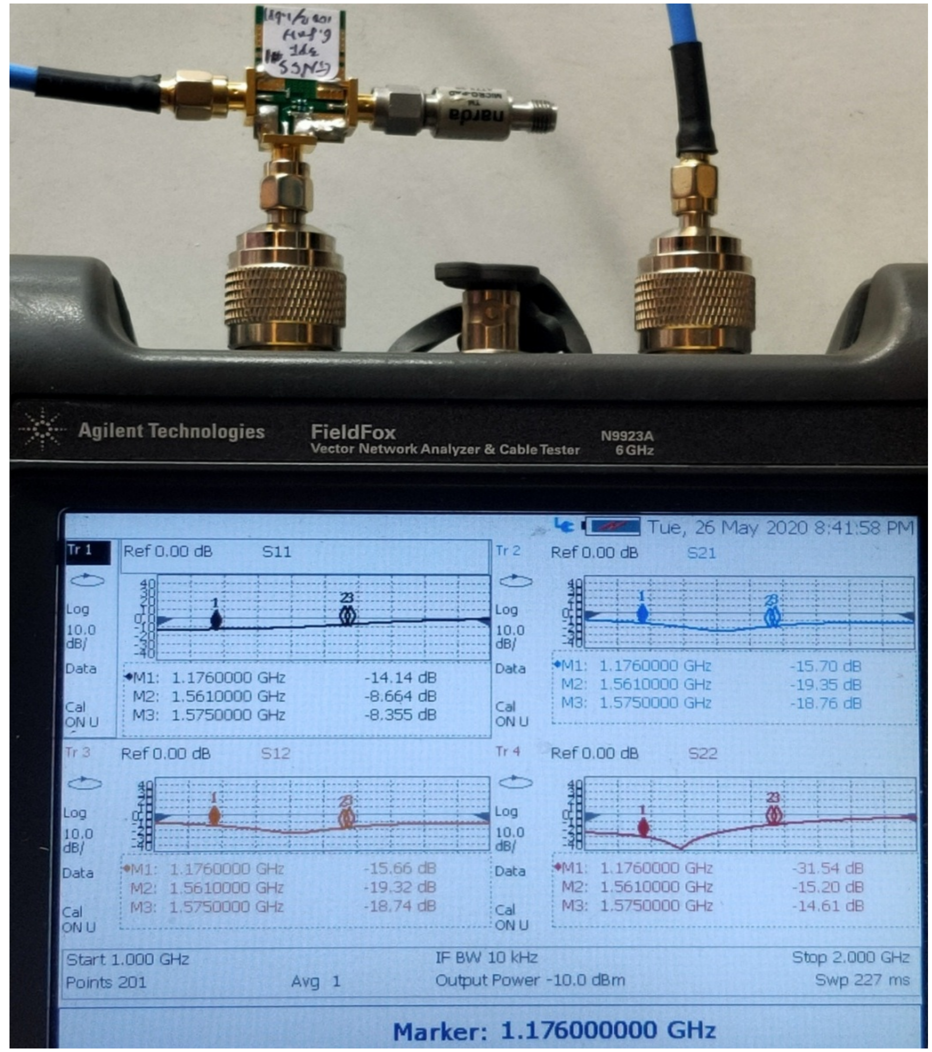
Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

GNSS Power Divider/Combiner EVB Test Data

Insertion Loss (Port 1 to Port 2)
S21=-3.6/-3.7/-3.8dB at L5/B1/L1

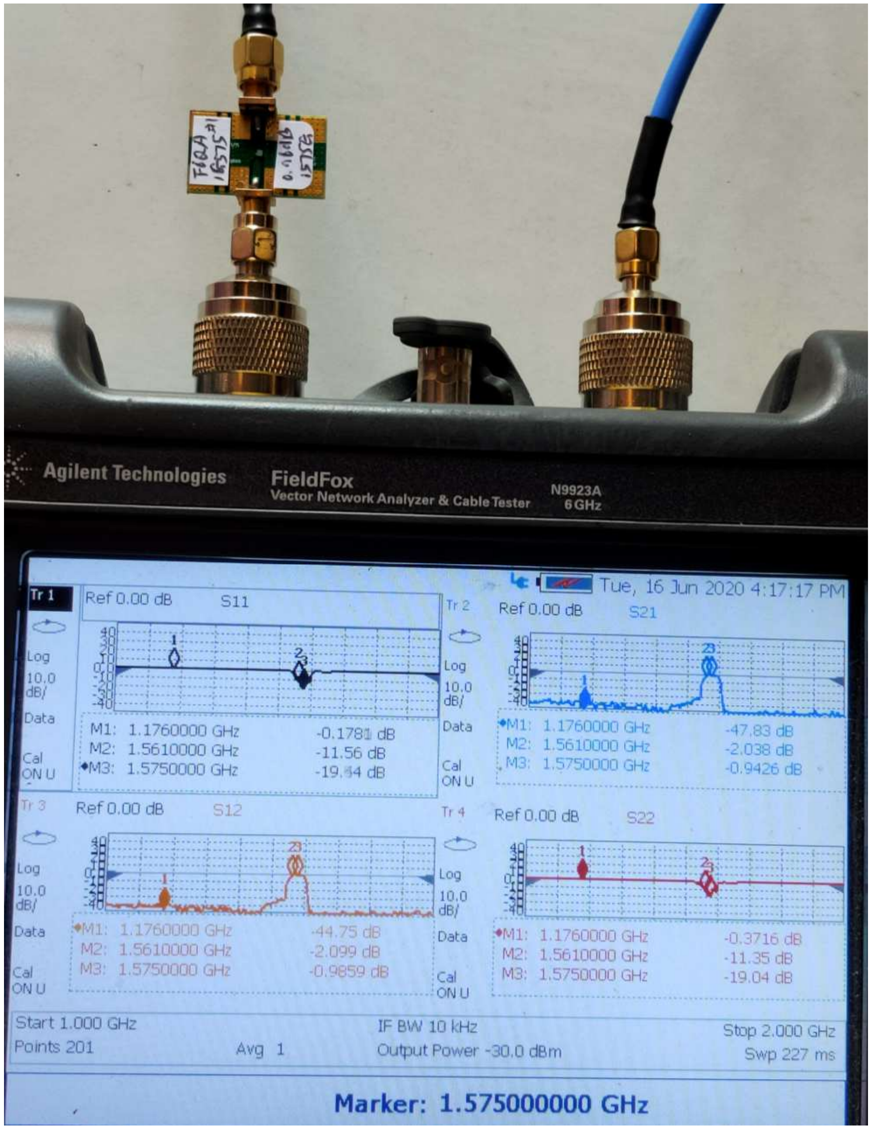


Isolation between Port 2 & 3
S32=-15.7/-19.4/-18.8dB at L5/B1/L1

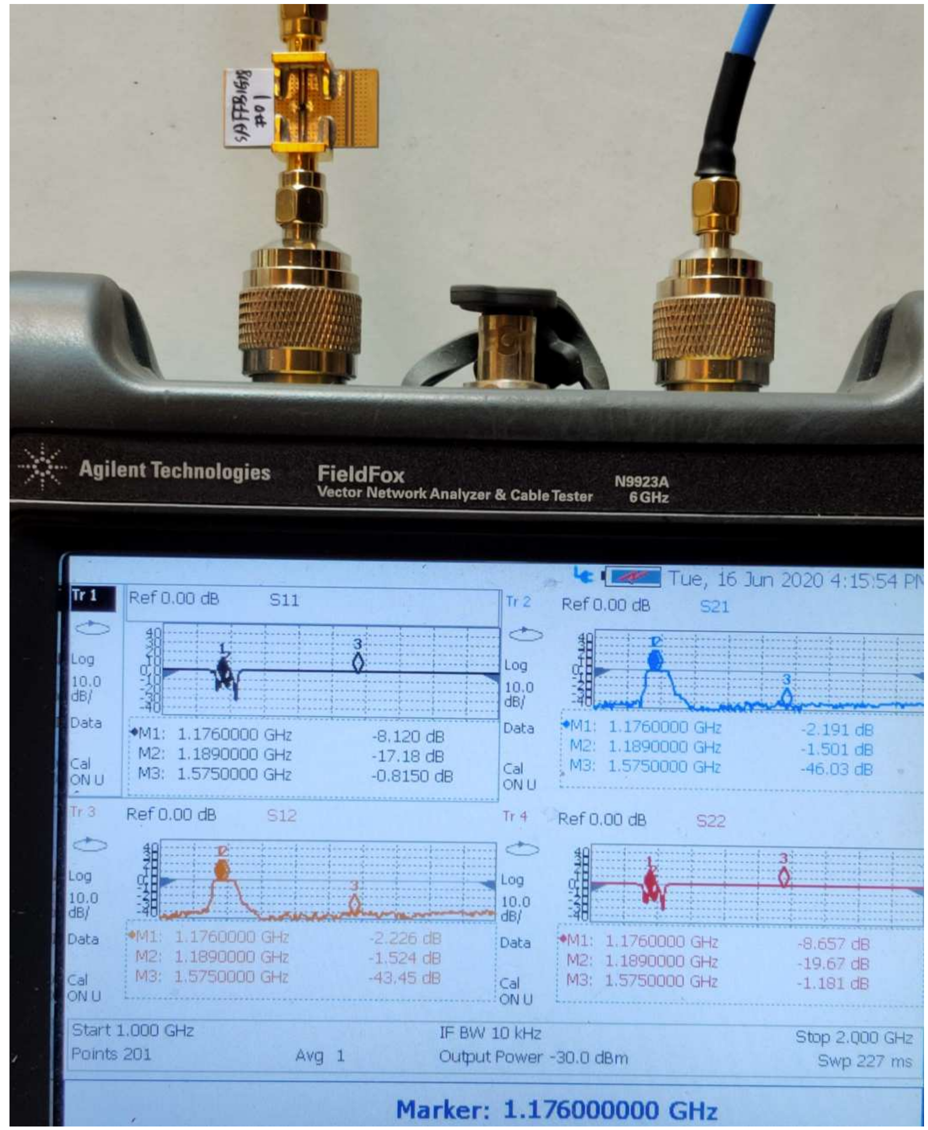


Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

Example SAW Filter for L1/B1/E1
(Taiyo Yuden F6QA1G575H2JF-J)



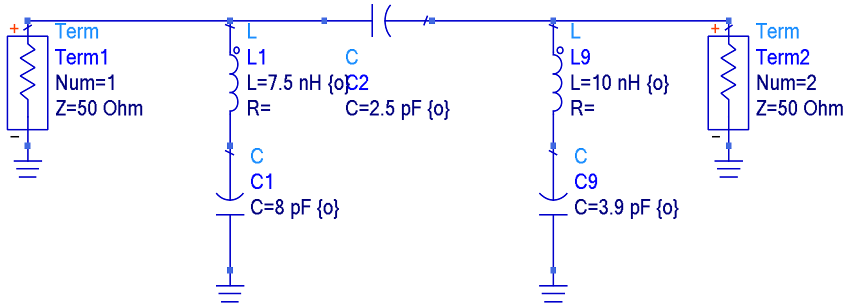
Example SAW Filter for L5/B2/E5
(Murata SAFFB1G18AA0F0A)



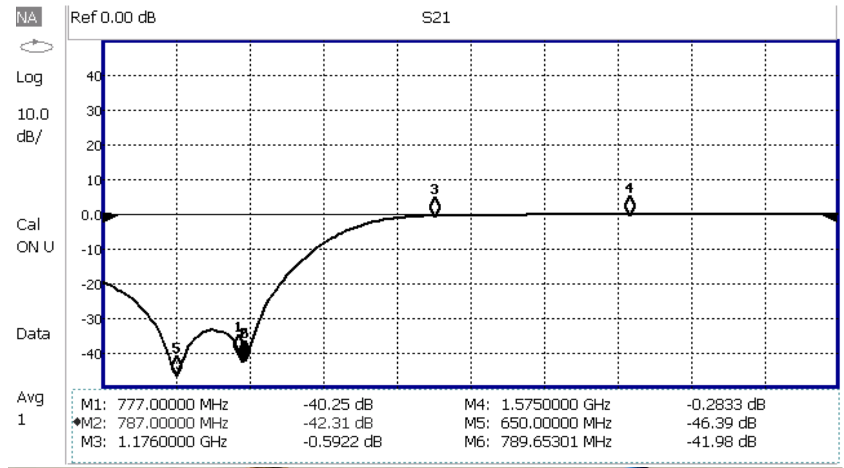
Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

Double-Notch Pre-Filter for Anti-Jamming Enhancement

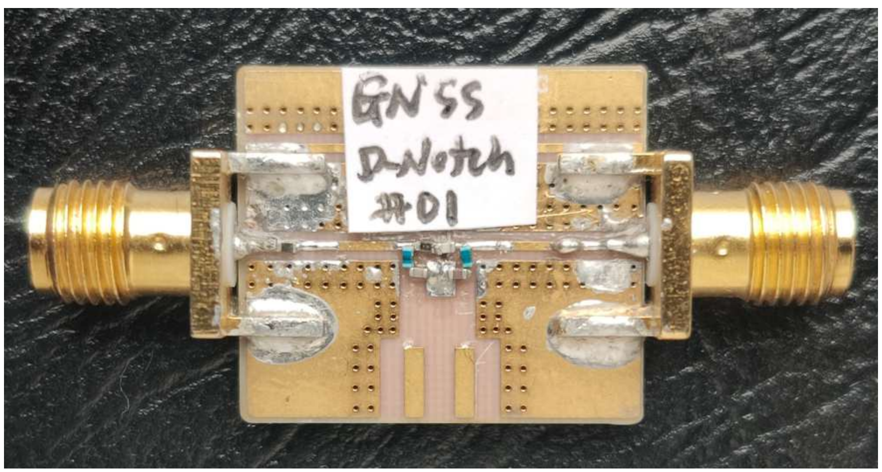
Schematic

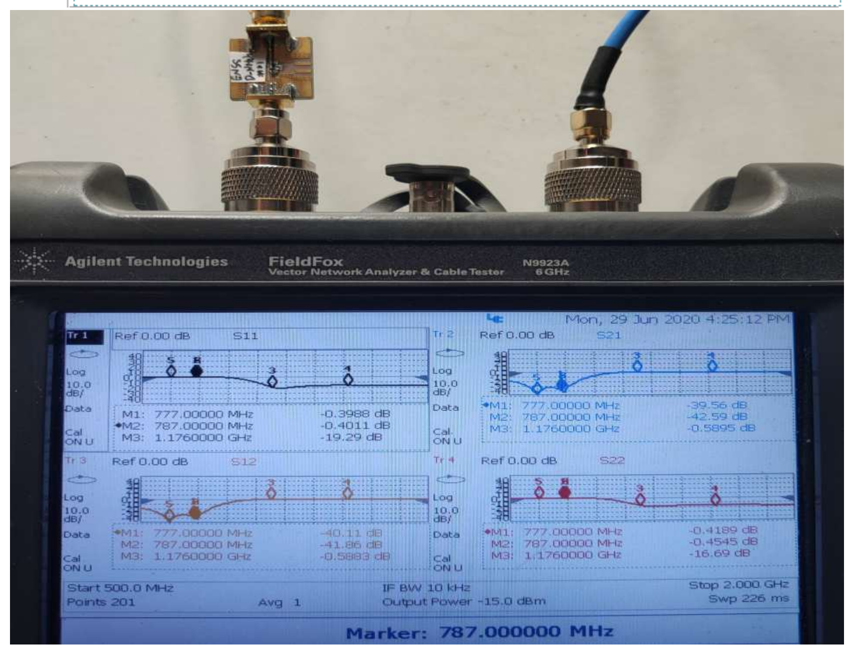


Measured S-Parameters



EVB

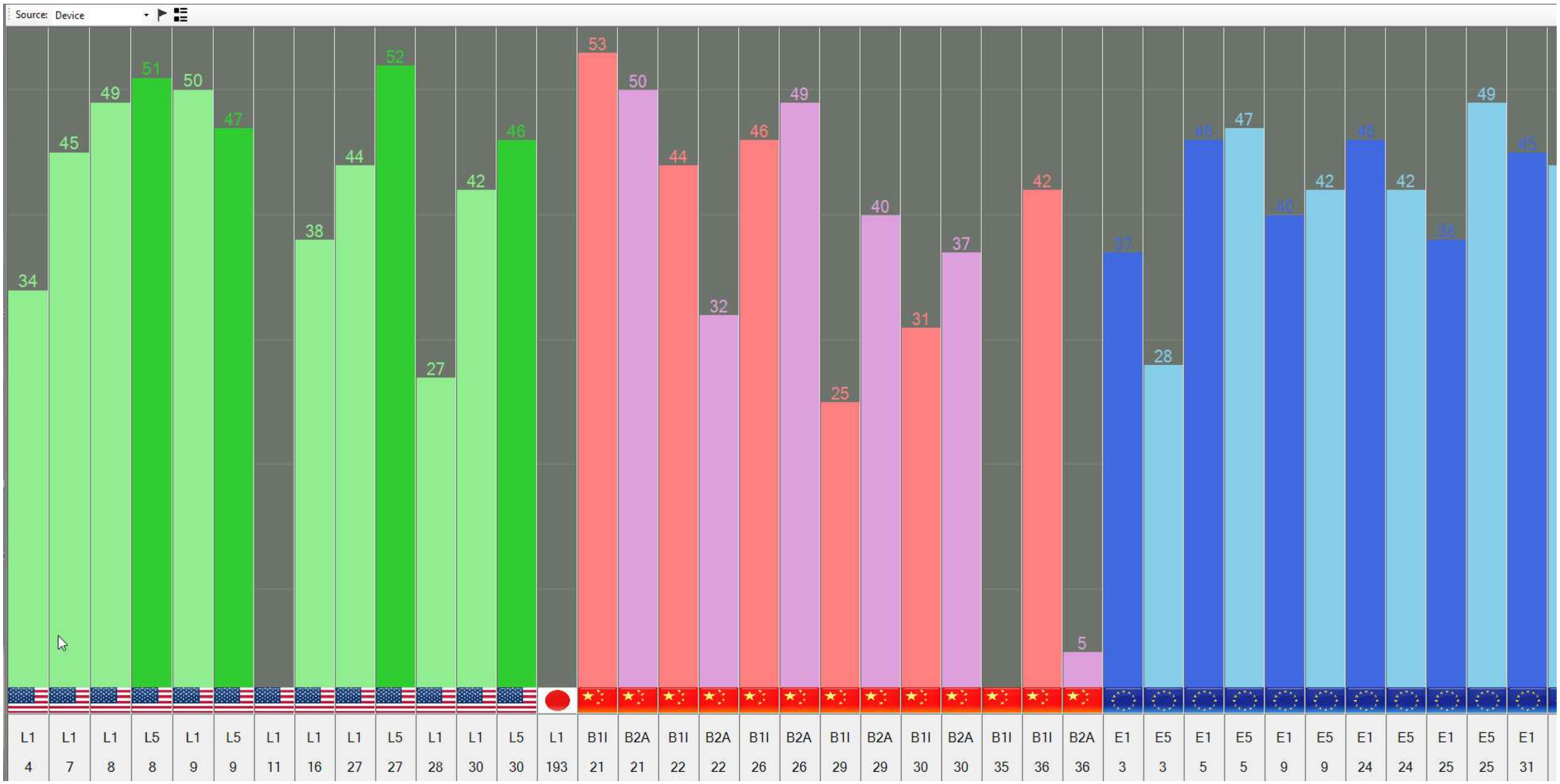




L1=7.5nH, L2=10nH (Murata LQW15A Series)
C1=8pF, C2=2.5pF, C3=3.9pF

Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

Measured C/N0: Without Double-Notch Pre-Filter

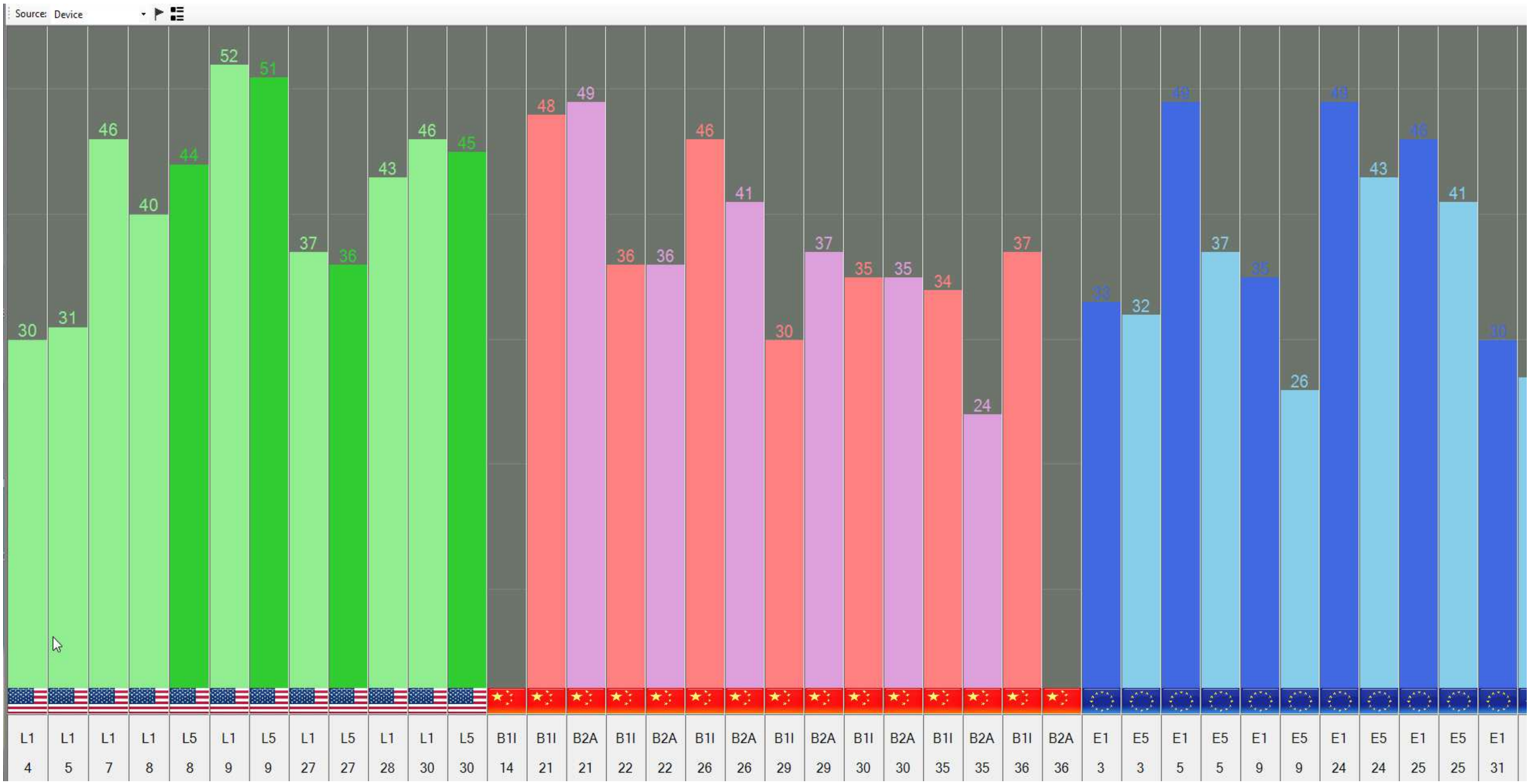


Comments:

- Maximum C/N0 of 50~53dB was measured in L1, B1, L5, B2 bands.
- C/N0 test results depends on several factors including sky clearance and satellite positions.
- This preliminary breadboard test verified the feasibility of the proposed dual-band LNB architecture, with best system NF and sufficient system IIP3 for most applications.

Post-LNA Solution #1: Dual-SAW + Splitter/Combiner

Measured C/N0: With Double-Notch Pre-Filter

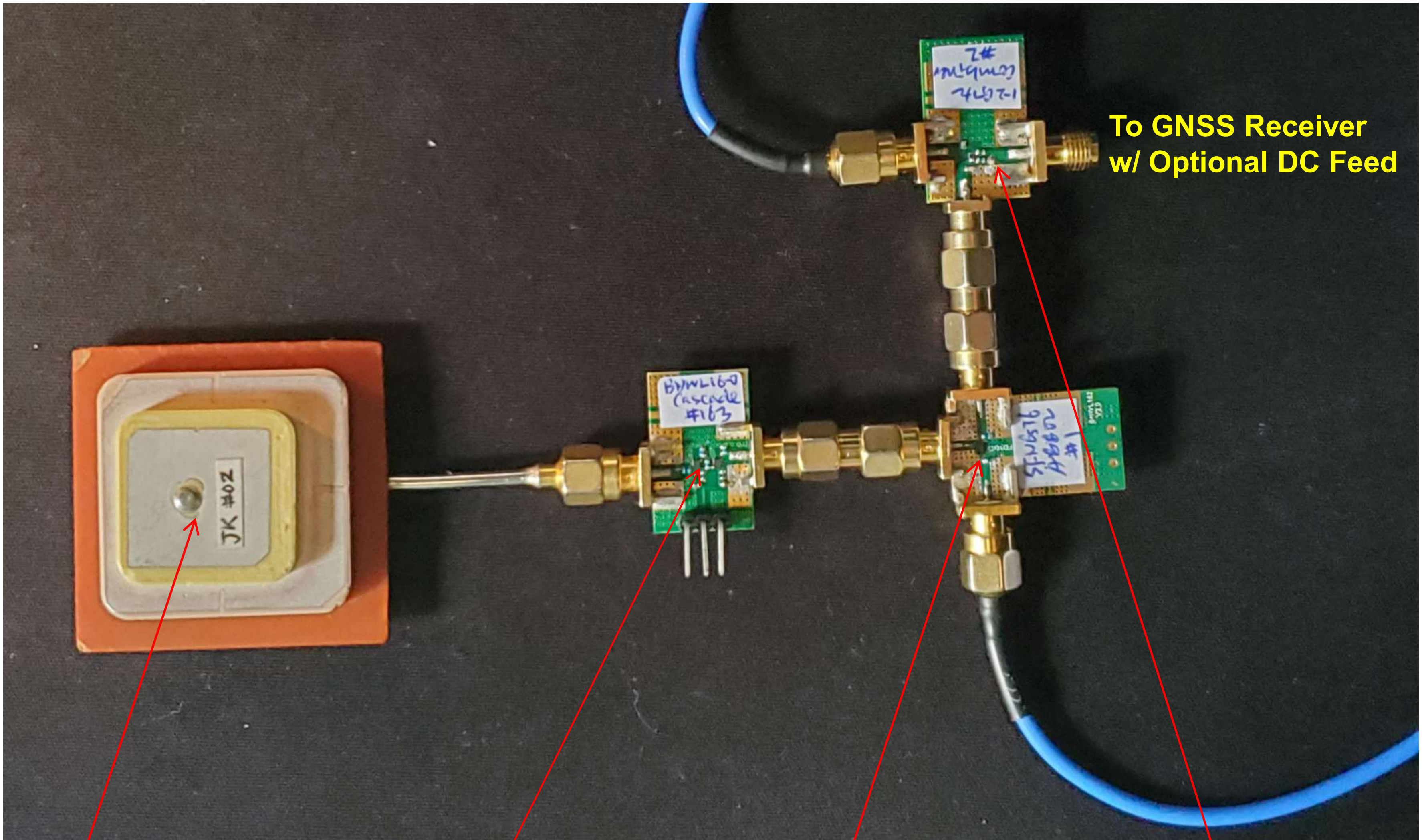


Comments:

- ➢ Maximum C/N0 of 49~52dB was measured in L1, B1, L5, B2 bands.
- ➢C/N0 test results depends on several factors including sky clearance and satellite positions.
- ➢ With ~0.3dB insertion loss only, the addition of the double-notch pre-filter causes very minor degradation in C/N0, while improving anti-jamming capability of the GNSS system significantly.

Post-LNA Solution #2: SAW Diplexer + Power Combiner

Applicable for Single or Dual-Port GNSS Receiver SoC



Dual-Band Antenna
Jiakang Electronics
DADA1176R-1568R3540E-2540AZDZ3-T

BHWL160
Cascade

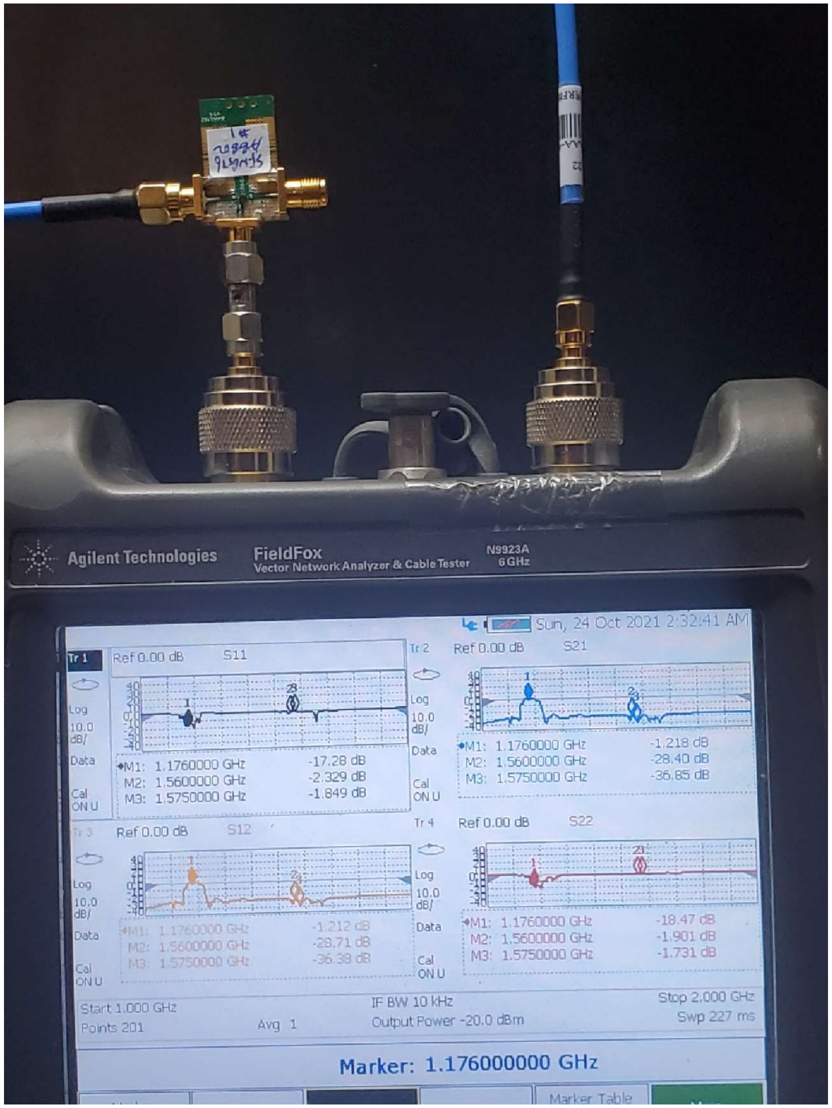
SAW Diplexer
(WiSOL SFWG76ABB02)

Power Combiner
(Optional)

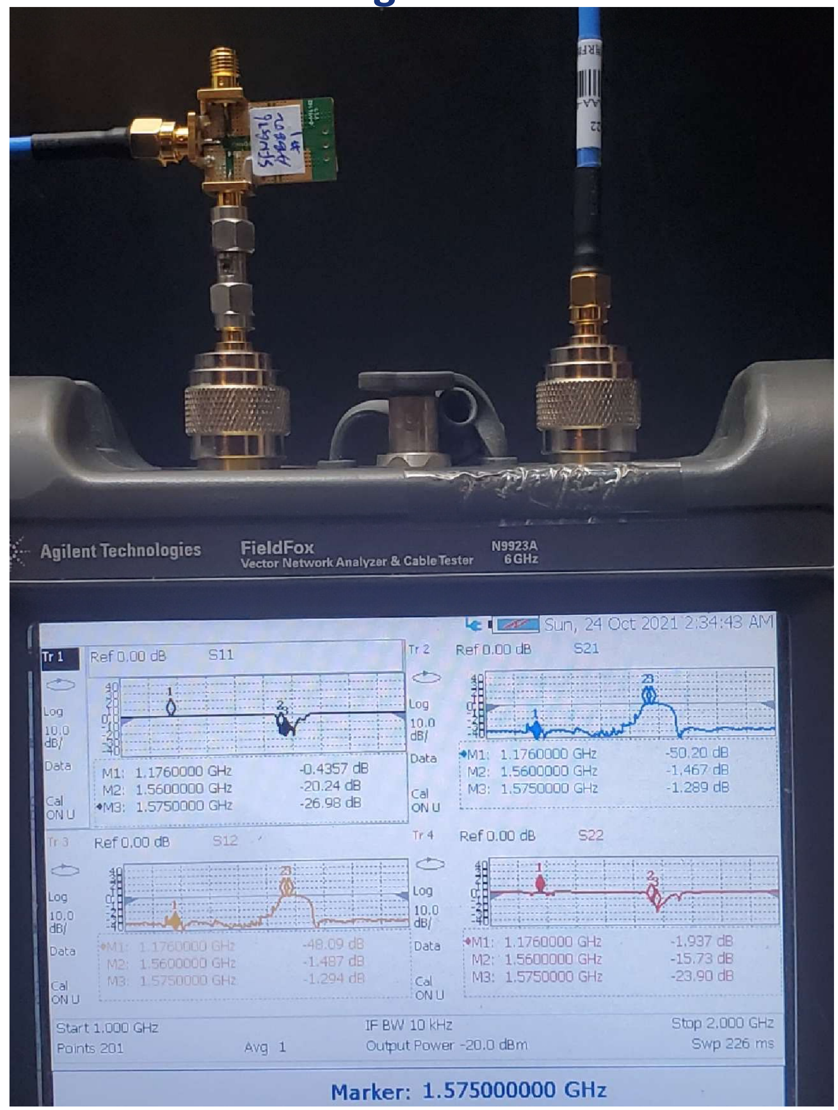
Post-LNA Solution #2: SAW Diplexer + Power Combiner

Example SAW Diplexer for L1/B1/L5/B2: WiSOL SFWG76ABB02

Low-Band



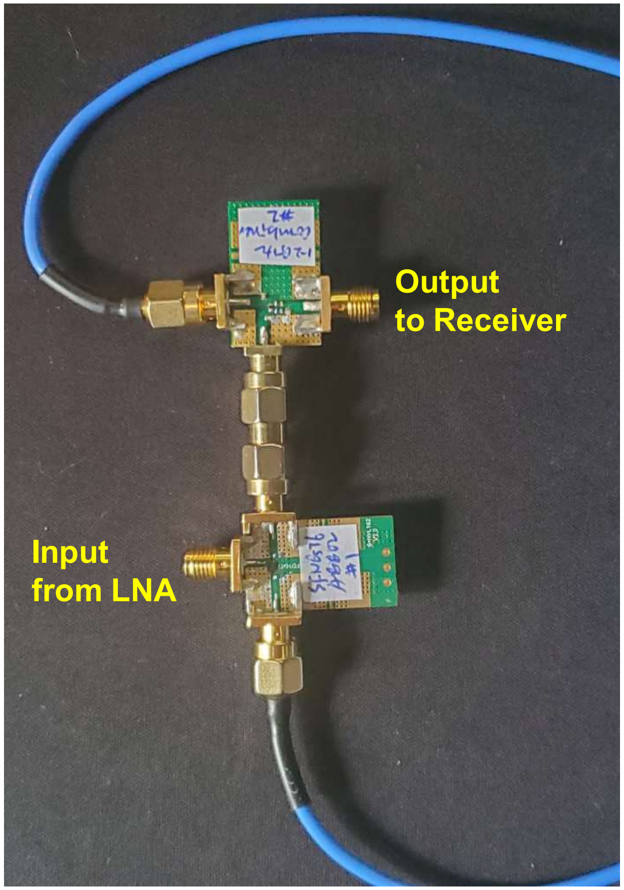
High-Band



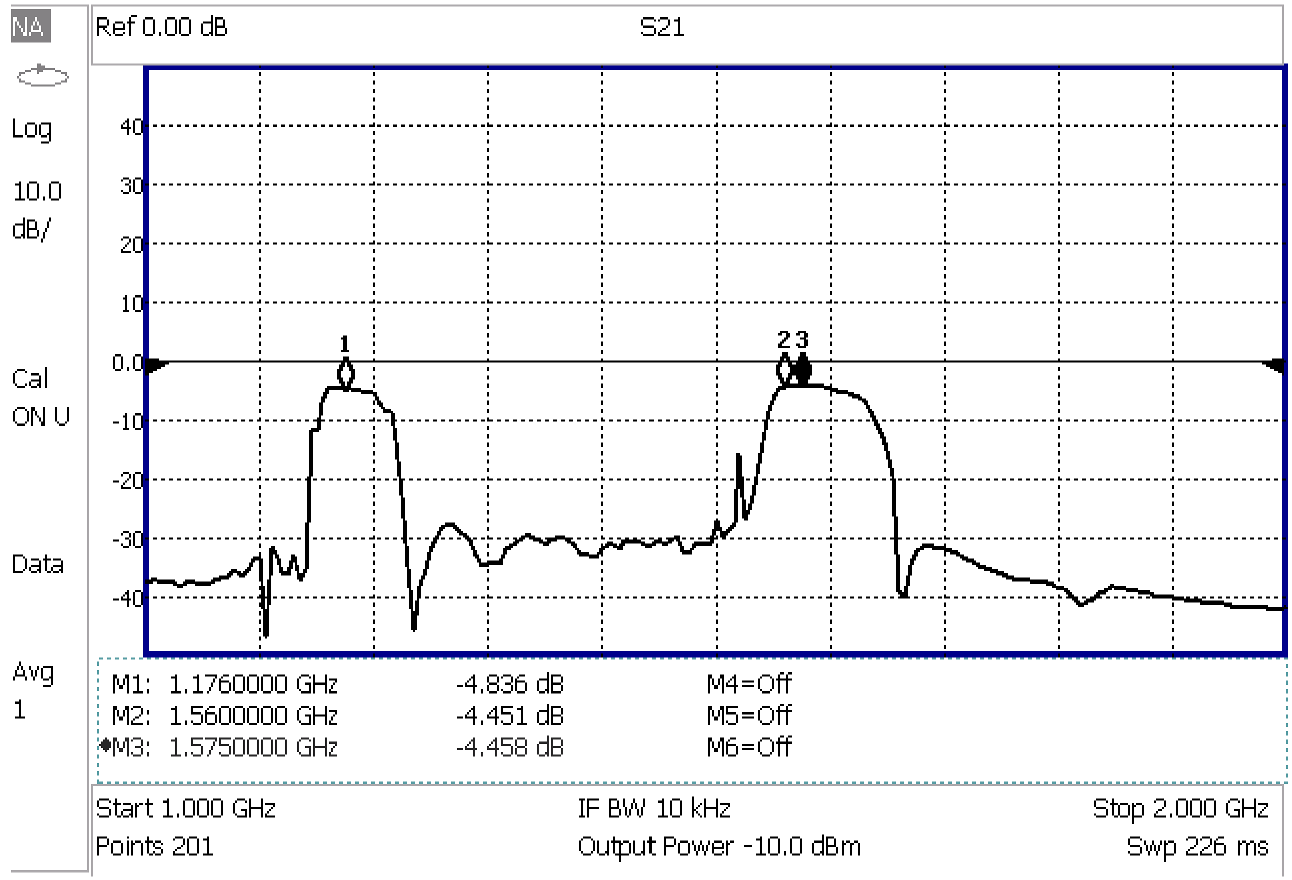
Post-LNA Solution #2: SAW Diplexer + Power Combiner

L1/L5 SAW-Diplexer Followed by Discrete Power Combiner

Breadboard for Proof-of-Concept



Measured S21 of the L1/L5 Double-Hump Filter



Notes:

-SAW diplexer used for this test is WiSOL SFWG76ABB02 and can be substituted with p2p solutions from other vendors.

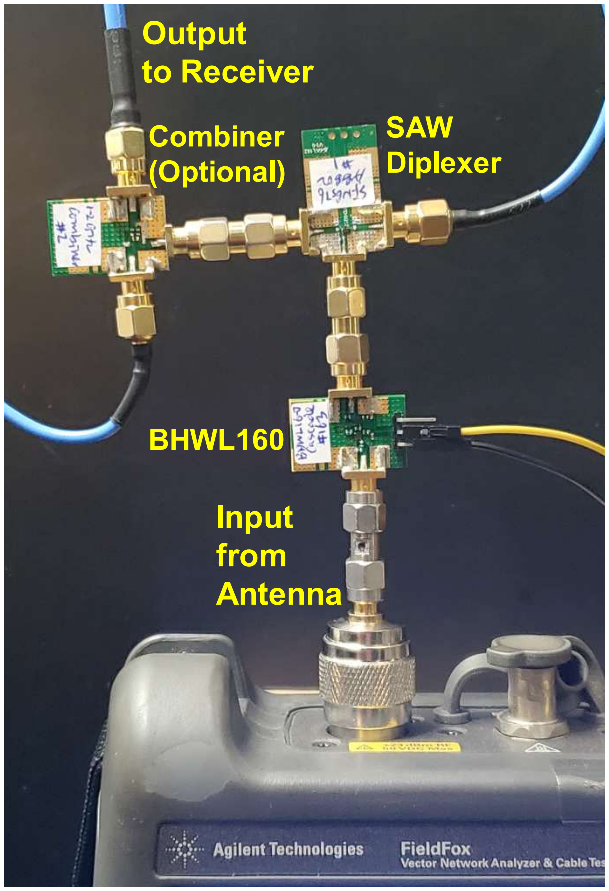
-See Pages 19~20 for details of the discrete power combiner.

-Insertion loss and rejection levels should be slightly better with optimized PCB design.

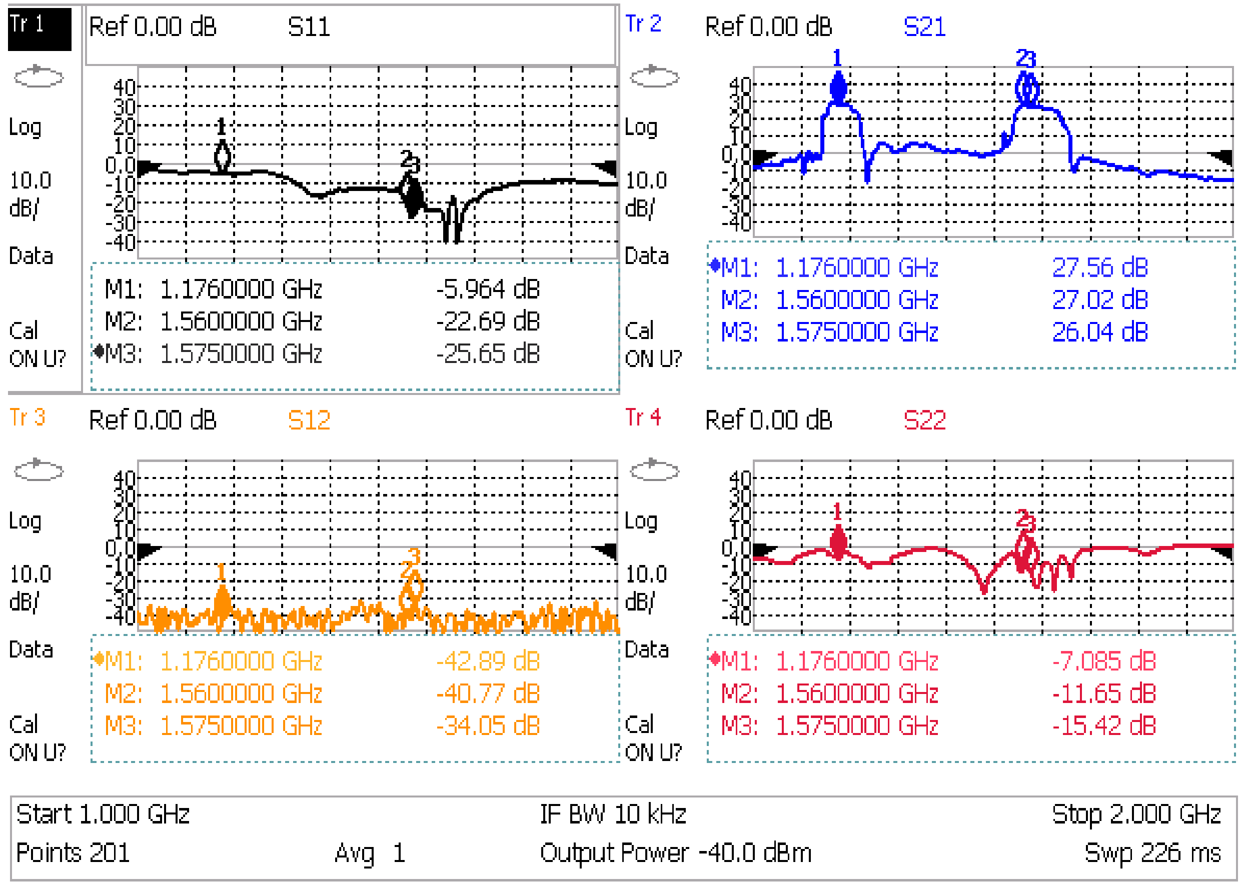
Post-LNA Solution #2: SAW Diplexer + Power Combiner

BHWL160 Cascade + Post-LNA Chain Performance Evaluation

Breadboard for Proof-of-Concept



Measured S-Para of the End-to-End Dual-Band GNSS Rx Front-End



Notes:

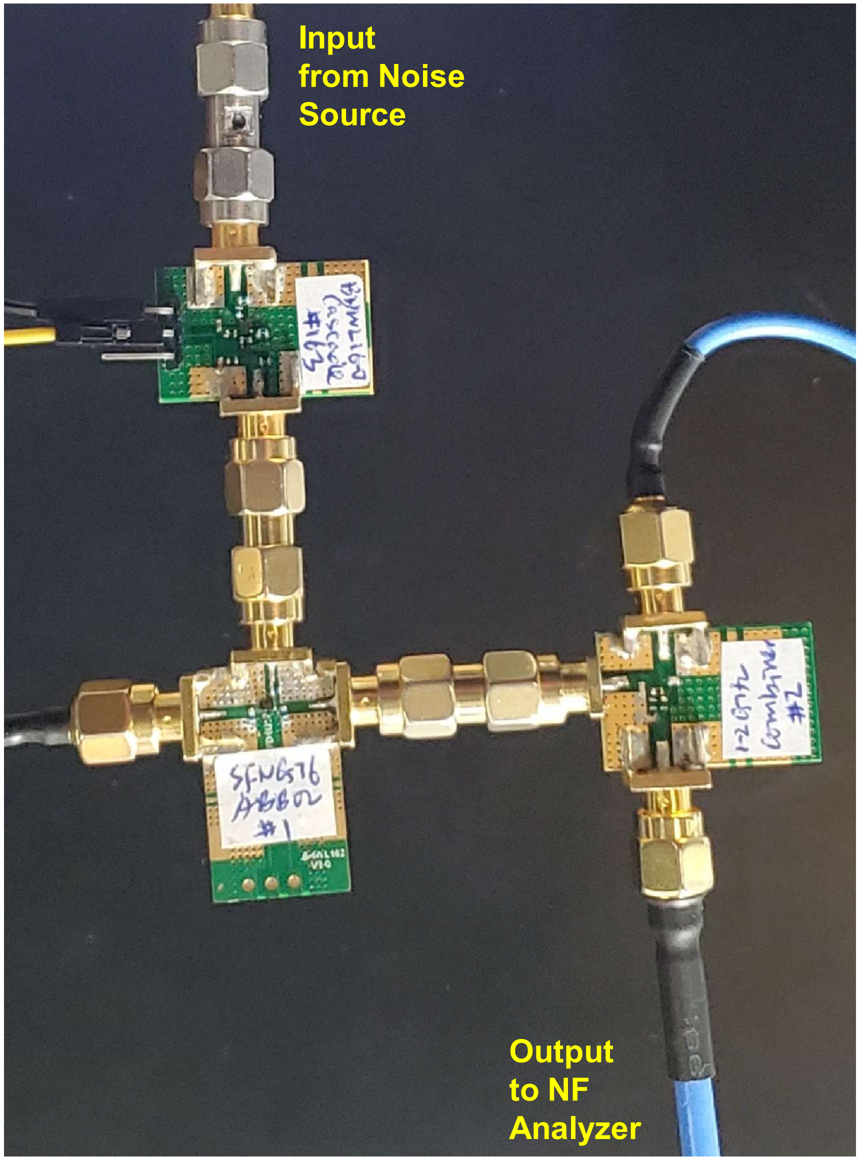
-BHWL160 Cascade EVB with broadband BOM (Page 14) is used for this test.

-SAW diplexer used for this test is WiSOL SFWG76ABB02 and can be substituted with p2p solutions from other vendors.

-Gain, Rejection and Impedance Matching should be slightly better with optimized PCB design.

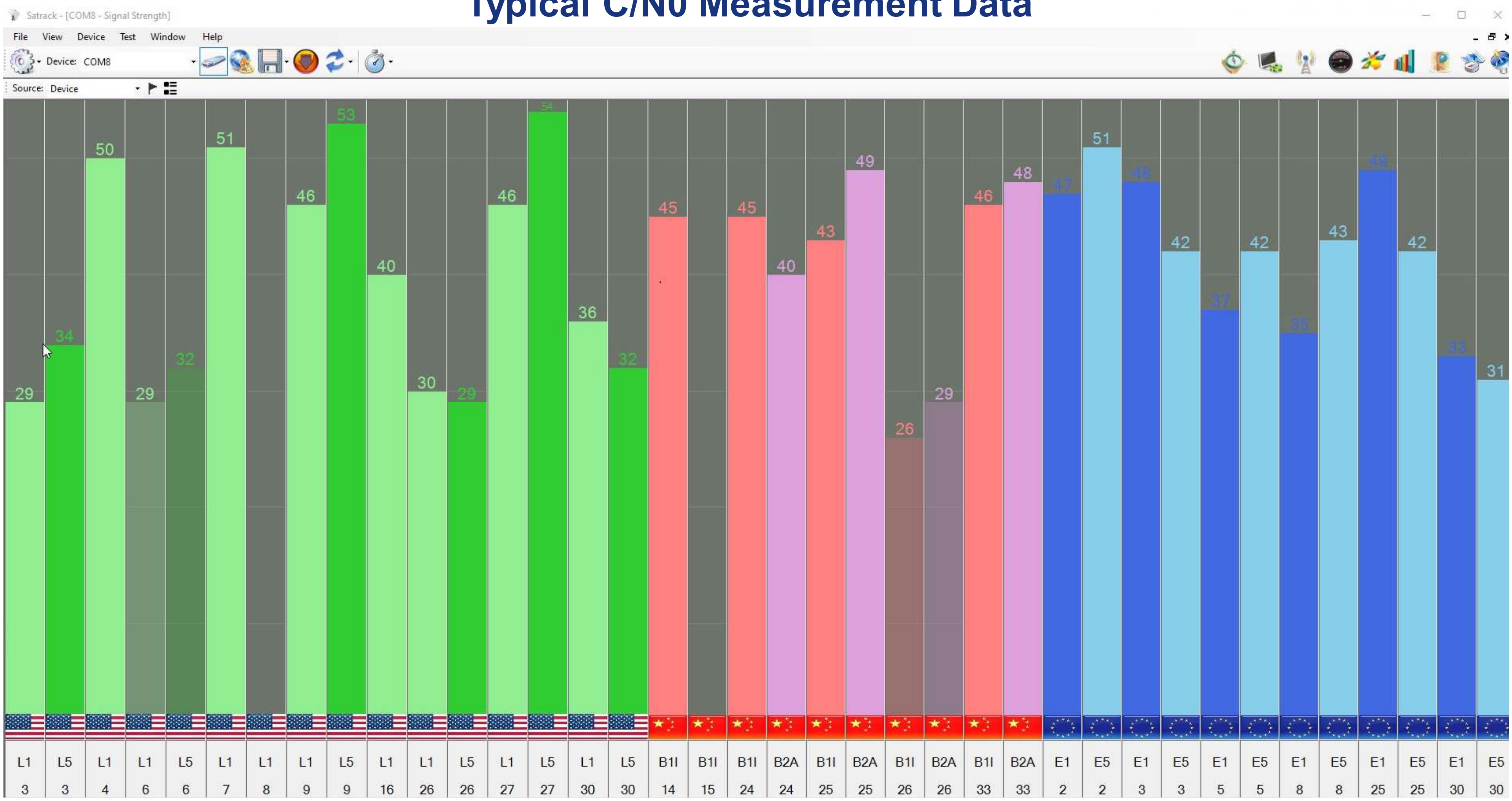
Post-LNA Solution #2: SAW Diplexer + Power Combiner

Measured Noise Figure of the End-to-End Dual-Band GNSS Rx Front-End



Post-LNA Solution #2: SAW Diplexer + Power Combiner

Typical C/N0 Measurement Data

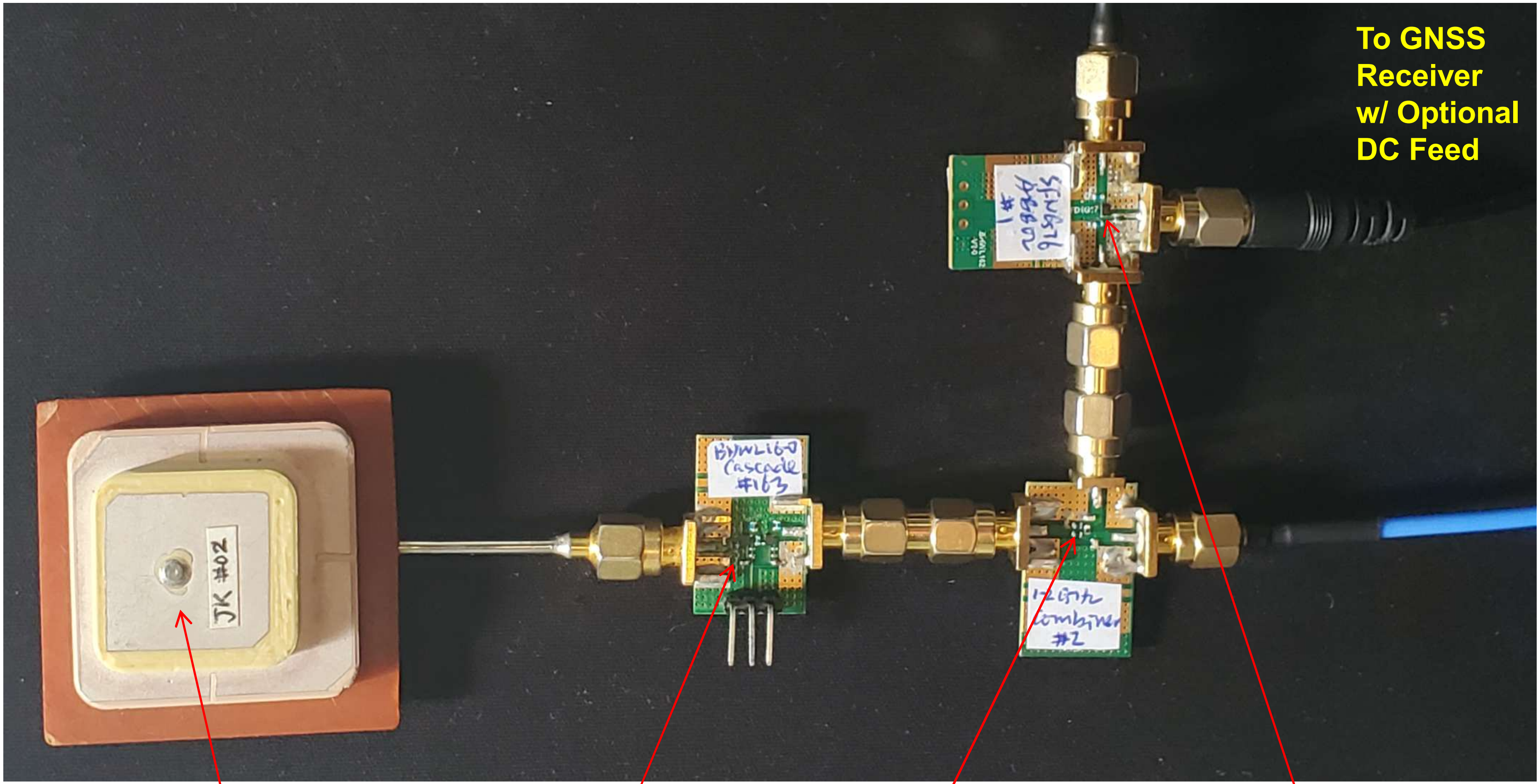


Comments:

- Maximum C/N0 of 49~54dB was measured in L1, B1, L5, B2, E1, E5 bands.
- C/N0 test results depends on several factors including sky clearance and satellite positions.
- This preliminary breadboard test verified the feasibility of the proposed dual-band LNB architecture, with best system NF and sufficient system IIP3 for most applications.

Post-LNA Solution #3: Power Splitter + SAW Diplexer

Applicable for Single-Port GNSS Receiver SoC



Dual-Band Antenna
Jiakang Electronics
DADA1176R-1568R3540E-2540AZDZ3-T

BHWL160 Cascade

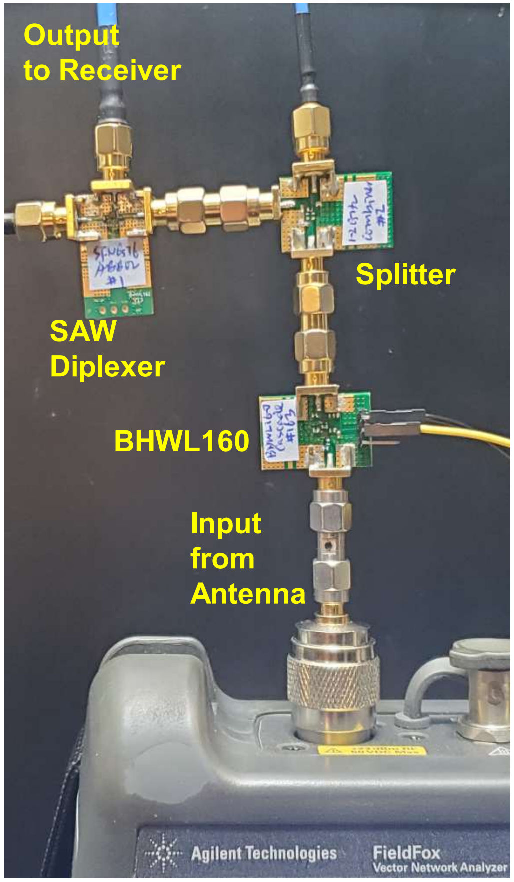
Power Combiner

SAW Diplexer
(WiSOL SFWG76ABB02)

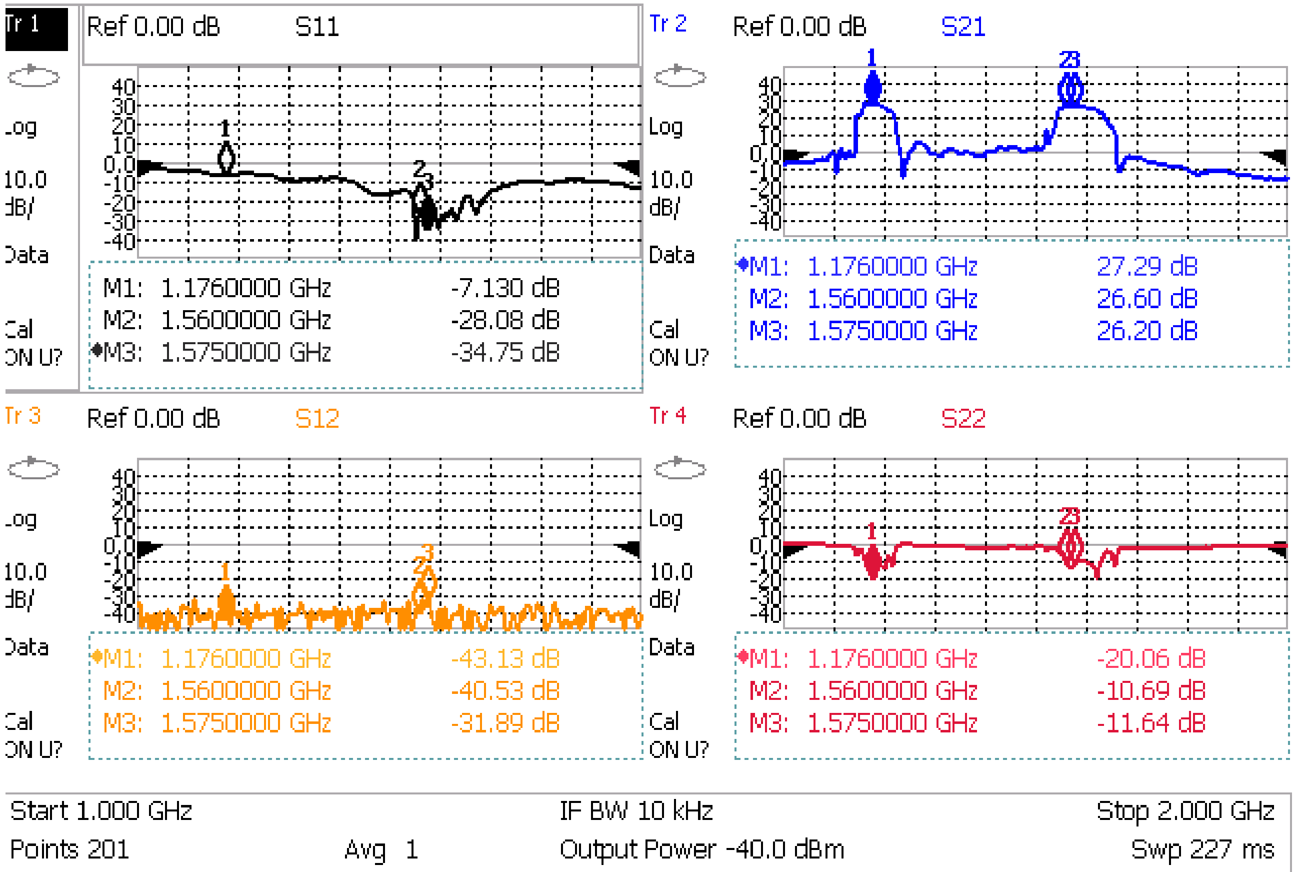
Post-LNA Solution #3: Power Splitter + SAW Diplexer

BHWL160 Cascade + Post-LNA Chain Performance Evaluation

Breadboard for Proof-of-Concept



Measured S-Para of the End-to-End Dual-Band GNSS Rx Front-End



Notes:

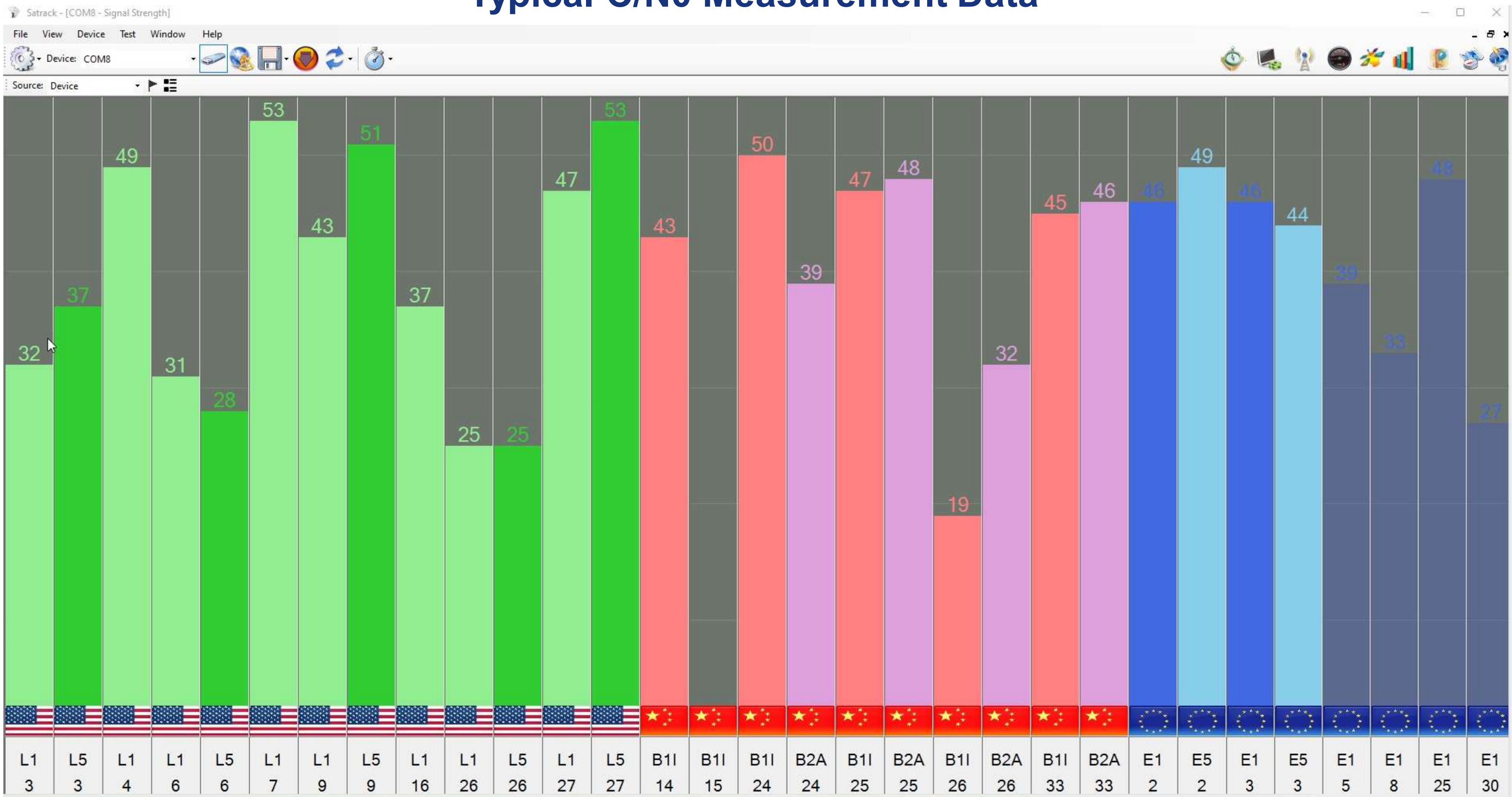
-BHWL160 Cascade EVB with broadband BOM (Page 14) is used for this test.

-SAW diplexer used for this test is WiSOL SFWG76ABB02 and can be substituted with p2p solutions from other vendors.

-Gain, Rejection and Impedance Matching should be slightly better with optimized PCB design.

Post-LNA Solution #3: Power Splitter + SAW Diplexer

Typical C/N0 Measurement Data

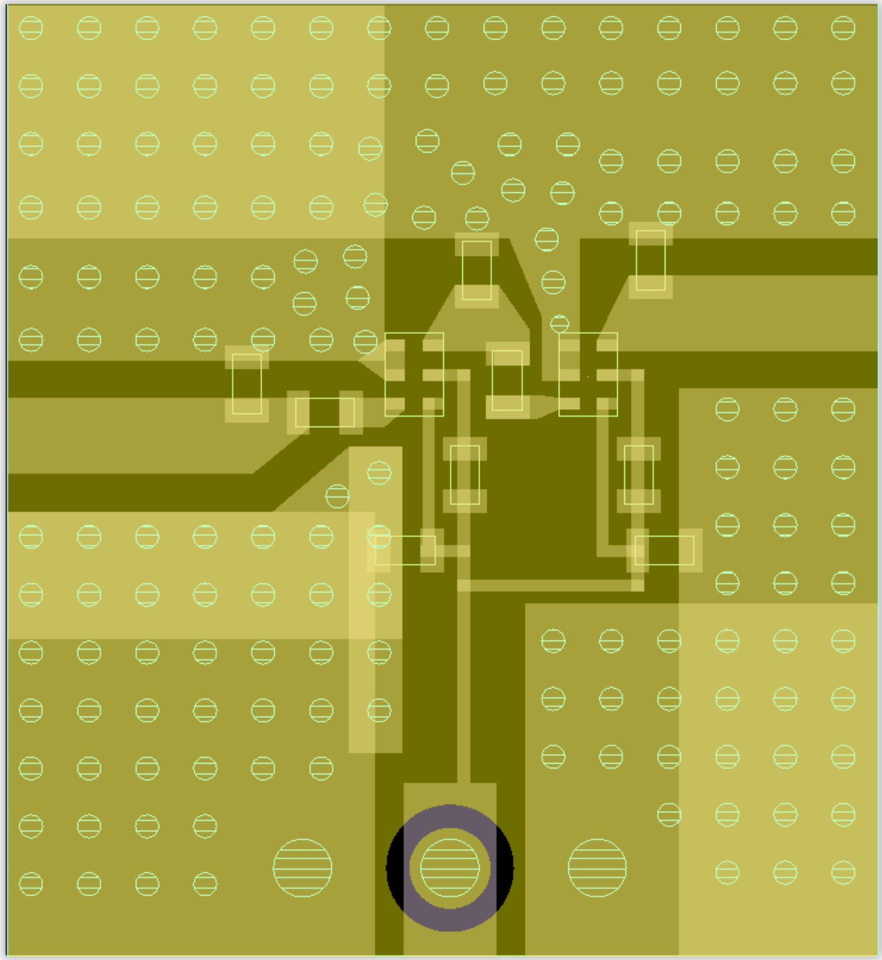


Comments:

- ➢ Maximum C/N0 of 48~53dB was measured in L1, B1, L5, B2, E1, E5 bands.
- ➢C/N0 test results depends on several factors including sky clearance and satellite positions.
- ➢This preliminary breadboard test verified the feasibility of the proposed dual-band LNB architecture, with best system NF and sufficient system IIP3 for most applications.

BHWL160 Cascade PCB Layout Recommendations

Example of BHWL160 Cascade EVB Layout



Notes:

-Both 2-layer and 4-layer board designed can be used. This is an example of 2-layer design using 30mil thick substrate.
-To minimize loss please select FR4 substrate with low DF(0.01 or lower), e.g, 生益S1000H， 台耀TU-872
-Pay attention to 50 Ohm line impedance control for the PCB materials used for your project
-Use sufficient (3~6) vias underneath & neat the device GND pad, as shown. Via diameter ~ 12mil, Via pitch ~ 20mil

BHW RF Front-End Solutions AppNote Library

In addition to standard datasheets and EVB/BOM info, BHW publishes an AppNote series that address various topics on RF front-end design and performance over a wide frequency range from 300MHz to 6GHz, as an effort to assist customers in developing cutting-edge, cost-competitive products:

- **BHW AppNote #001 - Cross-Over Cascade of BHWM253 to Boost Tx Power and Rx Sensitivity of 2.4GHz Systems**
- **BHW AppNote #002 - Accurate Benchmark of GNSS CN0 Using the Power-Splitter Method**
- **BHW AppNote #003 - Boosting Wi-Fi Tx Power and Rx Sensitivity with BHWA251 and BHWM252**
- **BHW AppNote #004 - UHF 900MHz RF Front-End Solution Using BHWA251 Half-Watt PA and BHWL160 Sub-1dB-NF LNA**
- **BHW AppNote #005 - Sub-1GHz Applications of BHWA350 2-in-1 Wideband Fully Matched Amplifier**
- **BHW AppNote #006 - Low-Noise High-IIP3 LNB Architecture Using Cascade of BHWL160 for Dual-Band High-Precision GNSS**
- **BHW AppNote #007 - UWB RF Front-End Solution Using BHWA350 and BHWM552**
- **BHW AppNote #008 - High-Power 5.8GHz RF Front-End Solution Using BHWA555 and BHWM552 for ETC, V2X and Wireless Video**
- **BHW AppNote #009 - 5.8GHz RF Front-End Using BHWA350 and BHWM552 for Wireless Audio**
- **BHW AppNote #010 - Multi-Constellation GNSS Active Antenna Using BHWL161 Cascade and Single-Fed Dual-Band Antenna**
- **BHW AppNote #011 - BHWL161 Super-Compact Low-Power Low Noise Amplifier for Range Extension of 2.4GHz RC and IoT**
- **BHW AppNote #012 - Enabling Cost-Effective High-Precision GNSS Using BHWL161 and Linear-Polarization PCB Antenna**
- **BHW AppNote #013 - GNSS Noise Floor vs Receiver Architecture**
- **BHW AppNote #014 - Designing Ultra Low-Power High-Performance GNSS Products Using BHWL160 GaAs PHEMT LNA**
- **BHW AppNote #015 - BHWL161 GNSS Full-Band High-Performance LNA in Super-Compact 1x1mm DFN with Relaxed Pin Pitch**
- **BHW AppNote #016 - Improving GNSS NF Measurement Accuracy Using Broadband LNA BHWL161 as Pre-Amp**
- **BHW AppNote #017 - High-Efficiency, Low-NF 2.4GHz Front-End Solution for IoT Using BHWA251 and BHWM252**
- **BHW AppNote #018 - Optimizing BHWA555 Wideband One-Watt PA for Long-Range 5.8GHz Transmitter Applications**
- **BHW AppNote #019 - Miniature 2.4GHz RF Front-End with Integrated Chip Antenna and BHWM253 for TWS and IoT**
- **BHW AppNote #020 - Multiplying the Range for 2.4GHz Music Streaming with BHWR250L Active Integrated Antenna (AiA)**
- **BHW AppNote #021 - Range Extension for 2.4GHz Wireless Systems with BHWR250M Active Integrated Antenna (AiA)**
- **BHW AppNote #022 - Enabling Long-Range Angle-of-Arrival for High-Precision Indoor Positioning with BHWR250N RF AiA**
- **BHW AppNote #023 - Extend the Range for 5.8GHz Audio/Video Streaming with BHWR580M Active Integrated Antenna (AiA)**
- **BHW AppNote #024 - Improving 5.8GHz Radio Link Budget with BHWR580L Active Integrated Antenna (AiA)**
- **BHW AppNote #025 - Improving Range and Throughput of 2.4GHz Wi-Fi with BHWR250 Array Antenna**
- **BHW AppNote #026 - Improving Range and Throughput of 5GHz Wi-Fi with BHWR550 Array Antenna**
- **BHW AppNote #027 – Coin-Cell and Batteryless 1km Long Range NanoBeacon with BHWR250A AiA and Energy Harvesting**
- **BHW AppNote #028 - Use BHWM252 Cascade to Extend Range of 2.4GHz Wireless Systems with Single-Port SoCs**
- **BHW AppNote #029 - Improving Range of 2.4GHz Wireless Microphones and Audio Systems with BHWR250A Active Integrated Antenna (AiA)**
- **BHW AppNote #030 - Simultaneous Improvement in Range and Battery Life of 2.4GHz Wireless Systems with BHWR250M AiA**

Contact support@bhwtechnologies.com or BHW distributors/representatives for your copy of the above and new up-coming documents.