Design Needs and Challenges of a Ku-band TX/RX module

Executive Summary

Ku-band TX/RX modules transmit and receive signals in the 12–18 GHz region and can be used in SATCOM, radar, or EW applications. The modules typically cover amplification in both paths, T/R switching or duplexing, and frequency conversion. High performance Ku-band TX/RX modules require optimizing design choices in output power, gain, receiver sensitivity, isolation, linearity, phase noise, thermal control, packaging, reliability, manufacturability and test.

Define the mission first

Depending on the end use, the design challenges may overlap or have a different emphasis. Key questions may include:

Requirement	Why it matters
SATCOM, radar, EW, data link, or seeker?	Drives architecture and performance priorities
Frequency plan	Ku is broad; TX/RX bands may be separated or overlapping
Duplexing method	T/R switch, circulator, diplexer, or separate antennas
Output power	Drives PA technology, heat, linearity, power supply
Receiver noise figure	Drives LNA choice, preselector loss, protection network
Linearity / EVM / ACPR	Critical for SATCOM and digital modulation
Phase noise	Critical for coherent radar, SATCOM, and frequency conversion
Instantaneous bandwidth	Drives filters, mixers, amplifiers, equalization
Environment	Airborne, space, ground, naval, missile, commercial
Size/weight/power	Often the dominant system constraint

Basic architecture

A typical Ku-band TX/RX module may include:

Transmit path

- IF/baseband input
- Upconverter or direct RF input
- Driver amplifier
- Variable gain control
- Power amplifier
- Harmonic/spurious filtering
- Coupler/detector for power monitoring

- T/R switch, circulator, or diplexer
- Antenna interface

Receive path
- Antenna interface
- Limiter/protection circuit
- Preselector filter
- Low-noise amplifier
- Gain control
- Image/spur filtering
- Downconverter or direct RF output
- IF/baseband output

Shared functions
- Local oscillator distribution
- Bias sequencing
- Power conditioning
- Control logic
- Temperature sensing
- Built-in test
- Calibration memory
- Shielding and packaging

Transmit-path considerations

Output power
The PA is usually the dominant design driver. Common technologies:
- GaAs pHEMT: mature, good Ku-band performance, moderate power
- GaN HEMT: higher power density, better efficiency, ruggedness
- SiGe/CMOS: useful for lower-power/high-integration designs
- TWTAs: still used where very high Ku-band power is needed

Trade-offs:

Higher output power gives…	**But causes…**
More link margin	More heat
Longer range	Larger power supply
Better jamming/radar capability	More harmonics/spurs
More antenna EIRP	Worse linearity if compressed
Smaller antenna possible	Higher cost and reliability burden

Linearity
For SATCOM, linearity can matter more than saturated power. Important metrics:

- P1dB
- IP3
- AM/AM distortion
- AM/PM conversion
- Error Vector Magnitude (EVM)
- Adjacent Channel Power Ratio (ACPR)
- Spectral regrowth

A PA operated deep into compression may look efficient, but it can ruin digitally modulated waveforms.

Receive-path considerations
The receive chain is usually dominated by noise figure and survivability:

Noise figure
Every dB of loss before the LNA directly hurts receiver sensitivity. Critical front-end losses:

- T/R switch loss
- Circulator loss
- Limiter loss
- Preselector filter loss
- Connector/launch loss
- Antenna feed loss

The LNA should be close to the antenna interface, but it must also be protected from high transmit power or external high-level signals.

Receiver protection
Ku-band RX paths often need protection from:

- Own-transmitter leakage
- Nearby emitters
- High-power jammers
- Lightning/ESD, depending on platform
- PA turn-on transients

Protection devices add loss, and that loss worsens noise figure. This is one of the biggest RX trade-offs.

TX/RX isolation
Isolation is one of the hardest parts of a Ku-band module. Poor isolation can cause:

- LNA damage
- Receiver desensitization
- Self-oscillation
- LO frequency shift (pulling)
- Spurious feedback
- Degraded noise figure
- False targets or self-interference

Isolation methods:

- T/R switch
- Circulator
- Diplexer
- Separate TX/RX antennas
- Shielding
- Absorptive filtering
- Physical separation
- Gain-stage isolation
- Timing blanking

Trade-offs:

Method	Pros	Cons
T/R switch	Compact, fast	Insertion loss, power handling limits
Circulator	Good duplexing, high power	Size, weight, bandwidth, magnetic material issues
Diplexer	Simultaneous TX/RX possible	Requires separated bands, filter complexity
Separate antennas	Excellent isolation	Larger system, alignment complexity

Frequency conversion and LO design

If the module includes up/down conversion, the LO system becomes critical. Design concerns:

- LO phase noise
- LO leakage
- Image rejection
- Mixer linearity
- Conversion loss
- Spur planning
- Harmonic mixing
- Reference distribution
- Frequency settling time

For coherent radar or SATCOM, poor LO phase noise can degrade:

- EVM
- Reciprocal mixing
- Doppler resolution
- Coherent integration
- Adjacent channel performance

Filtering

Filtering is essential at Ku band. Common filters:

- Cavity filters
- Waveguide filters
- Interdigital/microstrip filters
- Ceramic filters
- Suspended-substrate filters
- Lumped/distributed hybrid filters

Filter design challenges:

- Low insertion loss
- High rejection
- Temperature stability
- Power handling
- Group delay
- Manufacturability
- Tuning repeatability
- Size

In TX, filters suppress harmonics and spurs. In RX, filters protect the LNA and reject out-of-band interference.

Thermal management

Ku-band TX/RX modules are often thermally constrained, especially with GaN PAs. Thermal design must address:

- PA junction temperature
- Heat spreading
- Thermal interface materials
- Baseplate conduction
- Airflow or liquid cooling
- Temperature gradients across LO/RX/TX sections
- Gain drift
- Phase drift
- Long-term reliability

High temperature can degrade:

- PA output power
- LNA noise figure
- Gain flatness
- Oscillator phase noise
- Filter center frequency
- Device lifetime

Packaging and interconnect
At Ku band, packaging is part of the RF circuit. Key issues:

- Connector launches
- Wire bond inductance
- Ribbon bonds
- Via transitions
- Cavity resonances
- Lid effects
- Grounding
- Isolation walls
- Absorber placement
- Substrate choice
- CTE mismatch
- Hermetic sealing, if required

Common technologies:

- Machined aluminum housings
- Kovar/hermetic packages
- Ceramic substrates
- Thin-film alumina
- Rogers-type RF laminates
- Chip-and-wire assemblies
- LTCC
- Integrated MMIC modules

Gain budget
A Ku-band module needs a carefully planned gain budget. TX path:

- Enough gain to drive PA
- Avoid overdriving stages
- Maintain linearity
- Include temperature compensation
- Allow production adjustment

RX path:

- Enough early gain to overcome later losses
- Avoid compression from blockers
- Preserve dynamic range
- Manage gain control range

Too much gain can be as bad as too little. It can cause oscillation, compression, poor linearity, and unstable calibration.

Dynamic range
The RX must handle both weak desired signals and strong unwanted signals. Important metrics:

- Minimum detectable signal
- Noise figure
- Gain
- P1dB
- IP3
- Blocker tolerance
- Recovery time after overload
- ADC drive level, if digitized

For EW or radar warning applications, high dynamic range may be more important than lowest possible noise figure.

Phase and amplitude stability
For phased arrays, radar, and coherent systems, the module must maintain phase and amplitude over:

- Temperature
- Frequency
- Time
- Vibration
- Input power
- Bias voltage
- Channel-to-channel variation

This may require:

- Calibration tables
- Temperature sensors
- Gain/phase trim
- Matched paths
- Factory calibration
- Periodic recalibration
- Phase-stable materials

Bias, sequencing, and control
Ku-band MMICs often require careful bias sequencing. Design concerns:

- Gate-before-drain sequencing for GaAs/GaN
- Overcurrent protection
- Reverse-polarity protection
- Temperature shutdown
- PA blanking
- LNA protection during TX
- Fast T/R control
- Telemetry
- Fault reporting

A good module often includes built-in monitoring:

- PA current
- PA voltage
- Temperature
- Output power detector
- Reflected power detector
- LNA current
- LO lock status
- Switch state

Environmental challenges
For aerospace/defense/space applications, consider:

- Vibration
- Shock
- Altitude
- Thermal cycling
- Humidity
- Salt fog, if naval
- Vacuum, if space
- Radiation, if space
- Outgassing
- Multipaction, if high-power space RF
- EMI/EMC
- Lightning and ESD, depending on platform

Manufacturability
Ku-band modules are sensitive to small variations. Production challenges:

- Tuning labor
- Bond-wire repeatability
- Substrate tolerance
- Connector launch repeatability
- Filter alignment
- Cavity/lid resonance variation
- MMIC lot variation
- Thermal interface consistency
- Calibration time
- Automated test time

A design that performs well in the lab may fail commercially if it requires excessive hand tuning.

Test challenges

Important tests include:

- TX gain
- TX output power
- P1dB
- Harmonics
- Spurs
- EVM/ACPR, if modulated
- RX gain
- Noise figure
- IP3
- RX compression
- TX/RX isolation
- Switching speed
- Phase noise
- Group delay
- Return loss
- Phase/amplitude tracking
- Temperature characterization
- Vibration/shock testing, burn-in and ESS

The hardest measurements are often:

- Noise figure after protection circuitry
- High-power TX testing
- Low-level spurs
- Phase tracking over temperature
- Leakage from TX into RX
- Modulated linearity at operating power

Key trade-offs

Design goal	**Trade-off**
Higher TX power	More heat, larger size, worse linearity risk
Lower RX noise figure	Less protection/filtering before LNA
Better RX survivability	More front-end loss
Simultaneous TX/RX	Requires high isolation or separated bands
Smaller module	Harder thermal control and isolation
Wider bandwidth	Harder filtering and gain flatness
Better linearity	Lower efficiency or larger PA
Lower phase noise	Better LO, cleaner power, more shielding
Lower cost	Less tuning, screening, calibration, and margin
Higher reliability	Derating, thermal margin, screening, larger design

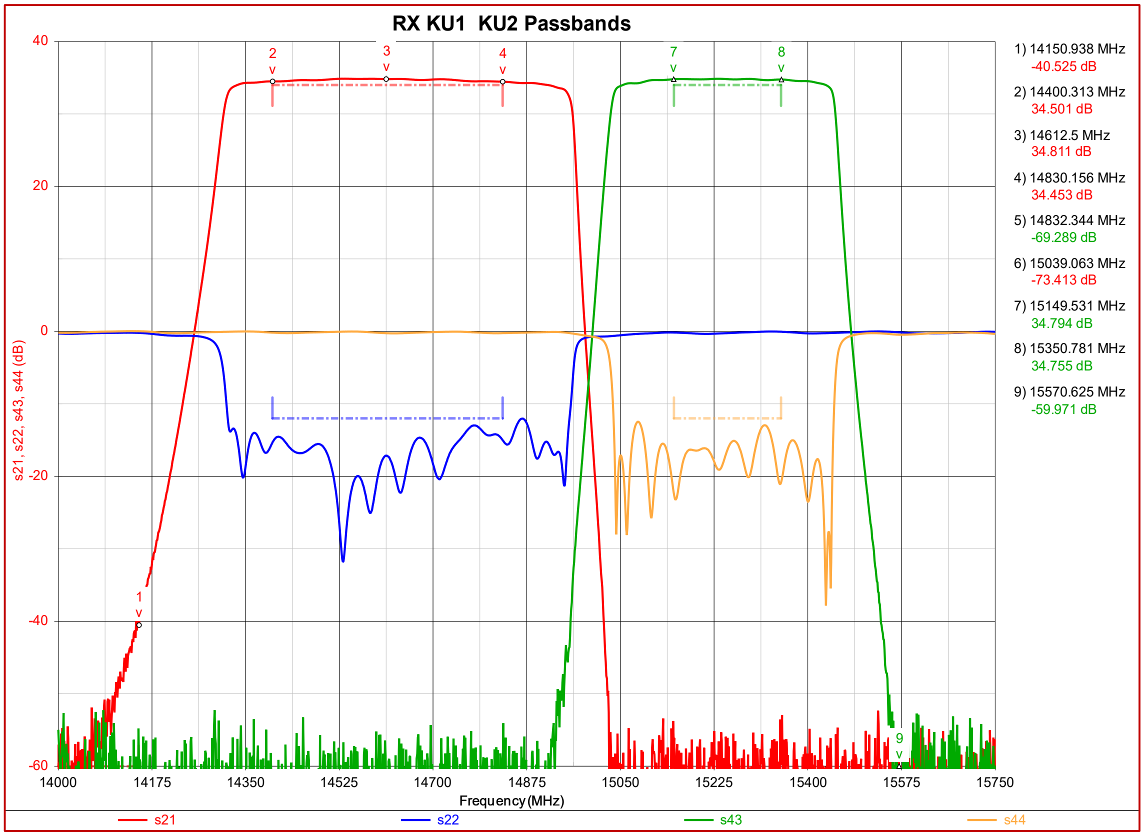
Ku-Band TX/RX Module example

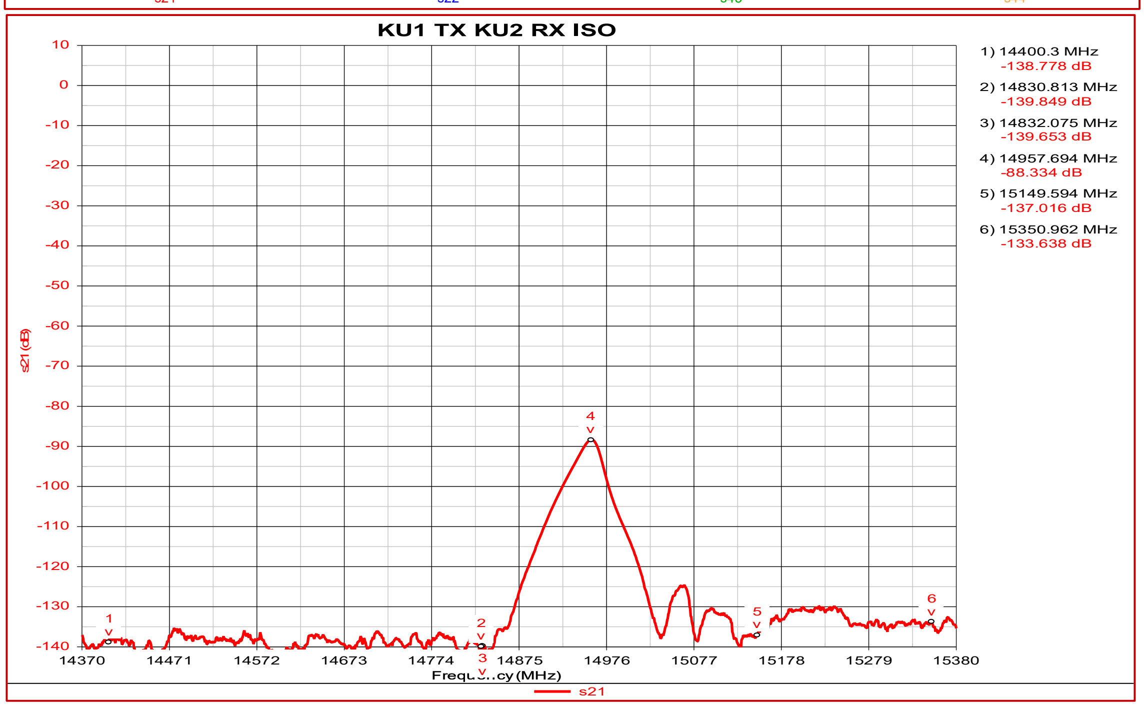
An integrated Ku-band TX/RX microwave assembly is shown in Figure 1 below, with performance plots following. The assembly incorporates low insertion loss, high power handling, high isolation between bands, Ku-band diplexer filters that are interconnected with two wave guide RF switches, a coupler and a low pass filter for harmonic suppression. RF cables are fed from the diplexers to a separate RF module consisting of a RF board with low noise amplifiers and a RF switch that switches the receive signal between the two paths. The module contains peripheral control and status circuitry for user access.

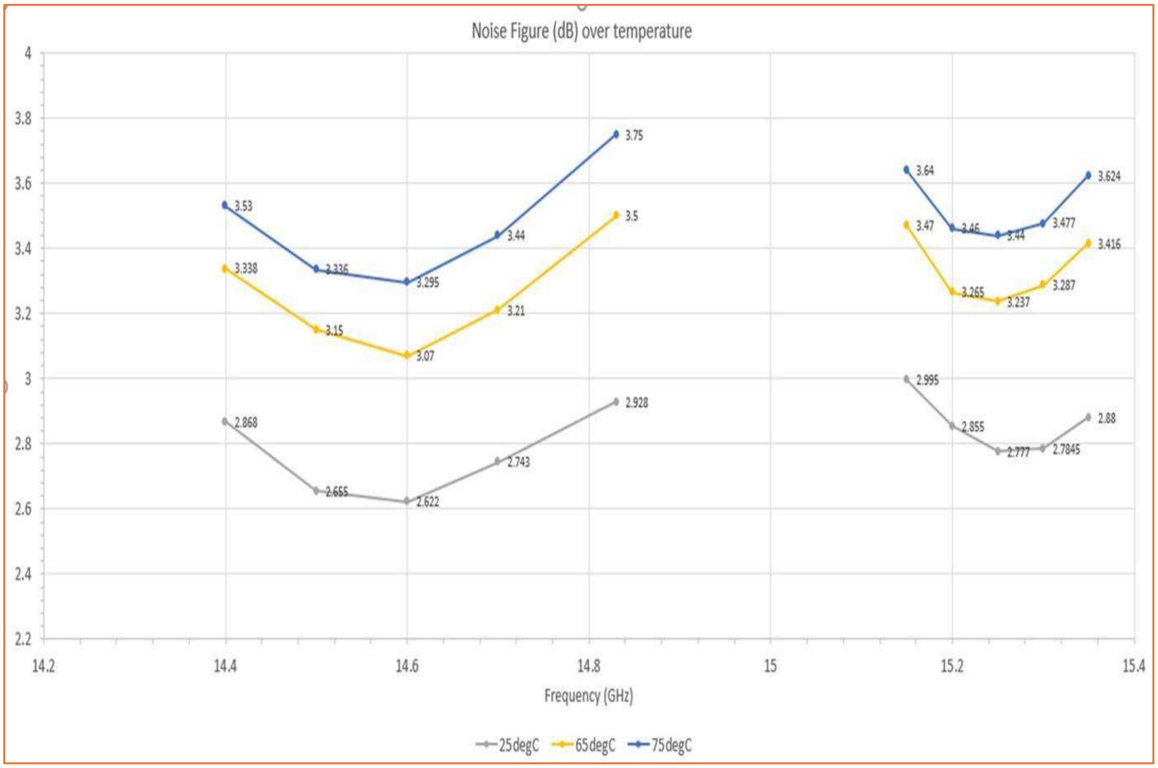
Uplink: 15.15 – 15.35 GHz
Downlink: 14.4 – 14.83 GHz
Low Insertion Loss: <2.0dB
High Power Handling: 100W CW
Isolation Between the bands: -125dB
Harmonic Suppression: 2nd -70dB, 3rd -25dB
Noise Figure: <3.8dB
Small Size: 8.3 x 6.7 x 3.3 inches max (21 x 17 x 8.4 cm)

Figure 1 – Example of an integrated Ku-band TX/RX microwave assembly

Performance Plots







Conclusion

A Ku-band TX/RX module is a balancing act between transmit power, receive sensitivity, isolation, linearity, thermal performance, frequency purity, size, and manufacturability. The most difficult design areas are usually TX/RX leakage control, PA thermal management, RX protection versus noise figure, LO spur/phase noise control, and repeatable Ku-band packaging.

Contact

Mtron
2525 Shader Road
Orlando, FL 32809
www.mtron.com

Author and Technical Contact:

Bill Drafts
bdrafts@mtron.com