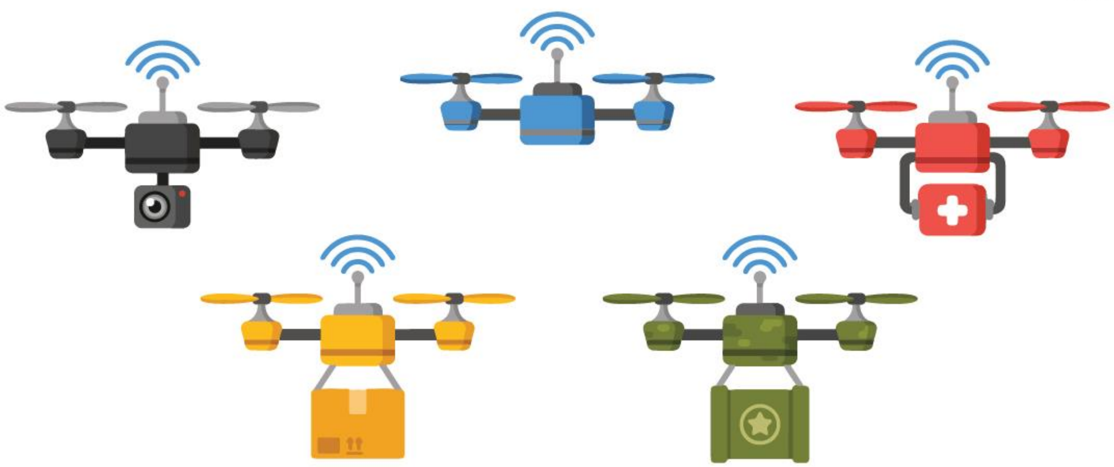
Solution Note

Wireless Broadband Solutions for Unmanned Aerial Systems

State-of-the-art MIMO for long range video streaming



Wireless Communication Link – The Lifeline of UAS

UAS manufacturers are rapidly improving the performance of their systems both in terms of flight and capabilities, fueled by growing demand from the market. However, an acute pain point for UAS designers is finding connectivity solutions that allow their systems to reach their full potential, including maintaining full functionality from several kilometers away. The communications link between a flyer and the ground station is the lifeline, and it is necessary to have a highly reliable, low latency, high throughput wireless communication link for Command, Control and streaming sensor data (e.g. 4K video).

Doodle Labs has an extensive portfolio of wireless building blocks developed specifically with UAS applications in mind. Our research is focused on leveraging the benefits of COFDM and MIMO technology to address the inherent RF challenges that unmanned aerial systems face. As a part of this effort, Doodle Labs has developed a set of UAS-focused features within our BII™ software stack that extend the flyer's communication range and supports Beyond Line of Sight (BLOS) operations.

A detailed look at a drone's operating environment shows that there are numerous factors affecting radio performance. The effects of rapidly varying orientation (e.g. antenna shadowing, tilt, roll) can drastically change RF attenuation, multi-path reflections, and link quality between the flyer and the ground control station. A COFDM based MIMO radio with a mix of cross-polarized H and V antennas can provide diversity and withstand these challenges.

With all the opportunities and challenges faced by UAS manufacturers, there is a strong need in the industry for the following communications features:

- **Minimal Size, Weight, and Power Consumption (SWaP).**
  Flight times are directly correlated to the power consumed by the system. Every millimeter and gram needs to be accounted for, and components should only be consuming power to the extent that they are being used.

- **Long-Range, Beyond Line of Site Communication.**
  Many unmanned systems have the ability to fly many kilometers away and across objects that impede direct line of sight, requiring data links that can do the same.

- **Command & Control and Sensor Data on a Single Link.**

The uplink connection to the vehicle needs to be highly reliable with low latency to send command and control information, while the downlink requires up to 20 Mbps of UDP throughput for streaming sensor data such as 4K video.

- **Encryption and Immunity against Cyber Attacks.**
  Public Safety, Defense, and many Commercial applications transmit highly sensitive data. Communications must be secure and the vehicles must be protected from unintended parties gaining access.

- **Ease of Integration.**
  Unmanned systems have unique, complex architectures and require communication solutions with a variety of interfaces and plug-and-play abilities to minimize time and effort spent on integration.

- **Licensed and Unlicensed-Band Operation.**
  International and Defense customers have access to special frequency bands. UAS manufacturers need the ability to communicate in each of these frequencies without needing to redesign their system for each new project.

- **Mesh Networking.**
  Wide area surveillance and multi-vehicle applications require advanced networking, including self-forming and self-healing mesh.

Doodle Labs Products for Unmanned Aerial Systems

In order to serve the wide range of system architectures, Doodle Labs has four solutions that meet the unique needs of unmanned systems.

All the models in these product families are built upon a foundation of COFDM and MIMO technology to provide wireless broadband links in the most challenging RF environments.

Each solution can be considered a building block, and multiple blocks can be used in conjunction to construct a solution that meets the UAS' requirements. The solutions are available in many different frequencies.

Solution	Description	Interface	Frequency	Max RF Power	Included Software	System Integration Requirements	Size and Weight
Smart Radios	Standalone radio system. Integrated CPU, transceiver, frequency shifter, and BII software	2x Ethernet, UART/USB	100 MHz ~ 4 GHz	33 dBm	Customized OpenWRT with BII extensions	N/A – Standalone router	1 stream: 37 x 57 x 11 mm, 40 grams 2 stream: 65 x 57 x 11 mm, 60 grams
Industrial WiFi Transceivers	High-power radio transceiver, which requires external CPU board	miniPCIe	2.4 GHz, 5 GHz	30 dBm	N/A	CPU board, Linux/OpenWRT with ath10k/ath9k driver	30 x 50 x 4.75 mm, 12 grams
Industrial Special Band Transceivers	Combined Industrial WiFi Transceiver and Frequency Band Shifter	miniPCIe	100 MHz ~ 6 GHz	33 dBm	N/A	CPU board, Linux/OpenWRT with ath10k/ath9k driver	1 WiFi Transceiver and 1 Frequency Band Shifter
Frequency Band Shifters and Range Extenders	Analog module that connects to existing WiFi and LTE radios to change operating frequency and extend range	RF ports, USB	100 MHz ~ 6 GHz	33 dBm	Freq Control API	In-line module between radio and antenna	1 stream: 30 x 56 x 6 mm, 23 grams 2 stream: 60 x 56 x 6 mm, 40 grams

This application note provides an introduction to each product family. Block diagrams in the Appendix illustrate how they can be integrated in various UAS design architectures.

Smart Radio

UAS-focused integrated router with Ethernet and UART interfaces

The Smart Radio platform, Doodle Labs' latest series of radios, was designed with the requirements of Unmanned Aerial Systems in mind.

The Smart Radio is a full-featured 2x2 MIMO radio and mesh router in a tiny form factor. A UAS-focused version of Doodle Labs' Broadband for Industrial IoT software stack is loaded directly onto the radio, providing an advanced set of features and tools for UAS developers.

Minimal Size, Weight, and Power Consumption (SWaP)

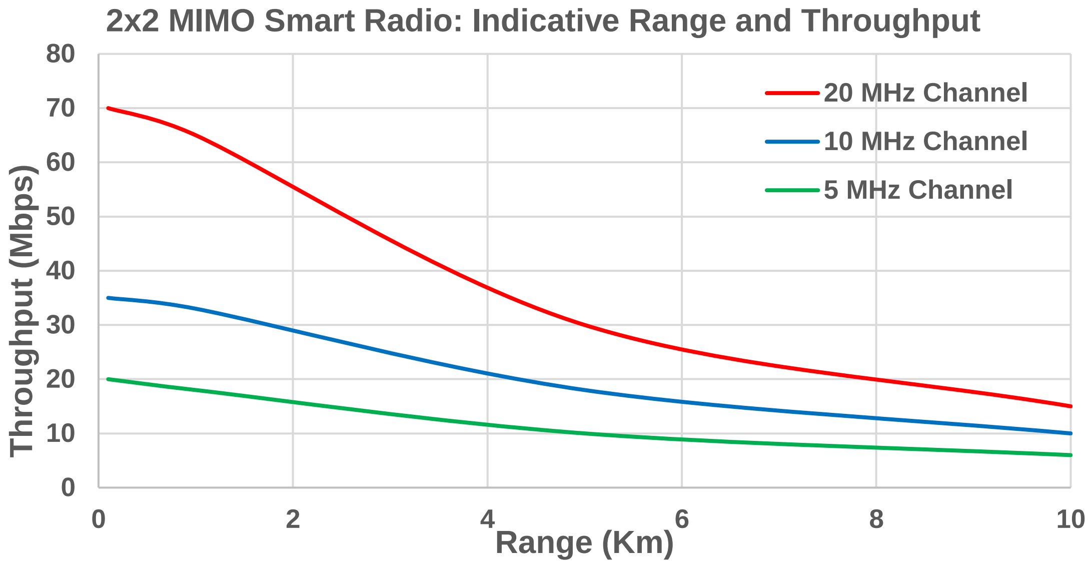
A central design objective for the Smart Radio was minimizing the overall footprint and weight of the radio. The Smart Radio model is available in two versions: single stream and 2x2 MIMO dual stream. The dual stream version is only 65x57x11 mm and 60 grams, while the single stream version is even smaller at 37x57x11 mm and weighs just 40 grams.

When deciding between the single and dual stream versions a consideration (besides throughput and range) is the positioning of antennas on the flyer's chassis. Many UAS developers have found that the dual stream radio enables antenna diversity by allowing an antenna to be placed on each side of the chassis, which ensures that the chassis itself doesn't impede direct line of sight to the ground station.

Long-Range, Beyond Line of Site Communication

It can be frustrating to have developed an unmanned system that has the potential to complete missions over many kilometers, only to be limited by the communications link. The Smart Radio has been deployed in numerous systems where high-definition sensor data, including 4K video, is streamed to the ground station from over 10 kilometers away. The Smart Radio combines 33 dBm of transmit power with the networking features of the BII software stack to maintain a stable, secure link.

The table below estimates real-world performance for reference configurations used by some customers. Antenna gain plays a major factor in determining range and throughput. Lower frequencies inherently allow for longer-distance communication, which means that lower gain antennas may be utilized. However, keep in mind that this advantage is slightly offset by the fact that antennas at lower frequencies are naturally larger.



Reference Configuration: Cross-polarized H and V antennas for maximum diversity. Flyer antennas with E-tilt down and GCS antennas with E-tilt up. >15 dBm fade margin used in calculations to account for changing RF conditions.

- For Sub-GHz frequency bands – 6 dBi antennas on the flyer for low weight, 12 dBi antennas on GCS.
- For 2 GHz bands – 9 dBi antennas on the flyer, 15 dBi antennas on GCS.

Optimized Link Quality and Performance

Most commercial and defense missions don't occur in sunny, cloudless, interference-free environments. Real world applications tend to be noisy with many competing devices operating on the same frequency bands. The Smart Radio is finely tuned with precise, customized filters on its front-end. It has a receive sensitivity of up to -96 dBi, which is superior to any comparable product on the market. The high receive sensitivity allows the radio to detect weak signals, and dramatically increases its operating range.

As the flyer moves around and changes direction, often times at very fast speeds, communications issues can emerge from the shifting orientation of the link. The BII software stack mitigates these risks through a host of advanced networking features like Convolutional Coding, Forward Error Correction, ACK-retransmits, Maximal Ratio Combining, Spatial Multiplexing, Beam Forming, and Space Time Block Coding.

The BII software stack also continously optimizes networking parameters in real-time. For example, it scans the specified frequency band to choose the best channel to operate on, automatically switching if a less congested channel is identified. Similarly, it optimizes modulation – from DSSS up to 64QAM – for each packet sent in order to maximize the link's performance. If line of sight obstructions appear, the Smart Radio automatically recognizes multipath signals (e.g. reflections off of a nearby building) to maintain connectivity.

Command & Control and Sensor Data on Single Link

A single radio on a flyer that can handle all communication needs mitigates the complexity of multiple data links and additional weight. Doodle Labs achieves this by recognizing that the types of data traffic vary and need to be handled separately. Command and control transmission needs to be highly reliable with low latency, while sensor data needs to be high-throughput and doesn't require the same latency performance. An Ultra Reliable Low Latency Channel (URLLC) was designed into the BII software stack specifically for command and control data. A concurrent, separate channel is optimized for sensor data, like streaming 4K video.

Advanced Security

Defense and highly-sensitive commercial applications that require maximum levels of protection can leverage the Smart Radio's 256-bit and 128-bit AES encryption capabilities.

The Smart Radio's ability to protect against interference and cyber attacks is better than most competitors. Built-in Firewall and VPN capabilities defend against the Denial of Service attacks. Additionally, the Smart Radio provides advanced noise filtration to defend against analog radio jamming attacks.

Ease of Integration

Unmanned systems often have unique and complex architectures that vary with the flight controllers and CPUs that are incorporated. With an objective of creating a plug and play solution, the Smart Radio has Ethernet, USB, and UART interfaces. The BII software stack is pre-configured with UAS-focused parameters, requiring minimal additional configuration during integration. In addition, APIs are available to gain direct access to the radio, allowing deep integration with the system's OS and software stack.

For more information, please see the block diagrams included in the appendix.

Licensed and Unlicensed-Band Operation

International and Defense customers, in particular, have access to special frequency bands. The challenge for UAS developers is to build a system that doesn't need to be redesigned each time a new end-user wants the functionality of the standard UAS while utilizing a unique frequency band. The full portfolio of Smart Radios covers frequencies between 100 MHz and 4 GHz, with each model optimized to operate within a specific band. The specific frequency channel can be manually selected using the BII software.

Many UAS manufacturers utilize the unlicensed ISM band, 902-928 MHz, which is significantly less congested than WiFi frequencies. In addition, lower frequencies naturally allow for longer-range transmission.

Channel sizes are also software-defined and can be as small as 3 MHz. In some international markets, private spectrum allocations can come in 1.25 MHz blocks. End-users who purchase 3 contiguous blocks can operate a broadband network using the Smart Radio.

Mesh Networking

As use cases for unmanned systems get more complex, users often utilize multiple flyers in concert with ground vehicles and scattered access points. In addition, real-world deployments mean that direct line of sight can occasionally be impaired. In response, Doodle Labs has integrated self-healing and self-forming mobile mesh networking into the Smart Radio.

Industrial-Grade Construction

The Smart Radio has been constructed using ruggedized, vibration-resistant components and casing. It operates within the industrial temperature range of -40°C to +85°C. We performance test each individual unit to ensure that high quality standards are met.

See Appendix 1A for system architecture block diagrams.

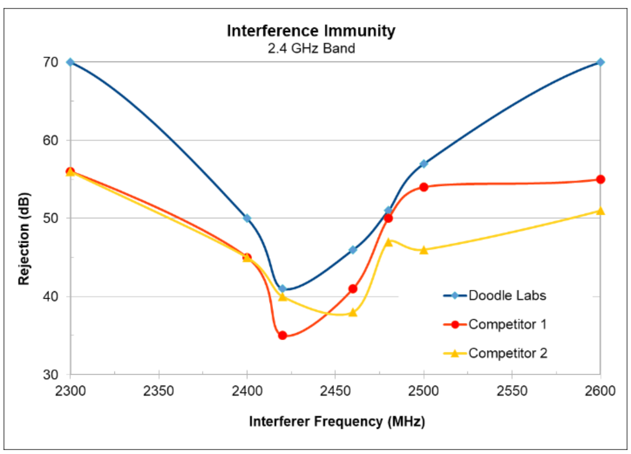
Industrial Wi-Fi Transceivers with miniPCIe interface

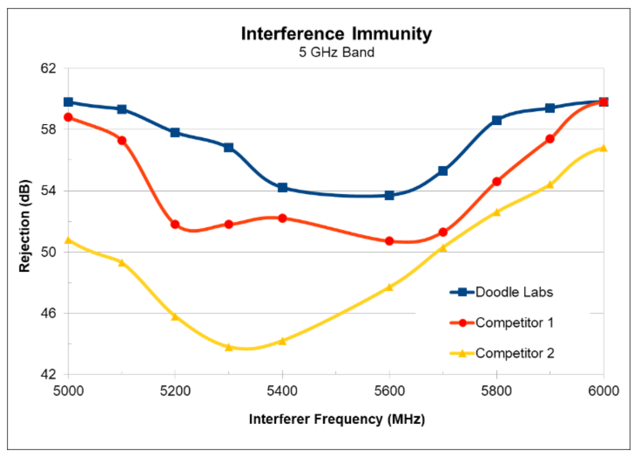
Long-range using 802.11ac and 802.11n standards

UAS architectures that have CPU boards and proprietary software require a long-range radio transceiver to operate as a transparent link between the flyer's onboard system and the ground station. For these architectures, Doodle Labs' portfolio of Industrial Wi-Fi Transceivers would provide the best solution.

WiFi spectrum can be very congested, especially in the areas that UAS are deployed. The Industrial Wi-Fi Transceivers have been designed to have better interference immunity that any of its competitors (see chart below). Moreover, the transceivers have incredibly high receive sensitivity, vastly increasing the range that they can communicate.

Interference Immunity of DL Transceivers vs Competitor Transceivers





Industrial Wi-Fi Transceivers - Features at a Glance

- Transmit streaming 4K video from 5-8km away, powered by 30 dBm of transmit power and best-in-class Rx sensitivity
- Standard miniPCIe interface
- Industrial-grade construction, including vibration-proof components
- FIPS 140-2, Level 2 compliant, including a tamper-evident seal
- Industrial extended temperature range, allowing operation from -40°C to +85°C
- Hardware "RF Kill" feature to meet the FAA requirement for airborne applications
- Modular FCC, CE, and IC certifications

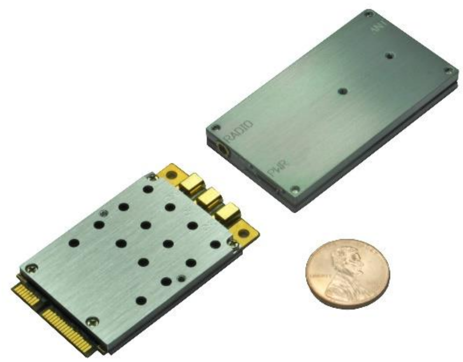
See Appendix 1B for block diagrams.

Industrial Special Band Transceivers with miniPCIe interface

802.11ac and 802.11n standards at 100 MHz – 6 GHz

Similar to the WiFi Transceiver, when the system architecture already has a CPU board and only requires a transceiver, the Special Band Transceivers can be utilized. Each Special Band Transceiver is a combination of a WiFi Transceiver and a Frequency Band Shifter that have been optimized to work in concert. They have been designed to be interchangeable, allowing customers to switch the UAS' operating frequency from 100 MHz – 6 GHz by simply swapping the modules. With up to 33 dBm of transmit power and 2×2 MIMO technology, these transceivers can transmit large amounts of data (e.g. 4K video) in real-time from over 10 km away.

Special Band Transceivers - Features at a Glance



- Available at any frequency between 100 MHz – 6 GHz
- Transmit streaming 4K video from 10km away, powered by 33 dBm of transmit power and best-in-class Rx sensitivity
- Standard miniPCIe interface
- Industrial-grade construction, including vibration-proof components
- FIPS 140-2, Level 2 compliant, including a tamper-evident seal
- Industrial extended temperature range, allowing operation from -40°C to +85°C
- Hardware "RF Kill" feature to meet the FAA requirement for airborne applications
- Modular FCC, CE, and IC certifications

See Appendix 1C for block diagrams.

Frequency Band Shifters and Range Extenders

Front-End Subsystems for pre-existing embedded radios

The Doodle Labs' family of Frequency Band Shifters (FBS) provide flexibility to UAS developers who already have a radio solution but need to operate at new frequencies. The FBS is an in-line module placed between the radio modem and the antenna. For example, a UAS that typically operates at Wi-Fi frequencies for commercial applications can attach an FBS module to operate at 4.9 GHz.

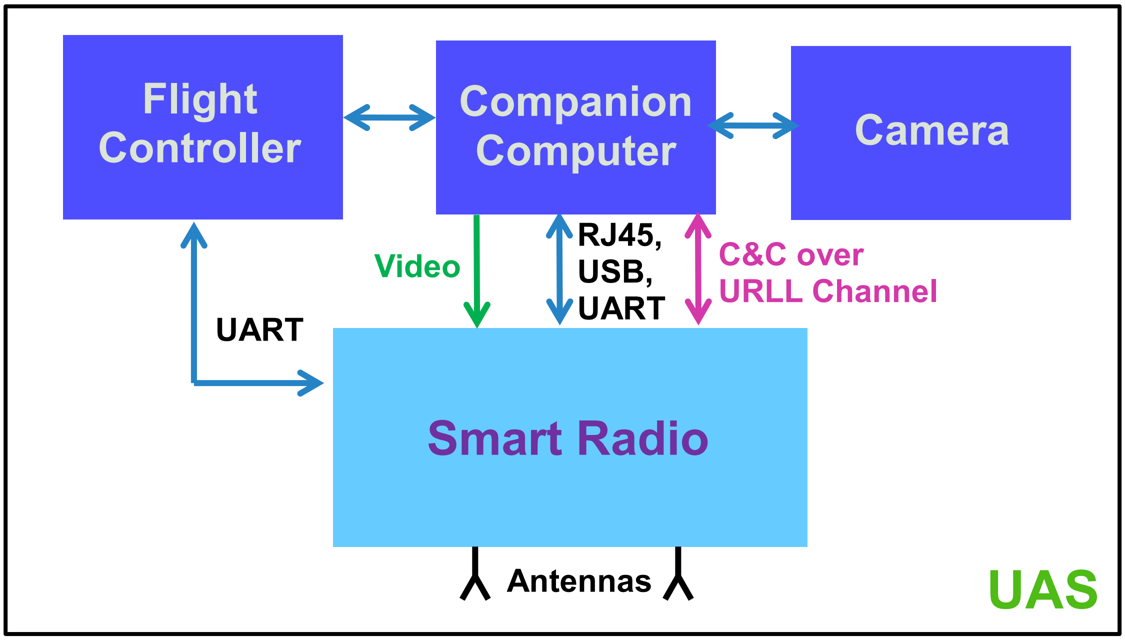
We offer a large family of form factor compatible modules in the 100 MHz – 6 GHz range, which means a simple swap of the FBS module makes the UAS operational in any market or country. A common use of the FBS is to integrate with newer generations of SBC boards that have built-in short-range Wi-Fi connectivity. In addition to shifting the operating frequency, the FBS amplifies the Tx power and Rx gain to increase the UAS' range. When the embedded WiFi is used in concert with the FBS, it can extend range by a few kilometers and avoid interference.

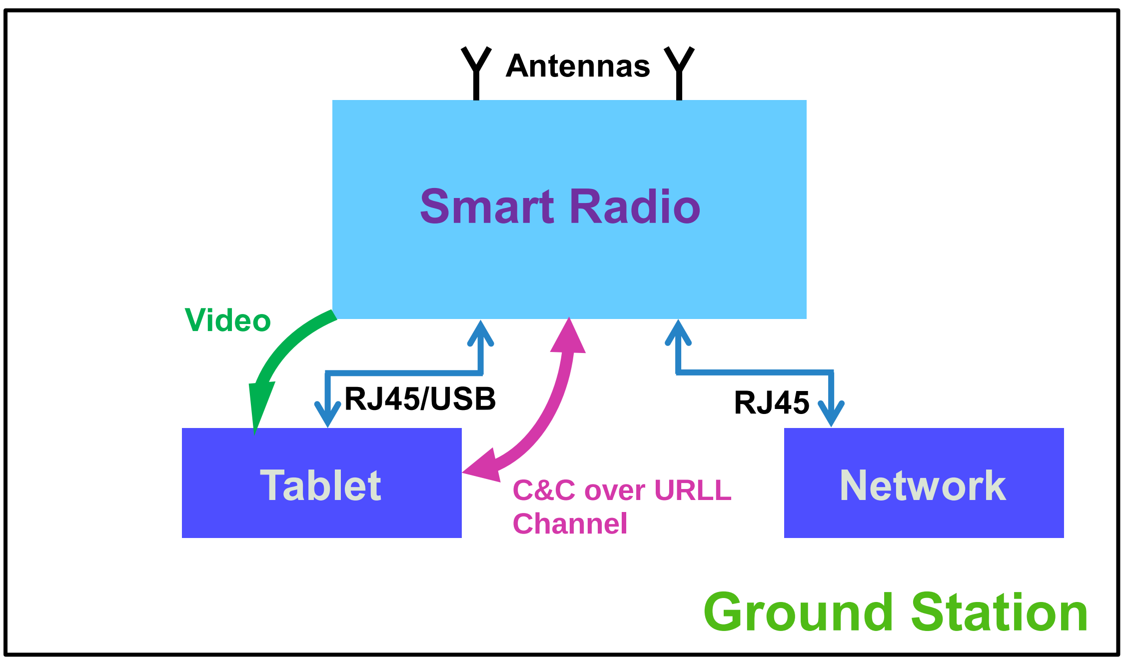
Frequency Band Shifters - Features at a Glance

- Increases the range of pre-existing WiFi modules to allow streaming 4K video from 10 km away (varies based on the range or pre-existing radio and antennas)
- Minimal size and weight: 30x56x6 mm and 23 grams for single stream, and 60x56x6 mm and 40 grams for dual stream
- Bi-directional band shifting and power amplification
- Software programmable Input-Output frequency offset
- High purity and zero distortion of RF signals to support 2×2 MIMO and 128QAM signals
- Rugged construction, industrial temperature range (-40C to +85C)

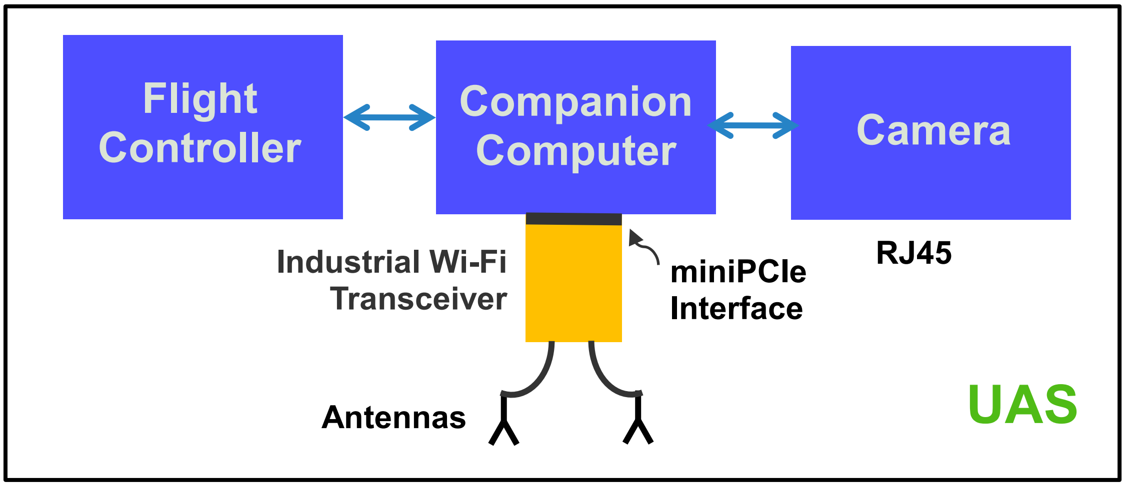
See appendix 1D for block diagram.

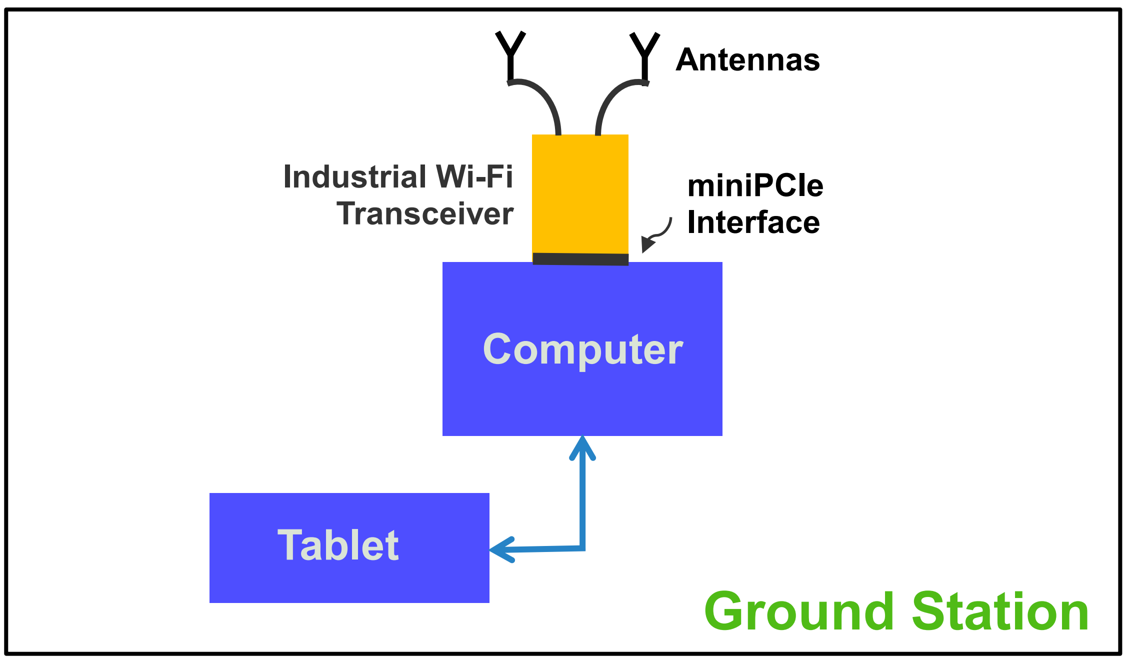
Appendix 1A – UAS with Smart Radio



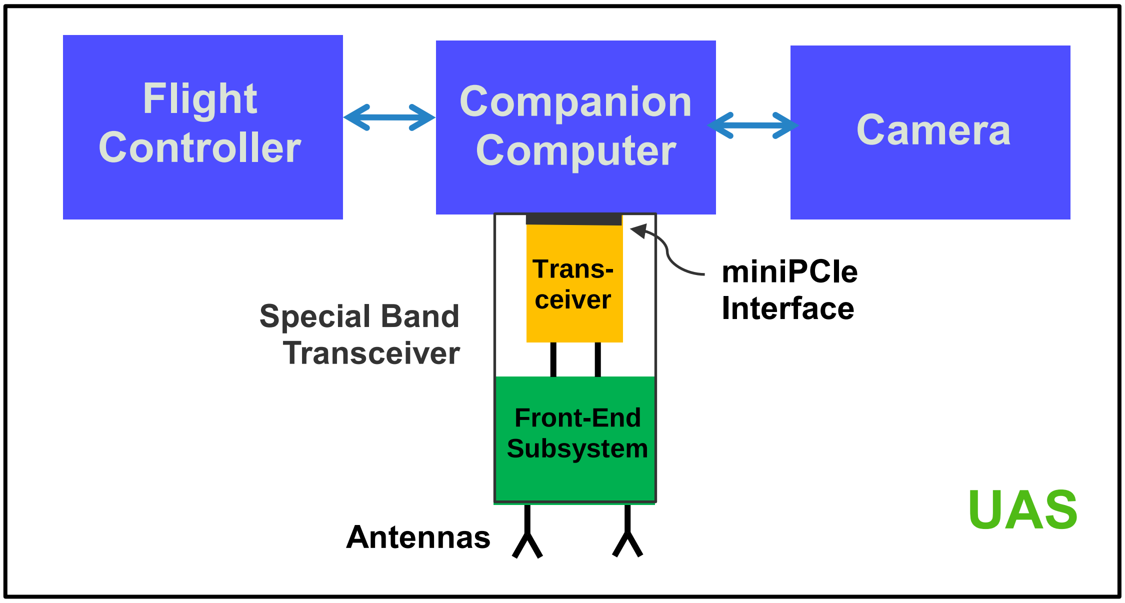


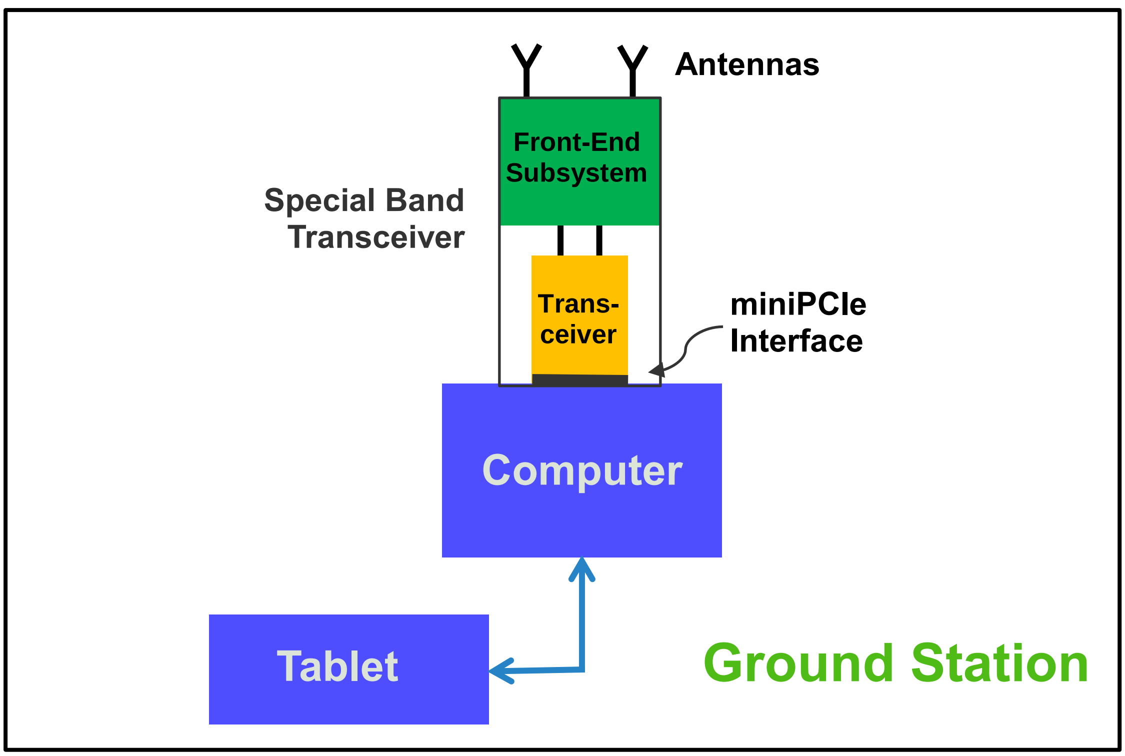
Appendix 1B – UAS with Industrial Wi-Fi Transceivers





Appendix 1C – UAS with Special Band Transceivers





Appendix 1D – UAS with Range Boosters and/or Band Shifters