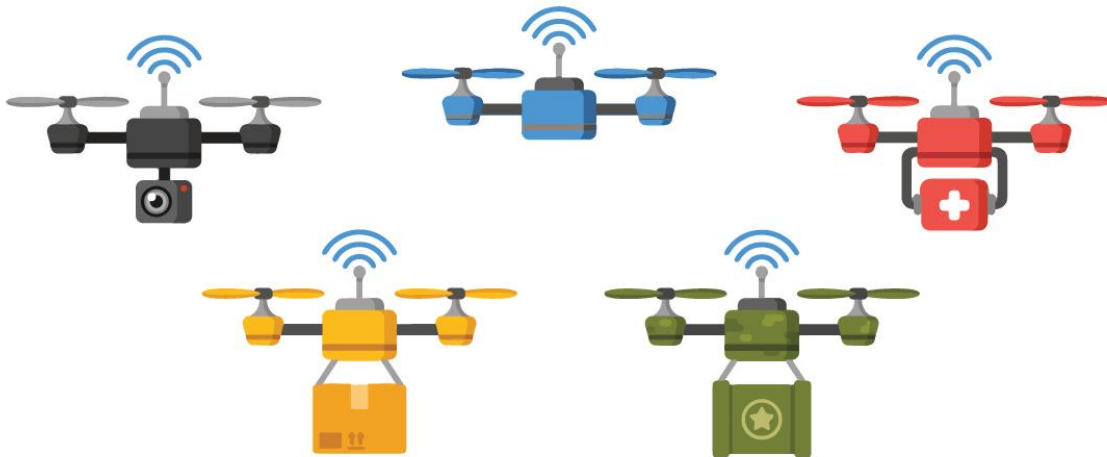


## Wireless Broadband Solutions for Unmanned Aerial Systems

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



## Wireless Communication Links: The Lifeline of Unmanned Aerial Systems

Unmanned Aerial System (UAS) manufacturers are rapidly improving the performance of their systems both in terms of flight and capabilities. However, an acute pain point for UAS designers is finding wireless connectivity solutions that allow their systems to reach their full potential, including maintaining full functionality from several kilometers away. The wireless communication 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, including the Smart Radio, developed specifically with UAS applications in mind. Our development is focused on leveraging the benefits of COFDM and MIMO technology to address the inherent RF challenges that unmanned vehicles face. As a part of this effort, Doodle Labs has developed a set of UAS-focused features within our BII® technology that provide the capabilities and features that OEMs require.

### Radio Requirements for Unmanned Aerial Systems

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)
- Command & control and sensor data on a single link
- Long-range communication
- Encryption and immunity against cyber attacks

- Unlicensed, licensed and special-band operation
- Mesh networking
- Ease of integration

## Smart Radio: High-Performance Wireless for UAS

The Smart Radio, Doodle Labs' latest series of radios, was designed with the requirements of Unmanned Aerial Systems in mind. The Smart Radio platform is a full-featured 2x2 MIMO radio and mesh router in a tiny form factor. It incorporates Doodle Labs' BII® technology, optimized for UAS applications that require long range, mobile, and high-throughput wireless broadband connections.



### Minimal Size, Weight, and Power Consumption (SWaP)

Minimal SWaP is one of the most important requirements for UAS. 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.

A central design objective for the Smart Radio was minimizing the overall footprint and weight of the radio. The 2x2 MIMO radio is only 65x57x11 mm in size and weighs just 60 grams.

### Command & Control and Sensor Data on a Single Link

A single radio on a flyer that can handle all communication needs mitigates the complexity of multiple data links and additional weight. The Smart Radio achieves this by applying different priorities to each packet of data.



The uplink command & control transmission to the flyer needs to be highly reliable with low latency. The Smart Radio has a special Ultra Reliable Low Latency Channel (URLLC) for transmitting C&C packets at the highest priority and enabling RF parameters that ensure reliable communication even in very noisy environments.

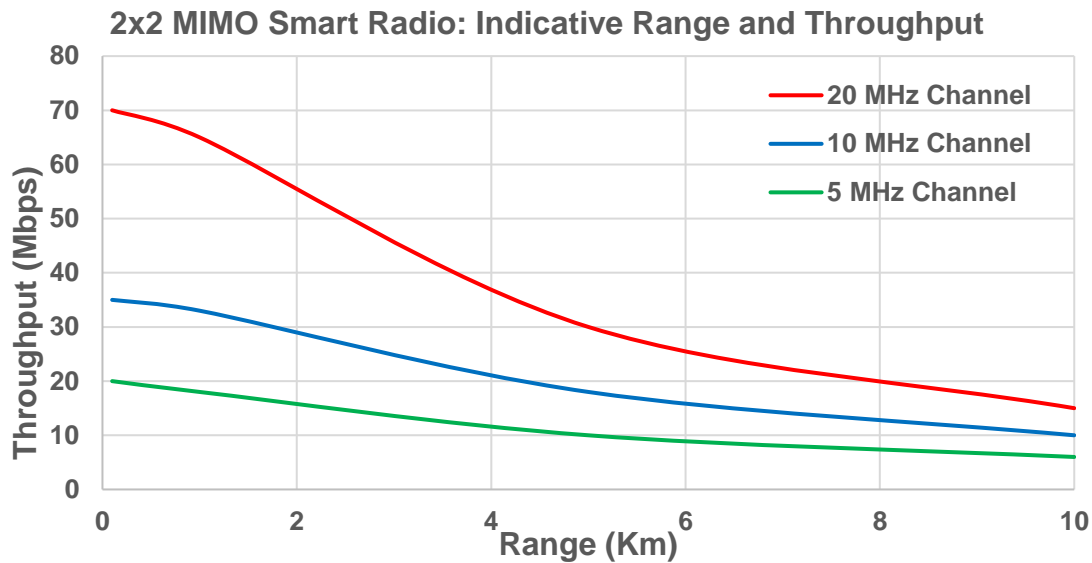
The downlink from the UAS to the ground station often carries large amounts of sensor data, for which the Smart Radio has a **concurrent optimized channel**. Streaming 4K video requires about 20 Mbps throughput, while about 5 Mbps is required for HD video. The Smart Radio uses its optimized streaming sensor channel to transmit at these rates over long distances.

### **Long-Range 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 situations where sensor data, including 4K video, is streamed to the ground station from over 10 kilometers away.

The chart below estimates real world field performance achieved by many Doodle Labs customers. Antenna gain plays a major factor in determining range and throughput, and the chart below utilizes a typical configuration.

Lower frequencies have lower transmission losses and allow for longer-distance communication, which means that lower gain (i.e. smaller) antennas may be utilized. Many UAS manufacturers utilize the unlicensed ISM band 902-928 MHz instead of WiFi frequencies for this reason. On the other hand, higher frequencies have smaller antennas, which means that a high-gain antenna will not be very heavy. Hence, a careful balance of the required range, operating frequency, and antenna configuration must be made.



**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 UAS missions don't occur in clean, 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 -100 dBm, which is superior to any comparable product on the market. The high receive sensitivity allows the radio to detect weak signals, and dramatically increases the operating range.

As the flyer moves around and changes direction, often at very fast speeds, communications issues can emerge from the shifting orientation of the link. The COFDM technology used in the Smart Radio mitigates these risks through a host of advanced features like per packet rate adaptation from DSSS up to 64QAM, RF power control, Convolutional Coding, Forward Error Correction, ACK-retransmits, Maximal Ratio Combining, Spatial Multiplexing, and Space Time Block Coding. The 2x2 MIMO technology used in the Smart Radio provides antenna diversity and addresses the dynamic link conditions caused by the roll and pitch of the flyer.

## Encryption and Immunity against Cyber Attacks

Public Safety, Defense, and many Commercial applications transmit highly sensitive data. Over the air communications must be secure and the vehicles must be protected from unintended parties trying to gain access.



Applications that require maximum levels of protection can leverage the Smart Radio's 256-bit and 128-bit AES encryption capabilities. Built-in firewall and VPN capabilities defend against denial of service attacks. Additionally, the Smart Radio provides configurable noise filtration to defend against radio jamming attacks.

## Unlicensed, Licensed, and Special Band Operation



International, Public Safety, and Defense customers 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 customer requires a new operating frequency for their market.

The full portfolio of Smart Radios covers frequencies between 100 MHz and 4 GHz, with each model optimized to operate within a specific band. Each Smart Radio is form-factor compatible, allowing OEMs to switch the frequency band by simply inserting a different model. The Smart Radio's channel sizes are software-defined and can be as small as 3 MHz, opening up many opportunities for customers who have access to private spectrum.

## Mesh Networking



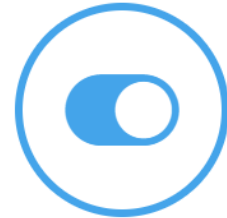
As use cases for unmanned systems get more complex, users often utilize multiple flyers in concert with ground vehicles and scattered access points. In addition, real world deployments mean that direct line of sight can occasionally be impaired. To overcome this challenge, Doodle Labs has integrated self-healing and self-forming mobile mesh technology to extend the operating range and support Non-Line of Sight situations.

## 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. Each individual unit is factory tested to ensure that performance and high quality standards are met.

## 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 and UART interfaces to integrate with various design architectures. In addition, BII software provides additional remote management APIs to gain direct access to Smart Radio, allowing deep integration with the system's OS. See the appendix for system architecture diagrams.



## Additional 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.

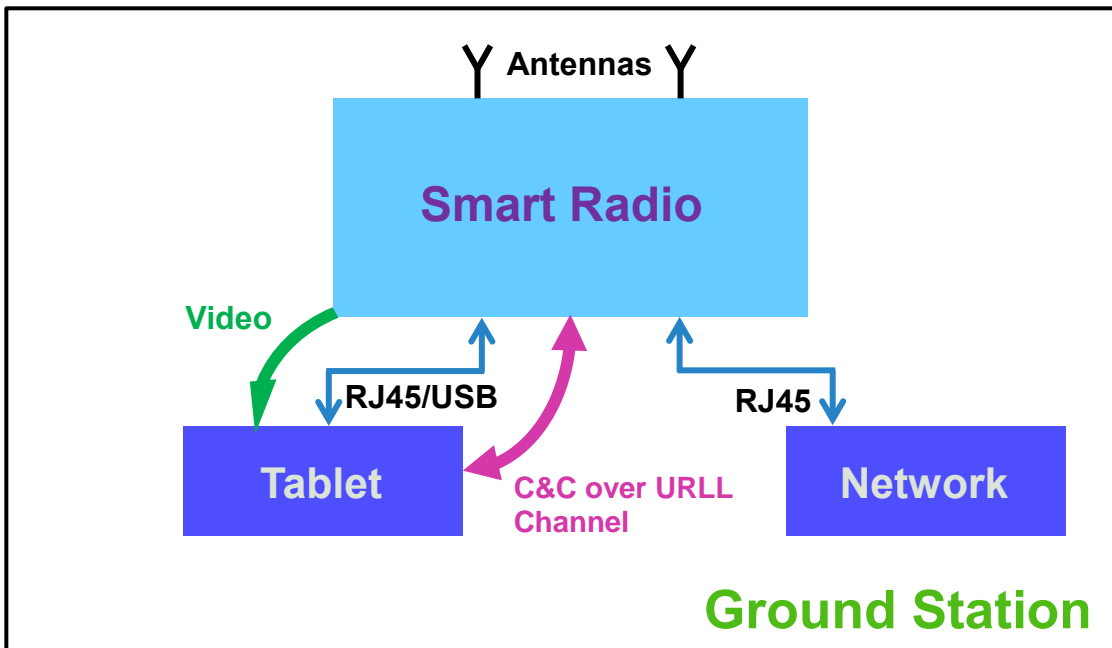
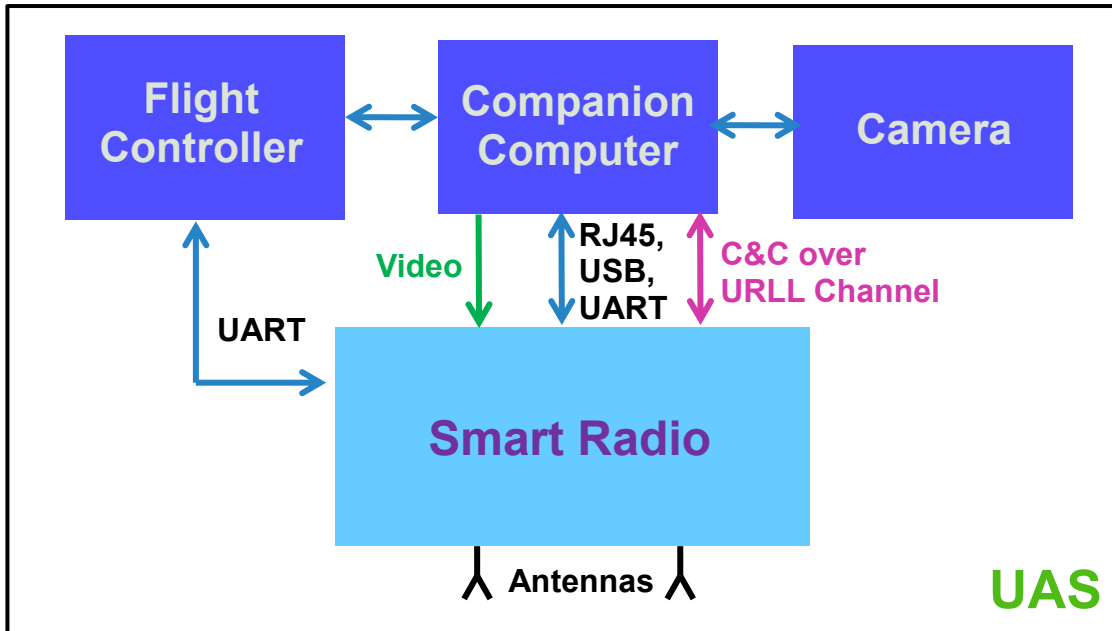
All the models in these product families are built upon a foundation of COFDM and MIMO technology to provide wireless broadband links in the most challenging RF environments.

Each solution can be considered a building block, and multiple blocks can be used in conjunction to construct a solution that meets the system's requirements. The block diagrams in the appendices illustrate how these products can be integrated in various UAS design architectures.

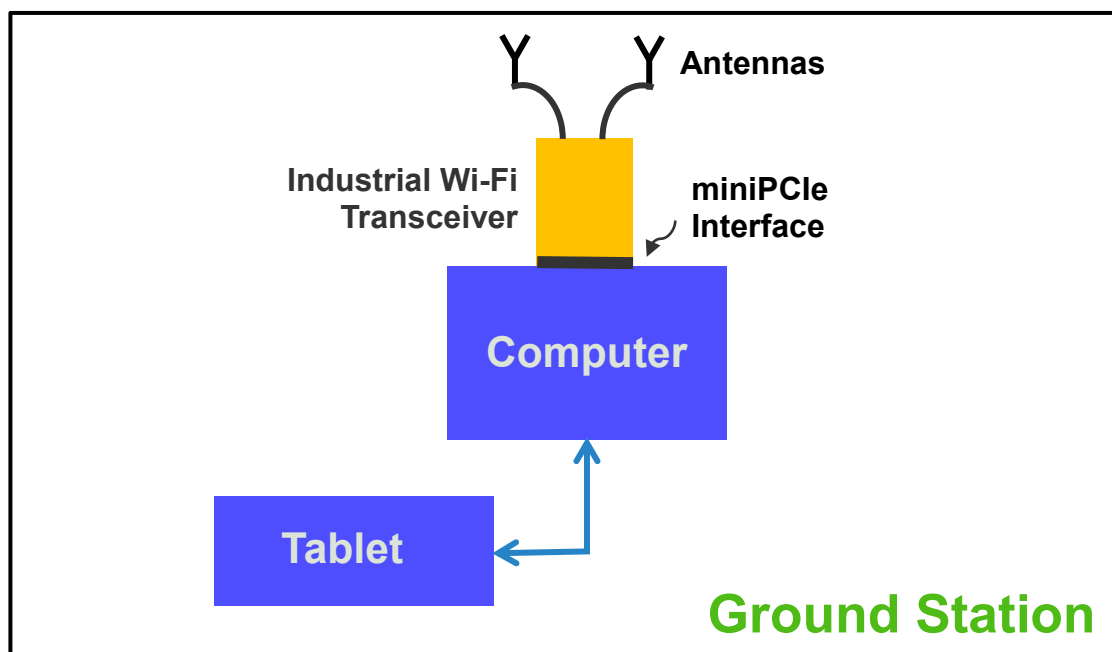
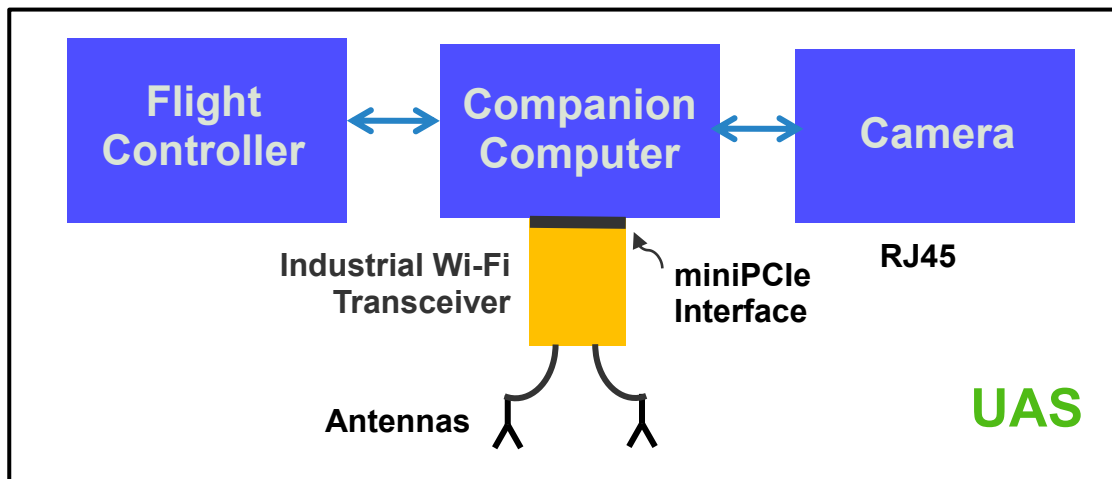
Product Family	Description	Frequency Range	RF Power	System Integration	Size Weight
<a href="#"><u>Smart Radios</u></a>	Full-featured 2x2 MIMO radio and mesh router in a tiny form factor; 2x Ethernet, UART	100 MHz ~ 4 GHz	33 dBm	Standalone router	65 x 57 x 11 mm, 60 grams
<a href="#"><u>Industrial WiFi Transceivers</u></a>	High-power, rugged WiFi (11ac and 11n) transceivers; miniPCIe	2.4 GHz, 5 GHz	30 dBm	CPU board, Linux/OpenWRT with ath10k/ath9k driver	30 x 50 x 4.8 mm, 12 grams
<a href="#"><u>Special Band Transceivers</u></a>	Frequency band-shifted WiFi transceivers; miniPCIe	100 MHz ~ 6 GHz	33 dBm	CPU board, Linux/OpenWRT with ath9k driver	30 x 50 x 4.8 mm, 60 x 56 x 6 mm, 52 grams
<a href="#"><u>Front End Subsystems</u></a>	Analogue SDR modules for frequency band shifting of WiFi and LTE signals, USB	100 MHz ~ 6 GHz	33 dBm	In-line module between radio and antenna	60 x 56 x 6 mm, 40 grams



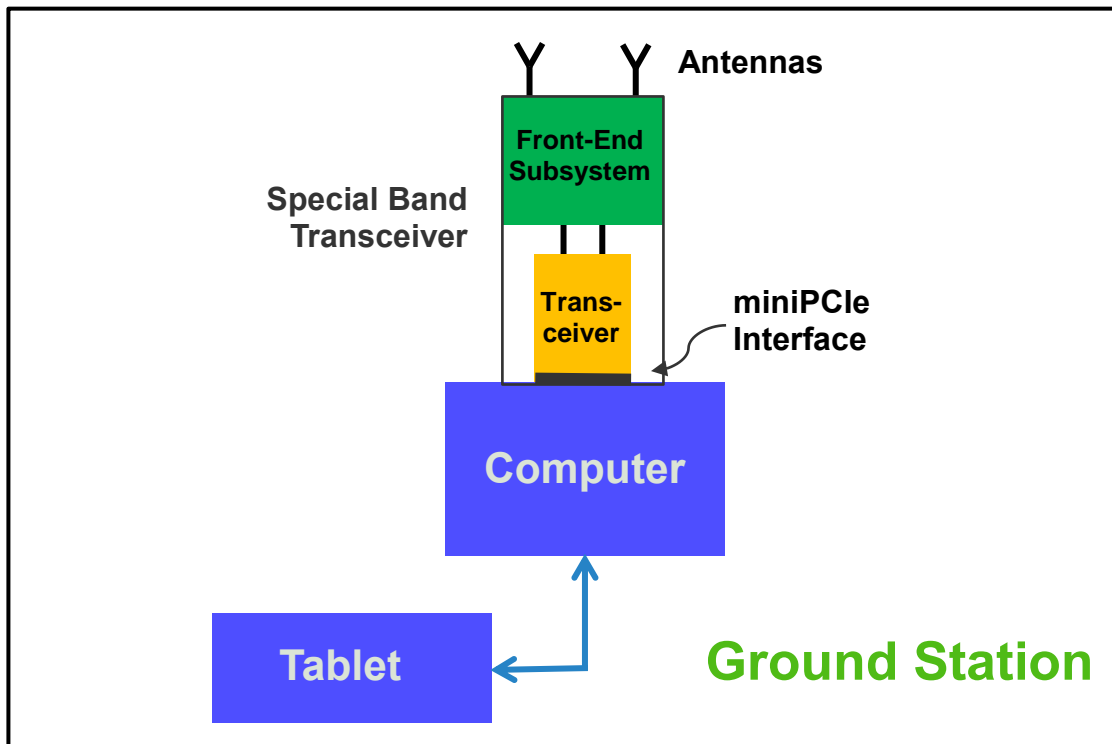
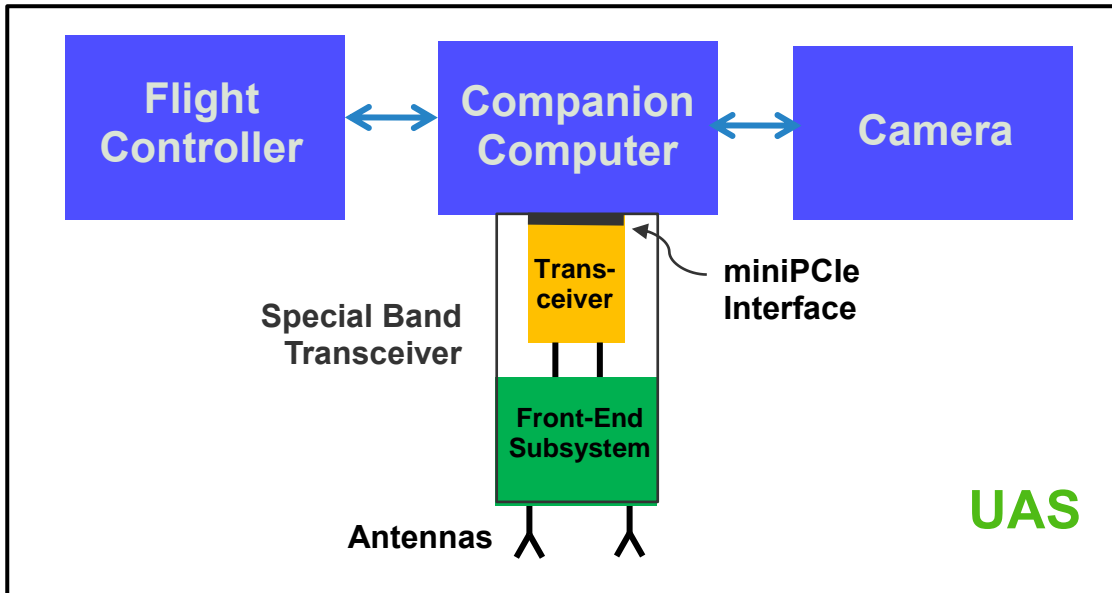
### Appendix A – UAS with Smart Radio



### Appendix B – UAS with Industrial WiFi Transceivers



### Appendix C – UAS with Special Band Transceivers



### Appendix D – UAS with Front End Subsystems

