

PAPER • OPEN ACCESS

## Design and Study UAV Data Link Terminal with One Station Controls Several Vehicles Dynamic Networking

To cite this article: MA Junkai *et al* 2020 *J. Phys.: Conf. Ser.* **1486** 052015

View the [article online](#) for updates and enhancements.

You may also like

- [Modelling and Control of Robot Manipulators](#)  
L Sciavicco and B Siciliano
- [Cooperative navigation of unmanned aerial vehicle formation with delayed measurement](#)  
Chenfa Shi, Zhi Xiong, Mingxing Chen et al.
- [IAEA Meeting on Application of the Concepts of Exclusion, Exemption and Clearance: Implications for the Management of Radioactive Materials, Vienna, 6 - 9 May 1997](#)  
J O McHugh



**ECS**  
The  
Electrochemical  
Society  
Advancing solid state &  
electrochemical science & technology

**DISCOVER**  
how sustainability  
intersects with  
electrochemistry & solid  
state science research

# Design and Study UAV Data Link Terminal with One Station Controls Several Vehicles Dynamic Networking

JunkaiMA, XiaoyanWang, KeweiChen and qingtaoLiu

College of Electronic Engineering, Naval University of Engineering, Wuhan, Hubei, 430033, China

E-mail: 752968873@qq.com

**Abstract.** Considering that there are UAVdynamic networking and collaborative communication requirements under complex mission planning conditions, this paper designs a UAV data link communication terminal with One Station Controls Several Vehicles dynamic networking. Firstly, this paper analyzes the structure of One Station Controls Several Vehicles dynamic networking and cooperative communication system in UAV data link, and combines the characteristics of dynamic networking and task cooperative communication to design a One Station Controls Several Vehicles dynamic networking communication protocol stack and design the structure and function of the man-machine data link, the terminal device hardware is realized by the FPGA chip. This paper focuses on digital zero-IF signal processing unit design and hardware implementation process. Finally, combined with the terminal to build an indoor test environment, this paper tests the network function and performance. The test results prove that the UAV data link terminal in One Station Controls Several Vehicles dynamic networking is effective, and it is practical.

## 1. Introduction

At present, the dronecombat function is expanding towards cluster operations, which poses a threat to the whole process of the war. In order to transform the battlefield advantage of the unmanned system cluster into real combat capability, it is necessary to solve the real-time and reliable information exchange and many other key technical issues between the unmanned platforms within the cluster and between the unmanned cluster and the control station, that is to break through the data link related in the UAV cluster. The UAV cluster data chain not only need to solve the communication problem between the ground station and the UAV [1], but also to solve the data exchange problem between the UAVs inside the cluster network. Aiming at the characteristics of autonomous clustering and cooperative communication of UAV cluster, this paper designs a UAV data link terminal to realize one control station to control one UAV (host) and other twoslaves. According to the specific protocol stack design, the autonomous dynamic networking communication function is realized. At the same time, it is necessary to comprehensively consider the issues including the unmanned aerial vehicle cluster communication and the high-speed data transmission and coexistence[2], the stereo random access and routing strategy design, physical layer-network layer tightly constrained with omnidirectional or directional antenna, antenna installation method and body shielding effect.

## 2. UAV data link terminal structure and function design

### 2.1Overall plan design



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

One Station Controls Several Vehicles dynamic networking and collaborative communication system diagram are shown in Figure 1. The ground control station and the drone platform (Host A, Slave A, and Slave B) are equipped with UAV data link terminals to form a drone dynamic networking and cooperative communication system [3]. It enables a ground control station to operate one drone (host A) and the other two slaves (slave A, slave B). Performing an autonomous dynamic networking according to the set multicast routing protocol includes completing communication between the host and the ground station and communication between the host and the two slaves.

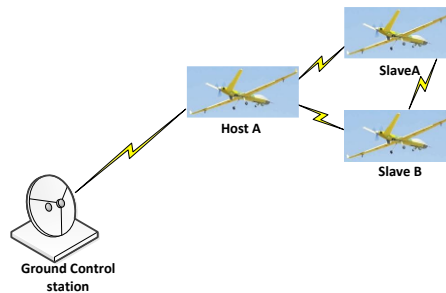


Figure 1. One Station Controls Several Vehicles dynamic networking and collaborative communication system diagram

The workflow in the system is as follows: After the UAV dynamic networking communication link is initialized, the two slaves send real-time video information and telemetry data to the host. The host integrates the received video data and telemetry data and transmits it to the ground. The ground end receives the downlink video data and the telemetry data and receives the video and telemetry parameters through the display, and the ground end uploads the remote control command of the control station to the host, and the host receives the uplink remote control command according to the multicast route[4]. The protocol is forwarded to two slaves, thereby controlling the three drones to perform different missions.

## 2.2 Functional structure design

The functional structure diagram of the One Station Controls Several Vehicles dynamic networking and cooperative communication drone data link terminal is shown in Fig. 2.

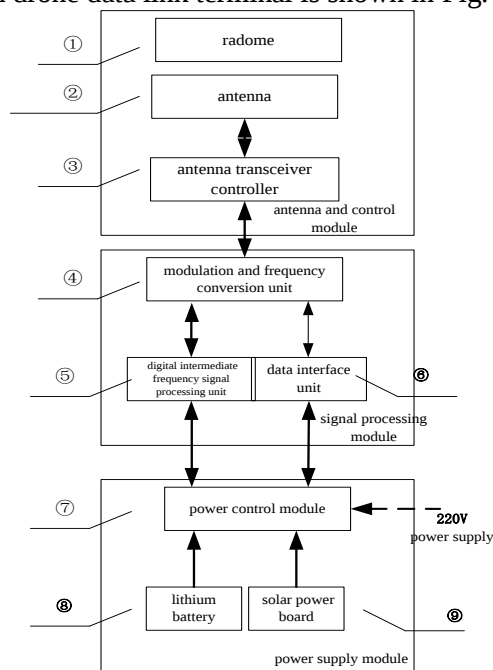


Figure 2. UAV data link terminal function block diagram

It can be seen from the functional structure diagram of the UAV data link terminal that the UAV data link terminal is mainly composed of an antenna and a control module, a signal processing module and a power supply module. among them,

(1) The antenna and control module are composed of the following devices: radome, antenna, and antenna transceiver controller;

The radome is made of a material that can transmit radio signals through the working frequency, and it is used to protect the communication antenna or the communication device from malfunctioning housings such as water showers; The antenna is made of a metal material and it can radiate operating frequency communication signals to the device in the space; The antenna transceiver controller is used for the ground communication terminal to switch the transmission communication signal and the reception communication signal, and the controller can ensure the direction of the antenna beam is aligned with the that of the communication antenna of the UAV[5].

(2) The signal processing module is composed of the following devices: modulation and frequency conversion unit, digital zero intermediate frequency signal processing unit, and data interface unit.

The modulation circuit in the modulation unit completes moving the baseband data signal to the microwave frequency to facilitate antenna transmission; The digital intermediate frequency signal processing unit processes the forward received signal and returns the baseband to the modulated signal processing. The digital zero-IF signal processing unit will process the intermediate frequency signal from the modulation unit, complete signal acquisition, tracking, bit synchronization processing, and then complete data demodulation [6]; Then, the data stream information is frame-synchronized, decoded, de-framed, and outputted through the relevant interface. The module also implements data processing from the ground communication terminal to the aircraft (back link), receives the remote control information from the control terminal through the relevant interface, completes the framing, coding and scrambling, and then performs the spread spectrum by the modulation and frequency conversion unit and outputs the frequency to the radio frequency amplifier, and the amplified spread spectrum signal is transmitted by the antenna to the receiving direction of the drone antenna. The data interface unit is divided into a network port and a serial port, wherein the network port mainly realizes real-time video data stream transmission, and the serial port mainly realizes remote telemetry signal transmission.

(3) The power supply module is mainly composed of the following devices: power control module, lithium battery and solar panel. It mainly provides 5V, 12V and 220V power supply to the system hardware circuit. At the same time, it uses solar power board design, which can be powered by solar energy.

### 3. UAV data link terminal design and implementation

#### 3.1 Terminal dynamic networking protocol stack design

The UAV data link is actually a dynamic wireless network system. Communication is often carried out simultaneously with multiple tasks. Improving the utilization of the communication channel needs to find a reasonable channel allocation method. The dynamic networking communication protocol and control algorithm in the data link are the key factors to solve this problem. In the network communication sharing radio medium, the dynamic networking communication protocol design can make full use of the wireless channel and solve the information conflict problem. Therefore, designing the One Station Controls Several Vehicles dynamic networking communication protocol stack mainly uses the TDD-TDMA system to realize relay communication between three UAVs, and the data transmission rate is between 2Mbps to 10Mbps. The structure of the drone data link dynamic networking protocol stack is shown in Figure 3.

Figure 3 Block diagram of the dynamic network protocol stack of the drone data link

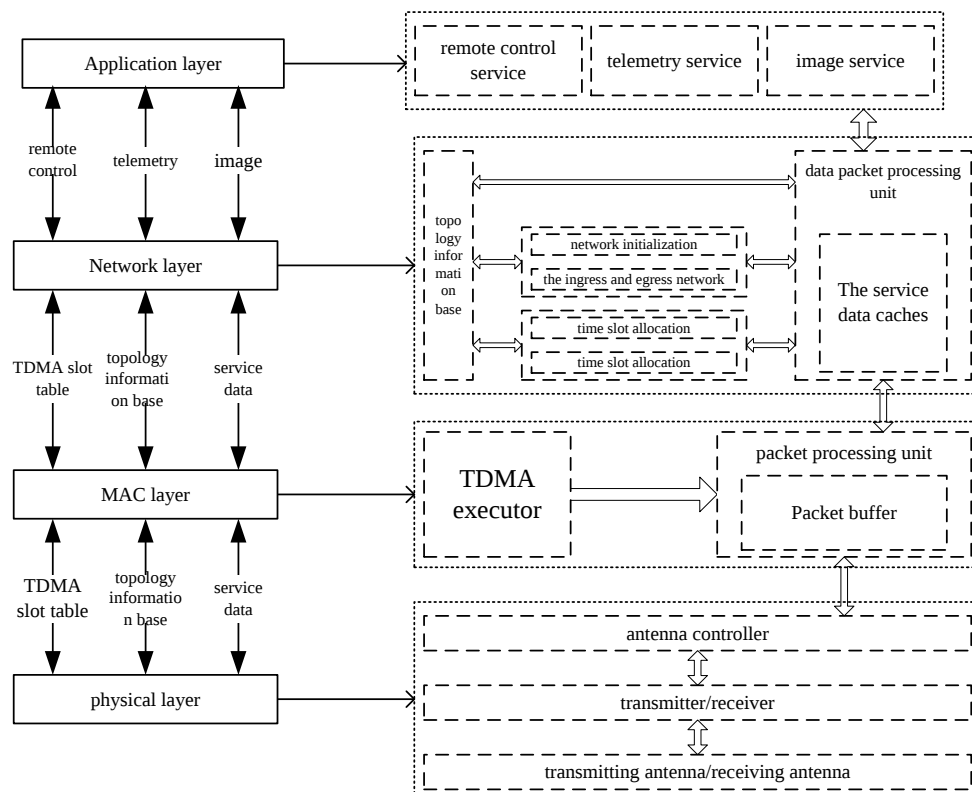


Figure 3. Block diagram of the dynamic network protocol stack in the drone data link

(1) The physical layer includes an antenna controller, a transmitter/receiver, and a transmitting antenna/receiving antenna. Among them, the antenna controller will analyze the control signaling such as the communication connection for each UAV from the Mac layer in the data link, control the transceiver and the antenna, and directly carry on the data transmitted from the Mac layer and received by the receiver[7]. The transmitter/receiver corresponds to the transceiver in the protocol stack in the data link of the drone, which completes the processing and generating the radio frequency signal. The antenna corresponds to the antenna part of the UAV protocol stack. The directional communication between the vehicles requires an omnidirectional antenna to maintain the link to complete the coordination task between the networked UAVs. Most UAVs in line-of-sight communication install omnidirectional antennas. Directional antennas are mainly used to extend the action range or increase the transmission rate. UAVs that require over-the-horizon communication generally use self-tracking Guardian antennas.

(2) MAC layer mainly includes TDMA executor and the packet processing unit, firstly, it caches the service data in the link, and the TDMA executor forwards and controls the data packets transmitted from the upper and lower layers according to the slot table.[8]

(3) Network layer mainly includes the topology information base, the data packet processing unit, and the network control unit, which mainly implements the data packet processing unit to intermediately forward information from the reporting packet and the delivered packet; According to the networking control algorithm, the network control unit implements the network initialization algorithm, the ingress and egress network control, the time slot allocation, and the slot table generation, which can realize to control the drone network. The topology information base implements the multi-machine routing control function of the drone.[9]

(4) Application layer mainly includes remote control service source, telemetry service source and image service source. It has a remote control and telemetry function for the drone through the data link of the drone, and the images and videos are obtained are used to judge the enemy situation and the surrounding environment.

### 3.2 Digital zero IF signal processing unit scheme design

The digital intermediate frequency signal processing unit is the core processing unit of the UAV data link terminal, including an analog signal interface module, a forward link signal processing module, an Ethernet signal processing and data interface module, a return link signal processing module, and a direct radio frequency modulation module, Ethernet physical interface, clock generation module, and power conversion module. The return and forward link processing modules and the clock generation module are integrated on the same FPGA board in the Gigabit Ethernet signal processing module.

(1) The forward link signal processing module includes functions such as carrier recovery, bit synchronization, decoding, frame synchronization, descrambling, and de-framing; wherein the carrier recovery module implements a digital zero-IF signal outputted by the A/D conversion circuit. Carrier recovery is performed by a complex digital zero-IF signal to complete carrier tracking; After carrier tracking is locked, bit synchronization is performed, and demodulation results and loop state information are output. Frame synchronization refers to that frame header detection is performed on the despread data stream for subsequent descrambling. The frame header is 32 bits and the hexadecimal notation is expressed as 1ACFFC1D. De-scrambling is consistent with scrambling, it XORs all data except the sync header. The generator polynomial in the pseudo-random code generator is:  $h(x)=x^8+x^7+x^5+x^3+1$ . Decoding module completes the decoding function for the forward link data, it uses RS decoding. Deframe means that frame recognition is performed on the decoded data frame. If it is a valid data frame, its valid data packet is extracted and sent to the Ethernet signal processing module for further processing, if it is a filled data frames, it is discarded.

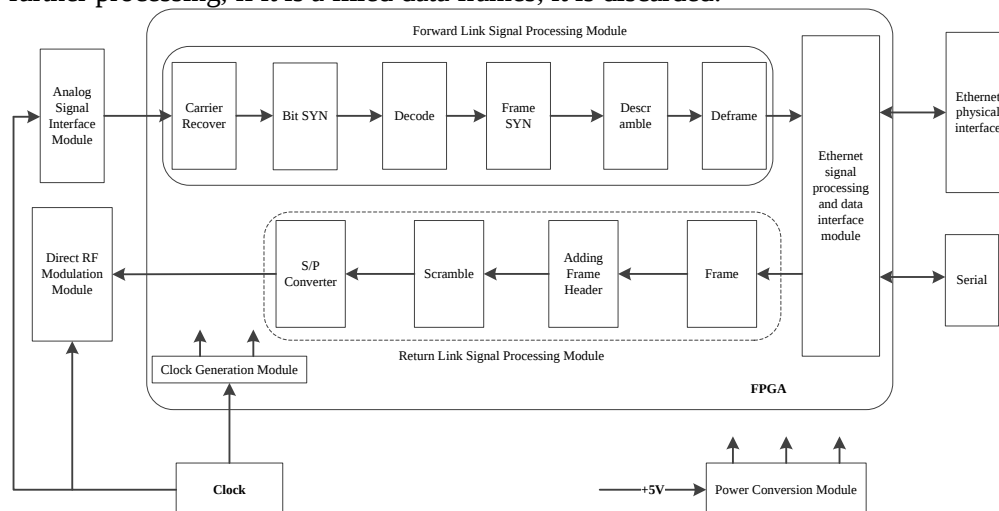


Figure 4. UAV data link terminal plan design

(2) The return link signal processing module includes functional modules such as framing, coding plus frame header, scrambling, and serial-to-parallel conversion. The framing packs the data packet from the Ethernet processing signal processing module into a fixed data frame with a fixed 1024-byte fixed frame length, and transmits a padding data frame when no data packet is sent. For code interleaving plus synchronization header, the coding method adopts RS coding. The sync header is 32 bits in CCSDS and it is expressed as 1ACFFC1D in hexadecimal. For scrambling, only the transmission frame data except the synchronization header is scrambled, the synchronization header is not scrambled, and the data scrambling is implemented by using an exclusive OR of the pseudo random code and the transmission frame data. The generator polynomial in the pseudo-random code generator is  $h(x)=x^8+x^7+x^5+x^3+1$ , which is repeated once every 255 bits. For sync header addition, this paper uses 32 bits specified by CCSDS, expressed in hexadecimal as 1ACFFC1D. Serial-to-parallel conversion means to convert one serial baseband data into IQ two baseband data. The IQ data is used as input data for the direct RF modulation module.

(3) Clock generation module is based on the 25MHz clock input from the temperature-compensated crystal oscillator, working clock with the working frequency of the 60MHz and the direct RF modulation module in the zero-IF signal processing module is generated by the DCM of the FPGA. At the same time, it is used to generate the required working clock in all the functional modules in the FPGA unit[10].

(4) The Ethernet signal processing and data interface module performs TCP packetization on the data packet after de-framed from the forward link, and sends out through the physical network interface; It extracts the TCP data packet from the physical network interface signal and sends it to return to the link processing module for processing.

(5) Through the serial port module, the remote command of the ground station is sent to control the flight state of the drone, and the working status information of the drone is received through the serial port, including the position information, flight status and remaining power of the drone, and then the information is sent to the ground station.

(6) The power conversion module realizes to convert the inputted +5V secondary voltage into the working voltage required by each major component in the circuit.

(7) The Ethernet physical interface realizes that the drone transmits video data to the ground station through the Ethernet physical interface.

(8) The analog signal interface module realizes analog signal digital conversion such as video and telemetry information, which can allow the circuit miniaturized.

(9) The direct RF modulation module allows that the baseband signal to be moved to the set L, S radio frequency signals.

### 3.3 Digital zero IF signal processing unit hardware implementation

The zero-IF signal processing module in the UAV data link terminal system mainly performs demodulation, de-frame, descrambling, decoding and interface control for the radio frequency signal, and realizes the high-rate rate picture transmission/data transmission reception. The hardware schematic is shown in 5.

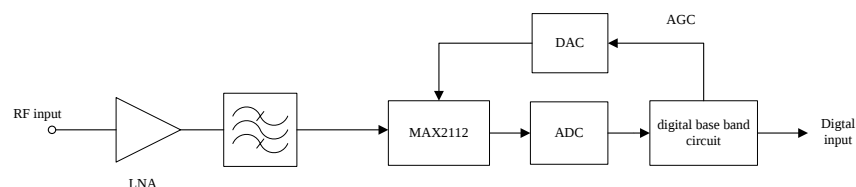


Figure 5. digital zero IF signal processing unit hardware schematic

The RF signal is sent to the zero-IF processing circuit module (MAX2112 chip) through the low noise amplifier and band pass filter, and the direct down conversion processing is performed through the chip. The chip integrates LNA, RF variable gain amplifier, I and Q down converting mixer, baseband low-pass filter with programmable cut off frequency and digitally controlled variable gain baseband amplifier. The chip realizes frequency synthesizer through 2-wire IIC serial port. For programming and device configuration, the external passive crystal provides a reference clock for the on-chip N-divider synthesizer. The RF signal is mixed with the local oscillator signal after passing through the low noise amplifier and the variable gain amplifier. The mixed signal is amplified by the digitally controlled variable gain amplifier, and then it passes through a programmable baseband low-pass filter with a cut off frequency. After the adjusted I/Q signal is blocked by the capacitor, two pairs of differential signals are output from the four ports. The two pairs of differential signals are converted into digital signals by AD sampling, and they are demodulated, decoded, and de-framed by the FPGA, and then the video data is sent to the ground control station through the network port, and the position information and flight of the drone are transmitted through the RS232 serial port, information such as status and remaining oil amount is sent to the ground station. At the same time, the signal processing

unit receives the control command through the serial port, and sends the received control command to the drone through the return link.

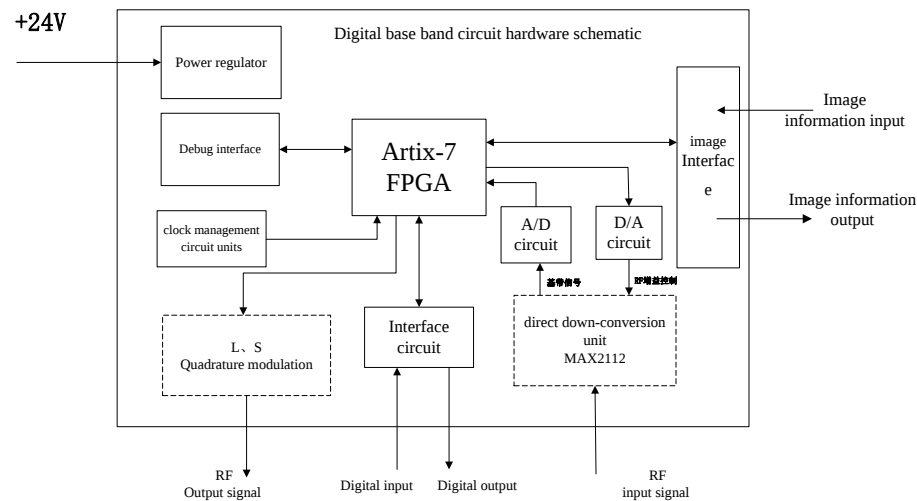


Figure 6. Digital baseband circuit hardware schematic

The digital baseband circuit function module is mainly composed of the Artix-7 series FPGA chip and related peripheral circuits. The circuit module implements clock management, digital AGC, RS encoding, decoding, framing, deframing, scrambling, descrambling, digital modulation, demodulation, RS232, SPI interface and other functions. In addition, the baseband circuit module is also designed with a full-board SMT package structure for integrating the quadrature modulation unit and the direct down-conversion unit.

As shown in Figure 6, the digital baseband circuit integrates A/D, D/A, related interface circuits, clock management circuit units, power management units, direct down conversion units, and FPGAs onto a single digital base band board, improving system integration degree. At the same time, in order to realize the closed-loop test of the entire communication link and improve the integration degree, the base band board integrates the RF orthogonal modulation transmitting unit, and the unit adopts the OQPSK direct modulation mode, and the base band signal is directly modulated onto the RF carrier, and the structure is simple, which is beneficial to realize the system Miniaturization.

On the drone, the remote control signal received from the ground by the RF front end is outputted by the low noise and zero intermediate frequency down-conversion, and the I and Q base band signals are respectively output in differential form. The base band signal with 150 kHz bandwidth is converted to a digital base band signal by an A/D sampling module. The digital base band signal is transmitted to the RS232 interface chip through the asynchronous serial interface after carrier recovery, bit synchronization, frame synchronization, descrambling, decoding, deframing, and serial protocol conversion in the FPGA chip, and the baud rate is 115200.

Compared with the receiving system on the aircraft, the radio front end of the ground transmitting link needs to receive flight state data from the drone, aircraft real-time position data information and image information, and the base band signal bandwidth is 10 MHz after the intermediate frequency down-conversion. Inside the FPGA chip, the digital base band signal needs to be separated after descrambling, and the different transmission frames are distinguished according to the virtual channel identifier at a specific position after the frame header, and the digital transmission frame and the picture transmission frame are separated.

In the digital intermediate frequency signal processing unit on the drone, the return link mainly transmits the combined video information and the telemetry information, and the forward link mainly completes the reception of the remote control command.

The secondary power conversion unit completes the DC operating voltage required to convert 220V AC to the whole machine.

#### 4. System experiment and verification

In order to verify the data link terminal performance of the One Station Controls Several Vehicles UAV, this paper constructs a prototype to carry out experimental demonstration.

(1) Test conditions: The UAV data link and test equipment are composed as follows: the equipment to be tested include the drone data link (3 sets), the ground terminal (1 set); the combined test equipment include directional coupler, Debug computer, spectrum analyzer, adjustable attenuator, debugging cable, network cable, shielding cabinet, camera, and network analyzer.

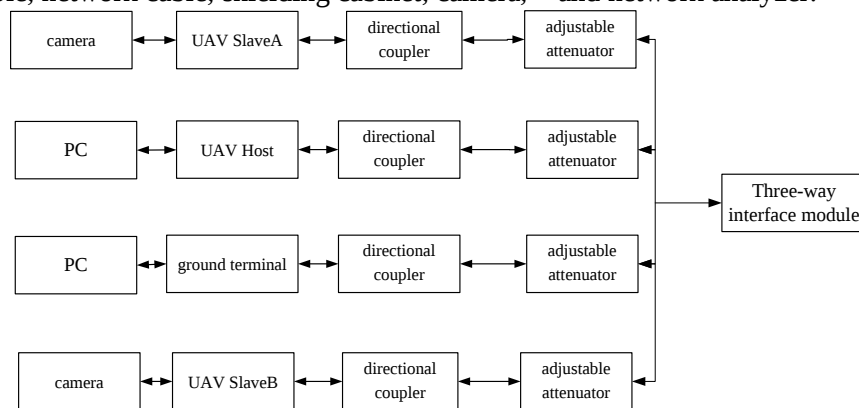


Figure 7. system test connection block diagram

(2) Test method: Connect the UAV data link and test equipment as shown in Figure 7, and connect to the power supply according to the requirements.

(3) Test simulation results and analysis

Step 1: The Ethernet port function test is completed according to the above figure. After power-on, the network debugging assistant on the PC is connected to the host A. The parameter configuration is as follows:

(1) Local receiving IP address: 192.168.1.100:1234; (2) Sending address: 192.168.1.70:1234.

(3) Transmit data: 33 33 32 64 3 FF DF AC; (4) Receive data: 33 33 32 64 73 FF DF AC;

Step 2: After power-on, this paper use the network debugging assistant on the PC connected to the ground terminal. The parameter configuration is as follows:

(1) Local receiving IP address: 192.168.1.70:1234; (2) Sending address: 192.168.1.100:1234;

(3) Transmit data: 31 36 34 64 73 6A; (4) Received data: 31 36 34 64 73 6A;

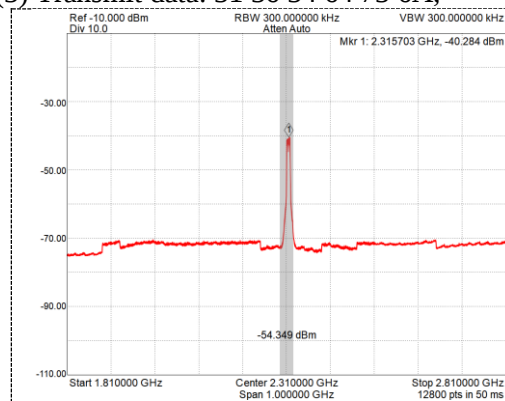


Figure 8. Host operating power performance test block diagram

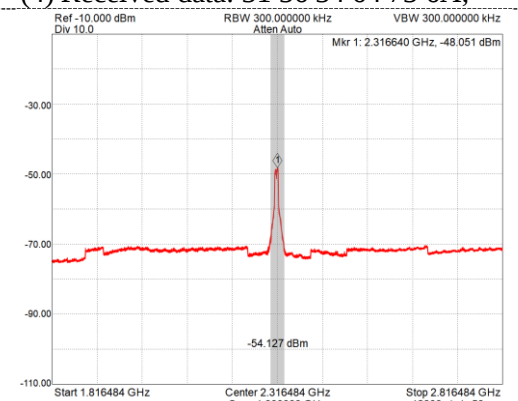


Figure 9. Ground terminal working power performance test block diagram

The third step refers to performance testing. According to the design requirements, the transmits power of host A in the UAV data link terminal is 37dBm, and the transmission power of other UAV

data link terminals are 30 dBm. Field test charts are shown in Figure 8 and Figure 9. To prevent the oversized input into the spectrum analyzer, this measurement adds 80dB attenuator.

The test results show that the communication system has 3 UAV terminals and 1 ground terminal; The signal-to-noise ratio is high in downlink from the terminal to the ground terminal and the uplink from the ground terminal to the terminal, and the ground terminal and terminal can receive and send data normally through the Ethernet interface. The working power of host A in UAV data link is 5w (37dbm), the working power in other UAV data links are 1w (30dbm), they all meet the design requirements.

## 5. Conclusion

The UAV data link terminal designed in this paper can meet the One Station Controls Several Vehicles dynamic networking communication needs for multi-task collaboration. This paper first studies the structure design for the communication protocol stack, combined with the hardware design in terms of the digital zero-IF signal processing unit, it carries out the indoor environment test for the terminal. The experimental data proves that the One Station Controls Several Vehicles dynamic networking UAV data link terminal meets functional indicators and performance indicators, and it is practical.

## References

- [1] TADIL. J. Introduction to Tactical Digital Information Link J and Quick Reference Guide [R]. AirLand Sea Application center 2000.
- [2] Naidoo Y, Stopforth R, Bright G. Development of an UAV for search & rescue applications[C]. IEEE AFRICON, 2011:1-6.
- [3] Cree.CGH40010F Data Sheet. [2014-04-14].<http://www.cree.com>.
- [4] Huang C, He S, You F, et al. Design of Broadband Linear and Efficient Power Amplifier for
- [5] Long-Term Evolution Applications[J]. IEEE Microwave & Wireless Components Letters, 2013, 23(12):653-655.
- [6] Luzzatto, Shirazi A, Gadi. Wireless Transceiver Design[J]. 2016.
- [7] Li Jinxi, DingYongfei, Fang Zheng. Key Techniques Research on UAV Data Link[J]. ProcediaEngineering, 2015, 99: 1099-1107.
- [8] Ezequiel C A F, Cua M, Libatique N C, et al. UAV aerial imaging applications for post-disaster assessment, environmental management and infrastructure development[C]. 2014 IEEE International Conference on Unmanned Aircraft Systems (ICUAS), 2014:274-283.
- [9] Zhang Tao, ChenYazhou, Cheng Erwei. Continuous wave radiation effects on UAV data link system[C]. 2013 IEEE Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC), 2013:321-324. Analog Device Inc.ADRF6702 Data Sheet. [2014-05-19].<http://www.analog.com>
- [10] Loke A, Ali F. "Direct Conversion Radio for Digital Mobile Phones –Design Issues, Status, and Trends"[J]. IEEE Trans. microw. theory Tech, 2002, 50(11):2422-2435.