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A Review Paper on High Definition, Full Duplex Video Transmission for UAV to Ground Data Link

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Abstract: **The rapid advancement of unmanned aerial vehicles (UAVs) has revolutionized various industries, offering unparalleled aerial imaging and data collection capabilities. However, the effective transmission of high-definition (HD) video data from UAVs to ground stations remains a critical challenge. Conventional methods often face limitations in terms of transmission range, bandwidth, and interference susceptibility. To address these concerns, this paper delves into the development of a high-definition, full-duplex video transmission system for UAVs, utilizing advanced radio frequency (RF) technologies and signal processing techniques. Apart from augmenting cellular networks, these devices are vital for a plethora of other domains, such as commerce, manufacturing, and the military. This project is to create a system that can send video across large distances quickly and without interference with other signals. Subsequently, the paper explores the theoretical underpinnings of full-duplex communication, examining the principles of signal processing, channel modeling, and interference cancellation techniques.**

Keywords: **Camera, ZedBoard@7000, AD9361, Wideband Dipole Antenna.**

1. INTRODUCTION

Unmanned Aerial Vehicles (UAV$_s$) are increasingly being used for an extensive array of applications. However, there is a problem in transmitting and receiving high-quality, low-latency video. An analog video transmission might have delays of several seconds and be loud and prone to interference [1]. SDR-based video transmission is a novel technique that offers several advantages over analog video transmission. Software-defined radio is a communication protocol that allows software to generate and process radio signals**.** Software-defined radio (SDR)-based video transmission offers several advantages over traditional analog video transmission systems. SDR systems can be customized to meet the specific needs of an application, and they can transmit high-definition video with low latency and high reliability. Additionally, SDR systems are more flexible than analog systems, allowing them to operate over a variety of frequencies and bandwidths [2],[3]. One promising SDR-based video transmission system is based on the Analog Devices AD9361 RF transceiver.SDR-based video transmission has the potential to revolutionize aerial photography, videography, and inspection by providing high-quality, low-latency video transmission. This enables drones to be used in a wider range of applications.

2. WIRELESS TRANSMISSION SYSTEM

Basically, Full duplex video Transmission consists of Camera, FPGA, AD9361, Wideband Dipole Antenna as shown in Fig.1:

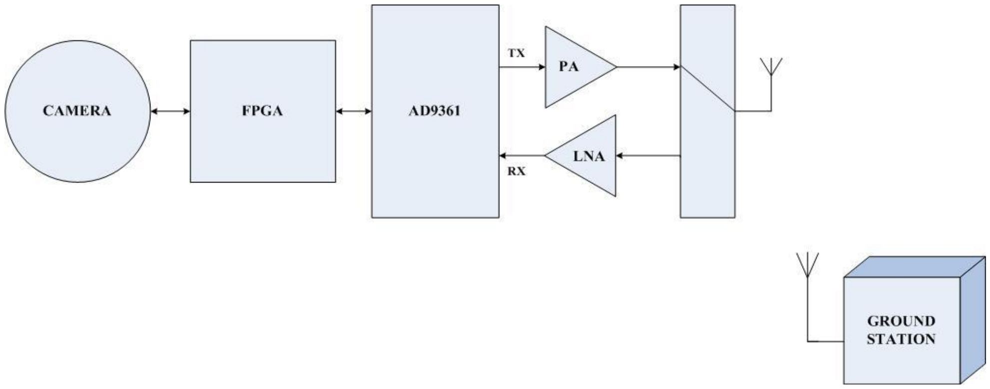

Fig.1 Block Diagram of Wireless Video Transmission.

Camera:

High-quality video cameras must have a minimum resolution of 720p, but 4K or 8K is recommended for optimal clarity. Additionally, a high frame rate of 60 frames per second or higher is required to provide smooth and continuous action in the video. Excellent low-light performance is also essential to capture readable and clear video in challenging lighting conditions, making high-quality video cameras ideal for a variety of scenarios. Meeting these requirements ensures reliable and high-quality video transmission [4].

FPGA ZedBoard@7000:

Zynq®-7000 All Programmable System on Chip (SoC) is the foundation of the low-cost, all-programmable development and prototyping platform ZedBoard. It provides engineers and hobbyists with access to the latest Xilinx FPGA and ARM processing technologies, offering a flexible and scalable platform for prototyping, and developing new products. The ZedBoard features a Zynq-7000 SoC with a dual-core ARM Cortex-A9 processor, a Xilinx Artix-7 FPGA, 1 GB of DDR3 memory, and various peripherals, including Ethernet, USB, HDMI, and GPIO. It also includes a microSD card slot, a JTAG connector, and various expansion ports [5],[6].

The ZedBoard is a popular choice for a variety of applications, including:

I. FPGA development**:** The ZedBoard can be used to develop and prototype new FPGA applications, such as image processing, video processing, and signal processing applications.

II. ARM development: The ZedBoard can be used to develop and prototype new ARM applications, such as embedded systems, robotics, and IoT applications.

III. Machine learning: The ZedBoard can be used to develop and deploy machine learning models.

IV. Computer vision: The ZedBoard can be used to develop and deploy computer vision applications, such as object detection and tracking applications.

The ZedBoard is a powerful and versatile development platform that can be used for a wide range of applications. It is a popular choice for engineers and hobbyists alike, and it is a great way to get started with FPGA and ARM development.

AD9361 Transceiver:

The AD9361 is a high-performance RF transceiver with a wide frequency range of 70 MHz to 6 GHz, a high data rate of up to 500 Mbps [7], and low latency, making it ideal for UAV video transmission. Its small form factor and power efficiency are also well-suited for UAV applications. The AD9361 also includes a number of other features, such as integrated frequency synthesizers, digital signal processing (DSP) capabilities, and a flexible interface to a processor. The AD9361 is often used in conjunction with a microcontroller or FPGA to control its settings and to process the digital data it generates.

LNA and PA

(I). LNA (Low Noise Amplifier): An LNA is used to amplify the weak signal received from the antenna before it is processed by the receiver. This is important because it helps to improve the signal-to-noise ratio (SNR) of the received signal, which in turn improves the sensitivity and performance of the receiver. (II) PA (Power Amplifier): A PA is used to amplify the transmitted signal before it is radiated by the antenna [8],[9]. This is important because it helps to increase the range and (Powerlity of the wireless communication system. In UAV video transmission systems, LNAs amplify the received video signal from the UAV camera, and PAs amplify the encoded video signal before transmission to the ground station. LNA and PA selection is important for system performance in terms of range, reliability, and image quality [10].

Wideband Dipole Antenna Array

A wideband dipole antenna array with a bandwidth of 4-6 GHz is a type of antenna that consists of multiple dipole antennas arranged in a specific way. This type of antenna is designed to have a wide bandwidth, meaning that it can operate over a wide range of frequencies [11],[12].

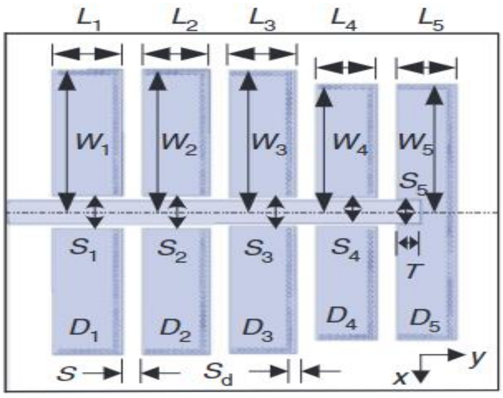

Fig.2 Wideband Dipole Antenna.

Although WDAAs can be created in many different ways, they all have a number of features in common. To obtain the intended bandwidth and radiation pattern, the dipole antennas are first placed in a particular configuration. Secondly, the power feed to the dipole antennas has been optimized to reduce mutual coupling. This is significant because mutual coupling has the potential to skew antenna patterns and lower array efficiency.

Ground Station:

The main component of a transmission system is the ground control station (GCS). The GCS is the central hub for drone operations and the human-machine interface (HMI) of the entire system. From the GCS, the operator can monitor the drone's performance during flight and control its payload, such as a camera.

3. WORKFLOW

A UAV captures video footage using its onboard camera. The video footage is encoded by an FPGA using a suitable video coding/decoding standard, such as H.264 or MPEG-4. The encoded video data is then transmitted to the ground station using an AD9361 transceiver. The ground station receives the encoded video data and decodes it using the same video coding/decoding standard that was used on the UAV. The decoded video data is then displayed on a monitor at the ground station [13]-[16].

4. IMPLEMENTATION

4.1 Interfacing of camera with FPGA

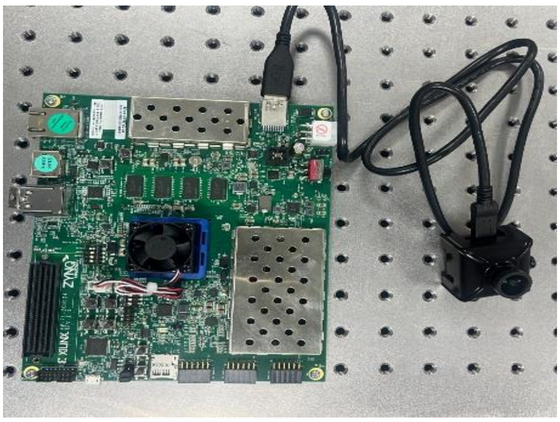

Fig.3 Interfacing of Camera with FPGA

In order to interface a camera with an FPGA (Field-Programmable Gate Array), a camera module must be connected to the device, and the hardware and software required for image data capture and processing must be implemented [17]. In Fig.3 it typically includes configuring the camera's interface, such as MIPI or parallel, and writing FPGA code to control the camera, receive image data, perform image processing tasks like filtering or object recognition, and possibly display or transmit the processed images [18]-[21]. Efficient interfacing requires careful consideration of data bandwidth, synchronization, and memory management, and it is a critical aspect of various applications, such as robotics, computer vision, and industrial automation, where real-time image processing is essential.

4.2 Interfacing of FPGA to AD9361

Fig.4 Interfacing of AD9361 With FPGA

The interfacing of the AD9361, a highly integrated RF transceiver chip, with an FPGA involves connecting the AD9361 to the FPGA's high-speed data interfaces, typically utilizing interfaces such as JESD204B or LVDS as shown in Fig.4 [7]. This connection enables bidirectional data transfer between the FPGA and the AD9361, allowing the FPGA to control the transceiver's parameters and process received RF signals. Additionally, software-defined radio (SDR) frameworks like the Xilinx Zynq platform can simplify this interfacing by integrating the FPGA and ARM processor, providing a seamless environment for developing SDR applications [22]-[28]. The FPGA configuration and data processing logic are then designed to manage the AD9361's RF functions, making it a crucial element in modern wireless communication systems and SDR applications.

5. CHANNEL LOSS MODEL

A channel loss model in wireless communications is a mathematical model that predicts the amount of power lost as a signal travels through the wireless channel [29],[30]. This loss is caused by a variety of factors, including:(I) Distance: The further the signal travels, the more power it loses. (II) Environment: Obstacles in the environment, such as buildings, trees, and hills, can reflect, diffract, and scatter the signal, causing power loss. (III) Frequency: Higher frequency signals are more susceptible to path loss than lower frequency signals. (IV) Antenna height: The higher the antenna, the less power loss is experienced. (V) Terrain: The terrain type can also affect path loss. For example, urban areas typically have higher path loss than rural areas. (VI) Weather conditions: Weather conditions such as rain, fog, and snow can also increase path loss.

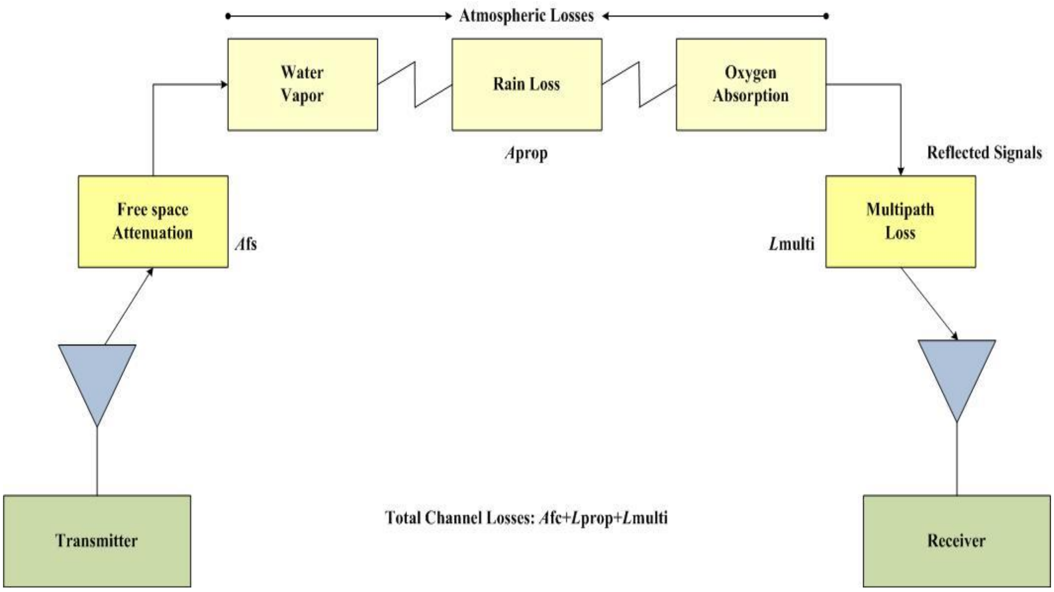

Fig.5 Channel Loss Model

The wireless communication channel-loss model is shown in Fig. 5. The minimum input signal (S_{min}) required to demodulate or extract the information from the transmitter is usually utilized for determining the receiver's sensitivity. In this case, the receiver sensitivity is -95 dBm. Once the receiver sensitivity has been determined, the maximum transmission distance can be calculated by applying the following assumptions:

$$S_{min} = 10\,log(kT_0B) + NF + \left(\frac{S}{N}\right)min = -174dBm + 10 \log \mathrm{B} + NF + \left(\frac{S}{N}\right)min \qquad (1)$$

Where, $(S/N)_{min}$ is the minimum signal-to-noise ratio needed to process a signal.NF is the noise figure of the receiver. K is Boltzmann's constant = 1.38×10^{-23} joule/k.T_0 is the absolute temperature of the receiver input (Kelvin) = 290 K.B is the receiver bandwidth (Hz).

6. CONCLUSION

This paper proposes a new method for high-definition wireless video transmission using an FPGA and the AD9361 RF transceiver. This solution is more stable and reliable than traditional methods because it can quickly switch between frequency bands, and more flexible because it uses two-way transmission to reduce latency. To deal with the more complicated radiation in space and lower the likelihood of a crash, it is possible to create a more solid and dependable wireless link. Using a two-way broadcast to shorten the wireless developing time and establish a low latency connection, the protocol layer conduct is flexible. It is perfect for commercial and industrial uses where robust, secure, and dependable communications are necessary, like surveillance, power-line inspection, and agriculture.

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