

Vilnius University

Faculty of Physics

Institute of Applied Electrodynamics and Telecommunications

Yilong Liu

HIGH-DEFINITION VIDEO WIRELESS DATA TRANSMISSION LINK IN W-BAND

Master's Thesis

Electronics and Telecommunications Study Program

Student	Yilong Liu
Approved	2026-05-22
Reviewer	dr. Domas Jokubauskis
Academic Supervisor	prof. dr. Alvydas Lisauskas
Director of the Institute	prof. dr. Robertas Grigalaitis

Vilnius 2026

Table of contents

Introduction	2
1. A Review of W-band Wireless Video Transmission Systems	3
1.1 Real-Time Wireless Video Transmission.....	3
1.2 Serial Digital Interface.....	4
1.3 W-Band Signal Generation.....	6
1.4 Existing W-Band Video Transmission Systems.....	8
2. System Design and Implementation	9
2.1 Component Part	9
2.2 Cable-Connected Link Transmission System Design	12
2.3 Wireless Transmission System Design.....	15
2.4 The Methods of Experiment	18
2.5 Experimental Device Summary	20
3. Experimental Result	22
3.1 Frequency Multiplier Linearity Test.....	22
3.2 Cable-Connected Link System Verification.....	24
3.3 Wireless W-Band Link System Verification	27
Future Work.....	30
Conclusions	31
Summary.....	32
Santrauka	33
References	34

Introduction

There is much interest in HD video transmission in modern broadcasting and wireless real-time communications due to growing demands for ultra-high rates and low latency in today's world[1]. Traditional wireless communication systems under 6 GHz suffer from scarcity of spectrum space and thus experience problems in satisfying future needs for high-speed multimedia transmission[2].

W-Band millimeter-wave communications (75-110 GHz) have been considered an effective approach since it allows for wide bandwidth usage at this frequency band[3][4]. Nevertheless, the realization of wireless systems operating at W-band frequencies is difficult owing to the significant losses during propagation, hardware complexities, and the challenges of RF system integration at high frequencies[5].

The generation of the W-band can be achieved through a mixer and frequency multiplier structure[6]. Using a W-band down-conversion mixer at the receiving end is a method to obtain the baseband signal at the receiving end[7].

After reviewing architectures that were applicable to the W-band launch, we turn our attention to architectures that are appropriate for the transmission of high-definition video signals. For transmitting uncompressed real-time video, using Serial Digital Interface (SDI) is a good choice. It supports various high-definition video formats and bitrates[8].

This work realizes a complete HD video in W-band system transmission solution and successfully achieves high-fidelity video reproduction at the receiving end. The study covers spectrum analysis of the video signal source and its subsequent RF up-conversion until eye diagram analysis is performed on the final W-band receiver output. To support real-time high-definition video, commercial HDMI-to-SDI and SDI-to-HDMI conversion modules are integrated to achieve stable interfacing.

The aim of this work is to build a W-band wireless link, successfully transmit real-time HD video sources, and reproduce real-time video at the terminal. It is proved that the system can maintain signal integrity.

1. A Review of W-band Wireless Video Transmission Systems

1.1 Real-Time Wireless Video Transmission

High-definition video transmission requires high data rates determined by video resolution, frame rate, and color depth[9]. Recent studies have also highlighted the growing demand for QoS-guaranteed real-time video transmission[10].

Due to the limited availability of spectrum resources in sub-6 GHz bands, conventional wireless communication systems operating in these congested frequency ranges are increasingly unable to satisfy the stringent and diversified requirements of future wireless services[2]. In this context, millimeter-wave communication has emerged as a promising solution, owing to its abundant spectrum resources and its capability to support high-data-rate transmission as well as large-scale multi-antenna systems[2].

In order to improve the transmission capability, sub-THz and THz communication systems have been widely studied. Experimental tests have shown that a wireless link using THz technology can provide multi-Gbps real-time transmission speeds. Specifically, a 0.22 THz system is able to transmit at an incredible speed of 84 Gbps for a distance of 1.26 km, providing real-time transfer of uncompressed 8K ultra-high-definition video streams[11]. As seen from Figure 1.1.1, these experiments prove the possibility of designing real-time video transmission systems based on THz technology[11].

In view of the above, communication bands with higher frequencies, such as millimeter-wave, sub-terahertz, and terahertz, are highly considered to be important facilitators of future high-capacity video communication systems.



Figure 1.1.1. A real-time 8K wireless video transmission system[11].

1.2 Serial Digital Interface

Serial Digital Interface (SDI) transmission is a great choice for real-time video transmission[8]. While transmitting, HDMI signal converts into SDI signal by using HDMI to SDI converter. In the same way, live video can be recovered by an SDI to HDMI converter[12].

The input signal is a High-Definition Serial Digital Interface (HD-SDI) stream with a data rate of 1.485 Gbps[14]. For The (3G-SDI) stream, according to the Society of Motion Picture and Television Engineers (SMPTE) ST 424 standard, the data rate of this interface is set at 2.97 Gbps[13].

SDI is composed of a luminance signal and two chrominance signals (Y/CBCR) that are multiplexed in the time domain. The format of the HD-SDI data stream is both EAV and SAV are parallel Y/CBCR data streams. So EAV and SAV signals in a multiplexed HD-SDI data stream are 8 bytes long each[15].

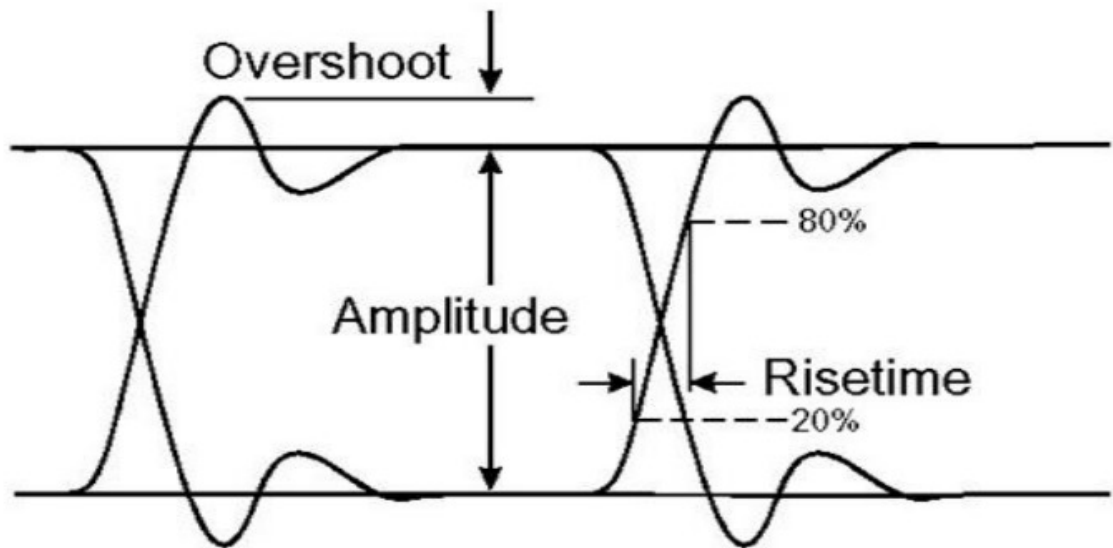


Figure 1.2.1. SDI signal waveform measurement dimensions[13]

Connected to 1m coaxial cable and then to SDI signal generator (The 75-ohm resistor), In practice, the signal can deviate from the perfect. So we will define some parameters to evaluate the quality of the signal, as it is shown in Fig 1.2.1. These are measurement parameters that describe the amplitude, the rise time and the overshoot[13][14].

For the HD-SDI signal standard, the amplitude of the signal shall be $800 \text{ mV} \pm 10\%$ from peak to peak. The dc offset defined as the mid-amplitude point, the signal is nominally $0.0 \text{ V} \pm 0.5 \text{ V}$. The rise

and fall times, measured at the 20% and 80% points of the amplitude, shall not exceed 270ps, and they shall not be different by more than 100ps. Overshoot of the rising and falling edges of the waveform shall be no more than 10% of the amplitude[13].

For the 3G-SDI signal standard, Amplitude of signal level of the 3G-SDI signal shall be $800\text{mV} \pm 10\%$ in peak-to-peak. The DC offset, i.e. signal midpoint, is $0.0\text{ V} \pm 0.5\text{ V}$ nominally. The rise and fall times (20% - 80% points) must not exceed 135ps, and the difference of each width must be less than 50ps. The overshoot on the rising and falling of a waveform should be less than 10% of the amplitude[14].

The measurement of the SDI signal is mainly based on eye diagram to indicate the quality of digital signal[16][17]. Both eye height and eye width are important parameters for measuring the quality of eye diagram[34]. An eye diagram of a 3G-SDI signal shown in Figure 1.2.2.

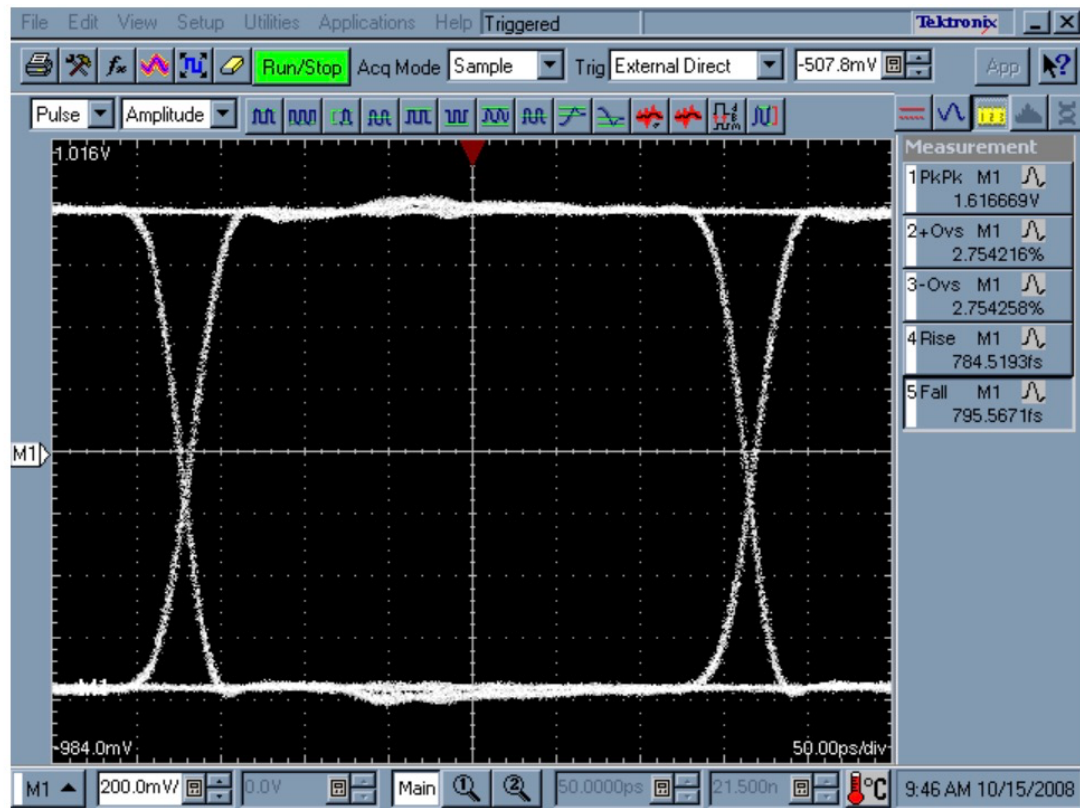


Figure 1.2.2. An eye diagram of a 3G-SDI signal[17]

1.3 W-Band Signal Generation

Direct generation of stable signals at the W-band frequency range has some limitations because of the restrictions posed by high-frequency oscillator-based signal generation circuitries that have limitations regarding phase noise, output power, and frequency stability[18]. Thus, to provide for high-speed communication at the millimeter-wave regime, IF architecture is employed, followed by frequency up conversion using mixers to the W-band range[19].

As a core subsystem in modern electronic architectures, the radio frequency (RF) receiver plays a crucial role in efficient signal reception and processing. A typical RF receiver architecture integrates a low-noise preamplifier, intermediate-frequency (IF) amplifier, mixer, local oscillator (LO), and bandpass filtering stages to perform signal amplification, selection, and frequency conversion[20]. Within this architecture, the mixer is a key functional block that enables frequency translation between RF, IF, and baseband domains for both down conversion and up conversion[20].

The RF up conversion stage is a key functional block in the proposed W-band wireless video transmission system, responsible for translating the intermediate-frequency (IF) modulated video signal into the radiofrequency (RF) domain for subsequent millimeter-wave processing and transmission.

As a key nonlinear element in frequency conversion systems, the mixer enables spectral translation by exploiting its intrinsic nonlinear characteristics[20]. A typical three-port mixer consists of an RF input, a local oscillator (LO) input, and an IF output, where frequency conversion is achieved through nonlinear interaction between the RF and LO signals[20].

Then if the mixer is also crucial for this structure. The principle of mixer is mixing operation generates both sum and difference frequency components, and the desired RF signal is obtained by selecting the sum-frequency component[22].

Conversion loss is one of the key performance metrics of a mixer and is defined as the power difference between the input RF signal and the desired output IF signal[24]. The most important mixer metric is conversion loss, which is defined as the difference in power between the input RF power level and the desired output IF frequency power level[23].

In modern electronics-based systems, the RF receiver is one of the essential subsystems and acts in an efficient way when it comes to the processing and receiving of signals. As seen from Figure 1.3.1, the structure of the RF receiver usually consists of such components as a low-noise pre-amplifier, IF

amplifier, mixer, LO, and a band pass filter[20]. Within the aforementioned architecture, the mixer plays an essential role in performing frequency conversions from RF to IF to baseband and vice versa[20]. It should be noted that accurate frequency conversion depends on proper synchronization with the local oscillator (LO) that is produced by a voltage-controlled oscillator (VCO) operating at the RF level [20]. Due to its critical role in determining receiver performance, the design of high-performance mixers with low noise, low power consumption, and high linearity is essential for modern communication systems.

In frequency conversion architectures, nonlinear mixing in RF mixers can lead to conversion loss and the generation of undesired spurious components due to device nonlinearity[21]. Furthermore, when low-frequency reference signals are extended to the W-band using frequency multiplication techniques, phase noise is inherently degraded in proportion to the multiplication factor, following the well-known $20\log N$ relationship[24]. This result impacts signal-to-noise ratio[25]. Therefore, careful RF front-end design is essential for W-band communication systems.

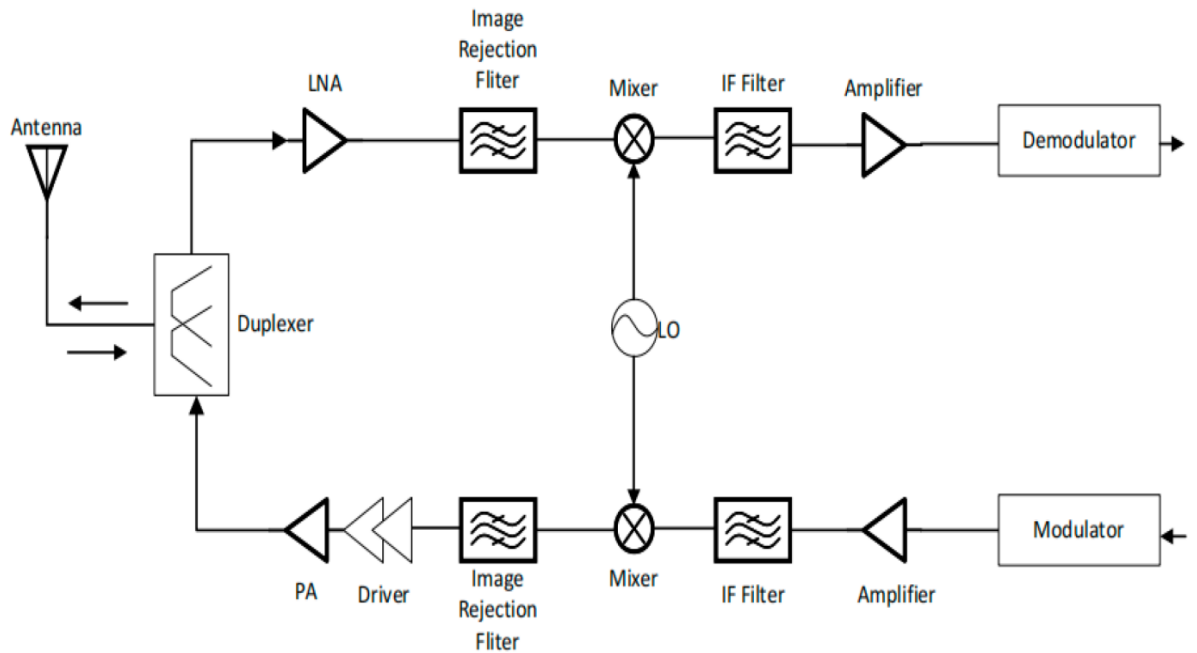


Figure 1.3.1. Schematic diagram of RF transceiver system.[20]

1.4 Existing W-Band Video Transmission Systems

Current W-band research is largely focused on system-level experimental demonstrations, including radio-over-fiber transmission links and PRBS-based performance evaluation to verify high-frequency signal propagation feasibility[26]. Photonics-assisted techniques further enable high-capacity W-band signal generation and fiber-wireless integration, supporting multi-gigabit transmission and seamless compatibility with optical communication networks[27][28].

Recent representative work has demonstrated end-to-end W-band wireless transmission systems capable of real-time uncompressed HD video delivery over 100 GHz links and transmission distances can reached 2 km. This work Based on All-Optical Frequency Up- and Down-Conversion.[1].

In addition, recent experimental studies have also reported photon-assisted W-band signal generation and fiber-wireless transmission systems based on OFDM modulation, achieving improved spectral efficiency and robust physical-layer performance under high-frequency conditions[27][28] .

As shown in Figure 1.4.1, a typical indoor W-band transmission setup includes both all-electric and all-optical receiver configurations, providing a complete system-level experimental framework for practical validation[1].

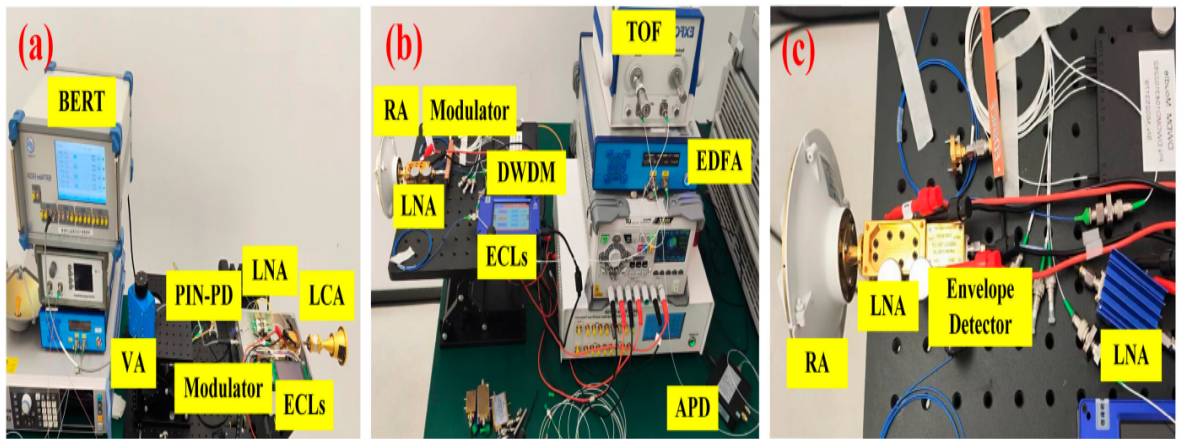


Figure 1.4.1. A typical indoor W-band transmission system. [1]

2. System Design and Implementation

2.1 Component Part

As far as the system viewpoint is concerned, SDI is known to be CBR. This transmission format guarantees deterministic behavior as well as signal stability and timing in real time, which plays a key role in performing tests related to the measurement of the bit error rate and the radio frequency system interface[29].

When we consider using SDI to transmit live video, then HDMI to SDI is a very good option. Black Magic mini converter because its reasonable price and good quality make it a great choice. This particular device can be used for transfer HDMI to SD, HD, and even Ultra HD signals up to 12G-SDI. Re-clock and equalization features incorporated in this particular converter are essential since they help to compensate jitter and improve the temporal stability of the digital signal before its RF modulation. After power supply and HDMI source are plugged in, the device sends a signal via the SDI OUT connection to an up-conversion process. The front-panel LED indicator helps to understand the current state of the device – the white LED lights up when power is on and green one when there is a valid video source[30].

At the other end of the wireless transmission, a complementary Blackmagic SDI to HDMI Converter is used to restore the video before its display. The module takes the de-converted signal through a process of equalization, which converts it back to its HDMI equivalent, ready to be displayed on any high-definition screen. Just like the transmitter, the indicators of the receiver show whether the video transmission was restored successfully. A green indicator denotes that a data rate of 2.97 Gbps has been received successfully by the receiver[30].

In this work, frequency conversion architecture use for transmitting High-Definition video through microwave wireless links. The input signal is a 3G-Serial Digital Interface (3G-SDI) stream with a data rate of 2.97 Gbps, as specified in the SMPTE ST 424M standard[14]. As shown in the figure 2.1.1, the tests of the two converters were successful. HDMI passes through the HDMI to SDI converter from the source of the laptop and is then connected to the SDI to HDMI converter by wires. Finally connect the display. Complete the successful test of this basic equipment.



Figure 2.1.1. Conversion and testing of HDMI and SDI

In this work up conversion in this work is implemented using the broadband double-balanced mixer ZX05-24MH-S+, which is selected based on its demonstrated performance within the 14–17 GHz LO operating range required for the subsequent $\times 6$ frequency multiplication stage. With consistent conversion loss in the range of approximately 6–9 dB[31]. The mixer ZX05-24MH-S+ is shown in the figure 2.1.2.

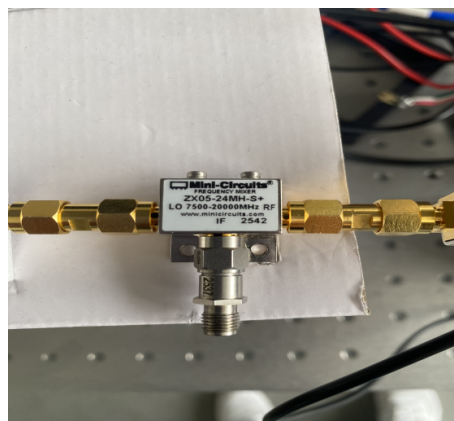


Figure 2.1.2. Mixer ZX05-24MH-S+

For the x6 frequency multiplier, we use a commercial module, including both the transmitter and receiver. The transmitter section can transmit the local oscillator frequency multiplied by six to the W-band, as shown in the Figure 2.1.3. The receiver is also a six-fold frequency receiver, with a built-in down-conversion mixer and a configured LO port. The signal at the baseband frequency can be obtained at the IF port, as shown in the Figure 2.1.4.

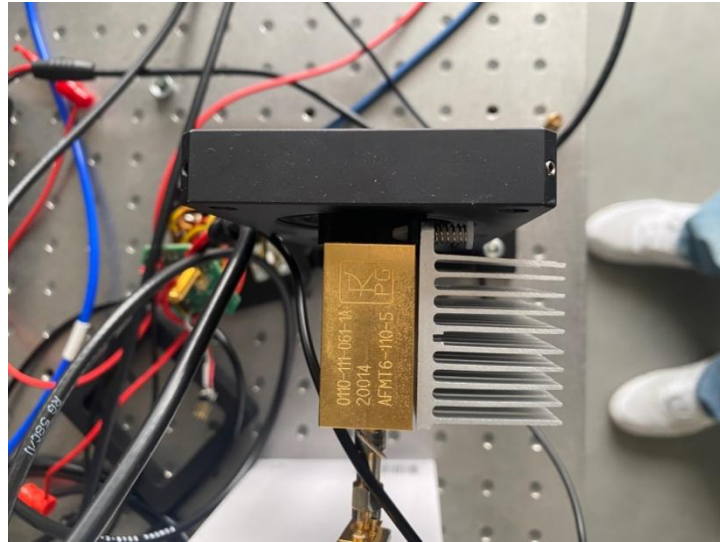


Figure 2.1.3. Commercial six-fold frequency transmitter

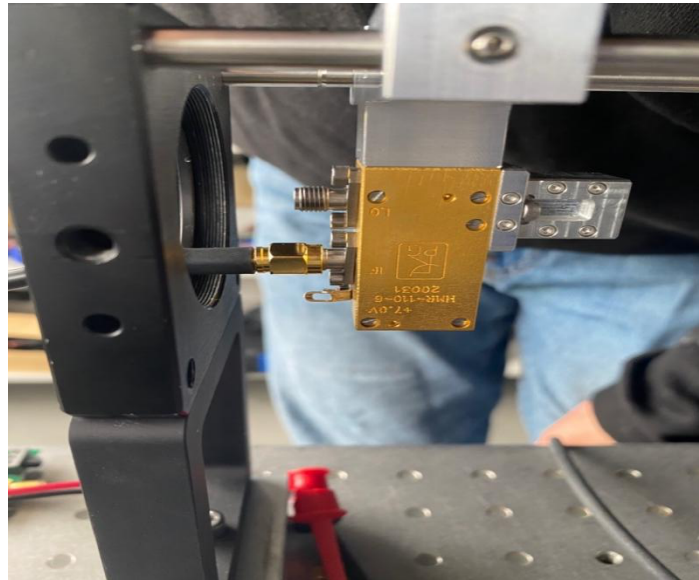


Figure 2.1.4. Commercial six-fold frequency receiver

2.2 Cable-Connected Link Transmission System Design

Prior to conducting the complete over-the-air transmission test for the W-band system, a conducted Cable-connected measurement system is first set up to verify the correct functioning of the RF front-end in a controlled environment.

Here, the wireless channel is substituted with a coaxial transmission line, directly coupling the output of the transmitter to the down-conversion mixer at the receiver end.

This receiver side-mixer makes use of the same local oscillator (LO) frequency reference source to ensure that there is coherent frequency between the transmission and the receiving end. Down-conversion results in the production of an intermediate frequency (IF), which can be analyzed using a spectrum analyzer.

When building the link, we first consider providing an HDMI source, converting it through a converter, and then sending it to the IF end. Then a frequency synthesizer is used to provide the local oscillator frequency for the mixer. Then connect a down-conversion mixer for testing. It should be noted that the down-conversion uses the same local oscillator frequency as the transmitting side. As shown in the Figure 2.2.1.

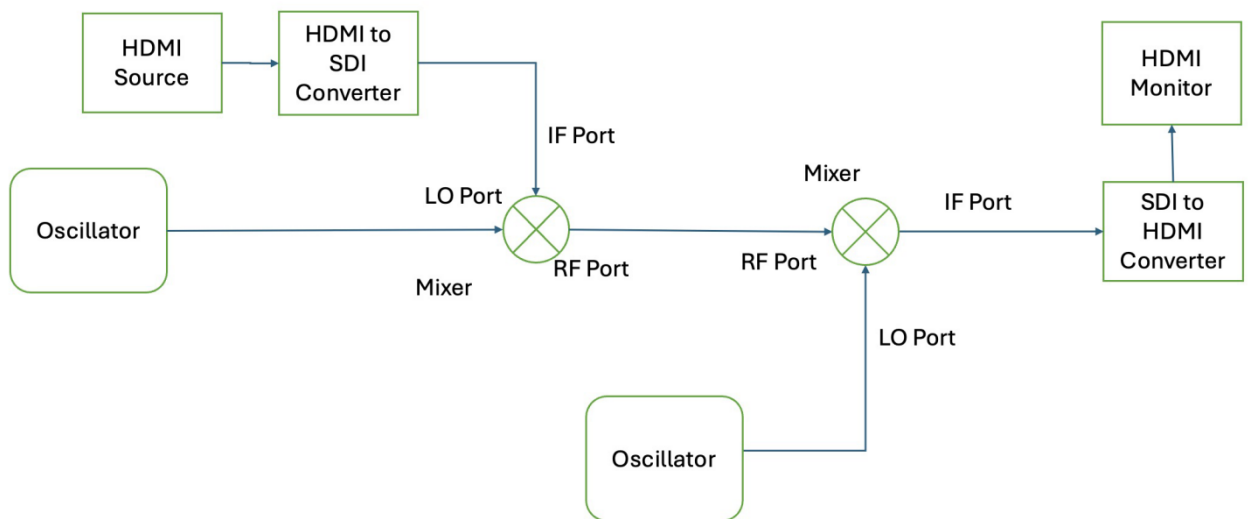


Figure 2.2.1. Architecture diagram of a Cable-connected system

For our testing, the first thing to consider is a frequency synthesizer that can emit a stable local oscillator frequency. Synthesizer LMX2592EVM is a frequency synthesizer capable of transmitting up to 20GHz. Its biggest advantage is that it can be connected to your computer via a single USB

cable, and the transmission frequency can be changed using the accompanying software, TICS PRO, which is very convenient. As shown in the Figure 2.2.2, The mark 1 and 2 are power supplies, both requiring a 3.3V power supply with a maximum of 600mA. The mark 3 shows the USB port, which allows connection to a computer for frequency changing. The mark 4 and 5 show the frequency output ports[33].

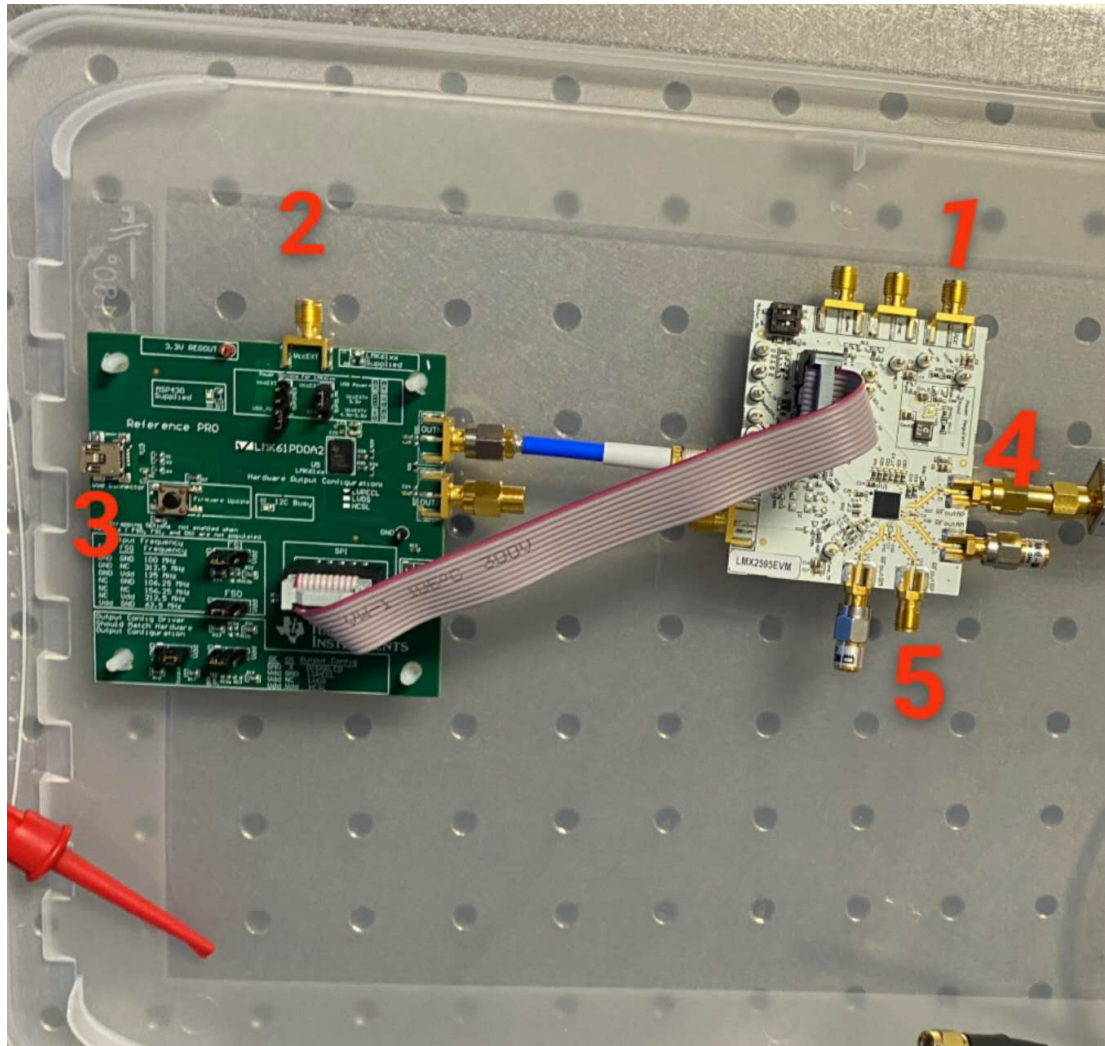


Figure 2.2.2. LMX2595EVM Synthesizer

But there are many unacceptable losses in our physical experiments, like cable losses. So, a real experiment, sometimes we use amplifier to compensate power. So, the basic scheme of our successful final experiment is that the local oscillator frequency is provided by different ports of the same Synthesizer. An Amplifier is inserted into the Synthesizer frequency output port 1, then connected to an up-converter Mixer. Next, an Amplifier provided at the RF end of the up-converter Mixer. Then connect the RF terminal of the down-conversion Mixer to maintain the stability of the link power. Then, an Amplifier is connected to the output port 2 of the Synthesizer. It can supply the local

oscillator frequency for the down converted mixer. Finally, the up-conversion Mixer is attached to the HDMI to SDI converter, and the down-conversion Mixer is connected to the SDI to HDMI converter. Achieve the Cable-connected high-definition video repro. As shown in the figure2.2.3.

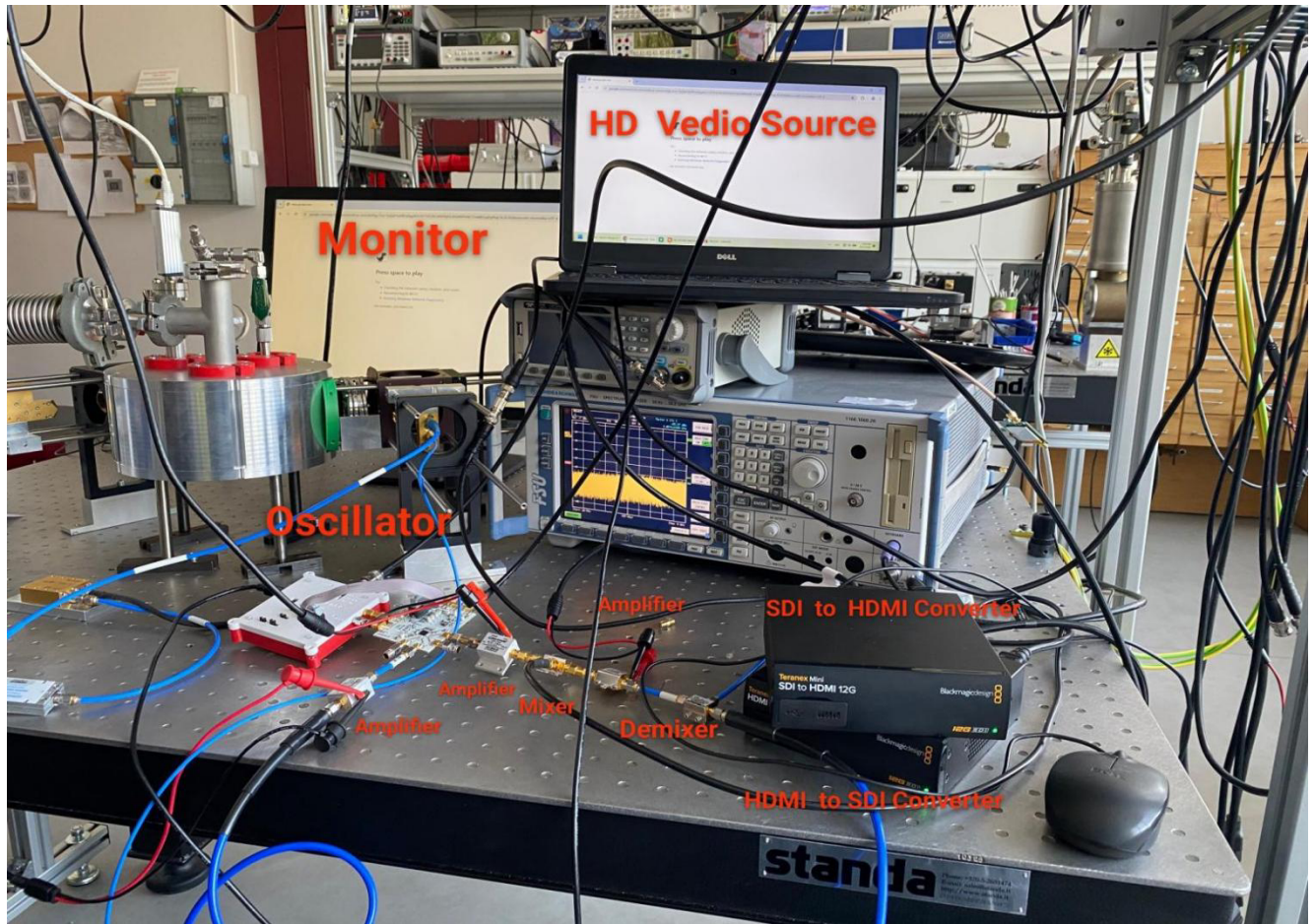


Figure 2.2.3. Experimental of the Cable-connected system

2.3 Wireless Transmission System Design

The proposed W-band wireless transmission system is configured based on the Cable-connected topology comprising of a transmitter, a free-space wireless channel, and a receiver with embedded down-conversion facility as illustrated in Figure 2.3.1.

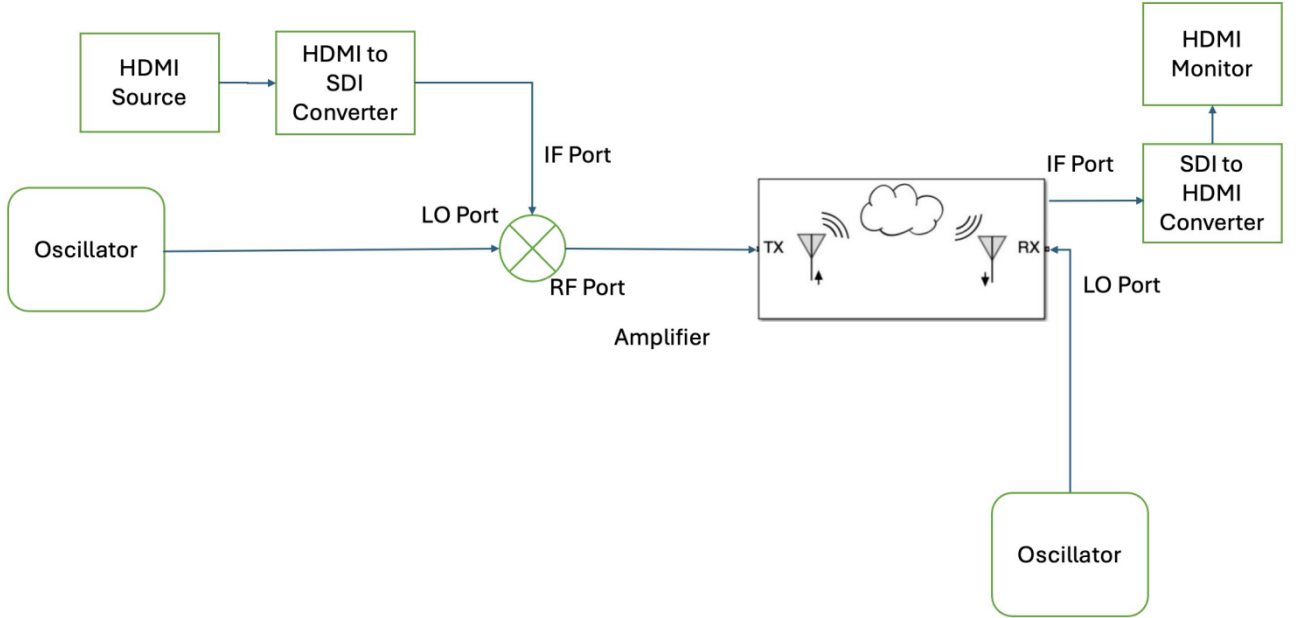


Figure 2.3.1. Architecture diagram of a W-Band Wireless system

At the experimental end, we need to ensure the power stability of the link, so power compensation should be carried out for the design we have proposed.

In the transmitter section, the IF carrier modulated with the HD video signal is mixed with LO signal using a nonlinear mixer circuit. The LO signal is provided by a common frequency oscillator and is delivered to both the transmitting and receiving sections via a power splitter circuit for frequency synchronization at both sides.

The branch that connects to the transmitting mixer on the other end of the splitter, whereas the branch goes to the receiving side and acts as a common reference point for LO. The frequency synchronized nature of the shared LO helps in coherently converting signals down at the receiver side.

The process of frequency up conversion leads to the production of RF signals that subsequently go through the transmit chain, which entails the process of amplification and multiplication of the signal by six times, ultimately leading to the transformation of the signal into the W-band frequency range.

On the other hand, the received W-band signal is collected through a receiving antenna which in turn feeds the down-conversion unit that consists of an inbuilt mixer and local oscillator interface. Therefore, external mixer hardware is not required at the receiver, as frequency down-conversion is performed internally within the integrated receiving front-end.

The down-converted signal is then analyzed using a spectrum analyzer to evaluate signal integrity and transmission performance. Although the receiver architecture is integrated, the system-level block diagram explicitly represents the mixer stage to maintain clarity in illustrating the full RF signal chain from up conversion to down conversion.

This architecture enables a complete end-to-end W-band wireless transmission link and provides a practical experimental platform for evaluating high-frequency RF signal propagation and system-level performance under real high-definition video transmission conditions. As illustrated in Figure 2.3.2.

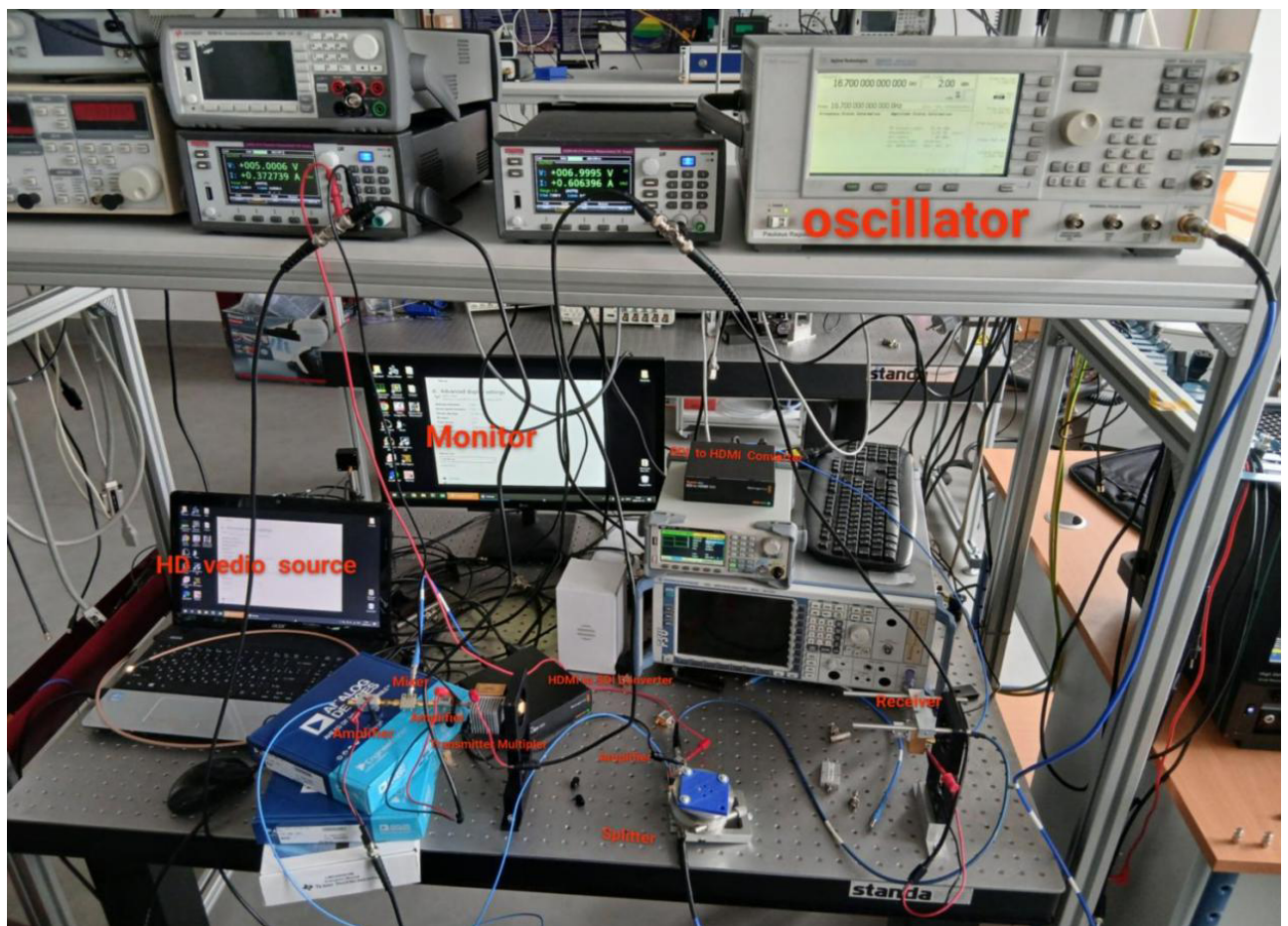


Figure 2.3.2. Experimental of a W-Band Wireless system

When conducting wireless link testing, we can adjust the frequency and power of the oscillator. The oscillator we used in our W-band wireless link testing was the Agilent E8257D PSG analog signal generator. Because the W-band loss is significantly higher than Cable-connected loss, we needed a stable and high-quality frequency source. Therefore, the oscillator we used was the Agilent E8257D PSG analog signal generator, which can stably provide the required frequency and has adjustable output power.

We can use an arbitrary waveform generator instead of our HDMI to SDI converter. We can simulate the transmission of an SDI signal to the arbitrary waveform generator using MATLAB, specifically a two-level square wave. This simulated signal is then transmitted to the IF port of the upconverter mixer, and the LO frequency and oscillator output power are adjusted. At the receiving device, we can see a clear two-level time-domain signal and an open eye diagram, indicating that we can potentially achieve video transmission at this local oscillator frequency and with sufficient link budget.

Next, we replace the IF port of the upconverter mixer with the port of our HDMI to SDI converter for further testing. When we tuned it to 16.7GHz and 2dBm, we successfully achieved high-definition video transmission over the wireless link, as shown in the figure 2.3.3.

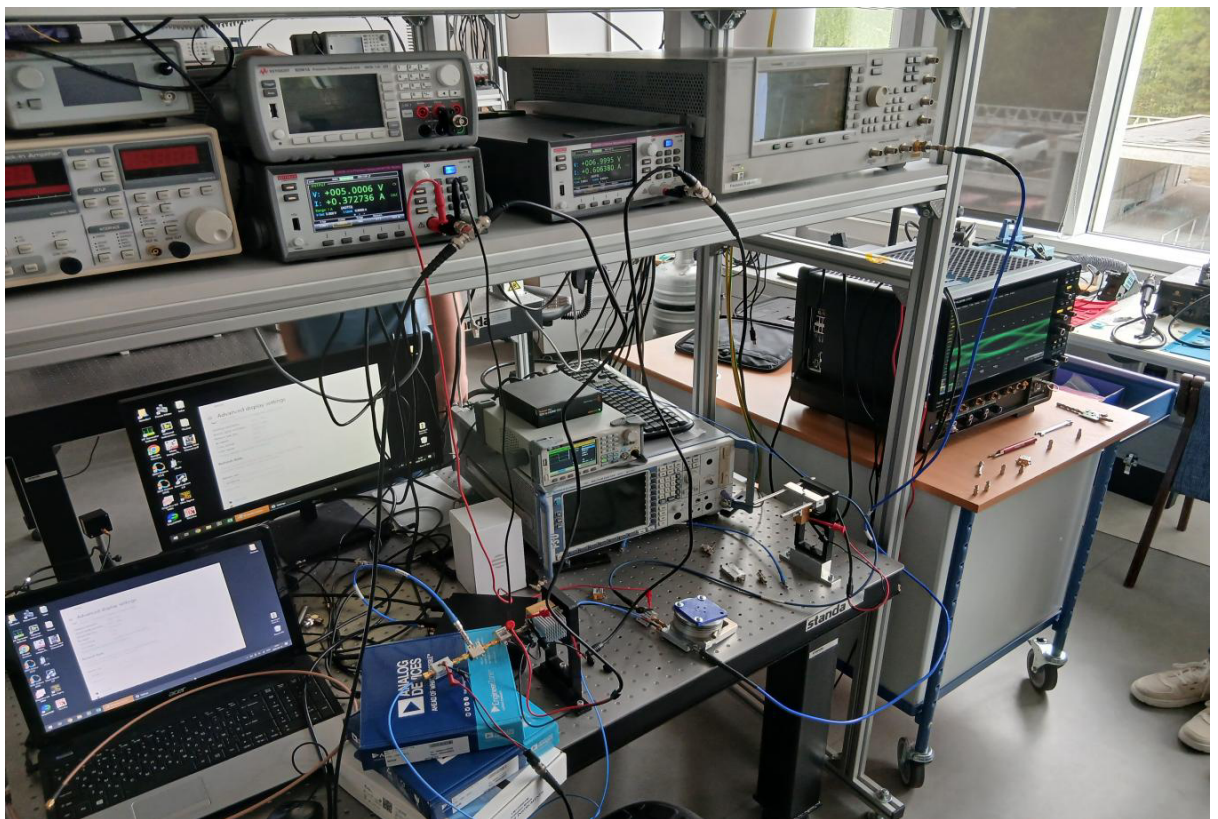


Figure 2.3.3. The wireless link video was successfully transmitted in the W-band

2.4 The Methods of Experiment

Since our ultimate goal is to transmit high-definition video on the W-band, the performance testing of the frequency multiplier is particularly important. Furthermore, this commercial module frequency multiplier was designed in the laboratory and does not have a data list, so this work is very necessary. Therefore, we conducted a linearity test on the frequency multiplier from the local oscillator frequency of 12GHz to 18GHz, which can cover all the W-band (75GHz to 110GHz) frequency range after up conversion using a 6x multiplier. This test not only allows us to understand the linearity of our frequency multiplier but also its output power characteristics.

We connected the local oscillator generator to our frequency multiplier and then tested from -15dBm in 3dBm increments until the output power reached 3dBm. We first modulate the signal output from the W-band multiplier, then use a detector to convert the high-frequency W-band signal into a low-frequency voltage signal corresponding to the modulation frequency. Finally, we use an SR865A lock-in amplifier to measure this voltage signal. We measured the peak-to-peak voltage of the frequency multiplier using a 50-ohm matching resistor, and then converted it to power in dBm. This completed the test.

During the cable-connected testing phase, we can test the spectrum of the SDI source, the spectrum after the mixer shifts the SDI signal to a higher frequency (the RF spectrum of the mixer), and the SDI signal spectrum of the receiver that successfully recovers the video. The spectral data is obtained with the aid of the Rohde & Schwarz FSU spectrum analyzer.

In wireless link system, the most important thing is to analyze the eye diagram. For the Cable-connected link also we will test. Because we need to know if a Cable-connected link can achieve HD video reproduction at the transmitting end. This would allow us to identify the eye diagram standard that enables video reproduction. Then, we'd have a basis for comparison when testing wireless links.

Our equipment can only export screenshots of time-domain signals and eye diagrams, so we need to use software to convert the time-domain signals into eye diagrams. The signal integrity of the proposed W-Band 3G-SDI wireless transmission link was evaluated using an offline digital waveform analysis methodology implemented in software MATLAB. For Cable-connected link experiment and wireless link part experiment, we both use SD8330HD digital serial analyzer get Eye Diagram, as shown in Figure 2.4.1.

The first thing is use get data from oscilloscope. The Raw time-domain waveforms from both the transmitter (TX) reference output and the wireless receiver (RX) were captured using a high-

bandwidth digital oscilloscope and imported for post-processing analysis. Then load the data to MATLAB for analysis.

The analysis of the eye diagram in the time domain is accomplished by analyzing raw voltage sequences using a customized eye diagram analysis technique through MATLAB. The analysis method involves applying a software clock and data recovery technique to recover the eye diagrams in 2.97Gbps. It facilitates the calculation of key parameters such as Eye Height, Eye Width, Crossing Percentage.

To achieve high temporal resolution for eye-diagram analysis, the acquired waveforms were resampled to 80 samples per unit interval (UI). Timing synchronization and waveform alignment were then performed before constructing statistical eye diagrams using more than 4,000 overlaid waveform segments.

The signal integrity evaluation focused on several standard physical-layer metrics for high-speed SDI analysis, including eye height, eye width, crossing percentage, peak-to-peak amplitude. These parameters were extracted from the statistical eye diagrams to quantitatively evaluate the signal degradation and overall transmission quality of the W-Band wireless 3G-SDI link.



Figure 2.4.1. SD8330HD digital serial analyzer

2.5 Experimental Device Summary

In the linearity test of the W-band frequency multiplier, we used an Agilent E8257D PSG analog signal generator to provide the pre-conversion frequency before the frequency multiplier, and then we used an SR865A lock-in amplifier to measure the voltage output. SR865A lock-in amplifier as shown in Figure 2.5.1.



Figure 2.5.1. SR865A lock-in amplifier

The proposed system adopts a cascaded W-band wireless architecture for real-time high-definition video transmission. The system is composed of three main modules, including a transmitter, a W-band wireless link, and a receiver. The transmitter integrates video interfacing, intermediate-frequency (IF) signal processing, RF up conversion, and W-band signal generation stages. The receiver includes radio frequency signal acquisition, frequency down-conversion and signal monitoring units for performance evaluation, and a converter for video recovery.

At the transmitter side, the system integrates a video interface unit, an intermediate-frequency (IF) generation stage, a frequency up conversion module, and a W-band signal generation chain. To ensure a stable digital interface, a commercial Blackmagic module is employed to convert the HDMI source into a 3G-SDI signal.

The IF signal is subsequently processed by a ZX05-24MH-S+ mixer. During the initial Cable-connected(P2P) verification phase, a low-phase-noise LMX2595EVM is utilized as the local oscillator (LO) to drive the up conversion. For the last transmission of the wireless link, the LO generator is changed to Agilent E8257D PSG analog signal generator for improved frequency stability and accuracy for remote link measurement purposes.

Next, the RF signal is amplified through successive broadband amplification (ZJL-153+ and ZX60-02203LPN+) to offset the conversion loss. Ultimately, a $\times 6$ frequency multiplication chain is utilized to create the W-band carrier, thus completing an end-to-end system that can effectively reproduce videos in real time at the receiver. The W-band wireless channel is established through antenna transmission for the free-space propagation of the millimeter wave signal.

For receiving, the transmitted signal at the W-band is received and processed via a heterodyne down-conversion system, in which an IF signal is obtained. When we need to obtain the spectrum, the spectrum characteristics of the received signal is measured by using a spectrum analyzer provided by Rohde & Schwarz FSU. For example, during the cable-connected testing phase.

For the purpose of ensuring the correctness of data transfer, the obtained IF signal undergoes additional processing using the Tektronix SD8330HD digital serial analyzer, which carries out eye diagram measurements with great accuracy in order to measure the timing jitter and noise margin. At last, for the final stage of video display, the Blackmagic SDI-to-HDMI converter is used to connect the standard monitor. With this hardware configuration, it is possible to implement the process of video signal recovery and reproduction from the HD source in real time.

3. Experimental Result

3.1 Frequency Multiplier Linearity Test

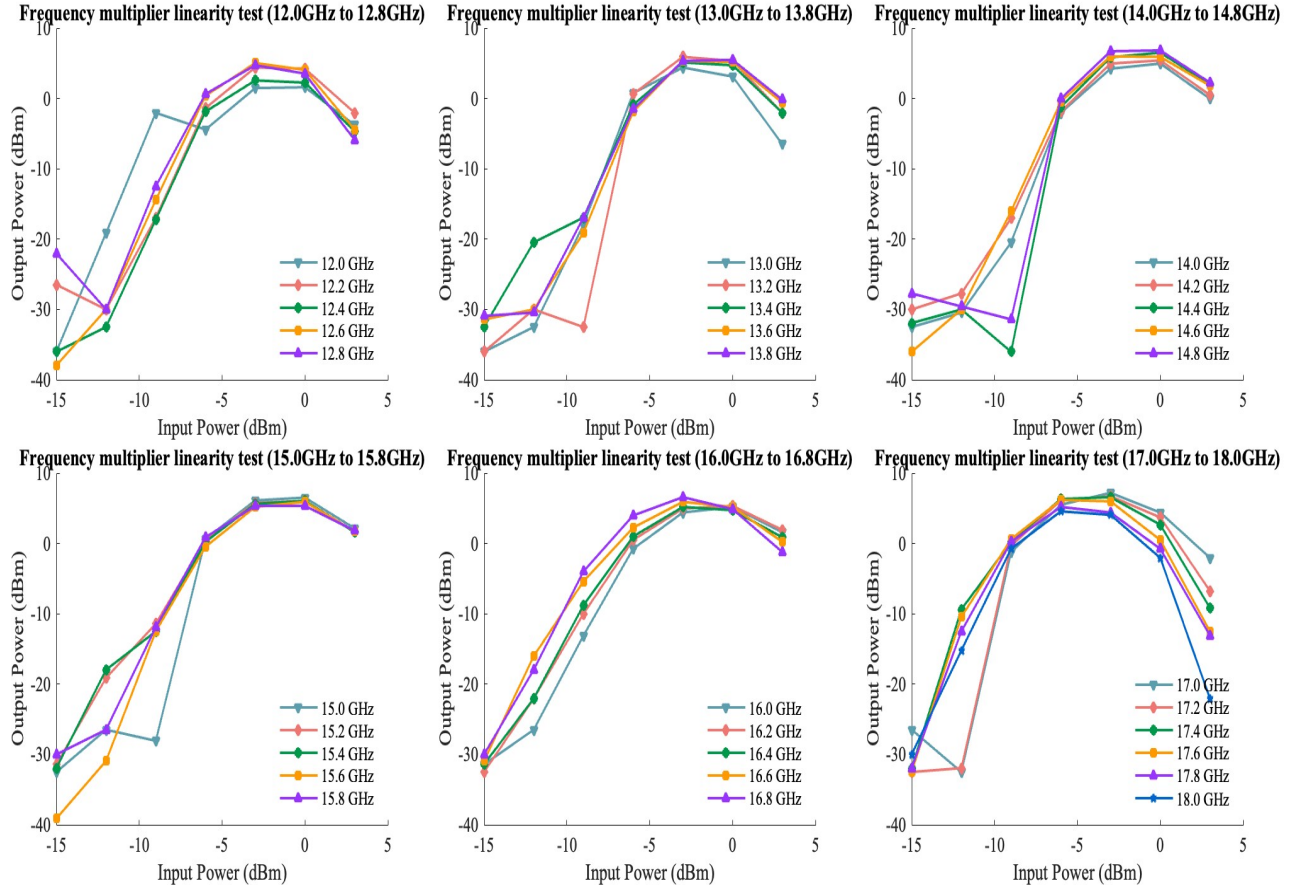


Figure 3.1.1 Frequency multiplier linearity test (local oscillator frequency from 12GHz to 18GHz)

As shown in Figure 3.1.1. We conducted linearity tests on the W-band frequency multiplier. The frequency range was 12 GHz to 18 GHz, with steps of 200 MHz. These tests revealed the power levels required for the multiplier's front-link budget to ensure linear W-band signal output within the 12 GHz to 18 GHz range, given the frequency synthesizer's local oscillator frequency setting.

With an input local oscillator frequency of 12 GHz to 12.8 GHz, the output frequency after the frequency multiplier is 72.0 to 76.8 GHz. Although some frequencies, such as 12 GHz, 12.2 GHz, and 12.4 GHz, are not within the W-band range after their sixth harmonic, we also conducted tests on this frequency to ensure data integrity and to detect whether the multiplier's output at frequencies below the W-band differs significantly from its output in the W-band. For this frequency range, the optimal output power is -3dBm, starting from an input of -3dBm to 0dBm, the output of the frequency multiplier no longer increases linearly.

With an input local oscillator frequency of 13 GHz to 13.8 GHz, the output frequency of the W-band after the frequency multiplier is 78.0 to 82.8 GHz. the optimal output power is -3dBm, starting from an input of -3dBm to 0dBm, the output of the frequency multiplier no longer increases linearly. Furthermore, when the input is greater than -3dBm, the multiplier output begins to decrease.

With an input local oscillator frequency of 14 GHz to 14.8 GHz, the output frequency of the W-band after the frequency multiplier is 84.0 to 88.8 GHz. For this frequency range, the optimal output power is 0 dBm, However, starting from -3dBm, the output no longer increases linearly.

With an input local oscillator frequency of 15 GHz to 15.8 GHz, the output frequency of the W-band after the frequency multiplier is 90.0 to 94.8 GHz. For this frequency range, the optimal output power is 0 dBm, and saturation begins at values greater than 0 dBm, the output no longer increases linearly.

When the input local oscillator frequency is 16 GHz to 16.8 GHz, the output frequency of the W-band after the frequency multiplier is 96.0 to 100.8 GHz. For this frequency range, the optimal input power is 0 dBm at 16 GHz and 16.2 GHz. The optimal input power is -3 dBm between 16.4 and 16.8 GHz. Furthermore, from 16GHz to 16.6GHz, starting from an input of -3dBm, the output power no longer increases linearly. And at 16.8GHz, starting from an input of -6dBm, the output power no longer increases linearly.

When the input local oscillator frequency is 17 GHz to 18 GHz, the output frequency of the W-band after the frequency multiplier is 102.0 to 108 GHz. For this frequency range, the optimal input power is -6 dBm at 17.6 GHz and 18 GHz. The optimal input power is -3 dBm between 17.0 and 17.4 GHz. Furthermore, from 17GHz to 17.4GHz, starting from an input of -3dBm, the output power no longer increases linearly. And from 17GHz to 17.4GHz, starting from an input of -6dBm, the output power no longer increases linearly.

3.2 Cable-Connected Link System Verification

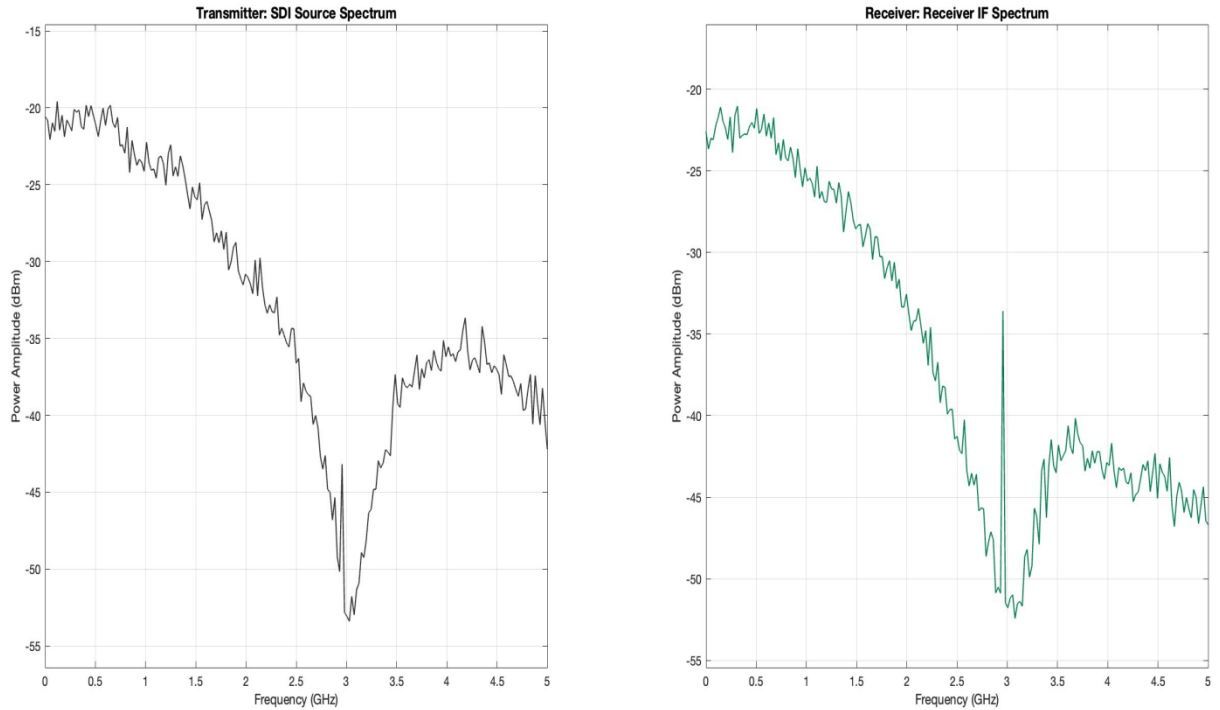


Figure 3.2.1. The spectrum between 3G-SDI source and the down-converter mixer receiver IF side

The Figure 3.2.1 shows a comparison of the spectra of the SDI source signal at the transmitting end and the SDI signal obtained from the intermediate frequency (IF) output at the receiver. The spectrum of the SDI source signal at the transmitter shows it is a standard digital NRZ signal envelope, with its main lobe energy concentrated within the 3GHz band, and a first spectral null dip at 2.97GHz. This is completely consistent with the theoretical calculation of the 2.97Gbps code rate corresponding to the 3G-SDI standard.

The spectrum of the IF SDI signal at the receiver reveals that the overall power, envelope shape, and main-sidelobe suppression ratio are highly consistent with the transmitting SDI source signal. This indirectly proves that the mixer used in the system operates in the ideal linear region. High-speed video signal spectrum shifting, and down-conversion were successfully achieved without significant in-band nonlinear distortion. Furthermore, the single-frequency spike at 2.97 GHz in the receiver spectrum is likely caused by local oscillator leakage (LO leakage) in the mixer. Since this point is located precisely at the null point where the signal energy is lowest, it has minimal interference with the decision and recovery of the baseband video data.

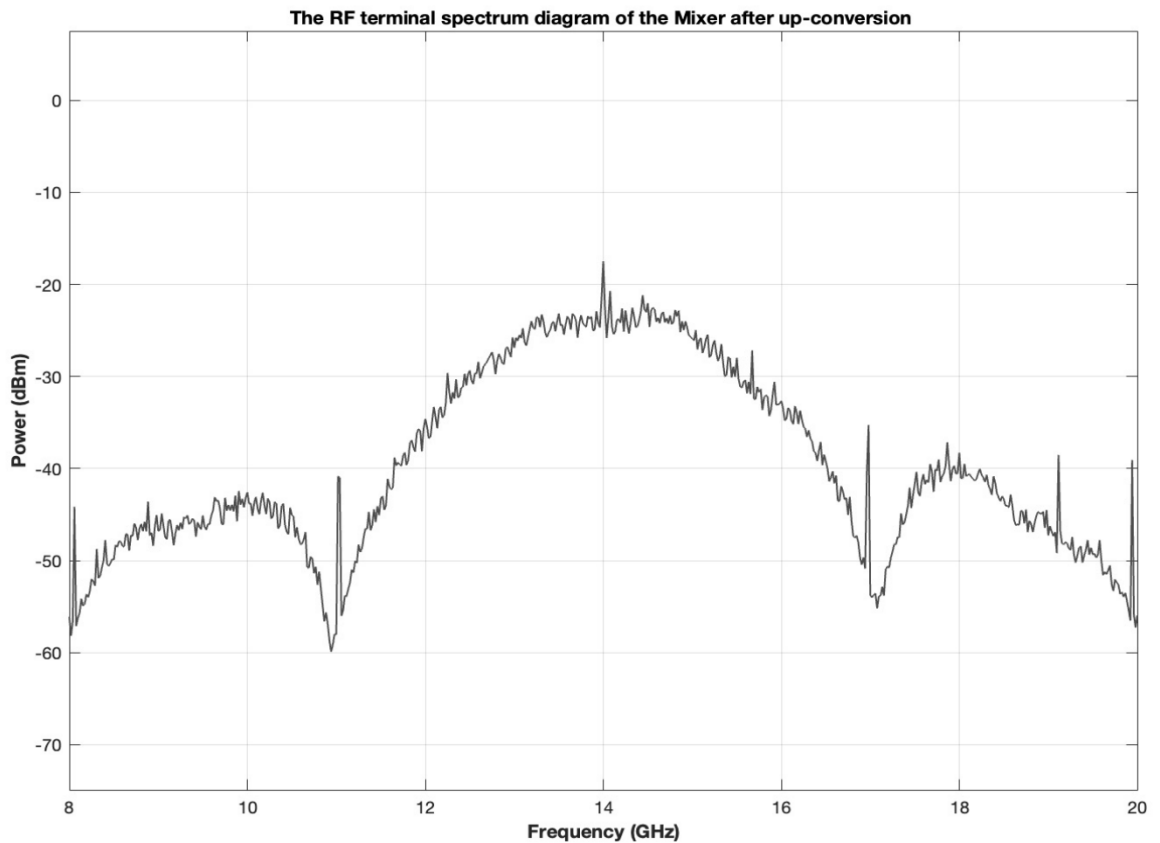


Figure 3.2.2. The RF terminal spectrum diagram of the Mixer after up-conversion

The Figure 3.2.2 shows the spectral characteristics of the baseband/IF signal after up-conversion via a mixer, measured at the RF terminal. The test band covers 8GHz to 20GHz. The main lobe energy of the signal is perfectly concentrated between 11GHz and 17GHz, with most of the high-energy points located near 14GHz. This is a typical envelope characteristic of a high-speed non-return-to-zero (NRZ) code signal after modulation.

Two obvious spectrally symmetrical sinking nulls can be observed on both sides of the main lobe, located near 11GHz and 17GHz respectively. The absolute frequency difference between the two nulls and the center frequency of 14GHz is exactly 3GHz, which precisely corresponds to the characteristic bandwidth of the nominal transmission code rate of 2.97Gbps for 3G-SDI signals, proving that the integrity of the digital signal is maintained after up-conversion.

The spikes emerging at the 11GHz and 17GHz null depressions may be due to local oscillator leakage in the mixer link, or they may be image spurious signals of a specific order. Because these spurious signals fall precisely at the null point of the signal energy, their impact on the signal-to-noise ratio (SNR) and error vector magnitude (EVM) of the main envelope of the RF signal is minimized.

Therefore, this spectrum demonstrates that the up-conversion section of the mixer operates in the linear region, successfully shifting the 3G-SDI signal to the 14GHz band with a symmetrical in-band power envelope and no significant RF nonlinear distortion, meeting the link requirements for subsequent high-frequency wireless transmission.

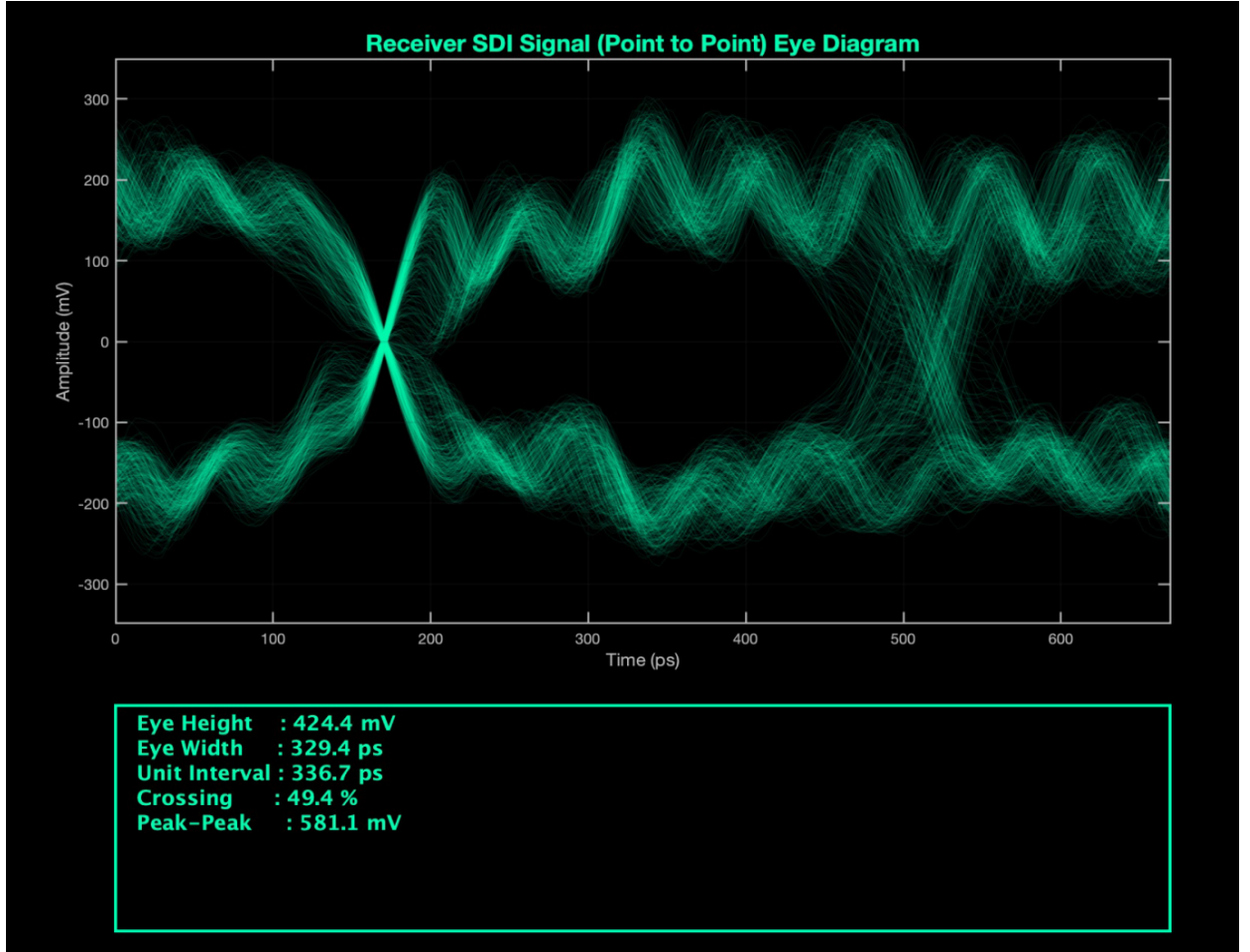


Figure 3.2.3. The eye diagram of down-converter IF side (Cable-connected Link)

As shown in Figure 3.2.3, The Cable-connected characterization of the receiver's down-converter IF output demonstrates near-ideal performance, with a robust eye height of 424.4 mV and an eye width of 329.4ps, representing a 97.8% UI opening. These results, complemented by a symmetrical crossing point of 49.4%, confirm that the hardware chain preserves the 2.97 Gbps 3G-SDI signal with negligible timing jitter and high noise immunity, ensuring a high-fidelity foundation for successful video reproduction. This also provides the basis for our subsequent W-band tests, which require eye width data to recover the signal.

3.3 Wireless W-Band Link System Verification

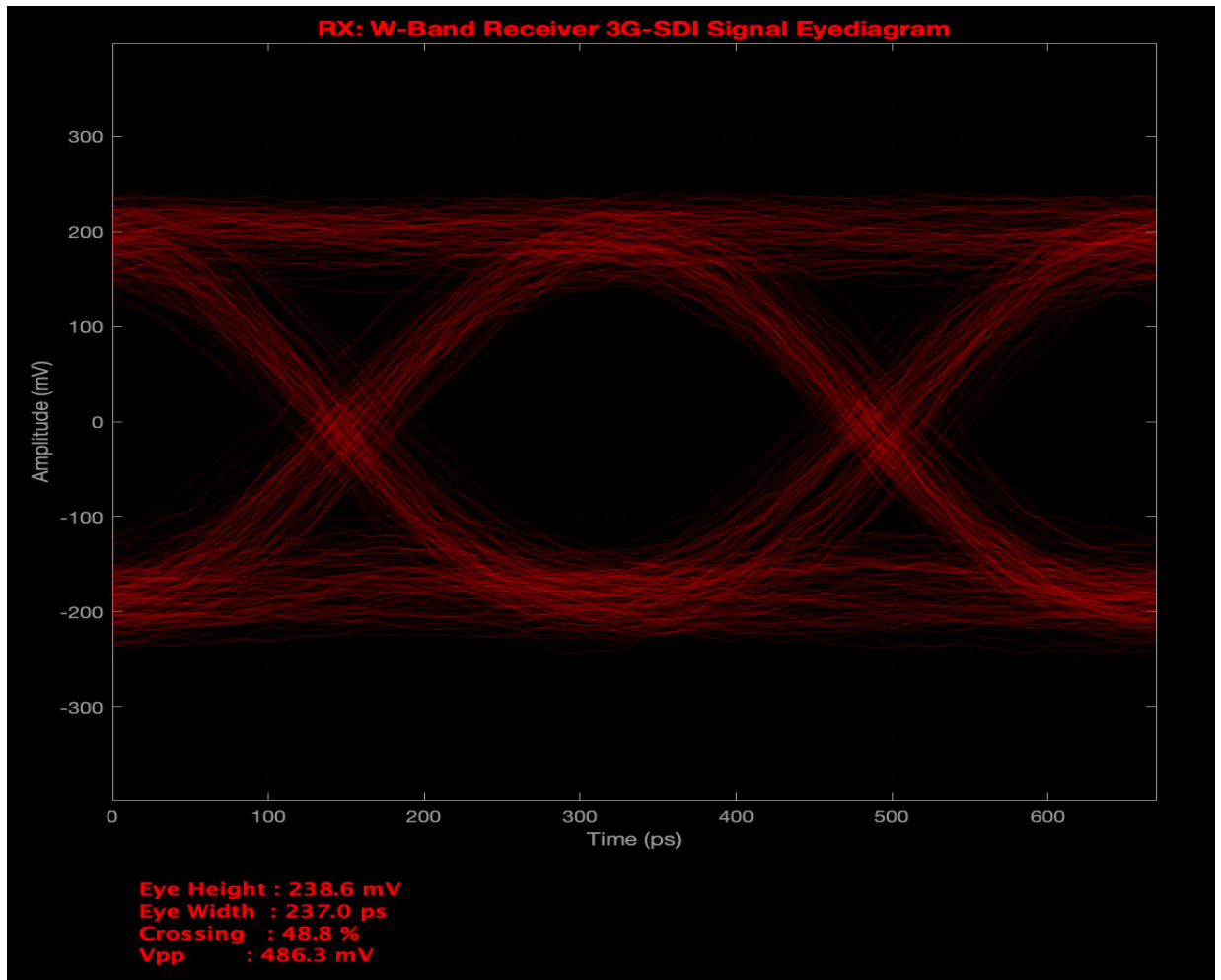


Figure 3.3.1. Eye diagram of the W-band wireless link receiving side

As shown in Fig. 3.3.1, The receiver demonstrated excellent communication robustness over the W-band link. Despite long distances and complex wireless environments, the eye height of 238.6 mV remained well above the receive tolerance of the 3G-SDI protocol. The 48.8% crossover percentage indicates that the system's clock recovery (CDR) is highly accurate, with no significant level offset distortion. Eye Width is 237.0ps, approximately 0.7UI. According to the 3G-SDI standard, the rise and fall times (20% - 80% points) must not exceed 135ps, and the difference in width must be less than 50ps. This calculates to a theoretical minimum recoverable eye width of 0.51 UI. Therefore, the eye width of our receiver's eye diagram is an excellent value. The amplitude at our receiver was 486.3mV, far below the $800\text{ mV} \pm 10\%$ of the 3G-SDI standard, but the video was still successfully recovered.

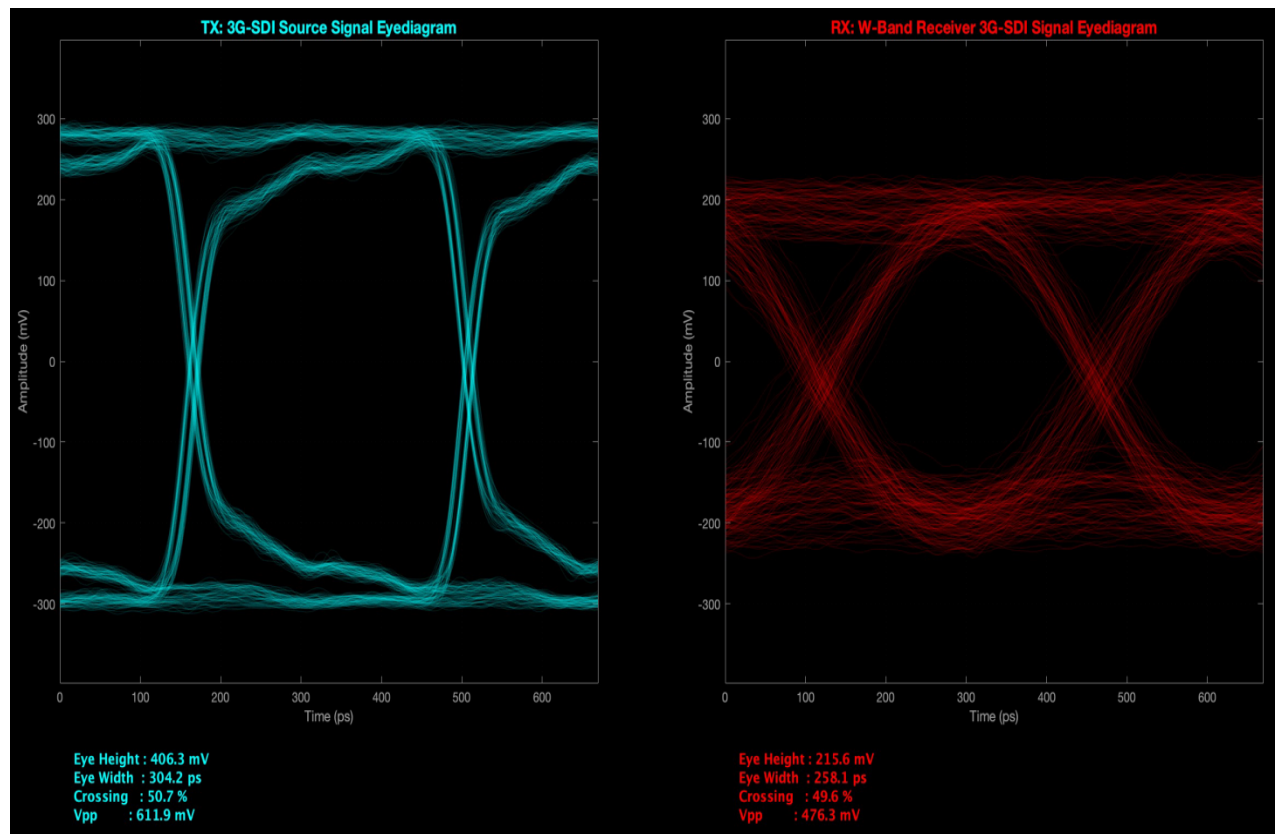


Figure 3.3.2. The eye diagram parameters between 3G-SDI source and the W-band receiver IF side

Table 1. The eye diagram parameters between 3G-SDI source and the W-band receiver IF side.

Measurement Metric	Source	Receiver IF side	Delta
Eye Height	406.3 mV	215.6 mV	-190.7 mV
Eye Width	304.2ps	258.1ps	-46.1ps
Peak-to-Peak	611.9 mV	476.3 mV	-135.6 mV
Crossing Percentage	50.7 %	49.6 %	-1.1 %

It should be noted that the Figure 3.3.2 compare test and the Figure 3.3.1. receiver eye diagram test is not conducted on the same day, so there will be slight differences in the data of the receiver eye diagram. As shown in Figure 3.3.2 and Table 1, The peak-to-peak amplitude at the wireless link receiver is 476.4 mV, but peak-to-peak amplitude at SDI source part is 611.9mV. The receiver's eye

height decreased from 406.3mV to 215.6 mV. Although this represents a 46.9% reduction. This indicates that the signal amplitude attenuated after transmission through our W-band wireless link. But the fact that the video can be successfully reproduced. This can prove that in W-band high-frequency wireless transmission, despite link loss, the signal retains sufficient vertical noise margin.

The eye width decreased from a perfect 304.2ps to 258.1 ps. The loss of 46.1ps eye width is likely due to jitter caused by the W-band RF front-end and local oscillator (LO) source. But 258.1ps eye width also can ensure accurate sampling by the backend CDR (clock recovery) circuitry.

The eye crossing percentage decreased from 50.7% to 49.6%, very close to the ideal balance of 50%. This indicates that the system produced virtually no significant duty cycle distortion (DCD) during modulation and wireless demodulation.

Future Work

In this work, we have built a W-band wireless link transmission system and implemented high-definition real-time video transmission on it. However, this is only the beginning of our research on W-band real-time video transmission.

For future work, we will focus on system optimization and link evaluation to make our video transmission more stable. In terms of system optimization, we can improve link linearity and modulation quality by introducing digital predistortion (DPD) technology in the baseband to compensate for the nonlinear distortion introduced by the frequency multiplier link. For link evaluation, we will use a bit error rate (BER) tester and an SDI video analyzer for better measurement.

In addition, the system is also prepared for higher data rates and longer transmission distances to evaluate its transmission capabilities in real-world W-band communication ability.

Conclusions

1. In this work, a complete W-band wireless HD video transmission system was successfully constructed. The W-band wireless video link demonstrated stable performance with the eye diagram height of 238.6 mV and the eye width of 237.0ps (70% UI), confirming sufficient noise margin and timing budget for reliable clock recovery and real-time high-definition video transmission.
2. In this W-band wireless HD video transmission link, the eye diagram crossing percentage at the W-band wireless link receiver is 49.6%, This ensures that the receiver clock data recovery (CDR) circuit can accurately and reliably recover data.
3. In this W-band wireless HD video transmission link, the eye diagram peak-to-peak amplitude at the W-band wireless link receiver is 486.3 mV, which did not reach the 3G-SDI standard of 800 mV $\pm 10\%$, but the video could still be successfully recovered.

Summary

Institute of Applied Electrodynamics and Telecommunications

Yilong Liu

HIGH-DEFINITION VIDEO WIRELESS DATA TRANSMISSION LINK IN W-BAND

Master's Thesis

This thesis designs and implements a high-definition real-time video wireless transmission system based on the W-band (75–110 GHz) and conducts system-level experimental verification. The system employs an HDMI-SDI converter to achieve stable 3G-SDI video input and utilizes a mixer structure combined with a W-band x6 frequency multiplier to achieve transmission in the W-band.

By constructing both cable-connected and wireless experimental links, the system's RF front-end, frequency conversion performance, and signal integrity were verified. Experimental results show that the system can achieve stable real-time high-definition uncompressed video transmission, exhibiting good signal consistency in the cable link and maintaining sufficient eye diagram opening and timing margin in the wireless link, achieving reliable video recovery.

In summary, this work verifies the feasibility of W-band wireless high-definition video transmission and provides an experimental foundation for the optimization of future high data rate millimeter-wave communication systems.

Santrauka

Taikomosios Elektrodinamikos ir Telekomunikacijų institutas

Yilong Liu

Didelės raiškos vaizdo belaidžio duomenų perdavimo linija W dažnių juostoje

Magistro baigiamasis darbas

Šiame baigiamajame darbe projektuojama ir įgyvendinama didelės raiškos realaus laiko vaizdo belaidė perdavimo sistema, pagrįsta W diapazonu (75–110 GHz), ir atliekamas sistemos lygio eksperimentinis patikrinimas. Sistemoje naudojamas HDMI-SDI keitiklis, siekiant užtikrinti stabilų 3G-SDI vaizdo įvestį, ir maišytuvo struktūra kartu su W diapazono $\times 6$ dažnio daugikliu, siekiant užtikrinti perdavimą W diapazone.

Sukūrus tiek kabeliu sujungtas, tiek belaidės eksperimentines linijas, buvo patikrintas sistemos radijo dažnių (RF) priekis, dažnio konvertavimo našumas ir signalo vientisumas. Eksperimentiniai rezultatai rodo, kad sistema gali pasiekti stabilų realaus laiko didelės raiškos nesuspausto vaizdo perdavimą, užtikrindama gerą signalo nuoseklumą kabelinėje jungtyje ir išlaikydama pakankamą akių diagramos atidarymą ir laiko ribą belaidėje jungtyje, taip pasiekdama patikimą vaizdo atkūrimą.

Apibendrinant, šis darbas patikrina W diapazono belaidžio didelės raiškos vaizdo perdavimo galimybes ir suteikia eksperimentinį pagrindą būsimų didelės duomenų perdavimo spartos milimetrinių bangų ryšio sistemų optimizavimui.

References

- [1] Gao, S., Jiang, Y., Li, Z., Zhong, Q., Zhu, M., & Zhang, J. (2024). 2 km Uncompressed HD Video Wireless Transmission at 100 GHz Based on All-Optical Frequency Up- and Down-Conversion. *Micromachines*, 15(12), 1488. <https://doi.org/10.3390/mi15121488>
- [2] Semiari, O., Saad, W., Bennis, M., & Debbah, M. (2019). Integrated millimeter wave and sub-6 GHz wireless networks: A roadmap for joint mobile broadband and ultra-reliable low-latency communications. *IEEE Wireless Communications*, 26(2), 109 – 115. <https://doi.org/10.1109/MWC.2019.1800039>
- [3] Tao, L., Lu, Q., Li, R., Wang, Z., Cheng, T., Yu, Y., & Huang, W. (2024). Investigation on the performance of photonics-aided W-band millimeter-wave wireless transmission. *Heliyon*, 10(12), Article e32684. <https://doi.org/10.1016/j.heliyon.2024.e32684>
- [4] Li, X., Xiao, J., & Yu, J. (2016). Long-distance wireless mm-wave signal delivery at W-band *Journal of Lightwave Technology*, 34(2), 661–668. <https://doi.org/10.1109/JLT.2015.2500581>
- [5] Jianguo, L., Jianxiong, P., Yujie, L., & et al. (2025). Key technologies of high frequency wireless communications. *Springer Nature Link*. <https://doi.org/10.1007/978-981-96-5894-7>
- [6] Bao, M., Malmqvist, R., Jonsson, R., Hansryd, J., & Andersson, K. (2022). A W-band up-conversion mixer with integrated LO frequency doublers in a 60 nm GaN technology. *2021 16th European Microwave Integrated Circuits Conference (EuMIC)* (pp. 108–111). IEEE. <https://doi.org/10.23919/EuMIC50153.2022.9783229>
- [7] Lin, Y.-S., & Li, G.-H. (2014). A W-band down-conversion mixer in 90 nm CMOS with excellent matching and port-to-port isolation for automotive radars. *2014 11th International Symposium on Wireless Communications Systems (ISWCS)* (pp. 54–58). IEEE. <https://doi.org/10.1109/ISWCS.2014.6933319>
- [8] Kazemi, H., Osahon, I. N. O., Jiao, T., Butler, D., Ledentsov, N., Jr., Titkov, I., Ledentsov, N., & Haas, H. (2025). Real-time transmission of uncompressed high-definition video via a VCSEL-based optical wireless link with ultra-low latency. *arXiv* (arXiv:2507.23746). <https://doi.org/10.48550/arXiv.2507.23746>
- [9] Alexander, L., Thang, T. P., Marta, B., & et al. (2011). Optimization of high-definition video coding and hybrid fiber-wireless transmission in the 60 GHz band. *Optics Express*, 19(26), B895 – B904. <https://doi.org/10.1364/OE.19.00B895>
- [10] Zinkan, X., & Chen, F. (2022). Multimedia real-time transmission protocol and its application in video transmission system. *Computational Intelligence and Neuroscience*, 2022, Article 8654756. <https://doi.org/10.1155/2022/8654756>
- [11] Liu, K., Feng, Y., Han, C. et al. High-speed 0.22 THz communication system with 84 Gbps for real-time uncompressed 8K video transmission of live events. *Nature Communications* 15, 8037 (2024). <https://doi.org/10.1038/s41467-024-52370-x>
- [12] J. H. Abril-García et al.(2018). Experimental optical transmission of HDMI signals. *2018 Photonics North (PN)* (pp. 1–1). IEEE. <https://doi.org/10.1109/PN.2018.8438847>
- [13] Society of Motion Picture and Television Engineers. (2018). ST 292-1:2018 – 1.5 Gb/s signal/data serial interface. <https://doi.org/10.5594/SMPTE.ST292-1.2018>
- [14] Society of Motion Picture and Television Engineers. (2012). 3 Gb/s signal/data serial digital interface (SMPTE ST 424:2012). <https://doi.org/10.5594/SMPTE.ST424.2012>
- [15] Chen, Y., & Zhang, W. (2016). The design of the SDI multiplexed digital audio data format and

- alysis software. *2016 IEEE International Conference on Electronic Information and Communication Technology (ICEICT)*, 271–275. <https://doi.org/10.1109/ICEICT.2016.7879698>
- [16] Li, D., Wang, X., & Liu, Y. (2019). A high-speed serial digital interface video signal jitter measurement method. *Journal of Physics: Conference Series*, 1419(1), Article 012009. <https://doi.org/10.1088/1742-6596/1419/1/012009>
- [17] Sauerwald, M. (2008). Design considerations for SMPTE 3 Gbps SDI interfaces (Application Note SNLA178). *Texas Instruments*. Available: <https://www.ti.com/lit/an/snla178/snla178.pdf?ts=1779027118011> [Accessed: May 15, 2026].
- [18] Trinh, V.-S., Nam, H., Song, J.-M., & Park, J.-D. (2022). A 78.8 – 84 GHz Phase Locked Loop Synthesizer for a W-Band Frequency-Hopping FMCW Radar Transceiver in 65 nm CMOS. *Sensors*, 22(10), 3626. <https://doi.org/10.3390/s22103626>
- [19] D. Hammou, E. Moldovan, and S. O. Tatu, Millimeter-wave heterodyne six-port receiver: new implementation and demodulation results. *ZTE Communications*. Available: https://www.zte.com.cn/global/about/magazine/zte-communications/2011/3/en_162/260198.html [Accessed: May 15, 2026].
- [20] Yang, Y., Li, X., Feng, Y., Liang, Y., Huang, X., Chen, J., & Peng, L. (2026). Recent Progress of Millimeter-Wave Silicon-Based Integrated Mixers for Broadband Wireless Communication: A Comprehensive Survey. *Electronics*, 15(5), 1043. <https://doi.org/10.3390/electronics15051043>
- [21] Lee, S., Yoo, C., Kim, W., Ryn, H.-K., & Song, W. (1997). 1 GHz CMOS down-conversion mixer. *ISCE '97. Proceedings of 1997 IEEE International Symposium on Consumer Electronics*, 125–127. <https://doi.org/10.1109/ISCE.1997.658368>
- [22] Herold, E. W. (1942). The operation of frequency converters and mixers for superheterodyne reception. *Proceedings of the IRE*, 30(2), 84–103. <https://doi.org/10.1109/JRPROC.1942.233661>
- [23] B. Henderson, Microwave Mixers Tutorial. *Microwave Journal*, July 30, 2018. [Online]. Available: <https://www.microwavejournal.com/articles/32203-microwave-mixers-tutorial> [Accessed: May 15, 2026].
- [24] H. Hausman, The Effect of High Stability Reference Oscillators on System Phase Noise, *Microwave Journal*, Feb. 7, 2005. [Online]. Available: <https://www.microwavejournal.com/articles/908-the-effect-of-high-stability-reference-oscillators-on-system-phase-noise>
- [25] B. Razavi, *RF Microelectronics*, 2nd ed., Pearson Education International, 2012
- [26] Cheng, L., Liu, C., Dong, Z., Ju, C., Jiang, W., & Chang, G.-K. (2013). Real-time dual-band wireless videos in millimeter-wave radio-over-fiber system. *Optical Fiber Technology*, 19(6), 529 – 532. <https://doi.org/10.1016/j.yofte.2013.07.005>
- [27] Liu, J., Bian, C., He, W., Wang, K., Yu, J., & Zhang, J. (2025). W-band photonics-aided OFDM system integrating sensing and communication with phase noise suppression scheme. *Optics & Laser Technology*, 180, Article 111432. <https://doi.org/10.1016/j.optlastec.2024.111432>
- [28] Chen, L., Luo, J., Tang, Z., Ju, C., & Chang, G.-K. (2019). Integration system of photon-assisted W-band millimeter wave wireless communication and free space optical communication based on OFDM signal transmission. *Optical Fiber Technology*, 52, Article 101973. <https://doi.org/10.1016/j.yofte.2019.101973>
- [29] Gao, L., Wang, C., Li, C., & Zhang, Y. (2022). P-7.5: A professional display system with multiple 12G-SDI interfaces. *SID Symposium Digest of Technical Papers*, 53(S1), 826–826. <https://doi.org/10.1002/sdtp.16108>

- [30] Blackmagic Design.Teranex Mini Installation and Operation Manual, *Blackmagic Design User Guide*. [Online]. Available: https://www.huss-licht-ton.de/images/products_download/User_Manual_18978_1.pdf [Accessed: May 15, 2026].
- [31] Mini-Circuits.Coaxial Frequency Mixer ZX05-24MH. *Mini-Circuits Datasheet*. [Online]. Available: <https://www.minicircuits.com/pdfs/ZX05-24MH+.pdf> [Accessed: May 15, 2026].
- [32] Analog Circuit Design.Eye Diagram and Bit Error Rate (BER).*Analog Circuit Design*. [Online]. Available: <https://analogcircuitdesign.com/eye-diagram-bit-error-rate> [Accessed: May 15, 2026].
- [33] Texas Instruments. LMX2595 EVM Instructions–20-GHz Wideband Low Noise PLL With Integrated VCO. *Texas Instruments User Guide*. Available: <https://www.ti.com/lit/ug/snau219b/snau219b.pdf> [Accessed: May 15, 2026].
- [34] Ahadi Dolatsara, M., Hejase, J., Becker, W., Kim, J., Lim, S., & Swaminathan, M. (2020). Worst-case eye analysis of high-speed channels based on Bayesian optimization. *IEEE Transactions on Electromagnetic Compatibility*, PP, 1–13. <https://doi.org/10.1109/TEM.2020.3012960>