Why Are Digital Wireless Systems Suitable for Acoustic Measurements?

Pourquoi les Systèmes Numériques Sans fil Conviennent-ils Aux Mesures acoustiques ?

Por qué los sistemas inalámbricos digitales son adecuados para las mediciones acústicas?

为什么数字无线系统适用于声学测量

V20260207

[EN]

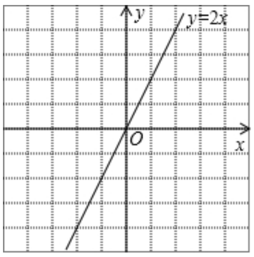
Modern acoustic measurement platforms, such as Smaart, SIM, and SysTune, rely on FFT-based analysis to evaluate loudspeaker, signal chain, and spatial sound field characteristics. These tools assume that the measurement signal propagates in a linear, time- invariant system. Any processing or instabilities introduced between the measurement microphone and the audio analyzer will directly affect the validity of the results.

1 What are the most important requirements for acoustic measurement in wireless transmission?

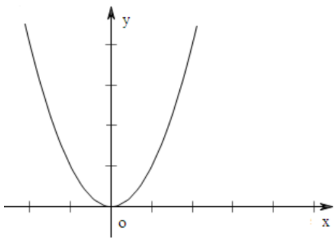
Linearity

1. The volume should be adjusted linearly, increasing or decreasing linearly.
2. the 20-20 kHz range should have the same gain or attenuation during wireless transmission, exhibiting a linear overall change, with similar requirements for other indicators.

Note: The mathematical relationship between the output y and the input x is shown in the figure.



y=2x (Linearity)



$y=x^2$ (Non Linearity)

2 Analog audio wireless communication cannot be used for acoustic measurements primarily due to the following reasons:

1. In reality, analog wireless technology cannot achieve linear modulation curves and have poor frequency response performance, which makes them unsuitable for acoustic measurements.
2. Analog wireless technology's method of transmitting volume information is outdated, resulting in insufficient dynamic range and necessitating the use of companders. However, the use of companders causes problems such as artifacts and phase distortion, which also fail to meet the requirements of acoustic measurements.
3. The signal-to-noise ratio is difficult to improve.
4. Nonlinearity results in less than ideal performance in terms of distortion and noise floor.

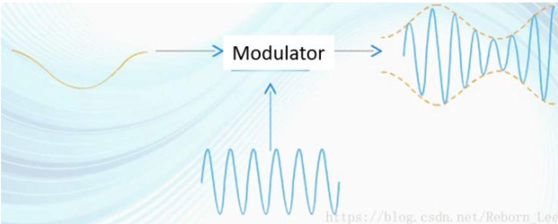
The specific details are as follows:

2.1 Analog wireless communication exhibits poor frequency response and attenuation in

the high and low frequency ranges, thus failing to meet acoustic measurement requirements.

2.1.1 First, it 's essential to understand the modulation principle of analog wireless communication .

The schematic diagram of analog wireless communication modulation and demodulation is as follows:



(Amplitude modulation principle diagram)

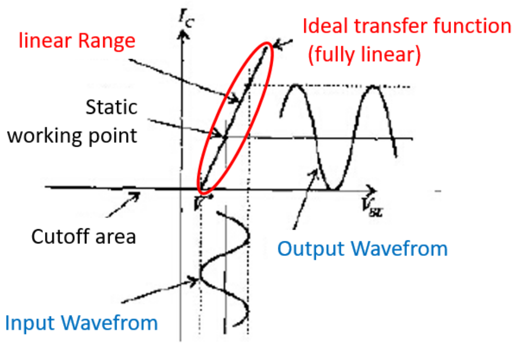
Essentially, it involves using audio signals (20-20 kHz) to influence certain physical properties of a carrier wave (e.g., 600 MHz, 2.4 GHz).

Electromagnetic waves have only three physical characteristics: amplitude, frequency, and phase.

Therefore, there are three main modulation methods: amplitude modulation, frequency modulation, and phase modulation.

2.1.2 Second point: What are the methods used to achieve modulation in analog wireless communication?

Essentially, Class A, B, C, and D amplifier circuits establish a linear relationship between audio and carrier frequencies. For example, a Class A amplifier circuit is shown in the diagram below:



Class A Amplifier Circuit

The ideal transfer function is key. Theoretically, if we can make all frequencies of the audio spectrum from 20 to 20 kHz linearly affect the carrier wave, then we can obtain a transmission frequency response of 20 to 20 kHz, and the entire audio range will have 0 dB attenuation.

Explanation:

Class A, B, C, and D amplifier circuits – these are multi-stage output amplifier circuits designed to amplify weak signals into high-power signals. There are four classic design schemes, hence the names Class A, Class B, Class C, and Class D.

All four circuits consist entirely of resistors, capacitors, diodes, and transistors, making them classic examples of analog circuits.

Because of their signal characteristic transfer properties, they were used in radio modulation and demodulation schemes, representing one of the most important breakthroughs in the development of human radio communication.

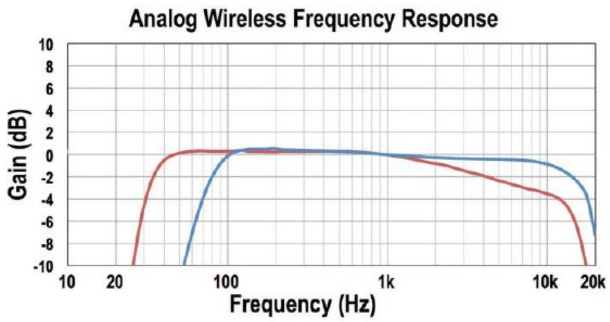
2.1.3 Thirdly, is it possible to achieve this perfect ideal transfer function?

Cannot.

Because Class A, B, C, and D amplifier circuits are all built using discrete components such as resistors, capacitors, and inductors, none of these components possess perfectly linear characteristics. This causes the entire modulation circuit to achieve a linear relationship only within certain frequency ranges (and often it's not even flat).

2.1.4 Fourthly, what are the consequences of imperfection?

This imperfection results in a limited frequency response range for analog wireless communication. See the diagram below:



Low frequencies can interfere with the frequency of a companding circuit . For example, a frequency of 20Hz is low enough that the gain changes with the period of the waveform. Therefore, low frequencies are filtered out. High frequencies are limited by analog frequency modulation techniques, which typically cannot produce frequencies above 15kHz.

This means that if analog wireless communication technology is used, the obtained audio will not be able to achieve 0dB attenuation across the entire 20-20 kHz frequency range, and there will definitely be strong attenuation in the high and low frequency ranges.

2.1.5 Fifthly, a poor frequency response in analog wireless communication can severely impact

acoustic measurements.

For acoustic measurements, "wideband" means that the system can pass through all frequencies from extremely low (e.g., 20 Hz) to extremely high (e.g., 20 kHz or even higher) without loss. More importantly, the flatness of the phase response is more important and more difficult to achieve than the amplitude response. A filter that appears flat in amplitude frequency response may still produce severe distortion in phase (manifested as a change in group delay).

1. Blurred impulse response: If the high-frequency response of a wireless system decays sharply at 18kHz, or if the phase is nonlinear, the "peak" of the impulse response you measure will be broad and less sharp, and subsequent reflection details will become blurred. This directly affects your ability to analyze sound field clarity and reflection time.
2. Phase diagram anomalies: On the phase diagram, you may see unnatural phase folds or abrupt changes that are not caused by the speakers or the room.
3. Degraded analytical accuracy: High-frequency phase responses are highly sensitive to bandwidth limitations, transfer function analyses compare relative amplitudes and phases at different frequencies, and impulse response resolution depends on the reserved bandwidth—all of which are compromised by non-flat responses.

Furthermore, this frequency response also causes severe distortion in sound quality.

Analog wireless communication can adequately transmit ordinary people's voices, but it cannot meet the requirements when transmitting instrumental sounds, soprano voices, or similar situations.

2.1.6 **Conclusion.**

Based on frequency response range analysis, analog wireless communication cannot meet the requirements of acoustic measurement.

2.2 Why do analog wireless communications use companders? They cause artifacts and other drawbacks, ultimately failing to meet acoustic measurement requirements.

The root of this problem is to solve the wireless transmission of volume information.

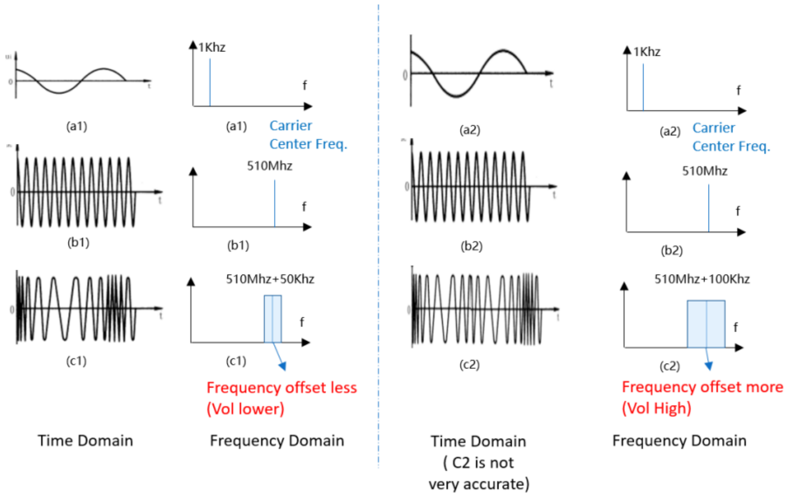
Essentially, volume information is not a fundamental property of audio signals (the volume can be defined by the receiver), so it cannot be carried by the amplification circuit during modulation during wireless transmission.

In order to solve the problem of volume information transmission, analog wireless communication created a series of troublesome issues, ultimately leading to a host of new problems in analog audio wireless communication that remain unresolved to this day.

2.2.1 First , we need to understand how analog wireless communication transmits volume information.

Analog wireless communication employs a clever method:

The change in volume is ultimately reflected in the ± frequency offset of the carrier center frequency. A larger frequency offset means a larger volume. See the diagram below:



2.2.2 Secondly , how effective is this method in engineering implementation?

In practical engineering, the maximum frequency offset is ±100kHz.

Above 100kHz, the modulation correlation becomes nonlinear, causing severe distortion.

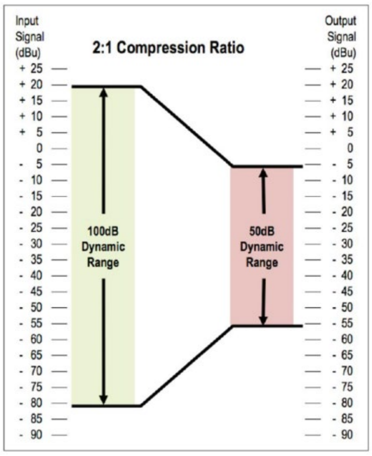
Direct consequences (new problems): The typical raw dynamic range of FM is about 50 dB . The dynamic range is extremely low.

Other consequences: FM microphones work normally at low volumes. However, when the volume is high, the bandwidth increases dramatically, potentially causing wireless interference to adjacent channels.

2.2.3 Thirdly , how does analog communication solve the dynamic range problem of analog wireless communication?

Compression expansion technology

To achieve a dynamic range of 100dB (the minimum requirement for high quality), analog wireless microphones employ compression-expansion technology. This technology compresses the 100dB input dynamic range by a 2:1 ratio, keeping it within 50dB. This process is achieved through a variable gain amplifier (VGA). The combination of these two technologies is called compression-expansion (i.e., a combination of compression and expansion).



2.2.4 Fourthly , compression diffusion technology brings new problems.

Companding essentially compresses the audio signal at the transmitting end and expands the signal at the receiving end—to improve the signal-to-noise ratio and dynamic range. While companding is effective for speech enhancement, it is inherently non-linear and dependent on the signal level.

Compression can be imagined as an automatic, volume-linked "fader." At the transmitting end, soft sounds are automatically amplified (compressed), while loud sounds are automatically muted (limited); at the receiving end, the exact opposite operation is performed. This is an advantage for voice communication, but a disaster for acoustic measurements:

a) Frequency response "drift"

When you change the volume of the test signal, the measured frequency response curve will change! This makes it impossible for you to determine whether it is the characteristics of the speaker or the wireless link that is causing the problem.

b) coherence collapse

The coherence curve in the measurement software (a "thermometer" of data reliability) will drop across many frequency bands, especially at low levels. This means the measurement data is "dirty" and unreliable.

c) Phase data disorder

The reverberation decay curve and phase response become unreliable because the way the system processes the signal changes dynamically with the level.

In summary, the compression ratio and frequency in compressive diffraction (in engineering, no component can possess linear characteristics across its entire range) are not linear, resulting in a non-linear system as a whole. The amplitude and phase data based on FFT are corrupted, the true characteristics of the system are masked, and coherence is reduced—all of which render the measurement results unreliable.

This also introduces acoustic artifacts and a breathing effect: these artifacts cause changes in audible gain. These changes are most pronounced during large transients. Essentially, compression-expansion processing cannot fully keep up with the dynamic changes of real sound.

If you listen carefully to the sound of an analog wireless microphone, you'll notice that when you finish speaking, the sound from the speaker doesn't stop immediately; the bass lingers for 10-20 milliseconds before disappearing. This is because of "acoustic artifacts," which cause the sound transmitted by the analog wireless microphone to retain a consistently muddy bass, making the sound less clear.

Sound limiting: When the gain exceeds 100dB, peak values that exceed the threshold will be cleared.

2.2.5 Fifth point; conclusion.

The existence of companding technology increases the nonlinear nature of analog wireless communication, making it even less able to meet the requirements of acoustic measurement.

2.3 It is extremely difficult to improve the signal-to-noise ratio (SNR) in analog wireless communication.

2.3.1 We must understand the importance of SNR for acoustic measurements:

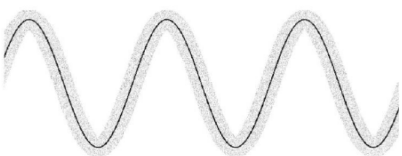
a) Measuring the noise floor in quiet rooms and the environment

b) Capturing long decay times and late reflections

c) Maintain coherence at low frequencies and low levels

2.3.2 SNR in analog wireless communication ?

a) First, analog wireless communication cannot shield itself from interference during transmission; any interference received will be superimposed on the audio signal, causing transmission noise. See the diagram below.



b) Secondly, most analog wireless communication circuits are built based on discrete components, which are themselves analog devices. During operation, these components introduce new noise that the circuit cannot shield. This interference noise is also superimposed on the audio signal.

2.3.3 Poor SNR in analog wireless communication has an impact on acoustic measurements.

The signal-to-noise ratio determines how quiet a signal you can measure. For example, when measuring the background noise of a room or the very low-frequency output of a speaker system, the noise of the wireless system itself acts as a "floor," limiting the depth of your measurement.

c) The reverberation tail was cut off:

When measuring reverberation with a long decay period, the noise of the wireless system itself can prematurely "overwhelm" the true acoustic decay tail, preventing you from measuring the complete reverberation time.

d) Low-level analysis is limited:

When performing low-level noise spectrum analysis, the system's intrinsic noise becomes a limiting factor.

e) Overall accuracy is limited:

If the noise floor of a wireless system is too high, the effectiveness of the measurement will be limited, regardless of the microphone quality or the performance of the analyzer.

2.3.4 Summarize:

The poor SNR performance of analog wireless communication also makes it unsuitable for acoustic measurement.

2.4 Distortion of analog wireless communication

The inherent nonlinearity of companders introduces nonlinearity, leading to increased distortion. Furthermore, high-level signals can cause overmodulation distortion. Most analog wireless systems specify their total harmonic distortion (THD) as the level at which the compander is stable and overmodulation does not occur. Under these conditions, THD specifications are typically between 0.1% and 0.5%.

2.4.1 The effect of distortion on acoustic measurements;

a) False frequency components:

Distortion can produce harmonic frequencies that are not present in the original test signal. These spurious components can be captured by the FFT analyzer, thus contaminating the data.

b) Decreased coherence

On a coherence map, distortion will appear as a coherence "collapse" in the corresponding frequency band.

c) Masking true characteristics:

On the transfer function amplitude curve, there may be abnormal "small bumps" (harmonic components) at multiples of the fundamental frequency, making it impossible for you to determine whether the bump is due to room resonance or distortion caused by the equipment.

2.4.2 Summarize

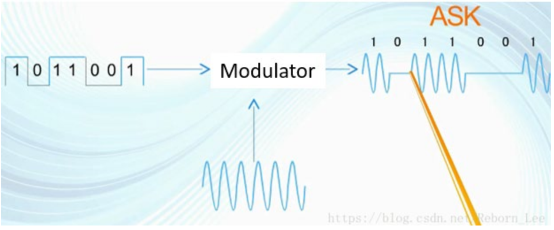
The inherent distortion characteristics of analog wireless communication also preclude its suitability for acoustic measurements.

Looking back at analog wireless communication, you'll find that because the entire analog wireless communication system is built on discrete components, and these components (capacitors, resistors, inductors, etc.) are inherently imperfect, all their property variations are not ideally linear. This results in the analog wireless communication system itself not being an ideal linear system. Nonlinear communication systems cannot support precise tasks like acoustic measurements.

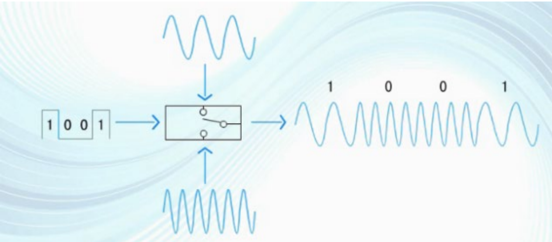
3 How can digital wireless communication achieve acoustic measurement functions?

3.1 Digital wireless communication bypasses the transmission function, thus enabling excellent frequency response characteristics.

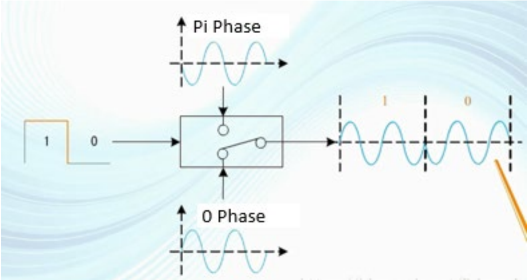
a) Digital audio wireless communication, in essence, transmits 1s and 0s, and does not require establishing a linear relationship between the signal and the carrier wave. See the diagram below:



ASK modulation

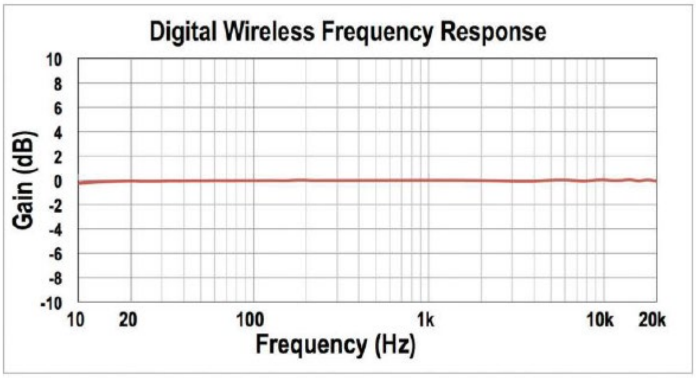


FSK modulation



PSK modulation

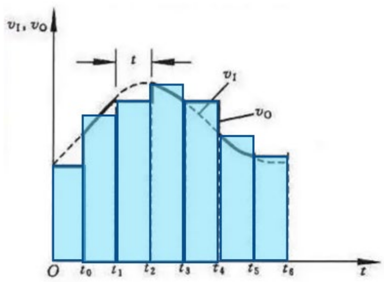
b) Due to the advanced modulation methods, digital wireless communication can easily achieve excellent frequency response characteristics.



Low-frequency and high-frequency responses are functions of the sampling rate, not any characteristic of radio frequency transmission.

3.2 Digital wireless communication can easily transmit volume information, avoiding the need for compression expansion technology.

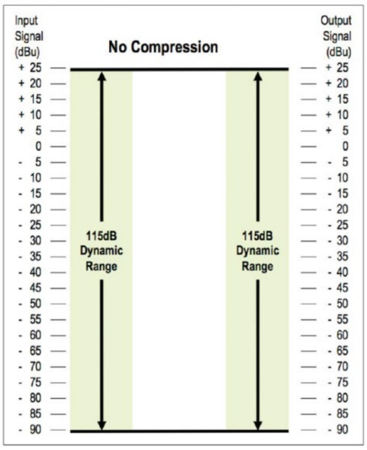
a) In digital communication, volume information is obtained during the A/D conversion process (which also involves a more advanced sampling process).



The deeper the encoding depth, the smaller the volume step interpolation, and the richer the volume dynamics. Therefore, 24-bit is better than 16-bit.

Finally, the maximum volume depends on factors such as the maximum input voltage that the AD/DA chip can withstand and noise, which ultimately affect the volume dynamic range.

b) Digital wireless communication adapts to a wide dynamic range.



It can directly receive audio signals without any compression, limitation, or pre-emphasis/de-emphasis. It can also adapt to...

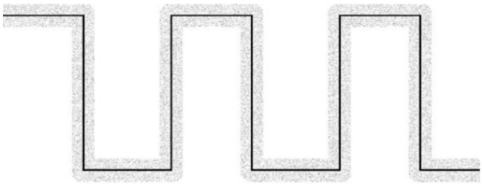
It offers a wider input dynamic range without the need for level control. Ultimately, the input signal can be accurately reproduced at the receiving end .

The dynamic range of the entire system is affected by the AD/DA chip.

Improving the chip itself is easier than improving modulation technology.

3.3 Digital wireless communication has strong noise floor control capabilities.

Digital wireless communication essentially transmits only two states: 1 and 0 (of course, more complex digital wireless communication can transmit more states from 0000 to 1111). This allows for the filtering of noise using a very high threshold. For example, see the diagram below:



Even when a signal is interfered with and superimposed with noise, we can still easily distinguish between 1s and 0s. The advantage of digital transmission is that it can include additional information to help the receiver determine if the data is correct. This is called error detection or correction bits.

This is the underlying principle behind how digital wireless communication can easily achieve a signal-to-noise ratio (SNR) of 120 dB. This superior SNR performance makes digital wireless communication well-suited for acoustic measurements.

3.4 Distortion of digital wireless communication

Distortion is a function of the overall linearity of the system. There is no compander and no possibility of audio overmodulation. The typical specification for total harmonic distortion is 0.03%.

4 Regarding the selection of wireless frequency bands.

Although this article aims to explain the differences between digital and analog wireless communication in acoustic measurements.

However, it is still necessary to explain the differences and importance of different frequency bands in acoustic measurements.

4.1 Regarding the 400 MHz ~ 900 MHz frequency

In addition, for professional-grade acoustic measurements, we need to choose digital wireless communication based on frequencies of 400 MHz to 900 MHz. This is also very important for the following reasons .

In the definition of wireless communication, the UHF band includes the 2.4 GHz frequency range. However, when people mention UHF, they usually think of the 400 MHz to 900 MHz radio frequency band, because most of the world's civilian-use radio frequency bands fall within this range.

From a wireless communication perspective, for long-distance wireless transmission of audio, the frequency band is typically 400 MHz to 900 MHz. It is the most ideal wireless frequency band. In the field of mobile communications, it is called the "golden frequency band":

a) It has excellent wavelength and excellent diffraction and reflection properties, making it suitable for crossing obstacles such as walls.
b) It has good vacuum attenuation performance and is suitable for long-distance transmission.
c) Its matched 1/2 wavelength antenna is within a range that is easy to carry.
d) It avoids the frequency bands used by Bluetooth and Wi-Fi, making the user environment more stable.
e) This perfectly meets the frequency bandwidth requirements for wireless audio transmission.

4.2 Regarding the selection of the 2.4 GHz wireless frequency band

2.4 GHz band was initially planned for mobile communication wearable products, emphasizing shorter antennas to provide wider bandwidth for video signals and solve the "last 10 meters" problem of mobile communication wireless transmission .

The Bluetooth protocol, introduced 2,000 years ago for wearable products, operates on a physical layer at 2.4 GHz . At the time, this was a remarkably intelligent technological solution. It satisfied the need for short-range, high-speed wireless communication while ensuring frequency band uniformity across all countries globally, avoiding the cumbersome certification requirements of different countries.

The subsequent WIFI protocol is also based on the above advantages and is also built on 2.4 GHz .

However, as the application scenarios for Bluetooth and Wi-Fi continue to expand, people's expectations for their range are also constantly increasing. While Bluetooth and Wi-Fi have undergone continuous technological iterations and improvements, the following problems still exist:

a) The wavelength is short, attenuation is poor, and diffraction performance is poor. These are physical characteristics that are difficult to improve through protocols.
b) Communication protocols based on 2.4 GHz (Bluetooth & Wi-Fi) are quite complex, resulting in excessive latency, typically exceeding 10 ms. Although the latest versions of the protocols have significantly improved in this regard, they are still not ideal for engineering applications and cannot meet the requirements of a power amplifier (PA).

c) 2.4 GHz is widely used in Bluetooth and Wi-Fi. In scenarios with a large audience, there will inevitably be a problem of insufficient channel capacity.

d) The use of mobile phones has created many sources of interference that are difficult to plan and control.

4.3 Regarding the selection of the 5.8 GHz wireless frequency band

5.8 GHz band is an extension of the 2.4 GHz band, designed to address the problem of limited wireless frequency resources caused by the increasing number of Bluetooth and Wi-Fi devices.

from the 2.4 GHz band to the 5.8 GHz band took nearly 20 years, and many wireless frequency resources were allocated by governments to mobile communications, military communications, satellite communications, and RFID communications. Considering the future expansion requirements of communication networks, only 5.8 GHz remains as a relatively unused wireless frequency resource for civilian use in various countries .

The biggest weakness of the 5.8 GHz wireless band is that its wavelength is only 5.2 cm, which has too weak penetration and poor vacuum attenuation, making it unsuitable for PA use.

This also explains why, in recent years, many governments have been reclaiming radio frequency resources in the 400 MHz to 900 MHz range.

5 Digital Communication and Protocols

The biggest difference between digital communication and analog communication is the protocol.

Analog communication does not have the concept of a protocol; a communication protocol can only be implemented after the coding technology for digital communication is developed.

5.1 What is the significance of communication protocols?

Wireless automatic control and management are only possible if a communication protocol is in place.

Analog wireless communication lacks a protocol, making even the transmission of volume information extremely complex. This, however, is a very simple matter for digital wireless communication.

Digital wireless communication with protocol capabilities can implement frequency hopping technology at low cost, which is an important way to solve radio interference.

5.2 Why do many companies use 2.4 GHz or 5.8 GHz ?

Everyone knows that 400 MHz to 900 MHz is more suitable for long-distance wireless transmission of audio, but we still chose 2.4 GHz .

The answer still lies in the agreement.

Because the 2.4 GHz band has globally compatible Bluetooth and Wi-Fi protocols and mature, universally applicable chips, businesses only need to purchase the chips to easily achieve digital wireless communication. This avoids the need for research and development of many fundamental technologies such as communication protocols, baseband, and antennas.

However, Bluetooth and Wi-Fi are essentially network communication protocols, which focus on address encoding, addressing, broadcasting, communication routing, and logical link stability. Therefore, latency is not a high-priority technical requirement.

This is why many digital wireless communication devices perform poorly in terms of latency.

6 Grateful

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Thank you to GAODIMIC's loyal users and fans. Friends from all over the world have provided GAODIMIC with a perfect stage and given it a lot of understanding, support, and help, allowing GAODIMIC to hear the beautiful sounds of the world.

---End----

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