Application of Automatic Gain Control Systems in Fiber-Optic Transmission of Microwave Signals (Postprint)

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Abstract

This paper analyzes the principles of microwave automatic gain control technology, circuit structures, and main system technical indicators, such as detector frequency range, sensitivity to minimum input signal variation, and input signal dynamic range. It also studies the technology and principles of microwave signal fiber optic transmission systems. Through digital and analog modulation of the system, effective application of automatic gain control systems in microwave signal fiber optic transmission is realized.

Full Text

Application of Automatic Gain Control Systems in Microwave Signal Fiber Transmission

Abstract: This paper analyzes the principles and circuit structures of microwave automatic gain control technology, along with key system technical indicators such as detector frequency range, sensitivity to minimum resolvable input signal variations, and input signal dynamic range. The study also investigates the technology and principles of microwave signal fiber transmission systems. Through digital and analog modulation, the effective application of automatic gain control systems in microwave signal fiber transmission is achieved.

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In the era of the Internet and Internet of Things, automatic gain control circuits have found extensive and comprehensive applications across various industries. The primary function of automatic gain control circuits is to maintain constant microwave signal fiber transmission in receivers based on feedback principles. This enables overall output while reducing information loss of high-frequency signals during long-distance transmission, thereby avoiding saturation, distortion, and compressed signal damage to backend system equipment, and meeting the demands of microwave communication in the high-capacity information technology era [?].

1.1 Principle of Microwave Automatic Gain Control Technology

Microwave signal fiber transmission represents the product of integrated optical communication and wireless communication technologies, and constitutes a frontier technology in China' s communications field. Since its establishment in 2003, the broadcast monitoring system at Sichuan Radio and Television Station' s 702 Transmission Station has been in continuous operation for 15 years. This system needs to acquire and transmit microwave signals including 1 VGA signal, 18 L-band QPSK signals, and 8 ASI signals. Although microwave signal fiber transmission offers technical advantages such as signal stability, large bandwidth, low loss, no radiation, and immunity to electromagnetic interference, the bandwidth of microwave optical signals can be affected and disturbed during long-distance high-frequency transmission. Therefore, microwave automatic gain control is required to achieve high-capacity microwave signal information transmission. Figure 1 [Figure 1: see original paper] illustrates the implementation schematic of microwave automatic gain control technology [?].

In the microwave signal transmission path, the signal first passes through a variable gain amplifier, which transmits the microwave automatic gain control signal to a directional coupler. The directional coupler then outputs DC electrical signals and microwave signals separately from its coupling and through ports. After the detector performs DC filtering and A/D conversion, digital signal analysis and simulation are conducted to finally output adjustable-gain microwave signals. At this terminal stage, analysis and control can automatically configure the microwave signal output to control the variable gain amplifier' s multiplication factor.

1.2 Key Technical Indicators

1.2.1 Detector Frequency Range The detector frequency range is a critical indicator for implementing microwave automatic gain control system technology. Under different operating frequencies, the control results from the system detector show significant deviation, which increases with the frequency span of the automatic gain control system. To prevent the detector' s inherent frequency range fluctuations from substantially interfering with and affecting the implementation results of microwave automatic gain control system technology, research should be strengthened on impedance matching between directional couplers and system detector input coupling signals in wideband systems to reduce detector frequency range errors [?].

1.2.2 Sensitivity to Minimum Resolvable Input Signal Variation The A/D resolution of the entire microwave automatic gain control system is directly related to its sensitivity indicator. The DC voltage output from the system detector is proportional to the actual amplitude of the microwave signal input into the system. However, this DC voltage output from detection is subject to ripple interference from radio signals. Since the actual microwave signal interference level varies across specific frequency bands, DC filtering should be applied according to the actual microwave signal input to the detector during microwave transmission automatic gain control.

1.2.3 System Input Signal Dynamic Range Both input and output microwave signals in microwave automatic gain control systems fluctuate within certain ranges, but the gain adjustment range of the variable gain amplifier directly affects the dynamic variation value of the microwave input signal. Generally, the smaller or larger the gain adjustment range, the smaller or larger the signal dynamic range input into the microwave automatic gain control system.

2.1 Microwave Signal Fiber Transmission System

Figure 2 [Figure 2: see original paper] presents the architecture of the microwave signal fiber transmission system, primarily consisting of five components: input microwave signal, light source and fiber, photodetector, and output microwave signal. In microwave signal fiber transmission, the microwave signal must first be modulated onto an optical signal with wavelength of 1260~1610nm. The microwave optical signal then undergoes fiber transmission and is input to a photodetector, which demodulates the microwave signal from the optical signal for final output.

In the aforementioned system, microwave signal fiber transmission requires the "light source" as a core module to achieve microwave modulation and conversion between analog and optical signals. Through digital modulation/analog modulation or direct modulation/degradation modulation, the desired microwave signal is output according to the principle shown in Figure 3 [Figure 3: see original paper], effectively avoiding signal distortion.

When performing microwave signal fiber transmission based on the automatic gain control system, the six signal sources from the existing earth station system can be transmitted to the earth station through broadcast television center microwave, high tower SDH microwave, and ASI baseband fiber. In automatic gain control, the microwave signal must first be modulated into the system light source, after which the modulated optical signal output from the light source can be input to the photodetector through fiber.

After demodulation, the microwave signal is extracted from the optical signal photodetector. Through automatic gain control by the variable gain amplifier, the microwave signal is automatically input to the directional coupler. During final output, one portion of the microwave signal outputs to the directional coupler while another portion automatically outputs to the system detector, from which DC signals are output. Following DC filtering and AD conversion, the variable gain amplifier module of the automatic gain control system performs gain control to output the required digital signal [**?**].

In Figure 3, the output optical power of the modulated microwave fiber signal can be expressed by the following formula [**?**]:

$$P(t) = P_0(1 + m_i \cos \omega t) \quad \text{(Equation 1)}$$

where P_0 is the average optical power of microwave signal fiber transmission, m_i is the intensity modulation coefficient, and ω_m is the modulation signal angular frequency.

2.2 Microwave Signal Fiber Transmission and Modulation Principle

Currently, the most commonly used external modulator is the lithium niobate (LiNbO3) Mach-Zehnder modulator. Through traveling-wave electrodes, it can achieve high-speed operation within a relatively small modulation signal frequency range. Under this external modulator, fiber can be effectively coupled with optical waveguides while reducing fiber loss in principle, decreasing wavelength dependence, and improving system modulation performance. However, in external modulation, the external modulator must be maintained at the optimal bias point, and the influences and interference from input optical power, ambient temperature, and modulation time must be analyzed to prevent distortion or drift in the modulated microwave signal.

Figure 4 [Figure 4: see original paper] illustrates the external modulation principle.

3. Application Analysis of Automatic Gain Control Systems in Microwave Signal Fiber Transmission

In our station's original signal source switching transmission system, the satellite earth station' s ASI baseband fiber, broadcast television center microwave (6 signal sources), and high tower SDH microwave sequentially pass through an automatic switching matrix 8$ \times 8 ASI module, without output ports connected to five modulators respectively, and the nac
ASI module requires signal source hopping during transmission, which not only suffers from poor security but also demands multiple signal modulators.

Based on the above process, the application test results of microwave signal fiber transmission technology based on automatic gain control were obtained, with detailed comparative data values shown in Table 1 and Table 2 .

Table 1: Application Test Results with Automatic Gain Control

Actual Input Signal Frequency in Microwave Signal Fiber Transmission (MHz)	Actual Input Signal Amplitude in Microwave Signal Fiber Transmission (dBm)	Test Results with Automatic Gain Control (dBm)
95MHz-105MHz	-20dBm	-10.96dBm
95MHz-105MHz	-15dBm	-10.65dBm
95MHz-105MHz	-10dBm	-10.72dBm
450MHz-550MHz	-20dBm	-11.05dBm
450MHz-550MHz	-15dBm	-11.26dBm
450MHz-550MHz	-10dBm	-11.03dBm
900MHz-1100MHz	-20dBm	-10.59dBm
900MHz-1100MHz	-15dBm	-10.67dBm
900MHz-1100MHz	-10dBm	-10.52dBm

Table 2: Application Test Results without Automatic Gain Control

Actual Input Signal Frequency in Microwave Signal Fiber Transmission (MHz)	Actual Input Signal Amplitude in Microwave Signal Fiber Transmission (dBm)	Test Results without Automatic Gain Control (dBm)
95MHz-105MHz	-20dBm	-11.89dBm
95MHz-105MHz	-15dBm	-5.81dBm
95MHz-105MHz	-10dBm	-0.92dBm
450MHz-550MHz	-20dBm	-13.46dBm
450MHz-550MHz	-15dBm	-6.79dBm
450MHz-550MHz	-10dBm	-2.41dBm
900MHz-1100MHz	-20dBm	-13.36dBm
900MHz-1100MHz	-15dBm	-7.69dBm
900MHz-1100MHz	-10dBm	-2.01dBm

Figure 5 [Figure 5: see original paper] shows the technical application flow.

The data comparison in the tables above demonstrates that under the same input signal frequencies and amplitudes, the output signal amplitude values obtained from microwave signal fiber transmission based on automatic gain control differ significantly from those without automatic gain control.

In addition to signal monitoring functions, the automatic gain system can promptly identify signal fault points, provide alarm prompts, and switch microwave signals to normal backup signal sources or equipment. When actual input signal frequencies are set to 95MHz-105MHz, 450MHz-550MHz, and 900MHz-1100MHz respectively, and actual input signal amplitudes are set to -20dBm, -15dBm, and -10dBm respectively, the test results of microwave signal fiber transmission technology based on automatic gain control are more stable. In contrast, the output signal amplitude from microwave signal fiber transmission without automatic gain control exhibits large fluctuations that vary with input signal amplitude changes.

These results demonstrate that automatic gain control systems in microwave signal fiber transmission offer numerous advantages including good reliability, strong practicality, advanced architectural principles, and excellent economy. Through automatic gain control systems, our station has improved the microwave signal transmission in the signal source switching system, resulting in a simple and clear system link. The newly configured modulators comply with international communication and network interface standards, provide good compatibility, and feature high informationization levels, meeting satellite communication, computer and network communication technology, broadcast television technology requirements, and the latest development trends.

The application of automatic gain control technology can effectively improve microwave signal fiber communication quality and signal fluctuation stability. Previously, in microwave signal fiber communication systems, fiber connectors and cable differential losses would cause unstable amplitude variations in microwave signals output from photodetectors, with significant differences in received optical power. Through automatic gain control, this paper not only solves this problem but also obtains high-quality microwave transmission signals through modulation.

References: [1] Yang Jianmei. Discussion on Microwave Signal Fiber Transmission Technology[J]. Digital Communication World, 2018(9): 59.
[2] Wang Na. Microwave Signal Fiber Transmission Technology and Application[J]. China' s Strategic Emerging Industries, 2017(36): 19.
[3] Guo Fang. Microwave Signal Fiber Transmission Technology and Application[J]. Communication World, 2017(11): 82-83.
[4] Li Qifeng, Jia Yanbin, Guo Linli, et al. Research on Signal Transmission in Communication Technology[J]. China High-tech Zone, 2017(10): 154.
[5] Zhang Jianwen. Microwave Signal Fiber Transmission Technology and Application[J]. Technology Innovation and Application, 2016(16): 86.

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