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Common-Source Modulated Frequency Modulation Synchronous Broadcasting via Terrestrial Microwave Transmission: Post-Print

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Date: 2023-10-08T00:00:00+00:00

Abstract

FM synchronous broadcasting is an effective means for saving frequency resources and expanding coverage range. This article, based on the design and construction of the Guangdong Radio Traffic Voice FM synchronous broadcast transmission and broadcasting system, introduces the technical principles, characteristics, and engineering implementation of a co-source modulation FM synchronous transmission network that uses ground microwave to transmit program source signals.

Full Text

Co-source Modulated FM Synchronous Broadcasting Using Ground Microwave Transmission

Abstract: FM synchronous broadcasting represents an effective approach for conserving frequency resources and expanding coverage. Drawing upon the design and construction of the FM synchronous broadcasting transmission system for Guangdong Radio Traffic Channel, this paper introduces the technical principles, characteristics, and engineering implementation of a co-source modulated FM synchronous transmission network that utilizes ground microwave to transmit program source signals.

Keywords: FM synchronous broadcasting; ground microwave; co-source modulation
Classification: G229.27
Document Code: A
Article ID: 1671-0134(2017)05-124-02
DOI: 10.19483/j.cnki.11-4653/n.2017.05.046
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FM synchronous broadcasting is an effective means to save frequency resources and expand coverage. This article combines the design and construction of the FM synchronous broadcasting transmission and emission system for Guangdong Radio Traffic Channel to introduce the technical principles, characteristics, and engineering implementation of a co-source modulated FM synchronous transmission network using ground microwave to transmit program source signals.

The system does not simply perform spectrum shifting of microwave signals but rather "regenerates" an FM signal using precision phase-locking technology. This regenerated signal is controlled by two factors: first, it tracks the instantaneous frequency variations of the input microwave signal to accurately "replicate" the entire dynamic spectrum onto the FM band; second, its center frequency is precisely locked by a highly stable 19KHz pilot signal delivered through the microwave channel. The frequency accuracy of the FM signal depends solely on the 19KHz timebase and has no direct relationship with the frequency accuracy of the microwave signal itself (including relay forwarding). The 19KHz timebase maintains its frequency precision throughout transmission, regardless of modulation at the microwave central station, forwarding at relay stations, or reception and demodulation at synchronous stations. Since the system only requires a single standard frequency source at the microwave central station, which can be transmitted to all synchronous stations via microwave signals, the grade of the standard frequency source can be made very high. Consequently, the system employs a rubidium atomic clock oscillator to enhance timebase stability, ensuring that the carrier frequency difference between transmitters far exceeds the standard requirement of 1×10^{-9}.

After years of exploration and refinement, following the domestic development and production of system equipment, the Traffic Channel's FM synchronous broadcasting system passed technical acceptance by the State Administration of Radio, Film, and Television in 2008, entering a new period of stable operation that continues to provide high-quality audio broadcasting services to the public.

1. Technical Specifications

This project references the "Technical Specifications for FM Synchronous Broadcasting Systems" (GY/T154-2000), with basic system technical requirements of "three sames and one guarantee": 1. Same frequency: relative frequency difference $\leq 1\times10^{-9}$ 2. Same phase: relative time delay difference $\leq$ 10 s (monaural), 5 s (stereo) 3. Same modulation depth: modulation difference $\leq$ 3% 4. Guarantee that the minimum usable field strength within the coherent zone meets ITU regulations

2. Technical Principles

2.1 Signal Transmission

Signal transmission employs ground microwave transmission, with the central station located on the top floor of Guangdong Television Station, transmitting to each synchronous station in a "central blossom" pattern. Microwave transmission uses analog FM modulation.

2.2 Same Frequency

A high-precision timebase serves as the standard frequency source at the microwave central station. The 10MHz standard frequency output from this source locks the 19KHz pilot signal in the stereo composite signal, achieving stability better than 5$\times10^{-9}$/24 hours as the system timebase. At the microwave central station, the stereo composite signal is modulated onto the microwave carrier and transmitted to each synchronous station.

The synchronous exciter at each station converts the received microwave signal to an intermediate frequency (IF), extracts the 19KHz pilot signal as the timebase, and locks its own carrier frequency through a phase-locking circuit with strong tracking capability. The synchronous exciter does not simply shift the microwave signal spectrum but regenerates an FM signal through precision phase-locking technology, controlled by two aspects: tracking instantaneous frequency changes of the input microwave signal to precisely replicate the entire dynamic spectrum onto the FM band, while the signal's center frequency is precisely locked by the highly stable 19KHz pilot signal from the microwave channel.

2.3 Same Phase

This system uses ground microwave to transmit audio source signals. The phase difference between two or more FM modulated waves manifests in two parts: first, different microwave signal transmission paths create time delay differences in signals arriving at each synchronous station; second, different transmission conditions and power levels at each synchronous station cause the coherent zone location to deviate from the midpoint of the straight-line distance between stations, resulting in time delay differences when signals reach the coherent zone. Both types of delay differences must be compensated. This system installs RF digital delay devices at each synchronous station to adjust the delay time of each synchronous exciter, ensuring the time delay difference within the coherent zone is ≤ 5 s.

2.4 Same Modulation Depth

The system's most prominent advantage is its ability to maintain absolutely consistent modulation depth across all synchronous transmitters. At the microwave central station, the microwave transmitter modulates the MPX stereo composite signal onto the microwave carrier for transmission to each synchronous station. At each synchronous station, the synchronous exciter converts the received signal to IF and "replicates" the entire dynamic spectrum to the FM band through a precision phase-locking circuit before amplification and output. This process does not involve demodulation and remodulation—audio signals are modulated only once in the microwave transmitter throughout the entire system—guaranteeing 100% consistent modulation depth across the system and avoiding system performance degradation caused by modulation depth deviations.

The synchronous exciter consists of two parts: microwave reception and synchronous excitation. At each synchronous station, the exciter receives the microwave signal, converts it to IF, extracts the 19KHz pilot signal as the timebase, and locks its carrier frequency through a phase-locking circuit with strong tracking capability.

2.5 Minimum Field Strength Guarantee

This is achieved by adjusting each transmitter's power and antenna position/pattern based on actual field strength measurements.

3. System Characteristics

The synchronization technology, circuit design, and supporting products used in this system originated from Silicon Valley in the early 1990s, where they were exhibited and awarded at NAB. We digested and absorbed the essence of the original design, improved its insufficient timebase accuracy, and developed relay equipment, various antennas, and other system products suited to domestic conditions, gradually perfecting the synchronous system and expanding coverage to Panyu and Huadu districts. The system features several notable characteristics:

The design concept is clear, the technology mature, and the system 配套 complete. Each component of the system fully considers the characteristics and requirements of synchronous systems, employing proven and reliable technical approaches—this is why the experiment achieved good results from its initial stages.

Modulation depth consistency and atomic clock application. Compared with other synchronous systems, a prominent feature of this system is its co-source modulation method, which ensures absolutely identical modulation depth at each transmission site. Additionally, the system uses a high-stability, high-precision, long-life, maintenance-free rubidium clock as the timebase signal to synchronize the entire system, improving the system's same-frequency index to the 10^{-11} level—far exceeding national standard requirements, stable and reliable. Moreover, within the station's control range, it avoids impacts from GPS signal loss due to military projects or various accidental factors during satellite signal transmission.

Application in medium-power synchronous coverage over long distances. After completing central urban area coverage, the station's goal was to cover Greater Guangzhou, including Huangpu District. The Guangzhou-Huangpu synchronous network employs "radial" coverage. Although inter-station distances increased and the theoretical coherent zone expanded, the coherent zone situation is much simpler than in urban areas, with simpler system parameter adjustment. The advantages of this synchronization technology in precision "three sames" are more fully realized in medium- and long-distance coverage, achieving better coverage effects.

Synchronous transmission sites feature numerous, dispersed locations, making remote monitoring system construction particularly important. Considering the different actual conditions at each synchronous transmission site, the remote monitoring system must support multiple data transmission links.

4. Implementation

4.1 Site Selection

Considering system operating costs and population distribution, and based on Guangzhou's geographical features of being "long east-west and short north-south," we selected transmission sites following the principle of approximately 18km spacing for monaural and 9km for stereo. We established two transmission stations in the east-west direction and selected one additional station in the old urban area as a fill-in site to achieve both central area coverage and coverage of newly developed eastern Guangzhou areas.

4.2 System Adjustment

Adjustment of delay times at each synchronous station: By adjusting the digital delay devices installed at each synchronous station, phase synchronization of signals in the interference zone is ensured. Since this system uses microwave to transmit program source signals, delay differences mainly result from different path lengths. With spatial RF transmission speed being constant, theoretical delay time values are relatively simple to calculate and can be fine-tuned within small ranges based on actual conditions.

Antenna and feed system adjustment: Through adjusting FM antenna orientation and inter-element phase relationships, as well as employing weak directional antennas, the system meets minimum usable field strength requirements within effective coverage areas. Based on each station's distance from the city center, adjusting transmitter power and antenna direction satisfies coverage requirements.

4.3 System Testing

(1) System timebase test: The system timebase is 19KHz. After locking with a rubidium atomic clock, 30 samples were taken over three days, with a mean value of 19000.00000091Hz, maximum drift of 0.00000039Hz, and daily stability better than 2.05×10^{-11}/day.

(2) Frequency test: After establishing a reference base station, frequency tests were conducted on each transmission station, with a maximum relative frequency difference of 1.81×10^{-10}.

(3) Modulation depth difference: Modulation depth tests were performed at different frequency deviations and audio frequencies, with a maximum modulation depth deviation of 0.2% (including equipment and measurement instrument errors).

(4) Field strength coverage test: Overall coverage tests basically achieved the target of 90% outdoor locations in the central urban area reaching a median FM broadcast service field strength of 66dB (metropolitan standard), 56dB in satellite towns, and 46dB in rural areas. Within municipal districts including Yuexiu, Haizhu, Liwan, Huangpu, and Baiyun, coherent zones are not obvious and remain small. Due to blockage from the Baiyun mountain range, FM signals in Conghua and Zengcheng districts and towns fail to meet minimum field strength requirements.

(5) Subjective listening evaluation: In areas with strong field strength (e.g., >66dB), ordinary radios can achieve stable reception with clear sound, free of noise and channel-switching clicks. In over 85% of the coverage area, subjective listening evaluation reaches or exceeds grade 4.

5. Conclusion

Traffic Channel's use of an FM synchronous transmission system to network coverage of Guangzhou's urban, suburban, and rural areas meets the station's field strength coverage requirements for urban, town, and rural areas. Coherent zone listening quality degrades compared to strong field strength areas, but the affected range is small and the degradation remains acceptable to most listeners, fundamentally satisfying both the station's and audience's listening requirements.

The greatest advantage of FM synchronous broadcasting systems is saving frequency resources and facilitating fill-in coverage and range expansion. After twenty years of operation, Traffic Channel's FM synchronous broadcasting system has fully leveraged this technical advantage, consistently ranking among the top three Guangdong Radio stations in both listenership and revenue generation, achieving excellent economic and social benefits.

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Note: Figure translations are in progress. See original paper for figures.

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