MF200 Multi-frequency Medium-wave Broadcast Transmitter Facilitates the Development of the Broadcasting Industry (Postprint)

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Abstract

The MF200 multi-frequency medium wave broadcast transmitter is a new-generation high-power medium wave broadcast transmitter led and developed by the Radio Administration Bureau of the National Radio and Television Administration. It employs the most advanced direct digital drive power amplifier module technology and multi-frequency automatic tuning technology, enabling it to switch from one frequency to other preset broadcast frequencies within 60 seconds. This transmitter has undergone a half-year trial operation and substitute broadcasting experiment at the 561 Station of the National Radio and Television Administration, with all indicators meeting the National Grade A standard and measured overall efficiency reaching over 90%. It has been deployed as a shared backup unit in the Jia machine room of the 561 Station. This paper provides a brief analysis of the project development status and technical breakthroughs of the MF200 multi-frequency medium wave broadcast transmitter, aiming to contribute to the development of the broadcasting industry through the MF200 multi-frequency medium wave broadcast transmitter.

Full Text

MF200 Multi-Frequency Medium Wave Broadcast Transmitter: Advancing the Broadcasting Industry

Abstract: The MF200 multi-frequency medium wave broadcast transmitter is a new-generation high-power medium wave broadcast transmitter led by the State Administration of Radio and Television Wireless Radio Bureau. It employs state-of-the-art direct digital drive amplifier module technology and multi-frequency automatic tuning, enabling frequency switching to other preset broadcast frequencies within 60 seconds. The transmitter underwent a six-month trial operation and substitution broadcast experiment at Radio Station 561 of the State Administration of Radio and Television, with all indicators meeting national Class-A standards and measured overall efficiency exceeding 90%. It has been deployed as a shared backup unit in the Class-A machine room of Radio Station 561. This paper provides a brief analysis of the development and technical breakthroughs of the MF200 multi-frequency medium wave broadcast transmitter, demonstrating its contribution to advancing the broadcast industry.

Keywords: medium wave transmitter; MF200; multi-frequency; digital drive; high-speed serial audio

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1. Current Status and Challenges of Medium Wave Transmitters

High-power medium wave transmitters both domestically and internationally typically operate at fixed frequencies. Changing frequencies requires extensive readjustment of numerous components. Taking the American HARRIS DX200 medium wave broadcast transmitter as an example, adjustments must be made to the pre-driver, driver stage, efficiency coil, output matching network, and various circuit boards. This series of adjustments consumes substantial time and manpower, making short-term substitution between different frequency medium wave transmitters nearly impossible, which severely impacts the secure transmission and broadcasting operations of the Wireless Bureau.

Radio Station 561' s Class-A machine room is equipped with three DX200 medium wave transmitters operating in single-machine mode without backup units or substitute stations. When failures occur, technicians must handle them on-site. Major faults or untimely repairs can cause prolonged broadcast interruptions, creating an urgent need for backup medium wave transmitters. To address this challenge, with support from the State Administration of Radio and Television and the Wireless Bureau leadership, Radio Station 561 established the "MF200 Multi-Frequency Medium Wave Broadcast Transmitter" development project team in 2010. Leveraging research capabilities from the Wireless Radio Bureau, Beijing Guangshi Wireless Responsibility Co., Ltd., and Radio Station 561, the team spent six years developing the MF200 multi-frequency medium wave broadcast transmitter, breaking foreign monopolies on medium wave transmitter technology and achieving the goal of one transmitter backing up multiple frequencies.

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2. MF200 Multi-Frequency Medium Wave Transmitter System Design Framework

The MF200 multi-frequency medium wave transmitter comprises RF, audio, control, protection, and power supply systems, utilizing self-developed direct digital drive amplifier modules. Compared with the DX200 medium wave transmitter, it eliminates complex RF front-end amplification and tuning components such as buffer stages, pre-driver stages, and driver stages, reducing the number of amplifier modules from 239 to 224. Module control signals employ high-speed serial synchronous transmission technology, significantly reducing wiring connections. The system features wide-frequency design, capable of completing switching between different preset frequencies within 60 seconds. The physical unit is shown in Figure 1 [Figure 1: see original paper].

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3. System Principles

The MF200 multi-frequency medium wave broadcast transmitter is a newly designed all-solid-state 200kW multi-frequency medium wave broadcast transmitter. The transmission system includes RF, audio, control, protection, and power supply systems, along with a specially designed antenna switching system and 400kW dummy load.

3.1 RF System

The transmitter' s RF system includes direct digital drive amplifier modules, RF audio distribution boards, module control boards, audio processing board RF modules, output matching networks, and antenna switching systems.

3.1.1 Direct Digital Drive Amplifier Module The module employs differential PECL balanced inputs to reduce high-frequency interference effects on the input signal. It utilizes programmable logic device PAL22V10 and numerous surface-mount chips to enhance module integration. The main circuits include: RF input conversion circuits, module control and monitoring, switching power supplies, RF isolation and drive, and an H-bridge output circuit composed of eight MOS field-effect transistors IRFP460LC. The basic principle of the direct digital drive amplifier module is shown in Figure 2 [Figure 2: see original paper].

3.1.2 RF Audio Distribution Board RF Module The RF audio distribution board RF module primarily designs a carrier clock distribution module based on receiving carrier signals and bit frequency (16 times the carrier frequency) from the audio processing board, dividing the bit frequency to obtain the carrier synchronization reference frequency Fc.

3.1.3 Module Control Board The module control board receives I2S-structured serial 12-bit digital audio data from the RF audio distribution board.

It uses an EPM7128SLC84 chip to form a CPLD online programmable circuit for decoding serial data. The decoded signals are sent through the synthesizer motherboard to eight direct digital drive amplifier modules under its control, thereby managing the on/off switching of the amplifier modules.

3.1.4 Audio Processing Board RF Module The audio processing board is one of the core functional processing components of the digital modulator, receiving and processing external RF and audio signals. The RF processing unit generates the bit frequency using the PLL module inside the FPGA based on an externally input 10MHz standard frequency or 10 times the carrier frequency. It obtains the carrier frequency through a designed frequency division module and transmits it using I2S serial data transmission mode to the RF audio distribution board.

3.1.5 Output Matching Network The output matching network resonates and impedance-matches the synthesized output waveform to obtain the desired smooth amplitude-modulated wave. It comprises two parts: first, vacuum capacitors and inductors for impedance matching, along with four segment-switching circuit breakers and four tuning motors that adjust variable vacuum capacitor values; second, an output matching network switching control board for tuning control. The matching network hardware schematic is shown in Figure 3 [Figure 3: see original paper], where L1 and L2 achieve inductance switching through circuit breakers, and C1, C2, C3, and C4 achieve capacitance value transformation through tuning motors.

3.1.6 Antenna Switching System The antenna switching system mainly includes a data acquisition system for primary and backup transmitters, a CPLD-based data logic processing and analysis system, and a user interface operation and display system.

3.2 Audio System

The audio system primarily completes the design of the transmitter digital modulator based on an FPGA+DSP platform, with its core being audio signal modulation processing, carrier synthesis and control output, as shown in Figure 4 [Figure 4: see original paper]. The audio system mainly includes audio signal sampling and processing, audio sample rate conversion, audio+DC, power control, and index compensation.

3.2.1 Audio Signal Sampling and Processing The audio processing board ADSP-21489 configures the external chip ADAU1961 to receive analog audio signals at 48kHz sampling rate. Simultaneously, it uses the internal SPDIF interface to receive external digital signal inputs. Audio signal processing includes FIR low-pass filters and CIC interpolation compensation filters.

3.2.2 Audio Sample Rate Conversion Input audio signals use the standard 48kHz sampling rate, which generally does not have an integer relationship with the carrier frequency. Therefore, this system employs a two-stage adaptive sample rate conversion method. The ADSP-21489 integrates an asynchronous sample rate converter, which, combined with asynchronous sample rate conversion in the DSP and synchronous sample rate conversion in the FPGA, elevates the signal sampling rate to the carrier frequency. Synchronous sample rate conversion is implemented using CIC interpolation filters.

3.2.4 Audio + DC Audio signals after sample rate conversion, Audio, are combined with a DC value DC using an adder to obtain 12-bit composite audio output signals. The subsequent modulation encoding distribution board receives the 12-bit signal data and implements audio signal modulation through encoding distribution and carrier frequency control.

3.2.5 Power Control Power control mainly includes the following functions: (1) startup power level control (high, medium, low); (2) fine power adjustment (power increase operation, power decrease operation); and (3) step-up power and power feedback control.

3.2.6 Index Compensation To improve the transmitter's frequency response and distortion indicators, algorithms are implemented in the DSP. Frequency response compensation uses multiple filter groups for segmented signal band processing. RF amplifier nonlinear distortion uses predistortion technology, employing a Volterra polynomial predistorter to implement predistortion compensation for baseband audio signals, reducing output signal harmonics and intermodulation distortion. Power supply ripple compensation improves transmitter noise level indicators by using an external AD sampling chip for high-speed sampling of power supply voltage feedback signals and using multipliers in the FPGA to cancel real-time feedback power supply ripple signals, thereby reducing noise levels.

3.3 Control and Protection

The MF200 multi-frequency medium wave transmitter control system consists of a main control board, digital board, analog board, multi-frequency switching module, and upper computer display operation interface, as shown in Figure 5 [Figure 5: see original paper]. The main control board comprises a 32-bit PIC processor and FPGA, jointly completing transmitter-related control. The main control board FPGA primarily uses a multi-channel DMA data acquisition and transmission controller and a general-purpose expandable data bus interface to implement data acquisition and transmission from peripheral inputs, digital boards, analog boards, audio boards, and other boards, ultimately handled by the 32-bit PIC microcontroller for system control processing. The digital board mainly implements real-time acquisition of various digital signals from the transmitter and transmits them to the main control board via DMA data communication bus, receiving corresponding execution commands from the main control board and outputting control signals. The analog main board implements real-time acquisition of various analog states of the transmitter and transmits them to the main control board via DMA data communication bus. The multi-frequency switching module mainly handles switching of transmitter output matching network adjustments, carrier frequency setting detection, audio period and VSWR detection parameters when the transmitter changes frequency. The upper computer display operation interface mainly implements transmitter status display, specific operations such as power on/off, transmitter operation data saving, and frequency switching tuning operations. The audio board completes digital audio sampling rate changes, power control, predistortion correction processing, and then packages them into 16-times carrier frequency serial signals transmitted to the RF audio distribution board.

The MF200 multi-frequency medium wave broadcast transmitter incorporates various monitoring and protection circuits, mainly including temperature, airflow, arc light, and VSWR monitoring and protection measures to ensure transmitter equipment safety.

3.3.1 Temperature Monitoring Temperature switches are installed on rectifier cabinet thyristors, freewheeling diodes, 250V power supply filter inductors, and discharge boards to detect the temperature of corresponding equipment. When any equipment temperature exceeds a certain value, the temperature switch activates, generating corresponding monitoring signals sent to the modulator controller for processing.

3.3.2 Airflow Monitoring Each cabinet is equipped with an airflow detection board to monitor airflow conditions inside the cabinet. When airflow in any cabinet becomes abnormal, the transmitter reduces power until shutdown to protect the equipment.

3.3.3 Arc Monitoring Arc detection boards are installed in the machine amplifier cabinet and network cabinet to monitor for arcing inside the cabinets. When arcing occurs in any cabinet, the arc detection board outputs a fault signal, and the transmitter reduces power; if arcing persists, the transmitter shuts down to protect the equipment.

3.3.4 VSWR Sampling Protection VSWR sampling protection includes automatic switching control circuits, network voltage and current tuning, amplitude adjustment circuits, etc. It activates automatic switching control circuits based on 3-bit frequency signals sent from the modulator controller to generate control signals, adjusting antenna voltage, antenna current, network voltage, and network current sampling signals, as well as phase detection signals, for the modulator controller to process accordingly to protect the transmitter.

3.4 400kW Dummy Load

The 400kW air-cooled dummy load is a high-power dummy load independently developed by Radio Station 561 of the State Administration of Radio and Television. It uses 80 custom-made 12kΩ, 5kW-rated ($±$5% tolerance) high-power non-inductive hollow-wound resistors in parallel, with an output impedance of approximately 150 ohms, capable of handling up to 400kW maximum power—more than 1.5 times the 200kW carrier power. In hot state, the individual maximum power handling is 5kW, greater than the 2.5kW during carrier operation, meeting power design requirements. These resistors use hollow-wound inductors with good ventilation effects, allowing forced cooling by fans. Made with special processes, they have small temperature drift, stable operation in hot states, and are fixed using stainless steel clamps for reliable connection and low contact resistance. The dummy load physical unit is shown in Figure 6 [Figure 6: see original paper].

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4. Power Supply Section

The multi-frequency transmitter power supply consists of 3Φ197VAC, 3Φ380VAC, +250VDC, +125VDC, +48VDC, and +12VDC, as shown in Figure 7 [Figure 7: see original paper].

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5. Key Technical Innovations

The main technical innovations include:

5.1 Direct Digital Drive Amplifier Module: The amplifier unit employs proprietary direct digital drive amplifier module technology, eliminating the RF front-end driver amplification stage similar to that in DX transmitters. RF filter output adopts a two-stage output network, namely the output matching network cabinet and Π-network cabinet, using vacuum circuit breakers to switch network inductors and stepper motors to control vacuum variable capacitors, thereby adjusting the RF network to required parameters for perfect tuning.

5.2 Direct Digital Drive Technology: The direct digital drive amplifier module uses differential PECL balanced inputs to reduce the impact of RF output on the input. Additionally, it employs programmable logic device PAL22V10 and numerous surface-mount chips, greatly improving module integration.

5.3 Output Network Automatic Fast Switching Technology: The output matching network mainly comprises two parts: first, vacuum capacitors and inductors for impedance matching, along with four segment-switching circuit breakers and four tuning motors that change adjustable vacuum capacitor values; second, an output matching network switching control board for tuning control.

5.4 Nonlinear Digital Predistortion Technology: Due to nonlinearities from amplifier module synthesis and power supply ripple, direct digital drive amplifier module synthesis exhibits nonlinearity. Therefore, predistortion compensation technology is necessary to achieve Class-A standards. This system employs multi-band predistortion technology in the digital domain to solve nonlinear distortion problems, meeting transmitter technical index requirements for nonlinear distortion.

5.5 VSWR Detection Circuit Automatic Switching Technology: The VSWR detection circuit automatic adjustment technology can automatically switch to corresponding parameters based on the set frequency, ensuring the transmitter can operate safely and reliably after efficient frequency changing.

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6. Application Status

The MF200 multi-frequency medium wave broadcast transmitter trial operation began on December 13, 2016 (729kHz) and ended at 17:00 on June 13, 2017, totaling 3,023 hours, 12 minutes, and 9 seconds. After the trial period, it served as a shared backup unit for three DX transmitters in the Class-A machine room. As of April 2019, it had substituted broadcasts seven times with a total substitution duration of 95 hours and 13 minutes, reducing outage time by approximately 22,446 seconds (equivalent to 6 hours, 14 minutes, and 6 seconds).

The MF200 multi-frequency medium wave transmitter is an independently developed new-generation high-power medium wave broadcast transmitter. Multiple technologies are pioneering domestically and internationally. The transmitter system features reasonable layout, advanced technology, and stable, reliable operation. After six months of trial operation and more than two years of service as a shared backup unit in Radio Station 561's Class-A machine room, all indicators have reached the national Class-A standard, with overall efficiency exceeding 90%—higher than the DX200 medium wave transmitter' s 86% efficiency. The transmitter demonstrates high technological innovation, breaking foreign monopolies on medium wave broadcast transmitter technology. Its successful development holds strategic significance and social value in China' s high-power medium wave broadcast transmitter field and merits large-scale promotion and application.

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