

Auto-Coaxial Switch Controller for Redundancy in FM Broadcasting Transmitter

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Abstract. *This paper presents the design and implementation of a Programmable Logic Controller (PLC)-based automatic coaxial switch controller for redundant Frequency Modulation (FM) broadcasting transmitters. The proposed system facilitates autonomous switching between the main transmitter (Tx1) and the backup transmitter (Tx2), ensuring seamless connection to the antenna and uninterrupted broadcast service. Experimental results indicate that the output power (P_{out}) during normal operation (signal from Tx1) and after switching (signal from Tx2) are comparable, measured at 939.61 W and 944.06 W, respectively. Furthermore, the switching process requires no more than 30 seconds per event, guaranteeing continuous FM broadcasting throughout the year, with the total switching time representing less than 1% of the annual transmission duration. Consequently, the proposed automated controller operates independently without the need for a computer, master clock, or human intervention.*

Keywords: FM Broadcasting Transmitter, Program Logic Controller, Auto Coaxial Switch.

1 Introduction

Nowadays international radio broadcasters, for example Voice of America (VOA) and British Broadcasting Corporation (BBC) could deliver voice and music programs to the listeners from their network control center to various transmitter sites around the world. The programs are fed via satellite and internet prior to the transmitter sites. Some transmitter sites are operated manually with human intervention, while others are operated independently and controlled remotely. Restrictions associated with transmitter operation in remote locations such as desert areas include limited accessibility, high travel costs, and significant time consumption for corrective maintenance conducted by the maintenance staffs, whether the Frequency Modulation (FM) transmitter station is located in Thailand or abroad [1].

Numerous techniques have been proposed for the remote monitoring and control of FM broadcasting stations. For example, the ACO FM Changeover Unit, developed by Electronics Telecommunications S.P.A., was introduced as a 1+1 FM transmitter redundancy system [2]. This solution enables real-time monitoring of the primary transmitter and facilitates immediate transfer to a standby unit in the event of operational failure. However, its implementation is constrained by substantial installation space requirements, high power consumption, and elevated cost. In another approach, a remote FM broadcasting monitoring system was developed to evaluate the broadcast content of FM stations [3]. Although this system supports remote access, it demands operation by highly skilled technicians. To address these limitations, an automatic coaxial switch controller has been designed and developed to manage two transmitters by utilizing a coaxial switch to interconnect coaxial transmission lines. The coaxial transfer mechanism, which has long been employed for switching between transmitters, operates through an AC-driven electrical system that shifts the coaxial switch between positions [4]. While the coaxial transfer switch provides benefits such as rapid switching and high-power RF handling capability, its considerable physical size and associated space requirements represent notable constraints during system planning and installation.

The objective of this study is to develop a controller capable of switching between two FM transmitters connected to a single FM antenna in the FM broadcasting system, which is operated over the frequency range of 87.5 – 108 MHz [5]. FM transmitters and associated antennas located in restricted or remote areas often present significant accessibility challenges, resulting in increased time and operational costs for maintenance activities. Therefore, an automatic coaxial switch controller is designed and implemented to facilitate seamless switching between the main FM transmitter (Tx1) and the standby transmitter (Tx2), which are illustrated as yellow modules in Fig. 1.

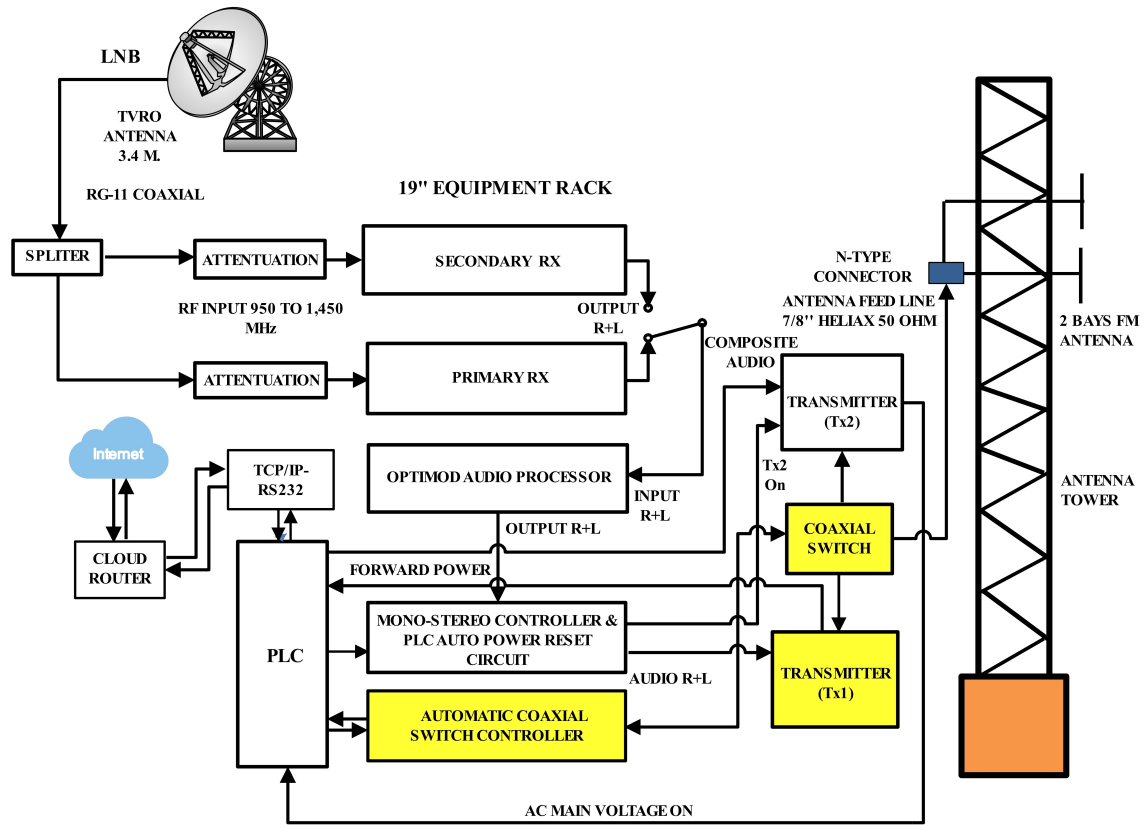


Figure 1: The simplified diagram of proposed auto-coaxial switching controller in the FM transmitter site [1].

2 Experiment Setup

The FM transmitters are used to broadcast unmanned programs 24 hours per day from distant locations. The controller is used to reduce the cost of operation and maintenance for commercial radio broadcasting stations that need unattended operation. The simplified diagram of the auto coaxial switch controller is shown in Fig. 2.

The concept involves the design and implementation of an automatic coaxial switch controller that enables seamless switching between two FM transmitters and a single FM antenna without requiring manual intervention. The proposed design is implemented in an FM broadcasting transmitter situated in a remote area. The system is comprised of a Programmable Logic Controller (PLC) [6], a servo control printed circuit board (PCB), a remote-control (RC) servo motor [7], a four-relay PCB, and a single-pole double-throw (SPDT) coaxial switch [8].

A. Programmable Logic Controller (PLC)

Programmable Logic Controller (PLC) is widely utilized in many applications such as security detection [9], radio frequency detection [10], and smart agricultural system [11]. In this study, the PLC, made by the Array Co., Ltd, model AF-20MR-D [12], is applied to control the auto coaxial switch. This model requires an external 12-24 VDC power supply and is equipped with digital input, twelve input points, and eight relay output points. The QuickII software utilizes the Function Block Diagram (FBD) programming language to develop control logic prior to uploading it to the PLC [13][14]. Through this programming, the PLC governs the servo drive PCB, which subsequently manages the mechanical operation of the auto-coaxial switch. The communication port of the PLC is connected to an RS-232-to-TCP/IP converter, enabling remote programming, monitoring, and control of the PLC over a network connection. Figure 3 illustrates the PLC and its connections to the controlled devices.

to 9 VDC and connected to the servo control PCB, after which the voltage is regulated to 5 VDC by a voltage regulator to provide power to the board.

C. Relay PCB

The four-channel optically isolated relays integrated on the PCB operate at a supply voltage of 5 VDC, with each relay requiring a driving current of 20 mA. [15]. The PCB incorporates a high-current relay, engineered to operate at a voltage of up to 30 VDC and a current of 10 A.

D. RC servo motor

In this experiment, the MG996R servo motor is employed, featuring a torque capacity of 10.00 kg·cm, an operating speed of 0.23 s per 60°, and a rotational range of 0–180° [16]. The motor is mechanically coupled to the coaxial switch.

E. Coaxial switch

The coaxial switch is a single-pole double-throw (SPDT) configuration, comprised of two input terminals that can be selectively connected to a single output port. This configuration enables users to switch between different transmitters to one antenna. The switch is designed to handle the power level of 1 KW and very low Voltage Standing Wave Ratio (VSWR) [17].

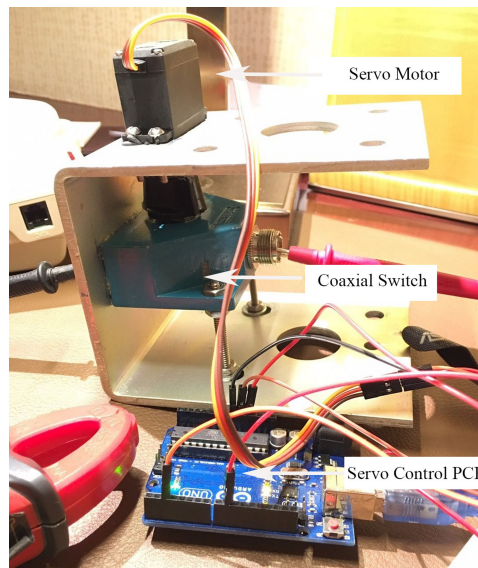


Figure 4: The coaxial switch coupling with servo motor and the servo drive PCB.

F. The assembly of auto coaxial switch

The assembly of the proposed auto coaxial switch is depicted in Fig. 4. The shaft of the coaxial switch has been mechanically coupled with the shaft of the servo motor and mounted on the U-shaft bracket. The coaxial switch has been precisely adjusted to rotate with the movements of the servo motor to 0 and 45 degrees. The servo motor has been forced to move from 0 to 45 degrees back and forth in response to the PWM output of the servo control PCB. The continuity between input port to output ports of the coaxial switch has been checked when the coaxial switch has been forced to move back and forth from 0 to 45 degree.

The flowchart in Fig. 5 illustrates the simplified workflow of the automatic coaxial switch controller. When the PLC detects forward power from Tx1, it transmits a logic '0' signal through the servo control PCB, initiating a 0.5 ms PWM pulse, which subsequently rotates the servo motor to 0°, thereby connecting the Tx1 input port to the coaxial switch. When no forward power is detected from Tx1, a logic '1' signal is generated by the PLC through the servo control PCB, and a 1 ms PWM pulse is applied to the servo motor. Consequently, the servo motor is rotated from 0° to 45°, resulting in the coaxial switch being shifted from FM transmitter Tx1 to FM transmitter Tx2.

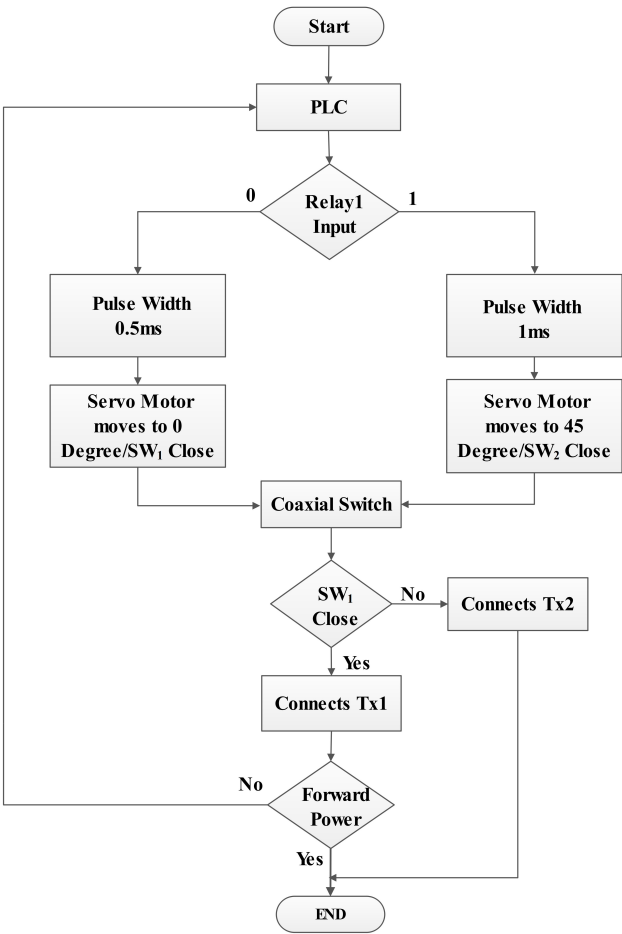


Figure 5: A flowchart explaining the procedure of an auto coaxial switch.

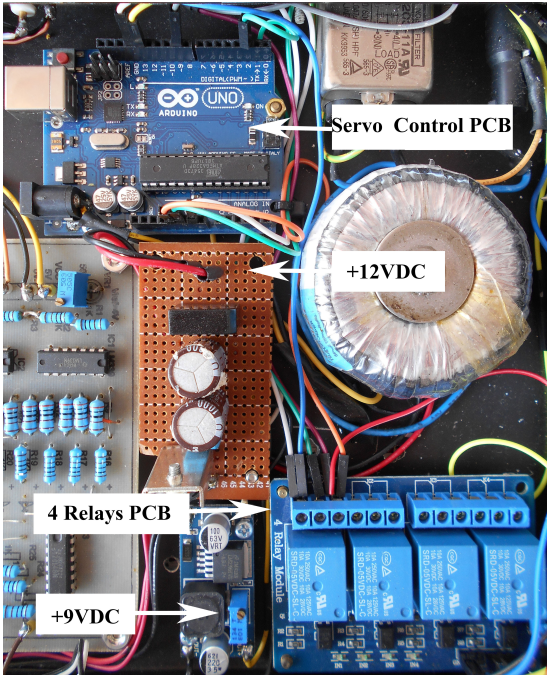


Figure 6: Servo control PCB, four relays PCB and power supply in the standard 19-inch case.

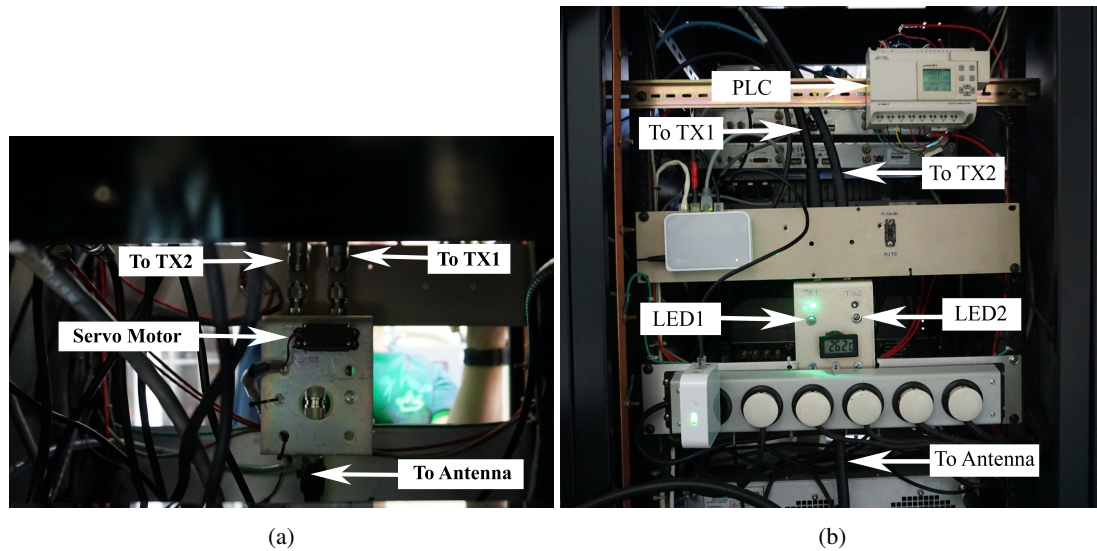


Figure 7: The installed coaxial switch controller on the transmitter control rack at the FM transmitter site; (a) front view and (b) rear view.

G. The installation of auto coaxial switch

The servo control PCB, four channel relays PCB and power supplies have been installed in a standard 19-inch case. The control cables between the relays and servo control PCB are externally wired to the PLC, the coaxial switch, and the servo motor when these devices are installed in the transmitter control rack as shown in Fig. 6.

The auto coaxial switch controller, auto coaxial switch, servo motor, and the PLC have been installed on the transmitter control rack in the FM transmitter site for 24 hours operation. The front and rear side of coaxial switch on the rack are shown in Figs. 7a and 7b, respectively.

3 Results and Discussions

The functionality of the coaxial switch was evaluated by repeatedly applying alternating logic inputs to the servo-drive PCB. A total of 100 cycles were performed to verify repeatability and reliability. Throughout the test, the servo motor responded correctly to all input commands, and no operational errors were observed.

Table 1 expresses the relationship between the commanded servo motor position and the results of switching state for the coaxial switch. The switch consistently routed the input port to the correct output port corresponding to each servo position.

Table 1: The servo motor position versus the status of input port and output port status of coaxial switch related to logic input at servo control PCB.

Logic at servo control PCB	Servo motor position (Degree)	Coaxial switch of input port to Tx1 port status	Coaxial switch input port to Tx2 port status
0	0	Connected	Not Connected
1	45	Not Connected	Connected

The auto-coaxial switch controller was installed in the FM transmitter site, the measured temperature in the operation room during day time was $23^{\circ}\text{C} \pm 3^{\circ}\text{C}$ and relative humidity was $40\% \pm 5\%$. While transmitter Tx1 or Tx2 was connected to the FM antenna for testing, the transmission and reflected power were observed and recorded from the front panel of each transmitter as shown in Table 2. The transmission and reflected power measurements can be used to calculate the Voltage Standing Wave Ratio (VSWR) using equation 1.

$$VSWR = \frac{1 + \sqrt{\frac{P_r}{P_t}}}{1 - \sqrt{\frac{P_r}{P_t}}} \quad (1)$$

Where P_r and P_t represent reflected and transmission power, respectively.

The following equation is used to calculate the power loss due to insertion loss, expressed in watts:

$$P_{out} = \frac{P_t}{10^{\text{Insertion loss (dB)}/10}} \quad (2)$$

From Table 2, it is observed that while the FM broadcasting system operates normally, a logic “0” signal is sent to the servo control PCB in the proposed coaxial switch controller system. This signal positions the servo motor at 0 degrees to connect transmitter 1 (Tx1) to the antenna. The signal transmitted from Tx1 has a transmission power of 993 W, with measured reflected power and VSWR values of 20 W and 1.33, respectively. The broadcast signal is then routed through the proposed system to the antenna, where the output power is measured at 939.61 W. When transmitter 1 (Tx1) is unable to transmit the broadcast signal, a logic “1” signal is sent to the servo control PCB to position the servo motor at 45 degrees, thereby connecting the backup transmitter (Tx2) to the antenna. The switching process requires no more than 30 seconds per operation. The signal transmitted from Tx2 has a transmission power of 1,000 W, with measured reflected power and VSWR values of 14 W and 1.27, respectively. The output power of the signal delivered from the proposed system to the antenna is measured at 944.06 W. The differences in reflected power and VSWR between Tx1 and Tx2 arise from their distinct circuit configurations, which result in varying levels of impedance mismatch between each transmitter and the broadcast transmission system. Hence, the proposed coaxial switch controller system can be employed to manage redundancy by switching operation between transmitter 1 and transmitter 2 in the event that transmitter 1 fails.

The auto-coaxial switch controller was successfully installed in the service station in September 2017. The auto-coaxial switch operation was observed and recorded as expressed in Table 3. It was found that there are some unidentified causes such as temperature fault, power amplifier failure, and depleted battery of UPS. These issues appeared to originate from unidentified or intermittent causes and warrant further investigation. Operational records from 2017–2020 verifies that the auto-coaxial switch controller operates fully autonomously. During routine operation, it initiates and completes an automatic switchover from the main transmitter to the backup transmitter within 30 seconds. The records indicate that Tx1 experienced three interruptions in 2018, amounting to a cumulative downtime of 90 seconds. This equates to an operational availability of approximately 99.99%, or well below 1% of total annual broadcast hours.

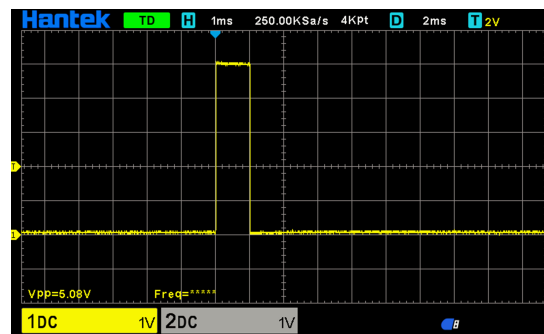


Figure 8: The waveform when servo motor is driven from 0 to 45 degrees

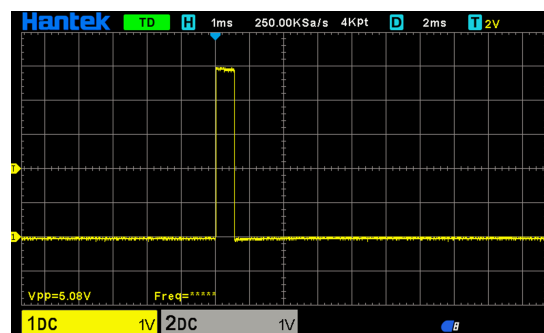


Figure 9: The waveform when servo motor is driven from 45 to 0 degree.

Figure 8 illustrates the servo control PCB generates a PWM waveform with a pulse width of 1 ms when Tx1 become inoperative, resulting in the rotation of servo motor from 0° to 45° to immediately connect to Tx2. In contrast, when the servo control PCB generates a pulse width of 0.5 ms, as illustrated in Fig. 9, the servo motor returns to the 0° position. It is indicated that Tx1 has been successfully repaired and restored to operational functionality.

Table 2: The record data of transmission power (P_t), reflected power (P_r), insertion loss calculated VSWR and output power (P_{out}) according to equations 1 and 2 of the Tx1 and Tx2.

Transmitter	P_t (W)	P_r (W)	VSWR	Insertion Loss (dB)	P_{out} (W)
Tx1	993	20	1.33	0.24	939.61
Tx2	100	14	1.27	0.25	944.06

Table 3: The record data of transmission power (P_t), reflected power (P_r), insertion loss calculated VSWR and output power (P_{out}) according to equations 1 and 2 of the Tx1 and Tx2.

Observation Period	Number of operations at transmitter 2 (Tx2)	Failure cause of transmitter1 (Tx1)
Year 2017	2	Unidentified Cause and Temperature fault
Year 2018	3	Unidentified Causes and Recovery VSWR
Year 2019	2	UPS & Power Amplifier Failure
Year 2020	1	Power Amplifier failure

4 Conclusion

The proposed auto coaxial switch and controller have been installed for operation at the FM transmitter site with excellent performance. The controller operates without the need for computer and human intervention. The results indicate that when transmitter 1 becomes unable to broadcast for 30 seconds due to a system fault, the proposed system automatically switches the transmission path to transmitter 2. Tx2 is then able to continue the broadcast with an output power of 944.06 W, which is comparable to the output power of Tx1 at 939.61 W. The proposed system ensures continuity of FM broadcasting by immediately employing Tx2 as a replacement for Tx1. Once Tx1 is restored and fully repaired, the proposed system switches the transmission back to Tx1. For future work, this system will be further developed to incorporate a signal quality monitoring mechanism for FM broadcasting systems.

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