DUAL CODE AUDIO FREQUENCY TRACK CIRCUITS AND THEIR USE IN VITAL TRAIN DETECTION

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ABSTRACT

The Metropolitan Atlanta Rapid Transit Authority (MARTA) utilizes dual code audio frequency (AF) track circuits to mitigate electromagnetic interference (EMI) with the consequence of preventing the unsafe condition of falsely energizing track relays during track circuit occupancy. The use of dual code AF track circuits enables AF track circuits to operate under tight constraints with immunity to EMI and adjacent track circuit interference. Dual code AF track circuits were initially implemented systemwide on MARTA in 1980 with great success.

This technical paper will discuss the issues that led to the dual code AF track circuit design, the history of dual code AF track circuits as employed on MARTA, and the qualification tests performed. A description of the design and operation of the dual code AF track circuits will also be explained.

INTRODUCTION

Audio frequency (AF) track circuits are used for both train detection and cab signal application. AF track circuits utilize a unique carrier frequency between 2 kHz and 5 kHz for train detection for each track circuit which is coded on and off by a low frequency code rate between 2 Hz and 21.5 Hz. Furthermore, a unique carrier frequency for train cab signal transmission is coded on and off in the 3 Hz to 21.5 Hz range. These cab signal carrier frequencies vary throughout the transit property. The actual cab signal speed command transmitted to the train is determined by six different code rates.

AF track circuits have the unique advantage of eliminating insulated rail joints at track circuit boundaries, except at interlocking boundaries, and using both running rails for negative propulsion return.

THE ISSUE – ELECTROMAGNETIC INTERFERENCE (EMI)

MARTA was the first transit property to utilize a new type of transit vehicle propulsion system with electronics to control the speed of DC traction motors. The propulsion system is referred to as a chopper propulsion system, and uses thyristors to modulate the DC propulsion power from the third rail to control the speed of DC motors. The chopper propulsion system eliminates the use of cam controllers traditional in transit vehicles, including subway cars and trolleys.

With the use of the variable frequency chopper controls, electronics are used extensively in the propulsion system. As the vehicle accelerates or brakes, the chopper does a frequency sweep through the frequencies from 0 Hz to approximately 400 Hz. This in turn causes unwanted frequencies from the train to be transmitted to the wayside impedance bonds. The car contains huge input and smoothing inductors which couple the unwanted signals into the impedance bonds. Harmonics are generated by the chopper control. The tenth or eleventh harmonic may result in a track circuit failing to detect the presence of a train.

The main type of interference is radiated or direct inductive coupling. The interference signals couple to a loop formed under the car comprised of the running rails, the axles, and Wee-Z® bond. The discovery on this issue quickly gained industry-wide attention.

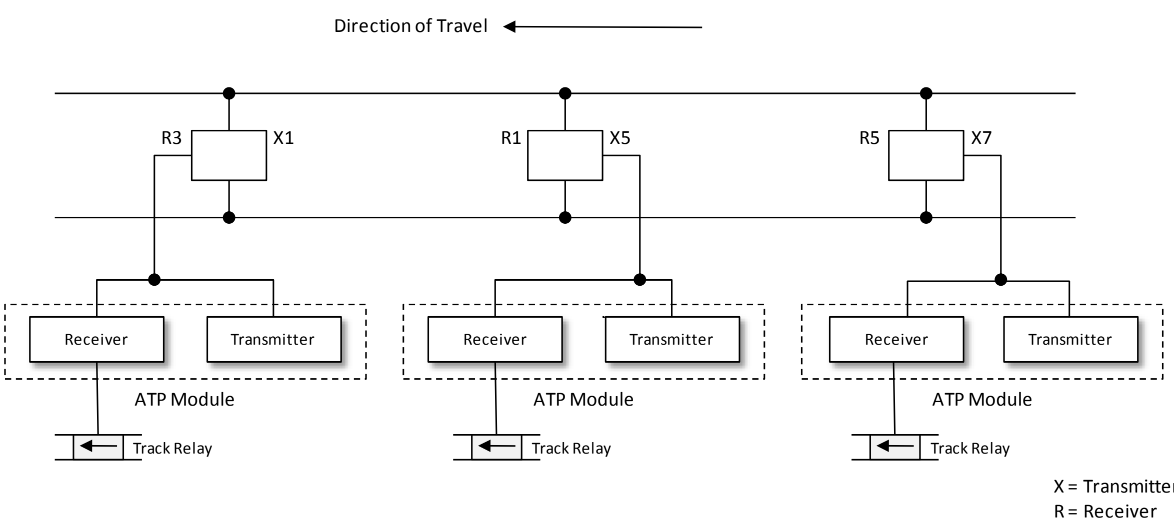
As a car passes over an impedance bond at full acceleration or during full service braking, interfering harmonics are induced into the impedance bond coils causing the associated track circuit to become intermittently unoccupied creating a potentially unsafe condition. Furthermore, the speed commands generated at the leaving end of the track circuit may turn off each time the track relay is falsely energized with the result of the train applying full service brakes until such time as the track relay drops. This results in erratic operation of the train.

The AF track circuit receivers could falsely energize the associated track relay with a train in the track circuit if the correct train detection carrier frequency is coded on and off at any code rate with a signal level at or above the adjusted amplitude. The train could create a carrier frequency with the tenth or eleventh harmonic which could be accepted by the receiver. When the train passes over the impedance bond, the car-generated carrier frequency is turned on and off simulating the track relay energizing code which would falsely energize the track relay. This situation led to the invention and the development of the dual code AF track circuit.

When the MARTA East-West line went into service in 1979, circuit changes were made to transmit speed commands in advance of a train occupying the track circuit. This precluded the turning on and off of speed commands and subsequent erratic train operation. However, the false picking of the AF track circuits persisted, and a fail-safe solution became all important.

In July 1979, the MARTA Transit Systems Development department; General Railway Signal Company (today known as Alstom); the Urban Mass Transportation Administration (UMTA) Transportation Systems Center in Cambridge, Massachusetts; the car builder, Société Franco-Belge (SFB); and the propulsion supplier, Garrett Air Research Inc. assembled in Atlanta at a vehicle/ATC electromagnetic compatibility meeting conducted to solve the EMI vehicle issues on MARTA that affected the AF track circuits.

GRS proposed three methods for addressing the EMI. Ultimately, the GRS dual code AF track circuit was the chosen solution to immunize the traditional AF track circuits against EMI.



Track Plan of AF Track Circuits

THE SOLUTION – THE DUAL CODE TRACK CIRCUIT

In order to understand the operation of a dual code AF track circuit, it is necessary to discuss AF track circuit principles.

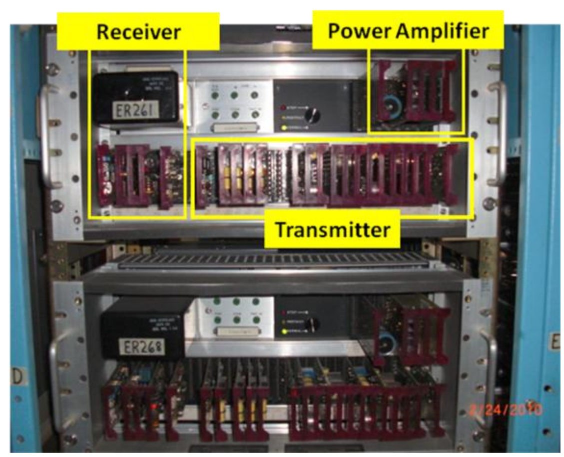
There are eight carrier frequencies used for train detection. Four frequencies are used on one track while the other four frequencies are used on the opposite track. The train detection frequencies are in an audio range from 2.97 kHz to 4.95 kHz. Four of the frequencies on one track are designated as odd frequencies. The other four frequencies on the opposite track are designated as even frequencies. This frequency rotation allows for the elimination of insulated rail joints.

These track frequencies are modulated or coded on and off at seven code rates between 2 Hz and 21.5 Hz. The same code rate frequencies from 3 Hz to 21.5 Hz are used to code the cab signal (train) carrier for the speed commands.

When the code rate frequency is high in amplitude, the train detection carrier frequency is turned on. During the other half of the code rate cycle, the train detection carrier frequency is turned off. The ratio of the on and off periods of the train detection carrier is typically 50% on and 50% off time. However, the design circuit tolerance is 30% on and 70% off or vice versa. This is known as the duty cycle.

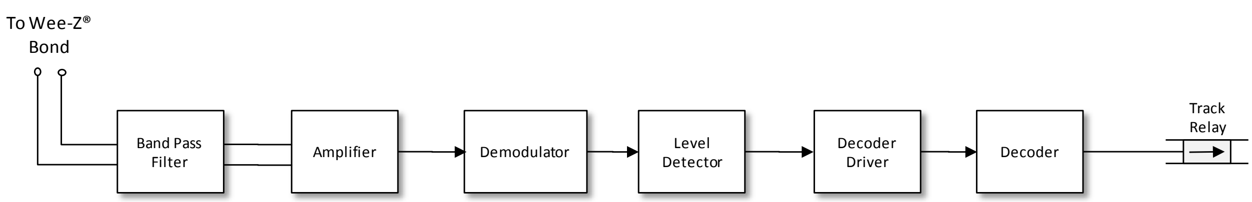
During the off portion of the train detection carrier frequency, the cab signal (train) carrier frequency is turned on. The train detection carrier and the cab signal carrier alternate once during each cycle. During the cab portion of the duty cycle, the code rate conveys the speed command, and is decoded on-board the train to determine the required speed command. This system, along with the overspeed enforcement on the train, is known as the automatic train protection (ATP) system on the vehicle. The wayside ATP system is the AF track circuit with associated ATP module and vital track relay.

In terms of the ATP module hardware, the major change in the ATP transmitter section is an additional modulator board. The fixed code rate from the code rate generator required for train detection is connected directly to the new modulator board. It is this board that is connected to train detection carrier oscillator. This will modulate the train detection carrier frequencies (2.97 kHz to 4.95 kHz) based on the frequency assigned to the track circuit. Both the modulated train detection and cab signal carrier frequencies will be mixed at the input to the power amplifier. This permits the modulated train detection and cab signal (train) carrier frequencies to be sent simultaneously through the power amplifier and out through a twisted pair cable to a Wee-Z® bond. Hence the two modulated signals on the bond line are coded by two different code rates, referred to as dual code.



Dual Code ATP Transmitter and Receiver Modules for East Lake Station Platform Track Circuit ER261

The ATP receiver section performs the following functions:



Block Diagram of Dual Code AF Track Circuit Receiver

1. Filters the train detection carrier frequency unique to that track circuit by the use of a bandpass filter.
2. Amplifies the coded carrier frequency.
3. Removes the carrier frequency element of the signal and leaves only the code rate. This is called the demodulator.
4. The code rate signal has spikes and is not a clean square wave form. The spikes are removed and a clean square wave is formed by the use of a level detector.
5. Sends square wave representing the code rate to the decoder driver board. The interface for the correct voltage and current to decoder, and eventually the track relay, is accomplished by the decoder driver board.
6. Filters the signal from the decoder driver for the correct code rate and then sends it to the track relay. The decoder contains a series tuned circuit on the primary winding of the tuned decoder transformer. The secondary winding of the transformer contains a full wave bridge rectifier and filtering capacitor to convert the code signal to DC to drive the track relay. It is the decoder that makes the dual code track immune to EMI and induced interference.
7. The track relay is a GRS vital B1 relay designed for the dual code application. This relay is a direct replacement for the original track relay.

DUAL CODE TRACK CIRCUIT TESTS ON MARTA

GRS first performed laboratory tests on the dual code track circuits at their facility in Rochester, New York. At the conclusion of that testing, the material required to convert four track circuits was furnished and installed at the East Lake train control room on MARTA's East Line.

This testing site was selected because the frequency showed intermittent no occupancy with full service braking and train movement over the receiver bond. This was caused by the variable frequency chopper system on the transit vehicle based on the eleventh harmonic. The results of the testing that occurred during April and May, 1980, are summarized in the following paragraphs.

Four track circuits on the ER track at the East Lake Station were modified to the new dual code scheme. These track circuits were adjusted per the provisions of the standard MARTA test procedure, MTP 35.1 adjustment procedure before being put into revenue service. A series of tests were performed on these circuits to ensure proper operation.

The first set of tests involved controlled acceleration and braking runs over each track circuit receiver bond. The receiver gain was set to the maximum (worst case scenario) for all runs, and an eight-car train was used. The series of tests was a partial repeat of the benchmark tests conducted earlier at the same location. The noise levels observed on the bond line for these circuits was comparable to the same measurements made during tests in August 1979.

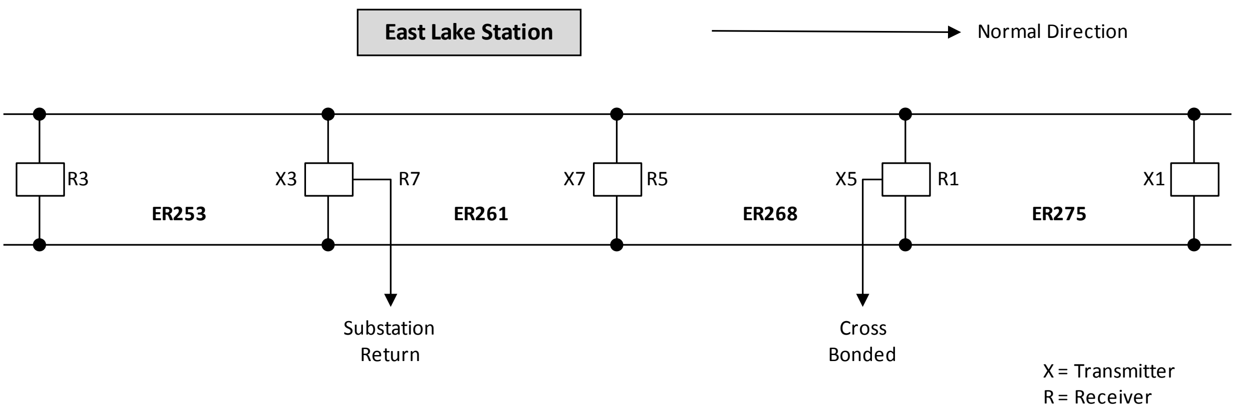
The second set of tests monitored each of the track circuits during revenue service. Each track circuit was monitored for three trains, and the relay drop and pickup times were recorded. The maximum decoder current was recorded.

The third set of tests deliberately forced the train into operating modes that caused the chopper noise to be modulated within the decoder passbands. The peak decoder currents were recorded. For all the test runs, chart recordings were taken of the level detector output and the decoder current. Although decoder currents of 21 mA were measured, the track relays were never falsely energized.

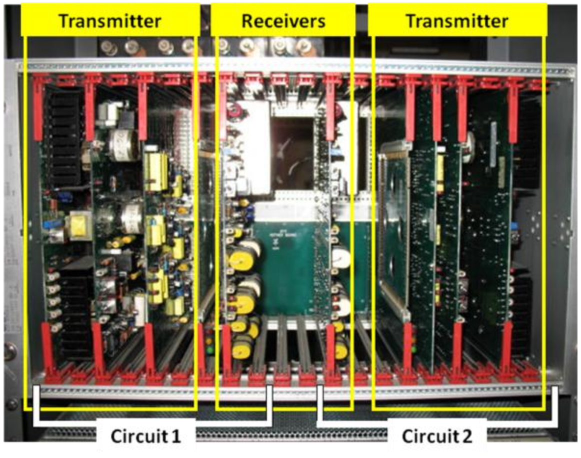
The dual code track circuit performed as intended in the chopper noise environment. Even with deliberate attempts, the track relay could not be falsely energized. Further, during normal revenue service, the track circuit exhibited good shunting and operating characteristics.

REVENUE SERVICE FOR DUAL CODE TRACK CIRCUITS

Once the testing was complete and all members of the engineering team were satisfied that the dual code track circuit was safe and reliable for revenue service, the dual code track relays were placed in revenue service at the East Lake test site. A chart recorder was connected to the track relay contacts to record when the track relay de-energized (dropped). This recorder was installed, monitored, and reviewed



Second generation of Dual Code ATP Transmitter and Receiver Module



Third and latest generation of the Dual Code ATP Transmitter and Receiver Module containing two track circuits

for one month, during which there were no issues with the dual code track operation. The recorder was removed and GRS was given the authorization to proceed with the production of the components, engineering drawings, installation, and testing of the commercialized dual code track circuit modifications.

SECOND AND THIRD GENERATION OF DUAL CODE TRACK CIRCUITS

The next line extension on MARTA awarded to GRS encouraged GRS to develop the next generation of the dual code track circuit ATP modules. These modules are very similar to the modified ATP modules except that the decoder was packaged in the module for a more compact installation in the Track Module (TM) equipment rack.

GRS totally redesigned and repackaged their ATP modules in the early 1990s. The same concepts were used; however, the decoder became solid state. This more compact design with larger printed circuit boards allows for two track circuits to be packaged in one module. Today, this Alstom signaling standard AF track product using dual code technology is installed on transit systems all over the world.

IDEAS OF QUAD CODE AF TRACK CIRCUIT

Perhaps in the future, to improve further the safety of audio frequency track circuits, the concept of the dual code AF track circuit could be applied using four train detection code rates.

Because there are four train detection carrier frequencies used for each track circuit, it is possible to associate a different code rate for each train detection frequency. These same code rates could be associated with the other four train detection frequencies on the adjacent track.

With this approach, it could possibly double the ability to mitigate EMI, inductive interference, and foreign signal interference, preventing a track relay to falsely energize.

CONCLUSION

The dual code AF track circuit clearly mitigates track relay false pick up with a train shunting the track circuit. This is true when there are other untended sources of signals replicating the ATP transmitter output signal.

The concept of developing a quad code AF track circuit could conceivably further mitigate unwanted modulated signals from foreign sources.

As a matter of information, Ansaldo STS has provided another approach to mitigating false track relay pick up with train occupancy. Ansaldo AF track circuits have the trade name AF600®. A 7.8 Hz code rate modulates the same eight train detection frequencies used for the GRS track circuits. The code rate from the transmitter's code rate oscillator is sent to the receiver and a phase comparison is made between the source and the received track code rate signals, and if the phase relationship is correct, the track relay picks up. This method is accomplished by a failsafe synchronous rectifier and uses a reed type relay in the receiver section of the track circuit card file. The AF600® track circuit method of mitigating noise and EMI issues utilizes a closed-loop principle. In comparison, the dual code AF track circuit and the proposed concept of the quad code AF track circuit is an open-loop type.

Ansaldo designed and furnished digital audio track circuits in the mid 1980s. Over the course of subsequent years, both Ansaldo and Alstom have perfected digital track circuit technology and have placed them in service in different cities in the United States and countries around the world. This type of track circuits eliminates EMI concerns and foreign signals from affecting safe track circuit operation. For new transit system startup programs and wholesale replacement of track circuits on existing transit systems, digital track circuits are the next generation of track circuit technology to ensure the safety of the riding public.

ACKNOWLEDGEMENTS

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Special thanks go to the late Klaus (Hank) Frielinghaus of GRS for his contribution to AF track circuit design. Mr. Frielinghaus holds 28 United States patents of railway signaling inventions in his 42 years with GRS.