By Durell Roth

The XERF Transmitter

In 1959, engineers at radio station XERF in Ciudad Acuña, Mexico, purchased a new 250,000-watt transmitter, model BTH-250A, manufactured by the Radio Corporation of America (RCA). The transmitter contains 66 tubes: 12 in the modulator, 18 in the RF section, and 36 in the power supply. Additional tubes contained in ancillary equipment are not pertinent to this discussion. The model BTH-250A uses an RCA high-efficiency modulation system which, when compared to conventional systems of the time, provided a significant savings for the station in terms of operating cost and space requirements.

Using the RCA super-power set and a halfwave vertical radiator, XERF consistently covered Mexico, the United States, and Canada; and reception reports from North and South Pole radio clubs became common. Station announcer Paul Kallinger received reports from as far away as France and much of North America jived to the rhythm and blues played by Wolfman Jack.

The BTH-250A is a one-of-a-kind super-power transmitter employing the RCA version of ampliphase modulation. Given the unique design of the system and the dearth of published ampliphase material, it is important to document the principles of ampliphase modulation and their application to the XERF transmitter.

In 1961, RCA engineer George W. Klingaman described the basic concepts of the XERF transmitter in his paper "The BTH-250A: New Ampliphase 250-kw AM Transmitter," published in the August-September issue of the *RCA Engineer.* Klingaman provides details of the XERF transmitter that are not available elsewhere, including minimal construction details, a brief description of the RCA ampliphase system, and a typical transmitter floor plan. It is important, however, to expand this work to include data and references not contained in the original document. The following, therefore, is a discussion of the principles of operation for the RCA, BTH-250A, including photographs, an RCA proof-of-performance report, *(page 24)* and a schematic diagram of the equipment as installed at XERF *(page 25).*

The Beginning

Ampliphase is a modulation technique that synthesizes an amplitude modulated (AM) wave by combining two phase modulated (PM) waves. French radio engineer Henri Chireix introduced the ampliphase system in his paper "High Power Outphasing Modulation," published in the November 1935 Proceedings of the Institute of Radio Engineers. Chireix compares the principles of the standard modulation systems in use at the time to those of the new method, clearly showing a savings in manufacturing and operating costs of the outphasing system. His use of the term "outphasing" relates to the phase relationships of two double-sideband reduced carrier signals and an unmodulated carrier wave used to generate the phase modulated wave.

The system described by Chireix employs a temperature controlled crystal oscillator that produces a carrier wave to drive two independent RF channels. One channel amplifies the carrier wave only. Simultaneously, in the other channel, program audio is introduced through a balanced modulator producing two sidebands having opposing phase vectors. The Chireix system shifts the unmodulated carrier wave by 90° and then combines the three signals to produce synthesized amplitude modulation at the output of the transmitter.

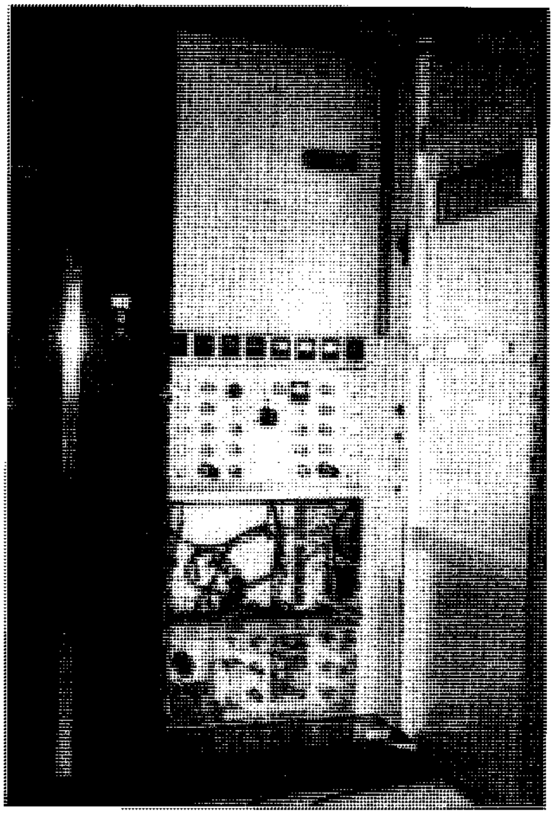
All photos courtesy of Noyes W. Willett

Once Chireix proposed this system, transmitter manufacturers developed outphasing methods using balanced modulators, frequency triplers, and Doherty amplifiers. Designers of the later systems, however, preferred the term "ampliphase," which more aptly describes the combining of PM signals in the synthesizing of amplitude modulated waves.

Regardless of the technique, efficiency, or reduced equipment size and cost, for more than twenty years the ampliphase technique remained little more than an unpopular and/or impractical method of modulation. With advancing technology, however, in 1935, engineers at RCA recognized the advantages of the method. In September of that year, engineer T. Douma, working at the time in broadcast transmitter engineering at the RCA Camden facility, published an in-house test report titled "Ampliphase Modulation Study."

Here, in addition to the Chireix system, Douma identifies four methods of producing ampliphase: the sum of two currents of equal amplitude, the sum of the two currents with linear phase modulation, the sum of two currents which have both amplitude and phase modulation, and the difference of two voltages (1-7). He then provides the mathematical derivation of each method and that of a complete ampliphase system. By early 1956, RCA had designed, tested, and introduced a new transmitter product line beginning with the 50,000-watt; model BTA-50G ampliphase modulated transmitter.

Ampliphase had become the modulation system of choice for super-power transmitters. The reduced size of a given power level combined with the unique RCA electro-mechanical design meant that even significant power increases involved little more than adding equipment cabinets containing higher power, class "C" RF amplifiers. To a station using the equipment, the small size and high efficiency meant a real saving in terms of operating costs and space requirements.

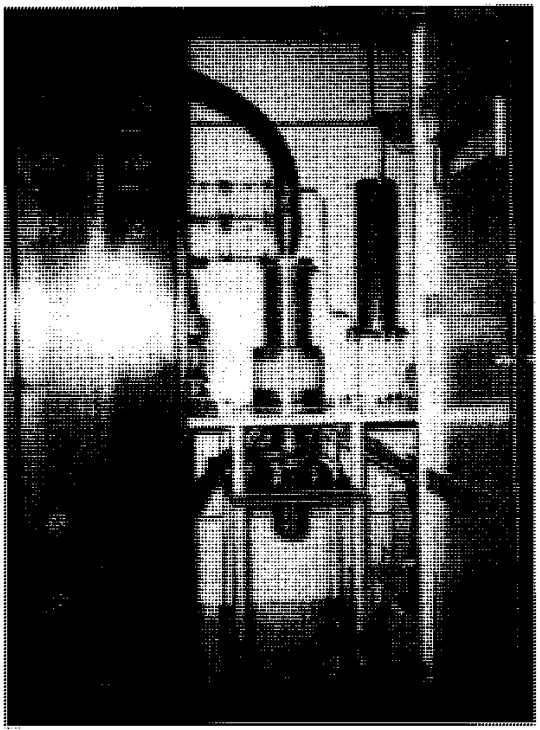


Exciter-modulator chassis BTH-250A

In 1958, when RCA proposed the 250,000-watt medium-wave system for XERF, the engineering staff retained the small transmitter size and the RCA ampliphase modulation method but departed significantly from the complexities of the balanced modulators, frequency triplers, and Doherty amplifiers.

BTH-250A Principles of Operation

The basic concept of the ampliphase system as employed in the BTH-250A consists of a low-level carrier wave that has been split into two signals with opposing phase vectors. In independent channels, these signals are antiphase modulated and amplified to the desired power level. At the output of each channel, the phase-modulated signals are combined in the load that is common to both channels. Each channel provides half of the total output power. And because of the opposing vectors, the signals combine algebraically in the common load



One of the final amplifier tubes.

audio rate, thus producing amplitude modulation of the transmitter output carrier wave.

Crystal Oscillator and Buffer, Signal Flow

The following discussion of signal flow is keyed to the simplified schematic diagram and followed in greater detail in the complete foldout schematic, (*available from the Radio Club of America - see footnote*).

The RF signal source for the BTH-250A is an 807 tube in a temperature controlled crystal oscillator circuit. The circuit uses a fundamental crystal with a frequency of 1570 kilocycles. RF energy from the oscillator is coupled through a d-c blocking capacitor to a 6SJ7 buffer amplifier. The plate circuit of the buffer is a parallel-tuned tank that functions as a signal splitter and provides two carrier signals having a phase difference of 180 electrical degrees. Each signal is applied to a separate voltage divider network composed of a 33 mmf capacitor connected in series with a 9-130 mmf trimmer-capacitor to ground. The networks function as a coupling system and an adjustable RF voltage divider for the input to the two RF channels. Signal voltage for each channel is taken from the junction of the two capacitors.

At the input of each RF channel, the carrier signal phase vectors are 180 electrical degrees apart. If this phase difference were maintained throughout each channel, the carrier voltage at the transmitter output would algebraically add to zero, and no output power would be obtained. It is necessary, therefore, to advance the phase in one channel and retard that of the other to obtain an output signal phase-difference of 135 degrees. This phase difference produces an unmodulated output carrier level of 250,000 watts.

The required phase changes are accomplished in the plate circuit of the first 6SJ7 stage of each RF channel. This stage is referred to in Klingaman's paper as a "dc shifter stage" (52). It is used in conjunction with an adjustable RLC phasing network for setting the output carrier phase angle. Klingaman states, "...if the reactance of L and C are chosen so that $X_l = 2X_C$ the impedance of the combination will be constant and equal to X_l, regardless of the value of R. If R is then varied, only a change in phase will occur without amplitude variation of the applied carrier"(52). This design characteristic is paramount to obtaining the 135-degree phase relationship between the two RF channels. Beyond the dc shifter stage, each section of the two RF channels are identical; therefore, only the operation of one channel will be discussed below.

The Phase Modulated Low-Power RF Amplifier

Following the d-c shifter stage are three cascaded LC-coupled amplifier stages, each using a single 6SJ7 tube in a cathode biased circuit. These three stages, referred to by Klingaman as "a-c shifters," are the phase-modulated amplifiers of each RF channel (52). To obtain maximum linearity, the phase vectors of each a-c shifter is rotated only +/- 7.5 degrees relative to the previous stage for a total shift in each channel of +/- 22.5 degrees in opposite directions. The opposing 22.5 degree shift produces a total carrier wave-angle rotation from 90-180° and a variation in the common-load carrier current from zero to twice the unmodulated carrier value.

The Reactance Tube Modulator

This portion of the transmitter includes two identical, independent, reactance-tube modulator channels; therefore, except as required, the operation of only one channel is discussed. Each channel comprises a 6AH6 voltage amplifier and two dual-triode 6SN7 tubes used as the reactance tube modulators. The schematic designations for these tubes are V312, V313, and V314, respectively. Audio for the modulator is obtained through a transformer having dual primary and dual secondary windings. To match the impedance of the audio line from the studio, the two primary windings are connected in series. The secondary windings, however, function independently and are resistively coupled to the control grid of the 6AH6 voltage amplifier at the input of each audio channel.

The audio signal voltage from the plate of the 6AH6 is coupled through a capacitor/resistor network to the control grid in the first section of V313. This section of V313 serves as a non-inverting, low-impedance, audio source for the exciter regulator, a section of the modulator to be discussed later. The first triode section of V316, the complement of V313 in the opposite modulator channel, currently serves only to balance the circuit electrically and performs no other function.

Three independent in-phase audio modulation signals are generated by the 6SN7 reactance-tube modulators. The first signal is obtained from the cathode circuit of the second triode in V313, while the second and third modulation signals are derived from the two cathode circuits of V314. The three independent audio signals phase modulate a-c shifters V303, V304, and V305, respectively.

The plate circuit of each a-c shifter contains a series resonate LC circuit that functions both as the plate tank for that tube and part of the phase-shift network. A second series-connect LC circuit composed of two capacitors and one inductor is connected from the plate of each a-c shifter to ground and functions as the primary phase-controlling element. Audio from the associated modulator tube is applied to the junction of the two capacitors in the phase-controlling network and shifts the signal phase +/- 7.5 degrees in each a-c shifter. The a-c shifter and modulator combination is equipped with an adjustable diode limiter that prevents phase excursions beyond +/-22.5 degrees.

The Intermediate Power Amplifier

The phase-modulated signal from each RFchannel is coupled through a .001 mfd capacitor to the control grid of the first intermediate power amplifier comprising a cathode biased 6L6 tube and associated circuitry.

RF signal voltage from the 6L6 plate tank is coupled through a .001 mfd capacitor to the input of the second intermediate power amplifier. The second power amplifier is a class "C" stage and contains an Eimac 4-250A tube that increases the r-f power to approximately 500 watts. The plate tank of this stage is a parallel fed L-network containing two fixed capacitors, one variable capacitor, and a tapped inductor. Output power of the stage is monitored through the use of a resistive voltage divider, diode rectifier and meter circuit from the plate of the tube to ground. The output power from this stage is coupled through a .0015 mfd capacitor to the control grid of the class "B" 4X5000A driver stage that amplifies the power to about 8,000 watts.

The 250,000-watt Final Amplifier

The plate load of the 4X5000A is an adjustable parallel-fed, parallel-tuned tank. Inductive link coupling is used to transfer power from the amplifier through an impedance matching network to the input of the final amplifier stage. The amplifier tube in each RF channel is a 4CV250,000A. The plate load of each final amplifier consists of a pi-network in which the output loading capacitor is common to both channels.

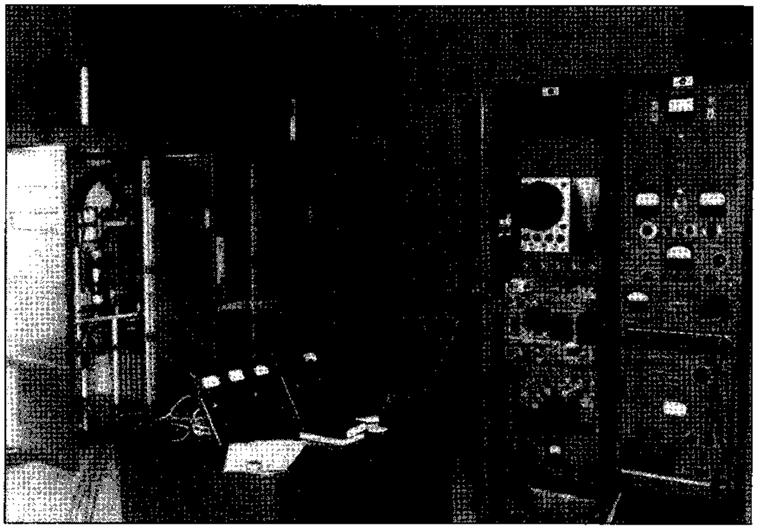
The coaxial feeder from the antenna tuning equipment normally presents a resistance of 50 ohms to the transmitter terminals. At the XERF installation, if the transmission line were connected to the harmonic filter, as it was in the past, the line impedance would be converted to 20 ohms; and this is the resistance seen as the common load to both RF channels. Because of the opposing RF signal phase-vectors inherent in ampliphase modulation—and which are present across the common resistance—the plate of each 6949 sees an equivalent variable resistance that changes from zero at the modulation trough to four times the carrier value at the modulation crest. The vacuum tube being a constant-voltage device performs poorly when subjected to continually changing load conditions and in the case of ampliphase modulation, would be incapable of correct algebraic addition of the rotating phase vectors.

In his paper, Klingaman shows the typical RCA ingenuity in surmounting such technical challenges and, in doing so clearly defines the term "impedance modulation" frequently applied to ampliphase and similar forms of modulation.

With respect to the RCA BTH-250A, Klingaman refers to the pi-network tank circuit in each amplifier as a 90° matching network that satisfies three requirements of the ampliphase system. Klingaman writes, " . . .first, the impedance is converted to a more satisfactory value; second, a suitable tank circuit is obtained; and third, if the RF voltage is maintained constant at the 6949 plates, the RF current in the termination will be constant, regardless of the manner in which the termination changes" (52). Under these conditions, power delivered to the load will vary from zero at the modulation trough to four times the carrier power at the modulation peak; this is the desired condition for a 100 percent amplitude modulated signal.

The varying plate-load impedance, which is the essence of impedance modulation, presents greater engineering challenges than do conventional forms of modulation. In his paper on the BTH-250A system, Klingaman states, "The varying impedance with modulation in the 6949 plate circuits presents a problem in selecting the proper load Q, bias voltage, optimum efficiency, and correct grid drive to maintain constant voltage across the 90° matching sections" (53). To compensate for these characteristics, Klingaman refers to the use of RF-swamping resistors, a grid leak, inverse feedback, and a drive linearity corrector.

The linearity corrector in the BTH-250A includes three parallel connected 807 tubes in a cathode-follower circuit that regulates the grid drive and grid modulates the 4CX5000A driver stage to about 90 percent. The 807 portion of the grid modulator/regulator is driven by three additional lower-power tubes performing the functions of frequency compensation and drive-level control. Audio for the linearity corrector is obtained from the cathode circuit of V313 in the phase modulator then applied to a three-stage wave-shaping amplifier. The amplifier compensates for the frequency deterioration inherent in phase modulation and that created by the algebraic addition of the phase-vector angles required to produce the trough of the synthesized amplitude modulation wave.


Transmitter equipment cabinets 5 through 7, transmitter control and audio input racks.

Klingaman states that through proper level adjustment of the drive regulator circuit in the BTH-250A, " . . .it is possible to dynamically adjust the operating point of the 6949 power amplifiers so that at the crest of modulation, grid bias, and grid drive are increased from the carrier value. At the trough of modulation, bias is reduced and the drive almost cut off. Thus the tubes will not be overdriven when the plate impedance is high" (53). Klingaman goes on to say that through the use of the drive regulator system, the exact 180° displacement of the vectors at the trough of modulation is not necessary (53).

The BTH-250A Performance Data at XERF

By 1961, when RCA published Klingaman's article, the BTH-250A had been in operation at XERF in Ciudad Acuña, Mexico for approximately two years. Diesel engine generators supplied power to the transmitter, and the following test data (*page 25*) from Klingaman's paper shows satisfactory performance.

Concluding Remarks

There are four facets of XERF history that re-

6 transmitter equipment racks, air ducts and coaxial cable visible above the racks.

quire additional brief comments. First, there is a common misconception that XERF is merely a continuation of the old XERA owned by Dr. John R. Brinkley. In late 1941, Mexican radio authorities closed XERA. In early 1942, the Mexican Radio Institute began dismantling the station, and on May 26, 1942, Dr. Brinkley died. When XERF began broadcasting in 1947, station engineers installed their first transmitter in the old XERA building. Other than the building and several personnel, the two stations are not related.

Second, such station ancillary equipment as the cooling-water system, control equipment, lightning protection, and even the transmitter's thirty-six tube power supply require an in-depth discussion that I have reserved for a future technical narrative.

Third, in reviewing the principles of ampliphase modulation and the BTH-250A, one gets the impression that XERF always operated at some super-power level, and that the transmitter always functioned a full power. In fact, neither is true, and both subjects warrant additional discussion. However, I will reserve these, too, for a later review of broadcasting regulations of the time and the business practices of other border stations, including XERF.

XERF began regular broadcasting in 1947 but not with 150 kw as indicated by official FCC records and by the Mexican Change List #61 dated May 7, 1946. The station's first transmitter was an RCA BTA-50G, a plate modulated set operating at only 50 kw. Change Lists were required by international agreement when changes were made that might cause interference to other stations in the North American Region, an area that was defined by the North American Regional Broadcasting Agreements.

In 1959, the station moved to a remote desert location about twelve miles from Acuña, and RCA engineers installed the new BTH-250A. Station advertisements and rate sheets now reflected the 250,000-watt level, but the transmitter could only be made to work at less than 80 kw.

The difficulty with the transmitter may never be entirely clear. However, XERF personnel offer the

Test Data, BTH-250A at XERF

Frequency	Audio frequency response 60% Modulation	Harmonic distortion 90% Modulation	Modulation Capacity
50 cps	+0.7 db	1.5%	100%
100 cps	+0.4 db	0.70%	100%
1,000 cps	0 db	0.60%	100%
7,500 cps	+0.8 db	1.75%	95%
10,000 cps	+0.9 db	3.00%	90%

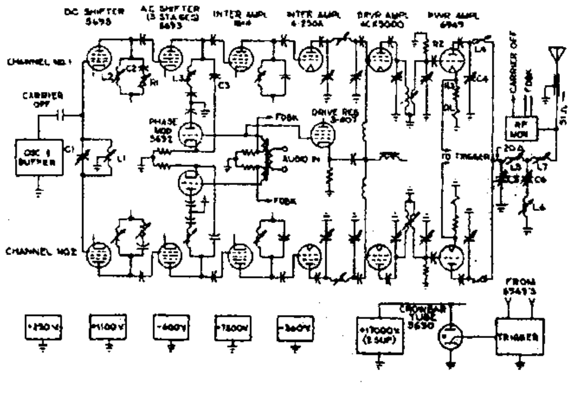
Power Output (carrier at antenna): 250kw
Frequency Stability: better than +/- 10 cycles
Carrier Shift (90% modulation): 2.5 - 3%
Noise Level (below 100% mod., 1,000 cps) : -56 db
Power Consumption (average program) 400kw

Klingaman (54)

explanation that the RCA engineers could not make the set function at full power, and a rift developed between RCA and the station management that resulted in the RCA personnel leaving with all the technical materials. In a 1997 interview, transmitter engineer Mike Venditi corroborated the difficulties with RCA; however, Klingaman presents a more plausible version of the incident. As Klingaman reports, "The transmitter is powered by a large 2,300-volt Diesel engine generator, a power source having inherent regulation problems" (54) [author's emphasis]. It is most likely that the generators were incapable of supplying the 400 kilowatts required for the transmitter plus other electrical equipment for extended periods of time. The difficulties were simply attributed to RCA, and the station operated at 80 kw—although printed advertisements' claims to super-power remained the same. By 1969, the BTH-250A had begun to work intermittently, and the engineers purchased a new CCA transmitter that operated at only 50 kw. All advertisements continued to claim 250,000 watts, and one boasted of the station's plans to move quickly to 500,000 watts.

Some time in 1969, engineers moved the transmitter site closer to Acuña and applied commercial power to the system. By this time, however, the rig was in such poor condition that the 50 kw CCA became the primary transmitter with the BTH-250A being relegated to backup status, a fact which changed in 1981, when the BTH-250A once again became the primary rig. Venditi repaired the transmitter and worked at the station for three years as Chief Engineer, using the set at its full 250,000 watts. In 1983, he handed control of the station back to the former Chief, Pedro Rodriquez Olivares.

The complexities of the ampliphase system were ill understood by the station personnel, and, again, the super set began to function at less and less power. It became the station's backup set for a second time and was then retired in 1986. Its demise signaled the end of the border-blasting era. Stories, however, are circulating among broadcasters that another American engineer has been employed to restore the station to its super-power capability. Freshly painted on the front of the transmitter building is the statement "XERF—250,000 watts."



BTH-25A simplified schematic diagram Klingman (53)

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Footnote:

For those interested, a detailed schematic of the XERF transmitter can be obtained from the Radio Club of America headquarters for a club donation of $5.00.