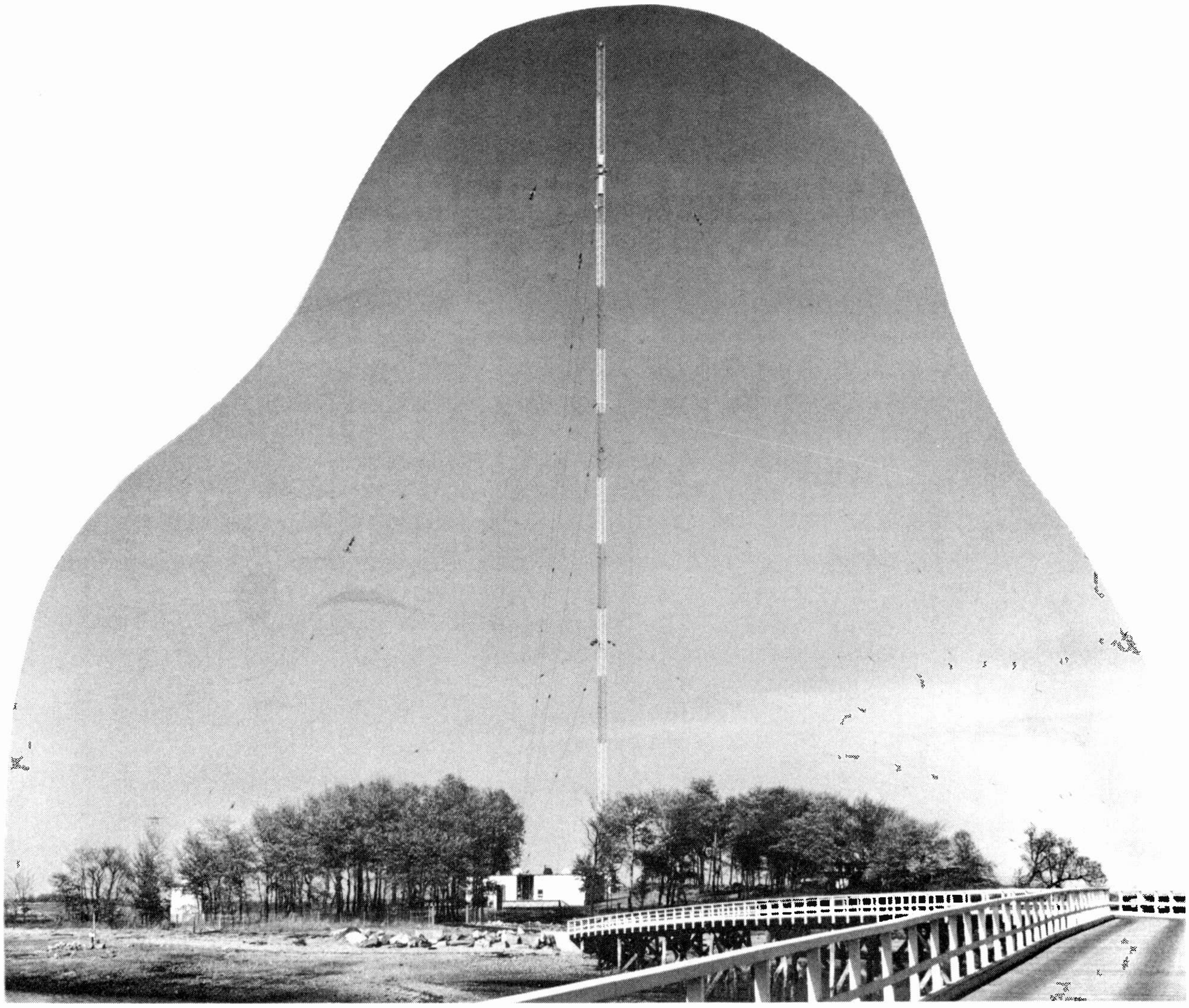
WNBC-WCBS SHARED ANTENNA SYSTEM



Presented at The 18th Annual NAB Engineering Conference April 7, 1964

LESTER A. LOONEY, Formerly
MANAGER, TRANSMITTER ENG.
NATIONAL BROADCASTING CO.

OGDEN L. PRESTHOLDT
DIRECTOR OF ENGINEERING
CBS RADIO DIVISION

WNBC-WCBS SHARED ANTENNA SYSTEM

In order to improve the service from WNBC, the National Broadcasting Company station in New York, a change in transmitter location was desired. After some search an island of about six acres known as High Island in Long Island Sound was obtained. The island is close to shore and accessible by bridge in the Borough of the Bronx in New York City. This location, being near sea level, had the advantage of permitting a higher antenna as well as a ground system extending into salt water.

The transmitter of WCBS, the Columbia Broadcasting System station in New York, was located on Columbia Island about one and one half miles from High Island. This Island was reached only by boat, and as remote control was anticipated, it was desirable to provide easier access to the transmitter. There had been occasions during winter ice conditions and storms when Columbia Island was isolated for a day or more. As good transmitter locations are not plentiful in the vicinity of New York City, it was natural to consider a joint project on High Island. After some study it was agreed that NBC and CBS together would plan, design, and construct, complete new transmitting stations using a common antenna. The two stations are both Class 1A with powers of 50 KW. WNBC operates on 660 kc/s and WCBS on 880 kc/s. The frequency separation, one being three fourths of the other, seemed sufficient to insure successful operation into a single antenna.

FCC construction permits when obtained, contained specifications for both stations that the antenna height must not exceed 549 feet above mean sea level, that the unattenuated field intensity at one mile, based on 1 KW antenna input, must be at least 225 millivolts per meter, and that any spurious radiations resulting from cross modulation be held to non-interfering levels.

Considering the ground elevation, the antenna height became about 528 feet above ground. The theoretical no-loss performance of a plain vertical antenna of this height is only 206 mv/m at 660 kc/s and 228 mv/m at 880 kc/s. It was then obvious that some increase in efficiency would be necessary at 880 kc/s to compensate for losses and that an appreciable increase would be necessary for 660 kc/s. To obtain the increase, a top loaded and reactance sectionalized antenna tower was indicated. To determine the optimum degree of top loading, position of tower sectionalizing and reactance insertion, the RCA Laboratories were engaged to model the antenna.

With the physical data arrived at, the antenna was specified as shown in Figure 1. The tower has a triangular constant cross-section, 4½ feet on a face, is sectionalized with a single pedestal type insulator about 85 feet from the top and guyed at four levels. The set of guys attached to the top of the tower (unlike the others) have no insulators at the tower, and are electrically bonded to the tower. The upper sections of these guys are therefore used for top loading to increase the electrical height of the tower. A suitable reactance is connected between the upper and lower sections of the tower to control the effective electrical height.

Vertical plane radiation patterns obtained from the model, indicated that a field of about 246 mv/m at one mile might be realized for one KW radiated power. The value was approximately the same for both frequencies. This meant that on the basis of 50 KW input to the antenna, the required field would be obtainable with about 42 KW radiated power, leaving 8 KW available to supply the system losses and any tolerance in the modeling data.

To provide additional information, a mathematical model was prepared for each frequency and arranged to program a computer, with variables of top loading, current distribution, (which would be obtained by variation of the sectionalizing reactance) and estimated values of tower ohmic resistance. These computations indicated a trend of increased field with reduced length of guy top loading, other variables being held constant. This results from using guys for top loading instead of the so called "HAT" of structural steel. The guy loading, while quite desirable from a structural viewpoint, has a vertical component which modifies the effective current distribution of the very top portion of the antenna. It was obvious, however, that appreciable reduction in top loading would result in excessive values of sectionalizing reactance necessary to maintain a suitable current distribution on the tower. This would cause high sectionalizing voltages and losses in the reactance network. The guy top loading was finally set at a length of about 120 feet. There would be some effective extension of this value due to the capacity of extra large insulators at the ends of the loading sections.

The antenna system was constructed in accordance with the above values. The design was based on 50 lbs./sq.ft. on flats for wind loading and the tower is constructed from 30 foot welded sections. In view of the voltages anticipated from the operation of two 50 KW transmitters (the peak voltages add arithmetically) three exceptionally large guy insulators were used at the ends of the guy sections used for top loading. The remaining insulators were spaced in an attempt to minimize guy currents and equalize insulator voltages. Considering that the antenna was to be used for two separate transmitters with the increased complexity in the networks for matching, isolation, and sectionalizing, it was felt advisable to have an auxiliary antenna with its own networks. For this use, a bottom segment of one of the top guys cables was made 200 feet in length with the top end terminated in large insulators and a corona ring. Although only the lower power auxiliary transmitters would be used on this antenna, the peak voltage at the upper end calculated to be well over 100 KV. All guys were fabricated from one inch diameter Alumoweld cables. Each strand in the cable is of steel with a thick aluminum covering providing good conductivity for the current carrying portions.

The tower being sectionalized and top loaded has a higher loop current than would be found in an equivalent unloaded antenna. Because of this higher loop current, conduction losses in the steel tower might have become significant. As a precaution, we obtained the cooperation of the tower fabricator in the control of the galvanizing process and obtained a galvanized coat thicker than normal.

An efficient ground system was designed and installed, starting with a conventional expanded copper mesh ground screen about 40 feet square around the tower base. From this screen 120 radials of one inch wide buried copper ribbon were extended approximately one fourth wave length to the island shore line. Further extension of the radials was by #2-0 stranded copper cable to a point where at least 50 feet was immersed in salt water. The ends were anchored by securing to concrete blocks.

At this stage, base impedance and tower current distribution measurements were made, on one frequency at a time, using various amounts of a temporary simple coil for the 660 kc/s reactance at the sectionalizing point, and a short circuit or capacitor for 880 kc/s. Field intensity measurements were next made to determine the antenna performance as well as to exactly confirm the optimum value of sectionalizing reactance for each frequency. This work was performed with the advantage of daylight while the two stations were still in operation at the old locations, by permission from the FCC to use a test power of 50 watts on the frequencies of 640, 680, 860 and 900 kc/s. Advantage was taken of the water of Long Island Sound bordering on the station to use a boat in making radial measurements in several directions. This method was faster and produced more consistent data than could be obtained on land with short radials in the built up city area. The boat was run on a radial starting from and ending with a fix. Speed was maintained as near constant as possible, with the start, finish, and measurement times recorded. An example of these measurements is shown on Figure 2. From these, as well as measurements on land, it was confirmed that the antenna would meet the required radiation efficiency. The sectionalizing reactances required, were determined at 180 ohms inductive for 660 kc/s and 50 ohms capacitive for 880 kc/s. The tower current distribution placed the minimum at about 23 degrees above the ground. The widely differing reactances were due to insufficient height for the low frequency, while at the high frequency the antenna with the top loading, was somewhat too high.

It was now necessary to consider a design for the permanent sectionalizing reactance. This component is of particular interest because of the two-frequency requirements and the necessity to avoid large losses. Several networks had been considered which would supply the separately required reactances. With the precise values now in hand the networks shown in Figure 3 were re-examined. #1 is the simplest, however, calculations indicated that the coil current would exceed 400 amperes and the loss at 660 kc/s would be about 6 KW. The reactance slope, or variation against frequency in the band ± 10 KC would also be excessive. The base impedance of a loaded antenna varies more rapidly with frequency than that of a simple antenna. Using a sectionalizing reactance such as is necessary for two frequencies causes a still steeper base impedance variation and results in concern for the proper loading and low distortion operation of the transmitter. These characteristics were sufficient to reject #1 network. The other three networks, by proper choice of values can all be made to exhibit nearly equal and acceptable amounts of loss and reactance slopes. #2 however, develops a peak voltage well over 100 KV across the capacitor, and #3 an effective current of 200 amperes in L_1. Voltages were computed for full modulation and the current for no modulation condition. These characteristics do not make for easy design, and in addition these two circuits would be critical to adjust, especially if it became necessary to do so after installation high up in the tower. #4 network provided a very happy compromise. The voltages and currents are not uncomfortable for design purposes and the adjustments, even after installation, can be made straight forward. At this point it should be explained that the provision for getting a power circuit past the tower sectionalizing to supply the top beacon had already been made. Previous measurements had shown that running power circuits up through the tubing of a sectionalizing coil and the consequent short circuiting of unused turns for adjustment, would reduce appreciably the effective Q of the coil. Therefore an insulating transformer such as is commonly used at the tower base was installed at the sectionalizing level to supply the top beacon. The operation of #4 network can best be seen in Figure 4. L_1 C_1 is made anti-resonant at 660 kc/s so that for practical purposes, all the sectionalizing current at that frequency flows in L_3. Thus with L_3 alone connected, it may be adjusted to the proper value by reference to the antenna base impedance determined during the tests. With the other leg of the network added, and an approximate value of L_2 in use, L_1 C_1 may then be adjusted for the same base impedance as obtained before. The frequency may then be changed to 880 kc/s and L_2 adjusted for the base impedance determined for that frequency.

Figure 5 shows the way in which the network was installed in the tower. A 5 foot open face section above the sectionalizing insulator made room for a shield cabinet containing L_3 and a 10 foot space below the insulator was provided for a double compartment cabinet for L_1 C_1 and L_2. As there is very little circulating current between the two legs of the network they are individually connected between the tower sections. The shield cabinets are constructed of one eighth inch thick aluminum with welded seams and ventillating louvres with baffles to minimize rain entrance. The doors have special RF bonding and weather strips. The coils for the network were specified so that there would be a minimum of unused turns and as good a Q factor as feasible. Before installing the coils in the cabinets the Q's were carefully measured by plotting resonance curves for each frequency. Q's between 900 and 1000 were found. When the coils were installed in the shield cabinets the Q's dropped to about 600. On the basis of a 600 Q the network loss computed at about 1500 watts for each frequency. The capacitors for C_1 are multiple vacuum units, three of which are variable. They are rated at 60 KV. The network provides a DC path for static drain and a ball gap across the sectionalizing insulator supplies protection to the network from lightning. The single sectionalizing insulator minimizes stray capacity between tower sections. It is equipped with a rain shield and was especially designed to tolerate a small amount of rocking, which can occur during high winds.

The pictures Figures 6 and 7, show L_3 mounted in the upper cabinet, and L_1, C_1, L_2 mounted in the lower cabinet. The cabinets were painted with Day Glo, the same as the two top orange sections of the tower. This paint, having florescent characteristics, provides increased visibility during daylight.

Figure 8 illustrates the effect on the antenna base resistance of using a two frequency sectionalizing reactance network instead of a simple coil as would be used in the case of the antenna being built for one station. The base resistance around 660 kc/s was measured using only the coil L_3 at the section and again when the entire network was connected. There is an increase in slope of about 1.3 over a 20 KC band when the complete network is connected. It may be noticed that the two plots cross at the carrier frequency.

Figure 9 illustrates the measured current distribution on the tower at 640 kc/s. The complete curve was obtained with a sectionalizing reactance of zero and indicates only the tower current. That is, the current in the guy loading and the effect of it is not shown. The partial curves show the locations of the current minimum for sectionalizing reactance values of j140 and j190 ohms.

Although some trouble was experienced initially with inadequate electrical bonding at the cabinet door edges, there has been no difficulty to date with the sectionalizing network proper. The antenna system as a whole is performing satisfactorily.

During the early stages of the project, we became aware of many serious problems relating to the design of the isolating and coupling networks. The general performance criteria we originally had in mind were not reducible to specific performance standards until several network designs had been studied in detail.

General problems relating to network losses were of particular concern in this instance because the circuitry required to provide the unusually high isolation necessary between these transmitters could very easily result in excessive losses. A second important factor relating to circuit performance dealt with the problem of maintaining reasonably constant load impedance over the bandwidth being transmitted. In normal installations, this requirement does not impose any special design requirements, but under some circumstances, the impedance bandwidth problem may become controlling in network design. A further requirement was that the coupling and isolating network for each station be capable of being disconnected from the antenna system in the event of failure in one network so that the other station could continue operation in normal fashion and that the station in trouble would be able to work in perfect safety on the network which had suffered a failure.

Past experience has established that a transmitter using a Class "C" final amplifier and having stray R.F. energy in its tank circuit will generate cross modulation products as though the amplifier behaved as a mixer with 25-30 db loss. If these spurious emissions fall on or near frequencies that are used by other services, it has been found that these spurious emissions in 50 kw plants must be kept at least 120 db below the level of the fundamental. Both the sum and difference frequencies were in use within 100 miles of the transmitting site; therefore, these first order effects had to be effectively removed. The net isolation required was such that attenuations in the order of 100 db at carrier frequency had to be obtained and, consequently, all networks had to be enclosed in well-shielded cabinets.

These problems in terms of defining the performance of the coupling and isolating networks indicated to us that a reasonably complete design of the networks would be necessary before specifications for the network could be written; consequently, we designed these networks ourselves.

Base impedance data from the model measurement work indicated that there could be impedance bandwidth problems. These data from the model work indicated that the antenna impedance would be significantly worse than that specified in EIA Standard TR-101-A for normal load impedance and that actual tests on transmitter performance should be made. An analysis of Class "C" amplifier performance indicates that the optimum load impedance as a function of bandwidth should be the equivalent of a dissipative parallel resonant circuit. Both NBC and CBS arranged for tests to determine transmitter performance into the then expected load impedance. These tests indicated that both the RCA BTA-50H and the G.E. BT-50-A transmitters would meet frequency response and distortion specifications with the expected load impedance if that impedance characteristic was properly oriented. The foregoing transmitter performance experiments also verified the fact that impedance bandwidth characteristics of other natures would not provide the same overall performance.

If the load impedance would be made reasonably constant over a frequency range significantly in excess of the bandwidth to be transmitted, transmitter performance could be further improved and overall operation significantly stabilized. These performance measurements indicated that serious consideration should be given to antenna coupling circuit design which would provide broad band impedance control in the same fashion as that provided by compensation used in television antennas.

The actual antenna impedance, as a function of frequency, was determined around both operating frequencies during the antenna tuning process. These data indicated that the impedance bandwidth problem was worse than that anticipated from the model measurements; a graph of these data is presented on Figure 10. Since suitable performance of the system was directly related to the proper matching of this impedance characteristic to the transmitter, considerable effort was devoted to the optimizing of these matching networks.

Consider for the moment a simple antenna whose resistance is constant and whose reactance varies as a series resonant L-C circuit. The terminal admittance and equivalent circuit of this antenna is shown in Figure 11 a, b. Suppose now, we put a reactive network across these input terminals, (Figure 11 b) and try to improve the admittance match thereby. Assume that the network in parallel with the antenna is a parallel L-C network resonant to the carrier frequency. The effect at frequency f_1, a lower side band frequency, will be that of transforming the admittance from the original value to a new value, along a constant conductance path as shown on the Smith chart of Figure 11 a. Similarly, the admittance at carrier frequency is not changed; and the admittance at f_2, an upper side band frequency, is also improved. It may be seen that for moderate impedance bandwidth problems a significant improvement can be made by proper choice of the L-C ratio of the compensating network. It may also be seen that for impedance mismatches that are sufficiently severe such as that for f_3 on Figure 11 a, that the reactive compensation network no longer offers a significant improvement. Our impedance bandwidth problem was severe enough to warrant a study of more effective methods of compensation.

Previous experiments had indicated that compensating networks using a dissipative element were capable of providing better overall driving point impedance characteristics. The circuit of Figure 11 c is such a network. This compensating circuit will add both susceptance and conductance to the antenna admittance as shown by the transformation of the f_4 admittance on the Smith chart of Figure 11 a. A brief analysis of this type of network indicated that it provided two principal functions: (1) that of absorbing the energy reflected by the admittance mismatch at the side band frequencies and (2) that of providing relatively broad band constant load impedance for the transmitter. Since both of these conditions fit the required performance objective, dissipative compensating networks were considered to provide satisfactory system performance.

The foregoing detailed circuit requirements were applied to the design of suitable isolating and coupling networks, Figure 12 shows the final networks. Since the base impedance was capacitive at both frequencies, a common antenna loading coil L_a performed a common tuning function and reduced the undesired voltages across both the isolating networks. The remainder of the circuit in Figure 12 may be described as follows: The first network at the antenna end of the circuit is an L or a T network for matching the antenna impedance to the transmission line; some of the circuit elements in these networks are rejection traps tuned to the undesired frequency. The T network at the transmission line end is a phase shift network to properly orient the load impedance to the optimum position at the plates of the final Class "C" amplifier. Calculations indicated that two traps would provide adequate isolation and, therefore, the third element could be used for other purposes.

A very low L-C ratio parallel resonant circuit connected in shunt to ground will provide an excellent filter to limit the generation and radiation of spurious frequencies. Calculations established that the antenna impedance could be properly transformed by the first series arm of the WCBS T network so that this shunt L-C network could also act as a reactive compensating network as previously described. These two functions, compensation and filtering, are performed by the shunt network in the WCBS circuit. (It was not practical to incorporate this feature in the WNBC side of the network.) A limited amount of compensation was provided for WCBS by this method. Further compensation of either the dissipative or non-dissipative type can be added, if needed, at this same point. On the WNBC side, the first T network was required to properly orient the impedance characteristic for compensation, and provision was made for compensation at the end of that network. Figure 13 is a photograph of the WCBS network; note particularly that L_{13} could not readily be made with half the present inductance and twice the diameter of the tubing as would be required for a significant increase in bandwidth impedance compensation. Figure 14 is a photograph of the network feeding the auxiliary antenna; this network provides only isolation and matching at the carrier frequency; no provisions were made here for broad band compensation or proper orientation of the load impedance.

An important consideration was that of obtaining maximum Q in the decoupling networks; properly designed coils for operation at this power level will produce Q's in the 500-1000 range. In a tuned circuit utilizing a coil and condenser in either series or parallel, it is important that the circuit connections also be made to provide minimum loss. No turns may be shorted in the coil; and the circuit should occupy the minimum physical space. Conductor sizes must be adequate for the current to be carried, a value of 20 amperes unmodulated carrier for each inch of circumference was used. Care was taken to make equivalent paths for each condenser, when units were used in parallel. Most of the resonant circuits in the decoupling networks were designed to operate at or near full design inductance. Detailed measurements of Q of these circuits have not been made, but those that were made of the antenna sectionalizing network suggest that Q's in excess of 600 were obtained in actual operation of these networks.

Stringent performance specifications were established for all characteristics of the plant. We believe that these performance criteria have been adequately met.

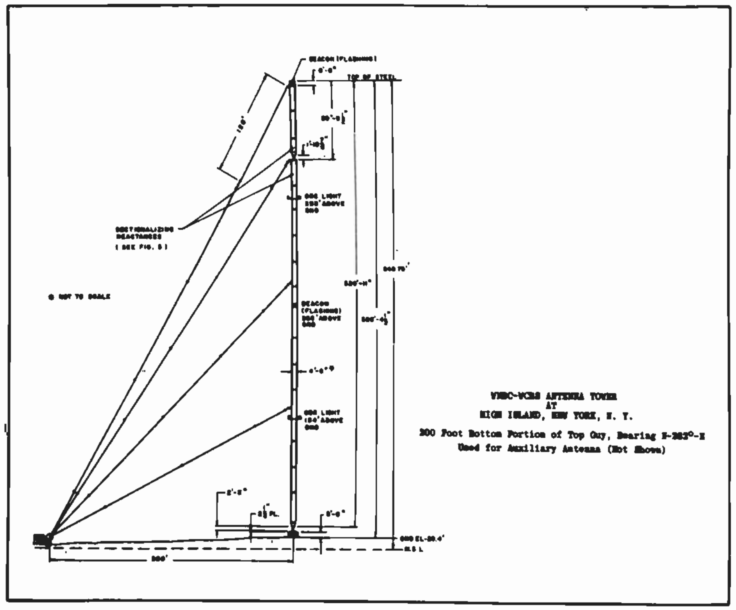
The transmitting site is almost completely surrounded by the New York urban area. It was not possible to find directions with relatively unobstructed sites for the making of the field strength proof. Therefore, the radials were chosen near the nominal cardinal directions 0°, 45°, 90°, 135°, etc. Minor variations of these bearings were made to fit available water navigation paths, parkways or other roads which would provide somewhat improved measuring locations. Four field crews were used each consisting of a driver and engineer. Each crew measured field strength of both stations at each location with careful calibration of the field set for each measurement at each location. Final analysis of these data indicated reasonably uniform radiations in all eight directions on both frequencies and yielding a radiation efficiency of 244 mv/m per kw at 660 kc/s and 256 mv/m per kw at 880 kc/s. These radiation efficiencies are both significantly above the required 225 mv/m per kw. The current minimum on both frequencies had been drawn up to a height sufficient to significantly control fading. As the current minimum is raised on the tower, the magnitude of the current at the loop increases and consequently, losses increase. The resultant radiation efficiencies demonstrate that the construction techniques used have kept the antenna losses to a minimum.

Since the coupling and isolating networks were designed with due consideration to the bandwidth problem, calculations and data were readily available for the values of various elements at side frequencies as well as at carrier frequency. The High Island plant is only a few miles from both old WNBC and WCBS transmitting plants; both stations operate 24 hours a day.

Difficulty was encountered in tuning these networks on the actual operating frequency. Considerable success was obtained in the tuning of these networks for side band frequencies with final trim up on carrier frequency. Figure 15 indicates the approximate normalized impedance characteristic as observed at the final amplifier plates in the WCBS transmitter. A similar impedance frequency characteristic was obtained for WNBC. Since the impedance bandwidth problem is significantly worse at 660 kc/s, a dissipative compensating network along the lines previously described has been built for WNBC's use and is currently under test. Figure 16 indicates the improvement in impedance characteristic available by this procedure; these measurements were taken at the transmitter output terminals, the impedance there should be similar to a series resonant circuit at that point.

The isolation networks were designed with the intention of reducing spurious signals to an absolute minimum. The approximate difference frequency, 219 kc/s, is used by a low power radio beacon at Teterboro Airport some 15 miles from the transmitter plant. The sum frequency, 1540 kc/s, is used in Philadelphia, Pennsylvania. The two spurious signals, 220 kc/s and 1540 kc/s, which could interfere with these services, are the highest order cross modulation products generated. The success of the installed filters in preventing cross modulation can best be guaged by the fact that both the 219 kc/s and the 1540 kc/s signals can be received with no noticeable interference from the WNBC and WCBS signals, within a quarter mile of the High Island transmitter. As a further demonstration of the isolation between the two transmitters, I asked our operating staff to connect a 500 ohm one tenth watt resistor between plate and ground of the final amplifier of the WCBS transmitter and have WNBC operate with 50 kw. I have that resistor with me; and as you can see, it shows no ill effects from that test. If that resistor had dissipated its rated power under the foregoing test, the isolation would have been 57 db. It may be of interest to note here that during tune up of the antenna system as much as 80 watts of the WCBS Columbia Island signal could be obtained in the High Island antenna system, this represents a natural decoupling of about 28 db between sites spaced 1.75 miles. The original 4 mile spacing between WNBC and WCBS resulted in an isolation of only approximately 35 db. It may thus be seen that significantly better isolation between transmitters has been achieved in the joint plant than existed when the plants were separated.

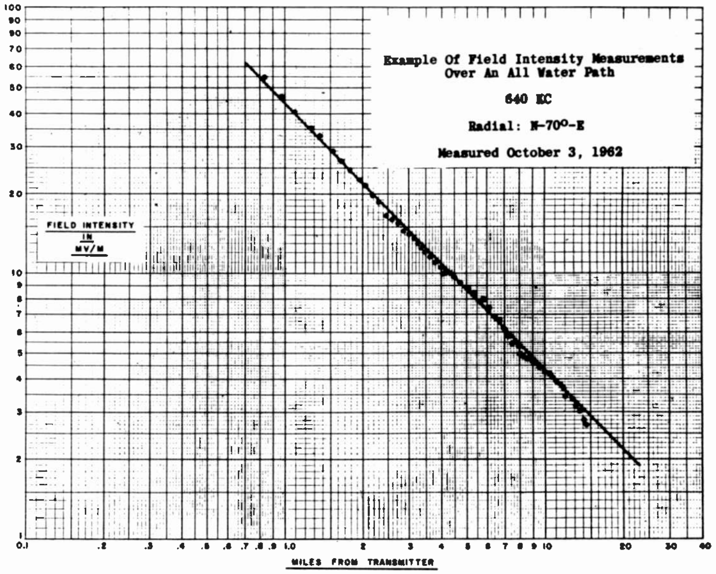
I am sure that you all realize that a project of this magnitude that has extended over several years has required the cooperation and the diligent efforts of many people in both organizations. Specific credit to all of them would take more time than is warranted, but there are two that I want to especially point out at this time. Mr. William Duttera, our Session Coordinator, who was responsible for the original idea, and continued to participate in the project; and Mr. John Seibert of NBC spent many months following the details of the joint construction as well as the details within the WNBC portion of the plant.



WNBC-WCBS ANTENNA TOWER
AT
HIGH ISLAND, NEW YORK, N. Y.

300 Foot Bottom Portion of Top Guy, Bearing N-282°-E
Used for Auxiliary Antenna (Not Shown)

FIGURE 1



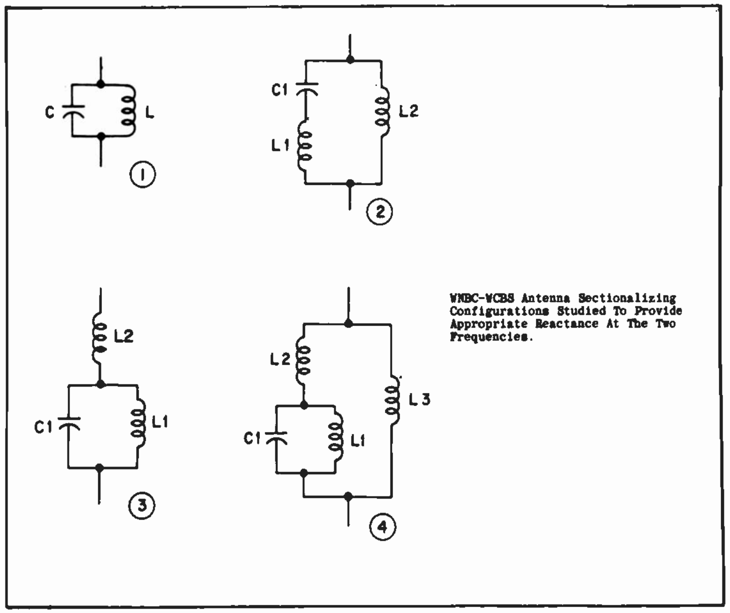
Example Of Field Intensity Measurements Over An All Water Path

640 KC

Radial: N-70°-E

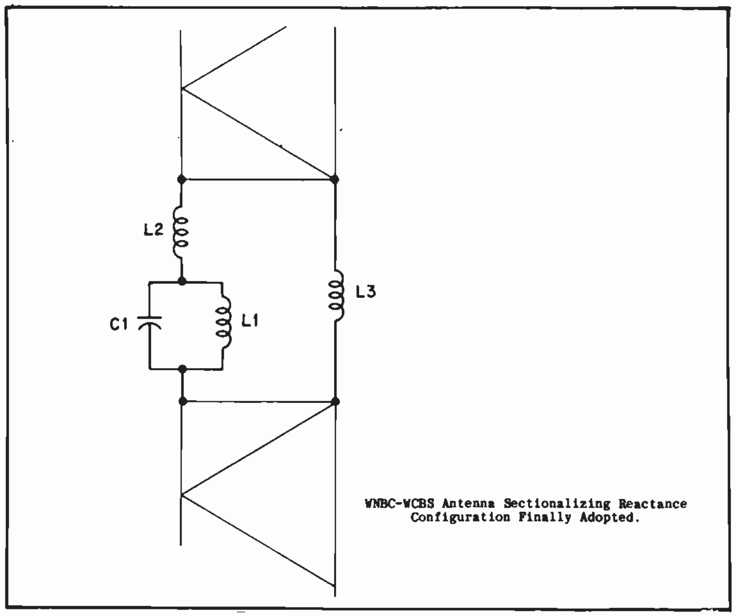
Measured October 3, 1962

FIGURE 2



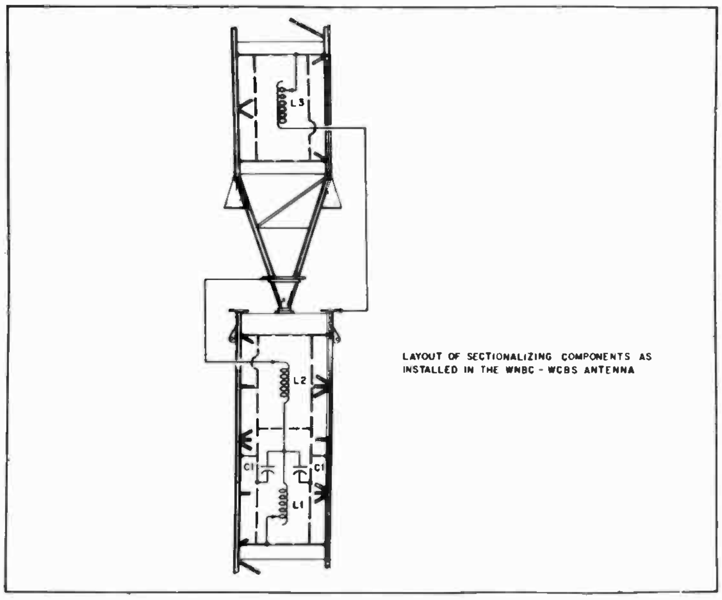
WNBC-WCBS Antenna Sectionalizing Configurations Studied To Provide Appropriate Reactance At The Two Frequencies.

FIGURE 3



WNBC-WCBS Antenna Sectionalizing Reactance Configuration Finally Adopted.

FIGURE 4



LAYOUT OF SECTIONALIZING COMPONENTS AS INSTALLED IN THE WNBC - WCBS ANTENNA

FIGURE 5

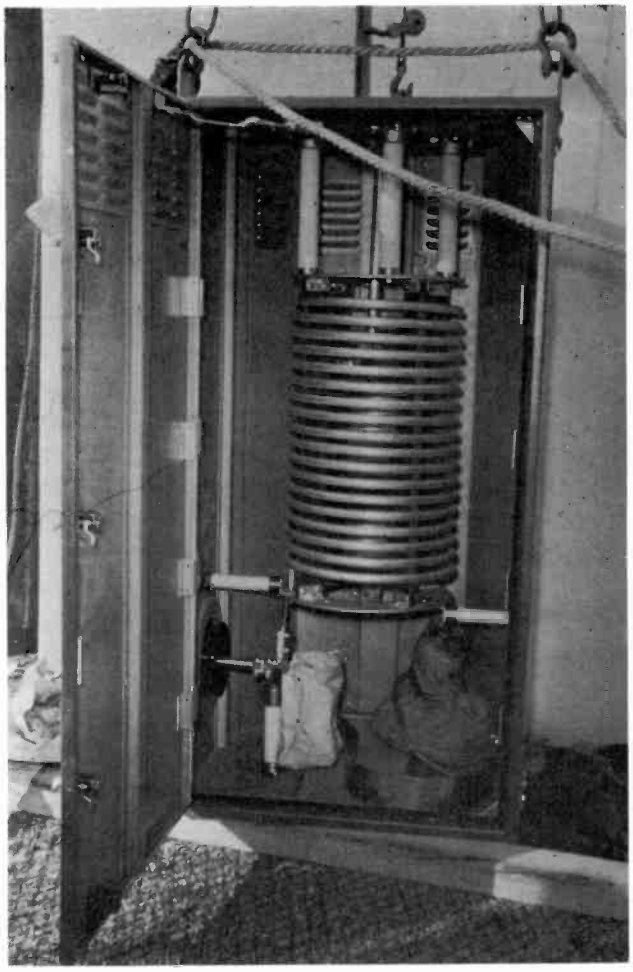


FIGURE 6

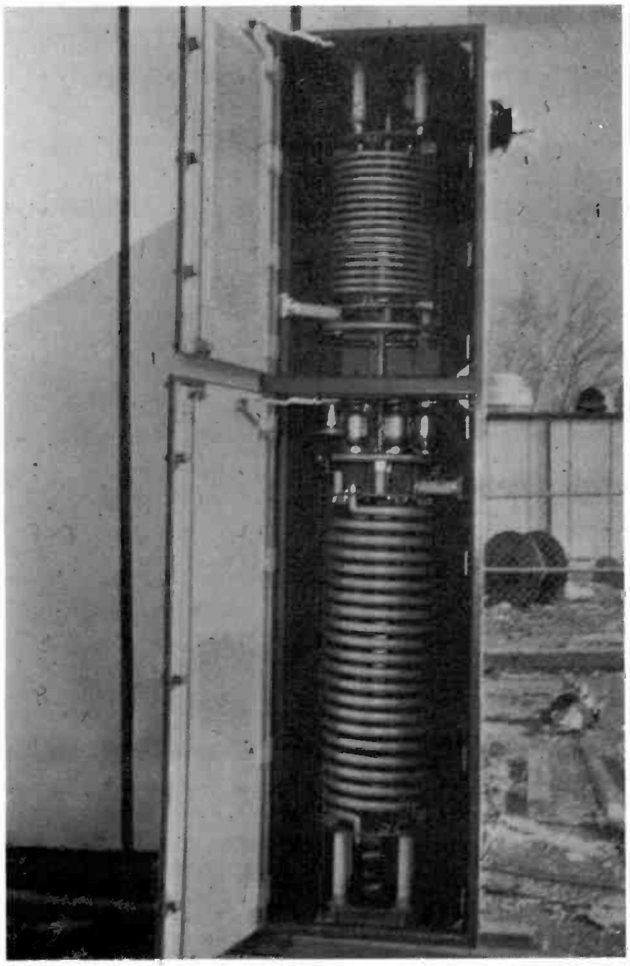


FIGURE 7

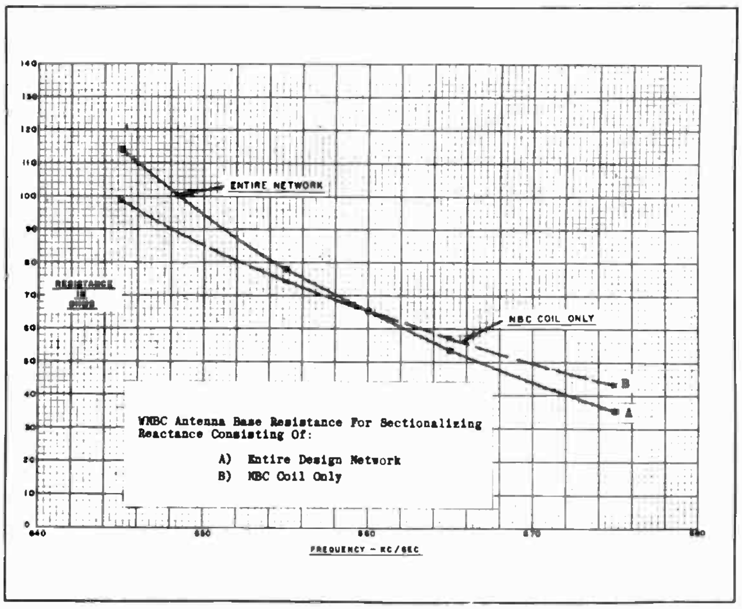


FIGURE 8

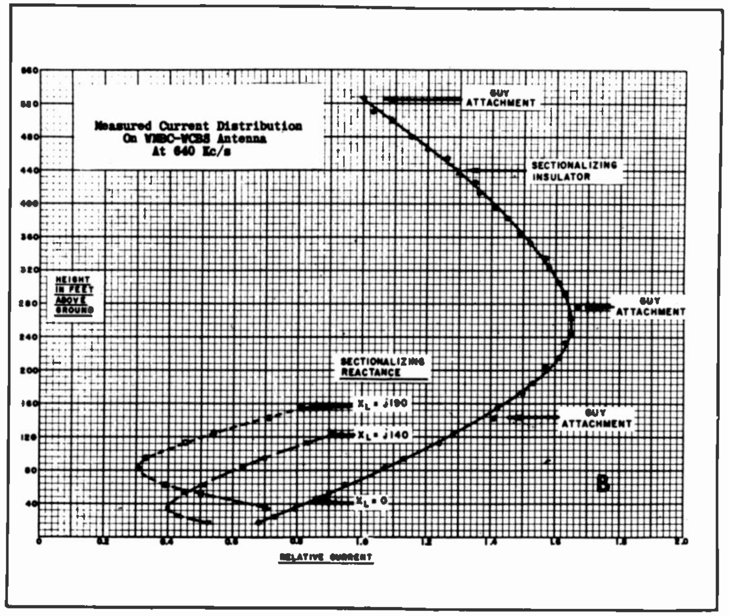


FIGURE 9

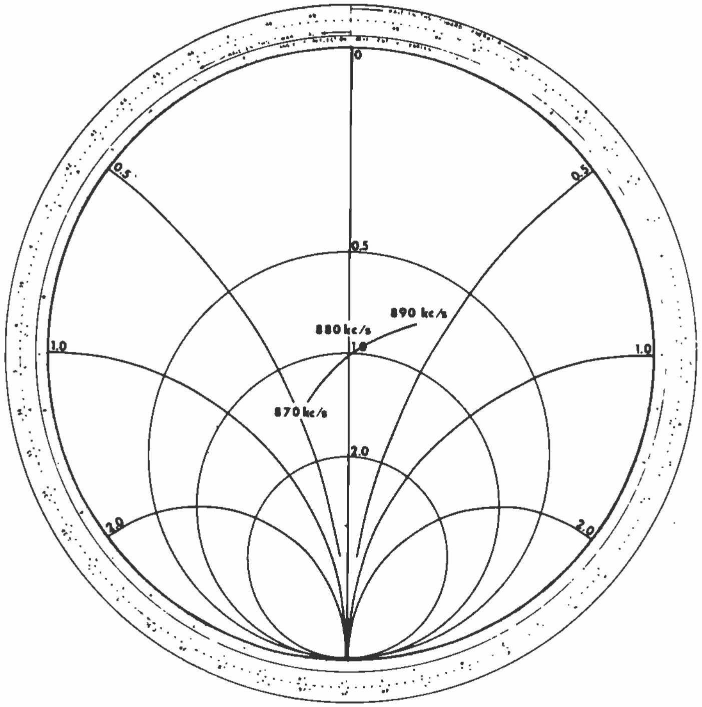


FIGURE 10

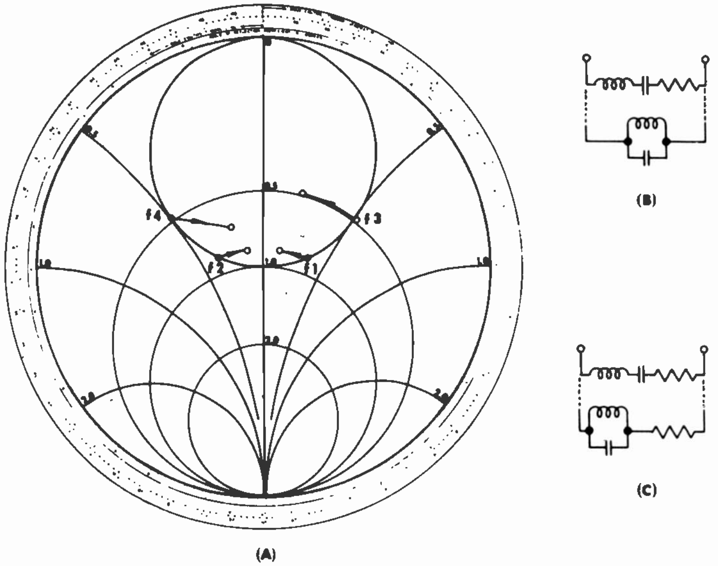
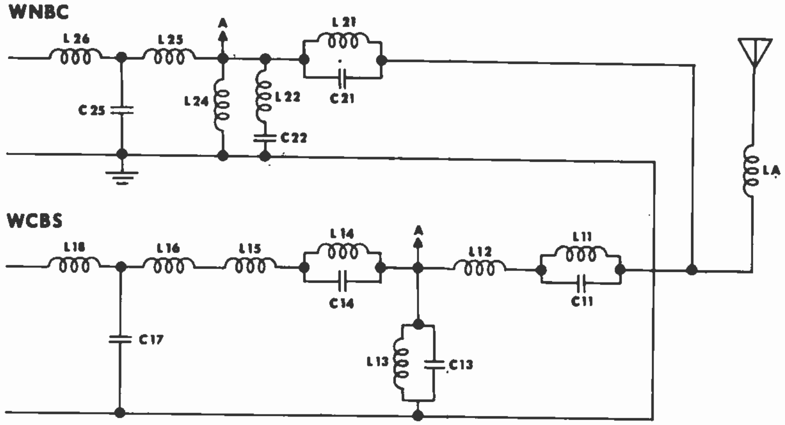


FIGURE 11



COUPLING AND ISOLATING NETWORKS
FIGURE 12