USING ISOLATION TRANSFORMERS TO LEASE AM TOWER SPACE

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Abstract- With the emergence of today's mobile communications technology-cellular telephone, paging systems, trunking systems, etc.--the need for vertical height of the associated antennas above average terrain has presented a possible new source of income for the owners of AM broadcast stations. Also as a result of a growing opposition to the erection of new tower structures, the installation of the mobile communications antenna(s) on an existing AM tower is a low cost and fast solution in getting the mobile site up and operating. A comparison of several types of isolation transformers appropriate for this application will be discussed.

INTRODUCTION

In this paper, the standard AM broadcast tower is a series-fed, base insulated, guyed or self-supporting tower. The point at the base of the tower above the base insulator, to which RF power is applied, presents a lumped impedance load to the RF source. This impedance is referred to as the self impedance for an omni-directional antenna and as the drive point impedance for an element in a directional antenna. In order to add any ancillary antenna to the AM tower structure requires that a corresponding transmission line be routed across the base insulator and up the tower to the antenna. This antenna and transmission line must be added to the tower in such a way that minimum change in the tower impedance and radiating characteristics results. This is in fact the purpose of an isolation transformer. From basic network theory if an impedance of magnitude greater than 10 times the tower base impedance magnitude is applied in parallel with the tower base impedance, the resulting impedance will be approximately equal to the original tower base impedance. In addition to effectively presenting a high impedance across the base of the tower, an isolation transformer must also present minimum insertion loss to the RF source driving the ancillary antenna or to the received RF signal coming from the antenna, whichever may be the case.

Three types of isolation transformers will be compared in this paper--the quarter-wave stub, the isocoupler and the multi-coax isolation inductor. This comparison will assess the relative merits of these three approaches with regard to the impedance presented across the tower base, insertion loss, peak voltage rating, throughput power rating, installation procedure and cost. Also the applicable FCC rules will be discussed.

The Quarter-Wave Stub

The quarter-wave stub is the oldest technique that has been used for isolating transmission lines across an AM tower base insulator. Figures 1A and 1B illustrate two approaches of quarter-wave stub installation for tower electrical heights greater than or equal to 90 degrees or less than 90 degrees, respectively[1]. For tower heights in excess of quarter-wave, the transmission line is insulated from the tower up to the quarter-wave point at which the outer conductor is

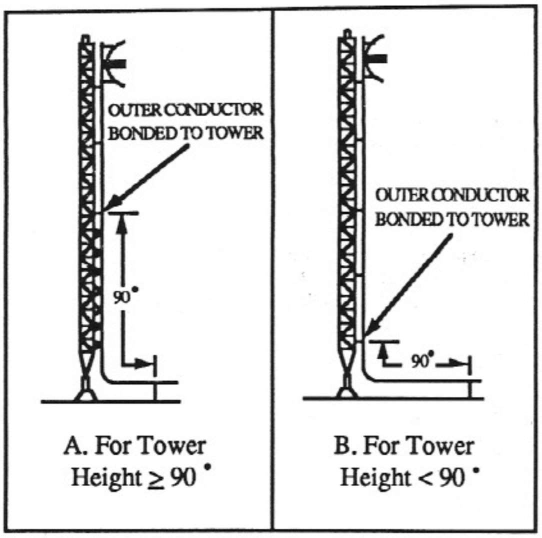

Fig.1 Typical Quarter-Wave Stub Installations.

bonded to the antenna ground just below the base insulator. The combination of the outer conductor of the coaxial cable in parallel with the tower leg electrically equates to a quarter wave section of transmission line. By bonding the outer conductor of the coaxial cable to the tower at the end of the quarter-wave section, a shorted quarter-wave transmission line is formed, which in accordance with classical transmission line theory,[2] presents an open circuit to the RF source, i.e., the AM transmitter.

It is too often the case that quarter-wave stubs are improperly installed on the tower resulting in poor impedance isolation and reduced tower radiating efficiency. If the coaxial cable is not bonded to the tower at the quarter wave point, a variable vacuum capacitor or variable inductor can be installed between the coaxial cable outer conductor and the tower base to effectively increase or decrease, respectively, the electrical length of the transmission line stub. This adjustment can be made to minimize the change in the original tower base impedance.

For tower heights less than a quarter-wave, the quarter-wave section of transmission line is insulated above ground as opposed to being insulated off the tower leg as illustrated in Figure 1B. The outer conductor is bonded to the tower just above the base insulator and to the antenna ground at the quarter-wave point toward the transmitter. This approach is rarely used due to the separation distance required between the tower and the transmitter.

The major drawback of the quarter wave stub isolation approach is the influence of the insulated quarter-wave coaxial cable outer conductor on the shape of the tower radiated field. The RF current flowing in the tower leg, which supports the insulated quarter-wave stub, produces an electromagnetic field. The presence of the outer conductor of the quarter wave stub in this field results in an induced current flow on the outer conductor as illustrated in Figure 2 below. The resulting interaction of the radiated field from the tower with the re-radiated field from the quarter-wave stub outer conductor will tend to directionalize the overall radiated field of the tower.

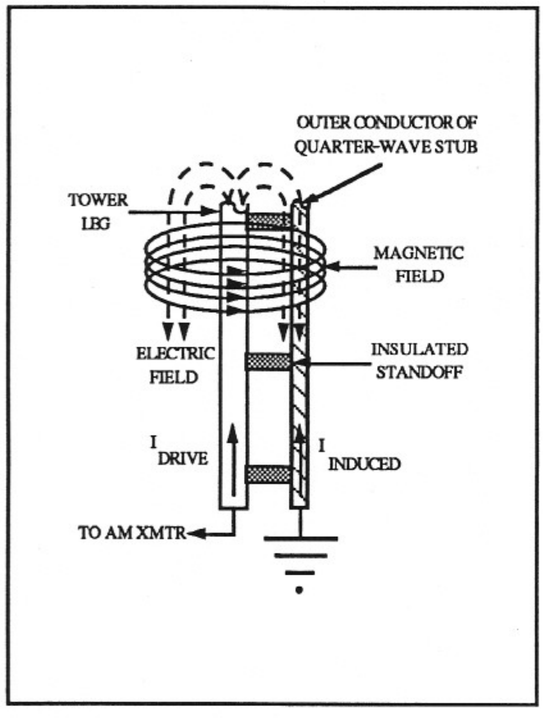

Fig. 2 Induced Current in the Quarter-Wave Stub Outer Conductor.

This is a particular concern if the quarter-wave stub is installed on a tower in a directional array. One way to minimize the effects of this induced field is to route the quarter wave stub to the inside of the tower structure. Also an alternate approach to the typical installation is to insert a 90 degree length of transmission line between the transmit or receive equipment and the base of the tower.[1] The outer conductor would be bonded to the tower just above the base insulator and grounded at the transmit/receive end, which would normally be the case anyway.

The relative merits of the quarter wave stub approach are summarized in Table 1 below.

Table 1. Advantages and Disadvantages of the Quarter Wave Stub

Advantages	Disadvantages
*Simple, Does Not Require Separate Isolation Device	*Reradiation From Insulated Outer Conductor Distorts Pattern Shape
*Not Bandwidth Limited	*Not As Conducive To Multiple Line Isolation As Other Approaches.
*Not Limited In Utilization By Peak RF Voltage Across Base Insulator	*Critical Install Procedure To Achieve Good Impedance Isolation
*No Additional Insertion Loss	*Tower Bond Point May Be At or Near Voltage Maximum, Hence May be Subject To Arcing

Isocouplers

The second approach for isolation of ancillary antennas on an AM broadcast tower is the isocoupler. An isocoupler may be described in electronic terminology as a double-tuned, inductively-coupled isolation transformer. These devices were originally used in the early 60's to isolate FM antennas on an AM tower. The same design concept has been expanded to higher frequencies to include remote pickups (450-455 MHZ), trunking systems (800 MHZ) and studio-to-transmitter links (948-955 MHZ) as well as other applications in the 24-1000 MHZ region.

Figure 3 below shows the internal components of a typical isocoupler.

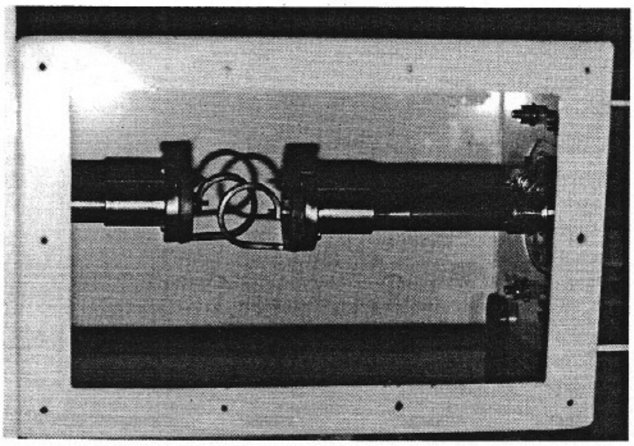

Fig.3 Internal Components of a Typical Isocoupler.

The isocoupler input and output transmission line sections are terminated in a series inductor and capacitor that form a low Q series resonant circuit at the pass frequency of the isocoupler soas to yield a 50 ohm termination in the desired passband. The terminating copper loop constitutes the inductor whereas the brass stud threaded into the base of the loop and extending into a teflon dielectric in an expanded end of the center conductor assembly equates to a variable capacitor, which is adjusted to yield the desired 50 ohm termination at the pass frequency. This capacitance value is fine-tuned in accordance with the mutual inductance that exists between the two coupled loops to yield the desired passband characteristics with minimum insertion loss, which is typically 0.2-0.8 db depending on the throughput frequency and the power rating. The throughput power rating of this isocoupler design is limited by the voltage breakdown of the variable capacitor assembly, which also impacts the operational passband of the isocoupler. Power rating is traded off for bandwidth in the design of the variable capacitor to yield the best possible performance.

The typical passband of an isocoupler utilizing the electrical design as shown in Figure 6 is illustrated by the oscilloscope trace shown in Figure 4 below.

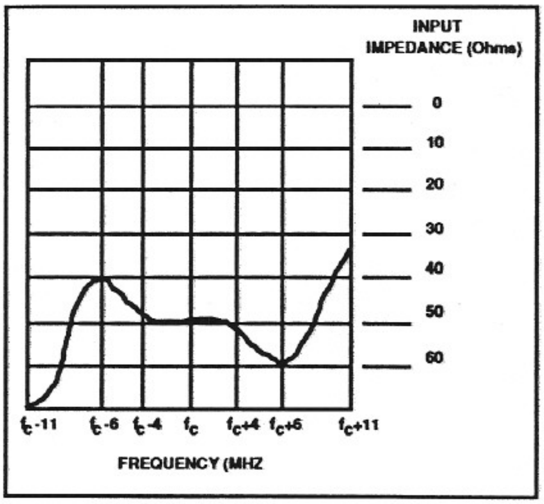

Fig.4 Typical Frequency Passband of Isocoupler.

This trace was achieved by coupling a sweep generator to the isocoupler input with the isocoupler output terminated in a 50 ohm load. The output of the sweep generator was fed into the X-input of an oscilloscope set up to operate in an X-Y format. The Y input was originally calibrated with a 50 ohm load prior to inserting the isocoupler in the test fixture. This passband contour illustrates the response of the input LC loop assembly on the left half of the graph and of the output LC loop assembly on the right half. As is evident in the sweep trace, the bandwidth over which 50 ohms input impedance is maintained is 8 MHZ.

Another consideration in determining the suitability of an isocoupler for installation on an AM tower is it's peak voltage rating in relation to the peak RF voltage that appears across the tower base with maximum AM transmitter peak modulation. The isocoupler voltage rating is determined by the minimum spacing between the conducting elements that are effectively across the tower base. This voltage rating ranges between 6 KV and 35 KV depending on the passband, power rating and manufacturer. A minimum safety factor in isocoupler voltage rating of twice the peak base voltage should be specified to accommodate lightning related voltage transients.

The impedance presented by an isocoupler across the base of an AM tower is typically represented as a lumped capacitance ranging in value from 6 to 200 picofarads, depending on the passband, power rating and manufacturer. In the AM band this will constitute a capacitive reactance between -j675 and -j40,000, which typically should result in minimal change in the tower base impedance. This fact also makes the isocoupler a more acceptable isolation approach for the installation of multiple transmission lines across an AM tower base insulator.

An excellent example of a multi-isocoupler installation is located at the directional antenna site of WROK Radio in Rockford, Illinois. The WROK array is a three-tower inline operating at 5 kilowatts daytime on 1440 kHz. The center tower of this array is 225 degrees electrical height or 440 feet. A total of twelve isocouplers are installed across the base of this tower as illustrated in the block diagram (see Figure 5 below) provided by Mr. Marvin Beasley of Sinclair Radio Laboratories.[3]

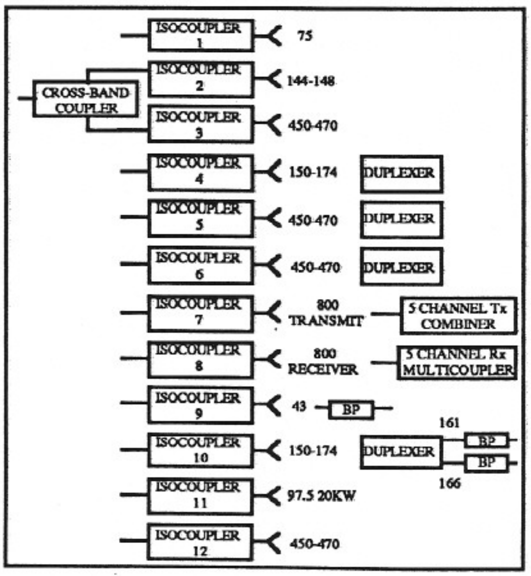

Fig.5 Block Diagram of Multiple Isocoupler Installation at WROK Radio.

As shown in Figure 5, these isocouplers are used for a variety of applications, including FM transmission, land mobile communications, remote pickup units and an 800 mHz trunking system, which has recently been increased to its maximum ten channel capacity due to increased user demand. According to Mr. Dennis Carter of Rock River Service Company, which is under contract to maintain this site, the operational reliability has been excellent since the original installation in 1986. Photographs of the WROK installation are shown in Figures 6A and 6B.

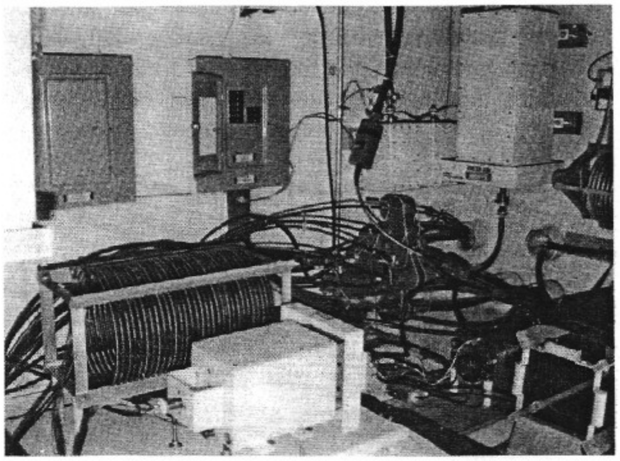

Fig.6A Multiple Isocoupler Installation at WROK Radio.

Regarding the proper installation of an isocoupler the outer conductor of the upper transmission line section of the isocoupler is bonded to the tower, and the outer conductor of the lower section is bonded to the tower ground system. The outer conductor of the transmission line between the isocoupler and the antenna on the tower should be bonded to the tower above the base insulator, at the antenna end and at intervals not to exceed 50 feet in between. The transmission line on the tower should appear electrically as an integral part of the tower structure soas not to effect the omni-directional shape and magnitude of the radiated field.

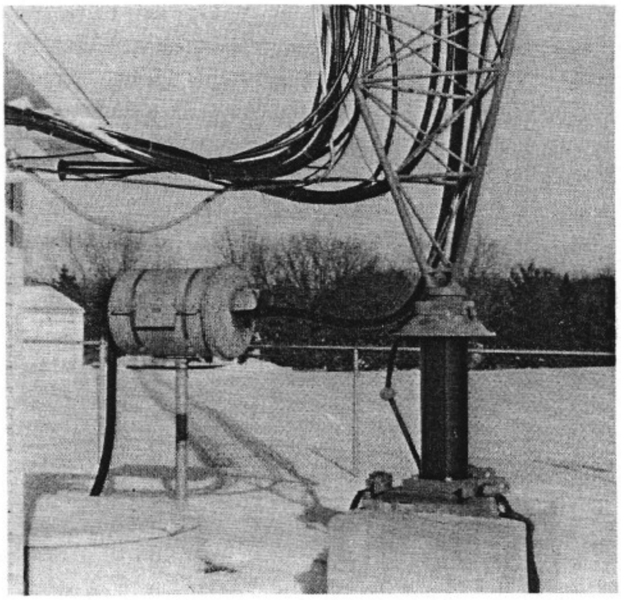

Fig.6B WROK FM Isocoupler and Ancillary Antenna Transmission Lines Routed Across Tower Base Insulator.

The pros and cons of the isocoupler isolation transformer are summarized in Table 2 below.

Table 2. Advantages and Disadvantages of Isocouplers

Advantages	Disadvantages
*High Impedance	*Susceptible To Lightning Damage
*Low Insertion Loss	*Insufficient Voltage Rating For Some Applications
*Acceptable Bandwidth For Most Applications	*Limited In RF Throughput Power Rating
*Peak Voltage Rating $\geq$ 15KV	

Multi-Coax Isolation Inductor

The third isolation transformer approach to be considered is the isolation inductor. This method of isolation has been historically associated with the use of sampling loops installed on the towers in an AM directional array. An isolation coil is simply an inductor wound with the same or different size of coaxial cable as that being fed across the tower base insulator. The outer conductor of the coaxial cable is attached to the tower RF feed on one end and to the antenna ground on the other end soas to constitute a lumped inductive reactance across the base insulator. The inductive reactance should be sufficiently large compared to the base impedance magnitude to result in a less than 2 percent change in the base resistance or common point resistance. Otherwise a new Form 302 showing the revised impedance value must be submitted to the Federal Communications Commission (FCC) in accordance with section 73.45 of the FCC rules.[4]

In a typical trunking system or cellular telephone installation a minimum of two transmission lines are required for the associated transmit and receive antennas. The bandwidth and throughput power ratings of isocouplers may be insufficient for this application, and the installation of multiple quarter wave stubs may be impractical as well as unadvisable in maintaining the AM station's coverage. The solution for this situation is a multi-coax isolation inductor as illustrated in Figure 7.

The intent of the multi-coax isolation inductor is to merge several isolation inductors together so that electrically they equate to one isolation inductor as opposed to several isolation inductors in parallel, which would reduce the effective impedance across the tower base to an unusable level. This is accomplished by forming a large copper tube with a slot in its side into an inductor. Individual coaxial cables are placed through the slot inside the copper inductor, and the outer conductors of each line section are electrically connected to the copper inductor winding at each end. The ends of each line section are terminated in a standard type N or UHF connector. The outer

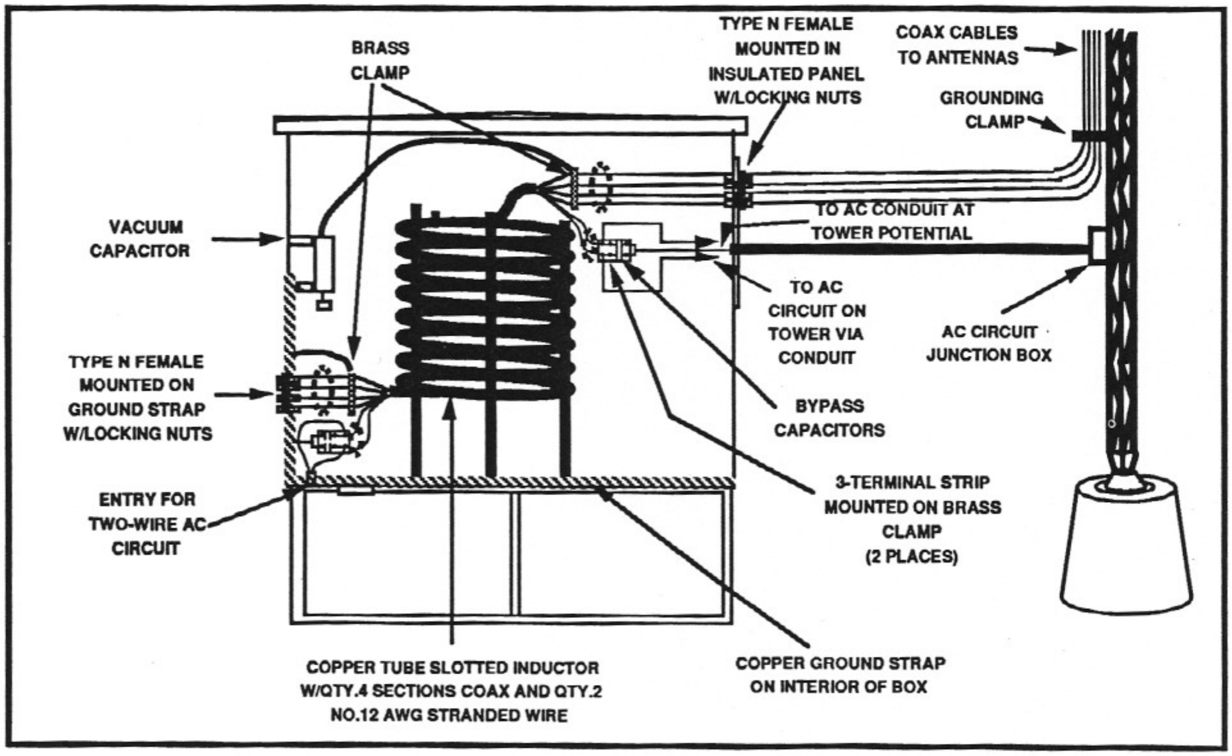

Fig.7 Multi-Coax Isolation Inductor Configured for Cellular Telephone Installation on AM Broadcast Tower.

conductors of all the lines going onto the antennas and at a maximum interval of 50 feet. The outer conductors of all the line sections, going to the transmitter building should be connected to the antenna ground.

Another feature of this isolation scheme is that other AC insulated wiring can be laid in the slotted copper inductor and terminated in bypass capacitors at both ends in a similar configuration to a standard lighting choke. This wiring could be used for tower lighting, antenna heaters, antenna rotors, preamplifiers or other applications.

In the event that the tower electrical height is in excess of 120 degrees resulting in a high base impedance, a variable vacuum capacitor could be connected in parallel with the slotted copper inductor to yield an anti-resonant tank circuit. In this case the reactance of the variable vacuum capacitor would be set equal to that of the copper inductor assembly at the AM carrier frequency. The resonant Q of the tank circuit should be low soas to maintain a high impedance at the AM carrier as well as at the $\pm$10 kHz sidebands. This will also help minimize the reactive volt-amperes that are produced in the tank circuit as a result of the AM transmitter modulation. It is also important to note that the peak voltage rating of the anti-resonated isolation inductor is limited to that of the variable vacuum capacitor.

The only disadvantage of this isolation transformation approach is the insertion loss added by the coaxial cable in the isolation inductor. Typically 1-5/8" foam coaxial cable is utilized to feed cellular antennas soas to minimize the attenuation in their operational frequency range. The slotted copper winding would be prohibitively large to allow for two or more sections of 1-5/8" line; hence smaller coaxial cables with higher attenuation must be used. The loss will typically range between 1.5 and 2 db, including the connector losses at each end. With additional preamplification, this loss can be offset if necessary.

An example of a multi-coax isolation inductor installation is shown in Figure 8.

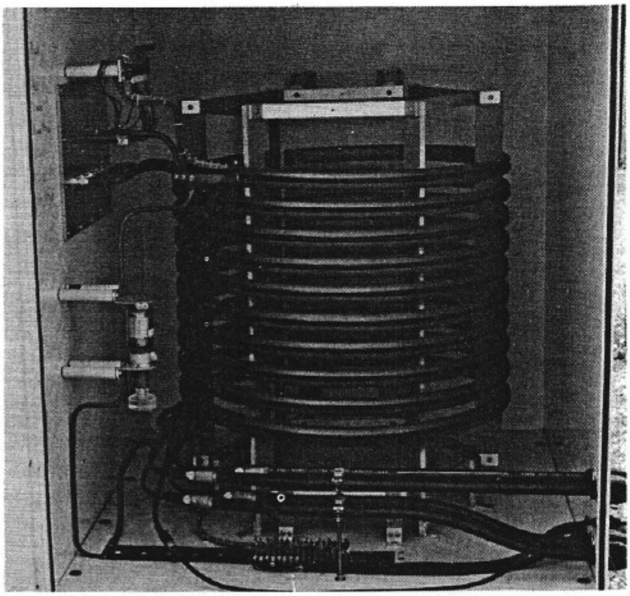

Fig.8 Multi-Coax Isolation Inductor Installation At WBET Radio in Brockton, Massachusetts.

This unit is installed at the base of one of the self-supporting towers in the two-tower directional array of WBET Radio in Brockton, Massachusetts. This slotted isolation inductor has the following cables and wire inserted in it:

A. Qty.5 Pieces of 3/8" Foam Transmission Line For:
   a. Sampling Loop
   b. 455.8 MHz Antenna
   c. 450.7 MHz Antenna
   d. 173.225 MHz Antenna
   e. 945 MHz STL Dish

B. Qty.3 No.10 AWG Wires For Tower Lighting

C. Qty.8 No.14 AWG Wires For An Antenna Rotor

D. Qty.3 No.12 AWG Wires For FM Antenna Heater

This example testifies to the versatile use of the multi-coax isolation inductor. A summary of the advantages and disadvantages of the multi-coax isolation inductor are listed in Table 3 below.

Table 3. Advantages and Disadvantages of Multi-Coax Isolation Inductor.

Advantages	Disadvantages
*Multi Transmission Line Isolation	*Higher Insertion Loss Than Isocoupler or Quarter-Wave Stub
*Accessory AC Circuit Isolation	
*Very High Effective Impedance Across Tower Base	
*Not Bandwidth Limited	
*Comparable In Cost To Multiple Isocoupler Installation	

Summary

For a comparison of the relative merits of the three isolation transformer approaches that have been discussed the quarter-wave stub, the isocoupler and the multi-coax isolation inductor--please refer to the bar chart in Figure 9.

If the throughput power rating and or tower base peak voltage exceed the ratings of available isocouplers, a properly installed quarter-wave stub is the best solution. For the majority of single or double transmission line applications, the isocoupler is the most cost effective solution. For applications involving more than two transmission lines and/or wide bandwidth and high throughput power requirements that exceed isocoupler ratings, the multi-coax isolation inductor is the best solution.

In closing, it is also important to remember the following FCC policy regarding towers in a directional antenna--any change above the base insulator requires a partial proof of performance.[4] This added cost factor makes non-directional towers the most desirable choice.

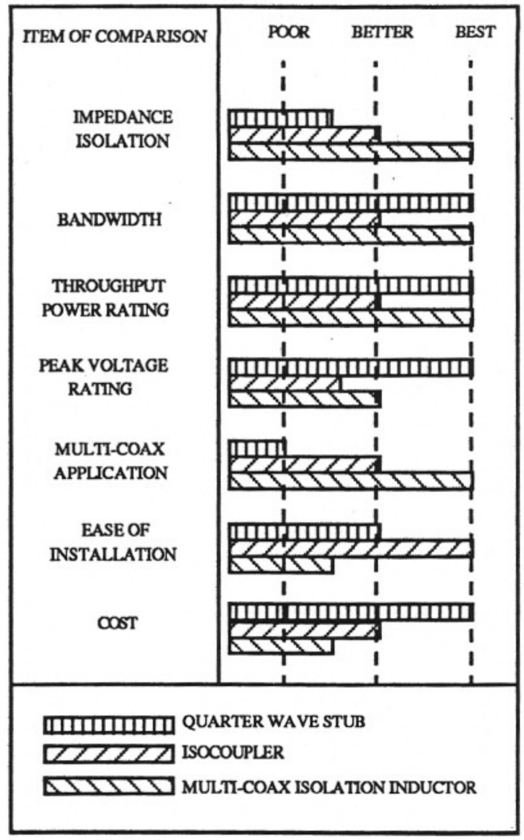

Fig.9 Comparison of the Relative Merits of the Three Isolation Transformer Approaches.

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