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# UP-DATE ON THE FOLDED UNIPOLE

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# UPDATE ON THE FOLDED UNIPOLE

By: John H. Mullaney, P.E.

## I. INTRODUCTION:

In the late 1950's, your author introduced the use of Folded Vertical Unipole Antennas for standard broadcast stations[a]. They now are widely used for both non-directional and directional antenna systems. There are over 1,200 licensed stations using the Folded Unipole method of feed.

Since the introduction of Folded Unipoles, many variations have been used. The F.C.C. requires that the folds must be symmetrically disposed around the tower. Your author has generally kept the height of his designs to not over about $130^{\circ}$ when the full efficiency of the system is needed.

Where it is desired to use a combination AM/FM tower where the tower height is greater than about $130^{\circ}$, the Folded Unipole technique can be used, but if the Unipole is not divided into two parts, the overall efficiency or unattentuated field intensity will be considerably lower than the normally expected field for the electrical height of the tower under consideration.

This paper will discuss the theory of design, expected base impedances and the bandwidth of a Folded Unipole System.

## II. THE FOLDED UNIPOLE TECHNIQUE:

### (A) General:

A Folded Unipole Antenna has significant advantages over both the series fed vertical or top-loaded antenna. The more salient advantages are:

1. When compared to a series fed antenna of the same height, the Folded Unipole has a greater radiation resistance.

2. The overall system bandwidth is greater for a Folded Unipole than a series fed.

3. The system does not require a base insulator, hence, the tower is at ground potential for lightning protection. In addition, being at ground potential eliminates the need for isolation between transmission lines and the tower if VHF or UHF antennas are mounted on the tower. No lighting chokes or transformers are required if tower lights are used.

4. The base impedance can be varied for ease of coupling and control of bandwidth; whereas the base impedance for a series-fed antenna cannot be changed.

5. Where a series-fed antenna is modified to a Folded Unipole System and the station has a poor ground system, one will generally obtain a higher unattenuated field intensity.

6. A short Folded Unipole is more stable in inclement weather than a series fed system.

(B) <u>Analysis by Superposition Approach:</u>

To understand how these advantages come about, let us calculate the input impedance of the structure sketched below:

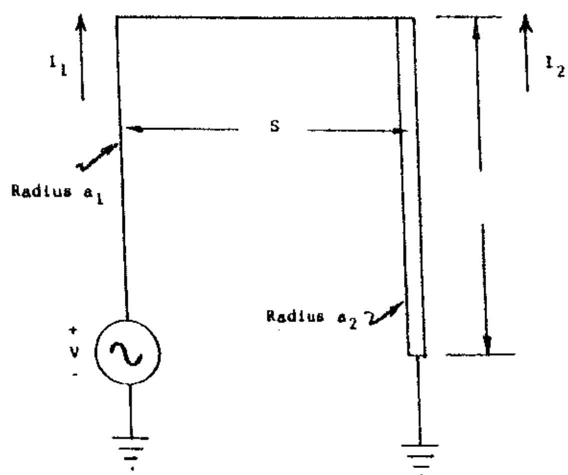



Figure 1

A Folded Unipole Antenna is excited or fed in an unbalanced manner by grounding the tower and exciting the folds tied together at the base. This results in unequal currents in the tower and folds, due to a balanced transmission line mode (considered non-radiating) and an unbalanced (in phase) mode which does the radiating.

The diagram of Figure 1 satisfies the same boundary conditions, and is therefore indistinguishable from the one sketched below.

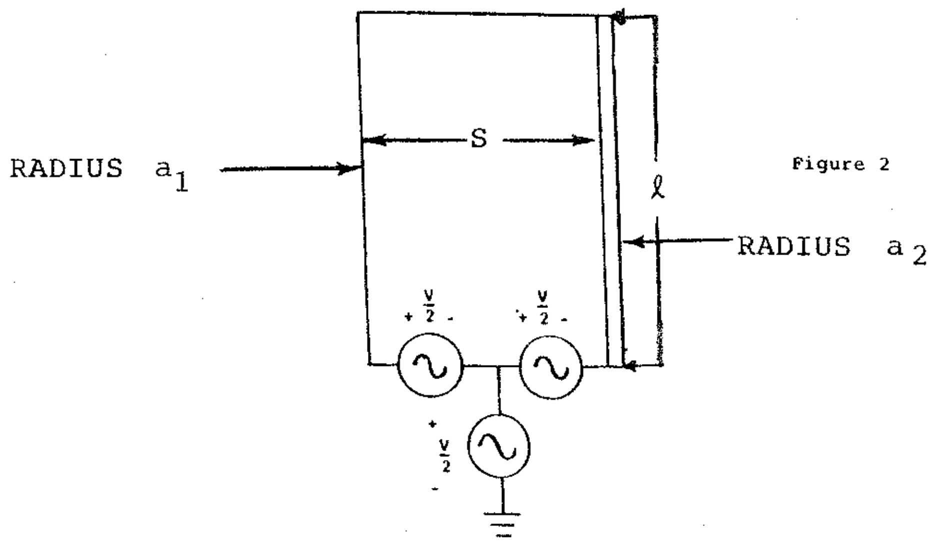



Figure 2

This structure may be analyzed by using transmission line and superposition theory. Briefly, the approach is to find the net current response in element 1, or the smaller conductor (fold). The net response is simply the response to this excitation.

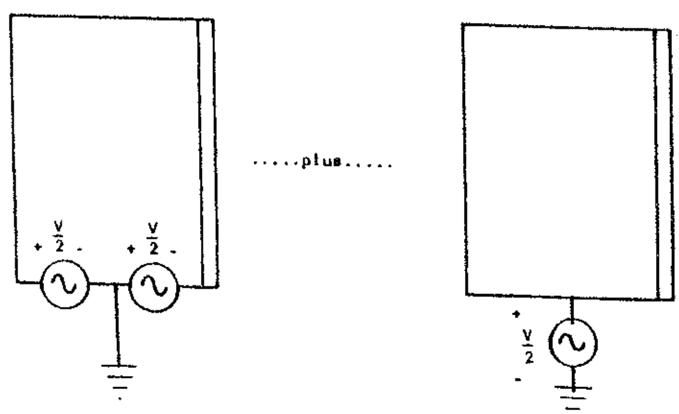



Figure 3

(C) First Response:[b]

The response to the first excitation is that of a transmission line terminated in a short circuit. That is:

$$I_1 = \frac{V}{j Z_{OL} \tan G} \quad \text{amps} \qquad (1a)$$

$$G = \frac{360 \, f \, \ell}{v} \quad \text{degrees} \qquad (1b)$$

$$v = 9.84 \times 10^8 \quad \text{feet/sec.} \qquad (1c)$$

The characteristic impedance of the line or fold is:

$$Z_{OL} = 60 \, \ell n \left( \frac{S^2}{a_1 \, a_2} \right) \qquad (2a)$$

$$\ell n x = 2.3 \log_{10} X \qquad (2b)$$

(D) Second Response:[b]

The response to the second excitation is that of a radiator with some input impedance $Z_a$ Ohms. The complex power delivered to the radiator is:

$$P = \frac{1}{2} Z_A \left| I_1 + I_2 \right|^2 \quad \text{Watts} \qquad (3)$$

The current in element 2 or larger conductor (tower) is simply related to the current in element 1 by:

$$I_2 = nI_1 \text{ amps} \tag{4a}$$

Where:

$$n = \frac{1}{K}\left[\frac{\ell n \frac{S}{a_1}}{\ell n \frac{S}{a_2}}\right] \tag{4b}$$

Where:

K = Number of Fold Wires

The result is presented without proof. However, it may be derived by considering the near fields of the elements as those of cylindrical radiators, and then satisfying the boundry condition imposed by Maxwell's equation.

Raines[b] has demonstrated this in a recent paper. Using his result:

$$P = \frac{1}{2} Z_A \left|I_1\right|^2 (1 + n)^2 \text{ Watts} \tag{5}$$

Recognize the expression $\frac{P}{\frac{1}{2}\left|I_1\right|^2}$ as the input impedance as measured at the feedpoint of element 1. the current in element 1 is therefore:

$$I_A = \frac{V}{(1 + n)^2 Z_A} \text{ amps} \tag{6a}$$

$$Z_A = R_{11} + j X_A \text{ ohms} \tag{6b}$$

The radiation resistance $R_{11}$ is:

$$R_{11} = 10 G^2 \text{ ohms} \tag{7a}$$

$$G = \frac{2\Pi f \ell}{v} \text{ radians} \tag{7b}$$

The reactance $X_A$ is that of a transmission line terminated in an open circuit:

$$X_A = -j\ Z_{OA} \cot G \text{ Ohms} \tag{8}$$

The characteristic impedance of the radiator is:

$$Z_{OA} = 60\ \ln \frac{2\ell}{a_m} \text{ ohms} \tag{9a}$$

$$a_m = \sqrt{S}\ (a_1\ a_2)^{1/4}\ e^p \tag{9b}$$

$$p = \frac{\left(\ln \frac{a_1}{a_2}\right)^2}{4\ \ln \left(\frac{S^2}{a_1\ a_2}\right)} \tag{9c}$$

Next, we add the two responses to obtain the total current in element 1, which is:

$$\frac{V}{j\ Z_{OL} \tan G} + \frac{V}{(1+n)^2}\ \frac{1}{(R_{11} - jZ_{OA} \cot G)} \text{ amps} \tag{10}$$

This is the response of a network with input impedance

$$Z_{in} = jZ_{OL} \tan G \ \|\ \left[(1+n)^2\ (R_{11} - jZ_{OA} \cot G)\right] \text{ ohms} \tag{11}$$

If we include loses in this network, we must distinguish between ground losses due to radiation and other losses. The former are amplified by the factor $(1 + n)^2$, while the others are not.

Let us write:

$R_g$ = resistance due to ground losses (12a)

$R_h$ = resistance due to heat loss, for example, in tuning components (12b)

then:

$$Z_{in} = R_h + (jZ_{OL} \tan G)\ \|\ \left[(1+n)^2\ (R_{11} + R_g - jZ_{OA} \cot G)\right] \tag{13}$$

The corresponding or equivalent circuit is sketched below:

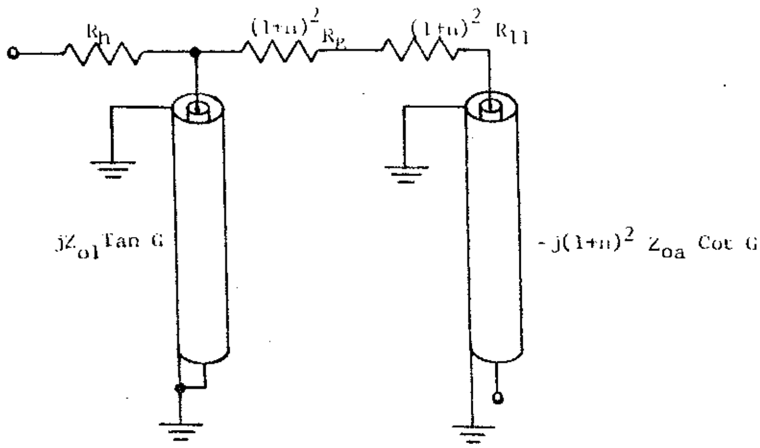
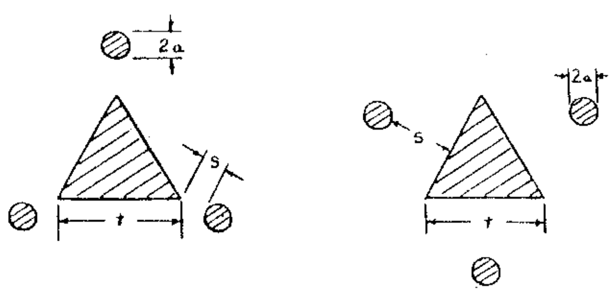



Figure 4

(E) <u>Two Configurations for Arrangements of Folds:</u>

The majority of Broadcast Folded Unipoles use three folds on towers having a width of 15 to 48 inches. The folds are arranged either near the apexes of the triangle of the tower, or near the sides of tower.

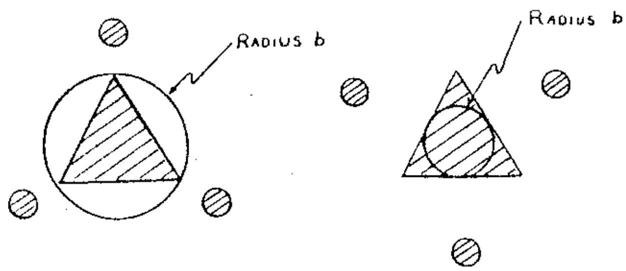
Let us consider two types of cross sections:




Where:

a = radius of fold wire
t = side of tower
s = separation of fold from tower

For purposes of calculation, replace the triangle by circles of the appropriate diameter:




Where:

$b = t/\sqrt{3}$ $\quad b = t/4$

The equivalent radius is chosen so that the separation of the fold from the tower remains unchanged.

Equation (4b) is a factor used to determine the current in the tower portion of a Folded Unipole. It should be noted that the expression 1/k relates to the number of fold wires used. This factor would then be 1/3 or 1/6 for three and six wires respectively. The placement of the folds in relation to whether they are located off of the apex or sides of a triangular tower makes a materially difference in the resulting $Z_{o1}$, n, and base reactance. Assuming a fixed base or input resistance of 50 Ohms for identical height towers spacing the folds off of the apex of the triangle will result in a lower antenna Q. It also will obtain a higher n and a lower $Z_{o1}$. The resulting jX at the feed point will also be lower. The end result is a better bandwidth even before any possible network modification.

Figure 5, is a tabulation for a $60^{o}$ high tower with various parameters for folds located at the side and apex of the tower. The tower is 165 feet tall. The radius of the fold wires is 0.125 inches and the operating frequency is 1,000 KHz.

When a short Folded Unipole System is used (less than 80°) if the folds are located at the Apex of the tower it may not be possible to obtain a 50 Ohm base resistance by stubing the folds. In such a case it will be necessary to match either the lower resistance obtained or shunt a capacitor across the tower to step up the base resistance. Under these circumstances as noted on Figure 5 the antenna Q for the side mounted folds is lower.

Figure 5 clearly shows the difference in base impedance when folds are re-arranged on the tower.

FIGURE 5

COMPARISON OF 60° FOLDED UNIPOLE PARAMETERS

WITH SIDE AND APEX FOLDS

| IGHT G.) | TOWER WIDTH (INCHES) | SPACING (INCHES) | SIDE $Z_{o1}$ | APEX $Z_{o1}$ | SIDE n | APEX n | STUB HEIGHT FROM TOP OF TWR. (FEET) SIDE | APEX | SIDE R | APEX R | SIDE X | APEX X | SIDE Q | APEX Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 48 | 48 | 714.70 | 444.98 | 3.699 | 5.923 | 37.65 | 40.76 | 50.08 | 40.76 | j478.17 | 424.39 | 9.55 | 10.41 |
| 60 | 48 | 36 | 680.39 | 429.2 | 4.087 | 6.807 | 27.53 | 26.49 | 50.09 | 26.49 | j504.20 | 368.6 | 13.91 | 10.08 |
| 60 | 48 | 24 | 623.14 | 399.2 | 4.790 | 8.436 | 12.00 | 15.172 | 49.92 | 15.17 | j550.18 | 313.6 | 11.00 | 20.67 |
| 60 | 48 | 18 | 598.03 | 384.5 | 5.431 | 9.944 | 0.22 | 10.528 | 50.09 | 10.53 | j593.57 | 286.09 | 11.87 | 24.10 |
| 60 | 36 | 48 | 714.70 | 450.6 | 3.225 | 4.974 | 39.36 | 47.46 | 50.10 | 47.46 | j483.67 | 459.9 | 9.67 | 47.56 |
| | 36 | 36 | 680.39 | 427.69 | 3.521 | 5.638 | 30.27 | 30.613 | 50.08 | 30.61 | j505.11 | 394. | 10.10 | 39.00 |
| | 36 | 24 | 632.14 | 399.27 | 4.05 | 6.856 | 16.11 | 17.349 | 50.08 | 17.35 | j543.67 | 328.73 | 10.87 | 30.24 |
| 60 | 36 | 18 | 598.03 | 382. | 4.53 | 7.978 | 5.31 | 11.94 | 50.09 | 11.94 | j578.63 | 295.8 | 11.57 | 25.57 |
| 60 | 24 | 36 | 680.39 | 436.4 | 2.912 | 4.426 | 33.0 | 38.446 | 50.04 | 38.45 | j510.33 | 440.332 | 10.21 | 43.13 |
| 60 | 24 | 24 | 632.14 | 403.49 | 3.27 | 5.236 | 20.69 | 21.54 | 50.09 | 21.54 | j561.60 | 358.17 | 11.23 | 31.89 |
| 60 | 24 | 18 | 598.03 | 382.58 | 3.59 | 5.978 | 11.20 | 14.695 | 50.09 | 14.70 | j565.60 | 316.32 | 11.31 | 27.97 |
| 60 | 18 | 24 | 632.14 | 409.28 | 2.851 | 4.397 | 23.05 | 25.43 | 50.09 | 25.43 | j540.59 | 385.19 | 10.81 | 35.63 |
| 60 | 18 | 18 | 598.03 | 386.36 | 3.092 | 4.952 | 14.42 | 17.27 | 50.09 | 17.27 | j561.60 | 336.11 | 11.23 | 29.93 |

(F) Summary Thus Far:

So far we have discussed the two responses of a Folded Unipole in relation to the antenna acting as a transmission line terminated in a short circuit and that of a transmission line terminated in an open circuit.

Equation (2a) explains the method of determining the characteristic impedance $Z_{o1}$ of the line or feed point. Figure 4 shows where $Z_{o1}$ fits into the equivalent circuit. Keep in mind that $Z_{o1}$ must be as large as possible if we desire any reasonable feed point resistance because it is in parallel with $Z_{oa}$. Unfortunately, the magnitude of $Z_{o1}$ is greatly diminished by the relatively tiny co-efficient, tan G.

Equations (8) through (9c) show how to determine the characteristic impedance of the larger structure (tower), and equation (8) gives the reactive component for this equivalent open wire transmission line.

It is apparent from a study of the various equations presented that the determination of the input impedance of the Folded Unipole is complex and various factors control its magnitude. One consideration not apparent from the equations is structural and environmental problems. The spacing of the folds from the tower can cause a wind loading problem depending upon the size of the tower and its wind loading capacity. Furthermore, the accumulation of ice on the fold wires can cause the VSWR to increase and detune the transmitter as the base impedance changes. This is due to ice building up on the bottom of the folds and on the strain insulators.

The above problems can be solved by using a triangular brace on the top cross-arm at the termination of the folds. The spacing of this arm should normally not exceed four times width or side of the tower. The best method to keep ice from building up around the base insulator termination is to make up a funnel shaped like a shield out of copper or sheet metal to cover the top of the insulator.

These funnels will not only protect the strain insulators from accumulation of ice but they also will act as a cornoa shield. The approximate diameter of the funnel should be about four to eight inches.

(G) <u>Ground System Loss:</u>

If we were to compare a series fed with a Folded Unipole Antenna of the same height and having the same ground system for all practical purposes, we would state that the unattenuated field efficiency would be identical. However, if we take a series fed system which has been up for some time and suffers from a deteriorated ground system, that is, the ground system has been eaten up by chemical action or cut up by vehicles moving over the system, modifying this antenna system to a Folded Unipole will show an increase in unattenuated field intensity. this is due to the fact that the antenna currents divide in accordance with the impedance of the line portion and the tower, thus less current flows in the ground resistance portion of the system resulting in a higher efficiency.

A Folded Unipole is not a panacea to eliminate ground systems, it just has the ability to work with a deteriorated system. The overall height of the tower will determine the maximum efficiency one can expect from an antenna system and the Unipole can only work within these limits.

(H) Second Resonance for Folded Unipole Antenna Systems:

Most broadcast antennas are at least $50^{\circ}$ in height so unusual techniques are generally not necessary for exciting this type of system. In your authors original article on Folded Unipole Antennas, mention was made of the use of second resonance for very short antennas. Second resonance is a point where an antenna goes into resonance at approximately 1/2 the length of the same antenna at first resonance. This is the same as saying that if a Folded Unipole Antenna had a length approximately $60^{\circ}$ we would expect second resonance to occur at approximately one half this length, or $30^{\circ}$.

Second Resonance is primarily used in the military LF programs, or for short test antennas in the broadcast band. Inasmuch as we in broadcast are primarily interested in antennas from about $50^{\circ}$ up, we refer anyone interested in that subject to review NAVORD Report 4634 (NOLC Report 388), Quarterly Report; Foundational Research Projects, July-September 1957, p. 44 (December 1957).

(I) Bandwidth & Coupling:

Bandwidth and coupling of power to an antenna go hand in hand regardless of the method used to excite the system. All elements between the transmitter output circuit and the antenna have to be analyzed, first by themselves, and second as part of the system bandwidth. In any transmission system one is interested in system bandwidth.

The bandwidth of an antenna depends upon its base impedance and the rate with which its reactance changes with frequency. The bandwidth is considered to be the frequency band within which the power is equal to or greater than one half the power at resonance. Expressed in equation form:

$$\Delta f = \frac{2Ra}{\frac{dx}{df}} \qquad (14)$$

Where:

$\Delta f$ = bandwidth in kilohertz between half power points.

Ra = measured antenna resistance in ohms.

$\frac{dx}{dx}$ = slope of reactance curve at resonant frequency.

The effective bandwidth will be doubled when the generator is matched to the antenna circuit. The Q of a folded unipole antenna can be determined from the equation:

$$Q = \frac{f_o}{\Delta f} \qquad (14a)$$

Where:

$F_o$ = operating frequency in KHz
$\Delta F^o$ = bandwidth of antenna in KHz

Antenna bandwidth is the difference in frequency between two points at which the power output of the transmitter has dropped to one half mid-range value. The points are called half-power points. A half-power point is equal to a VSWR of 5.83:1, or it is the point where the voltage response has dropped to 0.7071 of the mid-range value.

In broadcast we desire equal power in the sideband (power is proportional to the square of the amplitude of modulation so that power is equal to one fourth the power of the unmodulated carrier).

In practice it is desirable to have a sideband VSWR of less than 1.2:1 within the transmission range of the program content. where the VSWR is too high it is possible to reduce it and obtain modification.

Technical literature is replete with articles on bandwidth consideration and many of these go into detail on how to measure and or establish system bandwidth.

## III. DESIGNING FOLDED UNIPOLE ANTENNA SYSTEMS:

### (A) A Typical Design:

A client who operates on 730 KHz 1 KW NDA with a 300' series fed tower had been experiencing instability in his antenna system during inclement weather. The antenna system was over eighteen years old and a serious question existed as to the condition of the ground radials. Structures had been built over part of the ground system and a side mounted FM antenna had been installed near the top of the tower. The FM coaxial transmission line used an isolation transformer to get across the base insulator. It was determined that a new ground system could not be readily installed, therefore, the station was concerned about what could be done to improve the antenna system stability and possibly increase their AM coverage.

A study of the problem resulted in the following recommendations:

1. Re-measure the base impedance of the antenna system.

2. Next set up a series of four radials every $90^{\circ}$ from the antenna and then make field intensity measurements at ten locations along each radial.

Based on a review of the above measurements the station's antenna system had a very low unattenuated field efficiency. We recommend they convert the system to a three wire Folded Unipole. The following changes were made at the station:

(a) Power reduced to 500 watts and three folds were installed on the tower having a 36 inch side during daytime hours. Care was taken to make sure the folds did not touch the tower during the installation. Folds start at 300' level and go down. They are spaced 24 inches from side of the tower.

(b) After sign off, three pieces of four inch copper strap, were placed across the base insulator and hard soldered to the ground system and tower.

(c) Tower lighting chokes and FM isolation transformer were removed.

(d) Using transmission line bonding kits, approximately every 20 feet, the line was bonded to the tower, making sure a good electrical connection was made to the tower.

(e) The lighting system neutral wire was bonded at the base of the tower and at the twin lights and beacon.

(f) Three folds were bonded at top to the tower. Three shorting stubs for tuning the system were made up. These wires were cut to approximately 20 inches long.

(g) At the base of the tower, the folds were terminated into 3 to 6 foot long fiberglass strain insulators. Because the station is in an area which has quite a bit of snow, a funnel was placed over top of the insulators to keep rain and snow from icing up on the end of the insulators. The three terminated wires were then bonded together to make a good electrical connection and one wire was brought over to the antenna bowl insulator or coupling house. [These wires can be terminated as high as eight to 10 feet above ground if desired and the common wire then jumped over to coupling house.]

(h) The coupling network was re-configured to match a 50 Ohm antenna resistance. In order to obtain the 50 Ohm resistance, it was necessary to have a rigger short the folds at 160 feet from the top of the tower. The predicated impedance was 50 j122 Ohms while the measured impedance was 50 j135. The distance between the coupling house and tower accounted for the additional inductive reactance.

(i) Upon completion of the modification field intensity measurements were again made at the original locations on the four radials. These indicated an increase of approximately 11%. The thing of greater importance was the fact that the "broadcast sound" was louder, had a better frequency response, and to the listener appeared to tune much broader. Inasmuch as sound is all a station has to sell, the modification was considered to be a success.

(B) <u>The Use of A Program Called UNIPOL:</u>[d]

This paragraph will deal with the use of a computer program called UNIPOL, which has been programmed with the design formulas for a Folded Unipole Antenna System.

Figure 6 is a summary sheet for the antenna system just described. It furnishes a tabulation of the antenna parameters along with a tabulation of the base impedance. This sheet is used in conjunction with UNIPOL for determining the base impedance for a Folded Unipole Antenna when the user furnishes certain parameters. It will be noted that the program calls for eight basic parameters. These are:

1) location of folds.
2) side of tower in inches.
3) separation of folds from tower in inches.
4) radius of fold wire in inches.
5) height of tower in feet.
6) frequency in KHz.
7) loss resistance of tower in Ohms.
8) base inductance in micro henries.

The parameters set forth on Figure 6 are self explanatory except for the base inductance in micro henries. That inductance represents the inductance of the copper strap used to short out the base insulator if a base insulator is strapped out of the system; otherwise, a value of zero is given for this parameter.

```
OPTIONS AVAILABLE
  1 - TRIANGULAR CROSS SECTION, FOLDS NEAR APEXES OF TRAINGLE
  2 - TRIANGULAR CROSS SECTION, FOLDS NEAR SIDES OF TRIANGLE
      OPTION DESIRED ? 1
 SIDE OF TOWER IN INCHES ? 36
 SEPARATION OF FOLDS FROM TOWER IN INCHES ? 24
 RADIUS OF FOLD IN INCHES ? 0.125
 HEIGHT OF TOWER IN FEET ? 300
 FREQUENCY IN KHZ ? 730
 LOSS RESISTANCE OF TOWER IN OHMS ? 3.5
 BASE INDUCTANCE IN MICRO HENRIES ? 2
   CURRENT TRANSFORMATION RATIO IS     6.856

   CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINE IS   399.272 OHMS

              DRIVE POINT IMPEDANCE
             RESISTANCE    50.098 OHMS
             REACTANCE    121.845 OHMS

   DISTANCE OF STUB FROM TOP OF TOWER    160.080 FEET

  SELECT :
   1 - FIND LOCATION OF A SPECIFIC RESISTANCE
   2 - SWEEP THE STUB HEIGHT OF 160.1 FEET
   3 - DISPLAY ANTENNA DRIVE POINT AS A FUNCTION OF STUB HEIGHT

                 SPECIFY  (1,2 OR 3)  ?  2


   SWEEP FREQUENCIES IN KHZ(START,STOP,STEP) ? 700,790,5,
```

| FREQUENCY | RESISTANCE | REACTANCE |
|---|---|---|
| 700. | 30.040 | 130.364 |
| 705. | 33.617 | 130.581 |
| 710. | 37.318 | 130.201 |
| 715. | 41.006 | 129.144 |
| 720. | 44.500 | 127.371 |
| 725. | 47.597 | 124.905 |
| 730. | 50.098 | 121.845 |
| 735. | 51.845 | 118.361 |
| 740. | 52.746 | 114.675 |
| 745. | 52.796 | 111.021 |
| 750. | 52.068 | 107.612 |
| 755. | 50.694 | 104.609 |
| 760. | 48.832 | 102.113 |
| 765. | 46.646 | 100.162 |
| 770. | 44.277 | 98.749 |
| 775. | 41.843 | 97.835 |
| 780. | 39.430 | 97.363 |
| 785. | 37.097 | 97.270 |
| 790. | 34.883 | 97.494 |

Figure 7 is a schematic diagram of the coupling network installed for the modified 730 KHz Folded Unipole Antenna System. It has been designed to have good bandwidth by means of the Howard technique.(c)

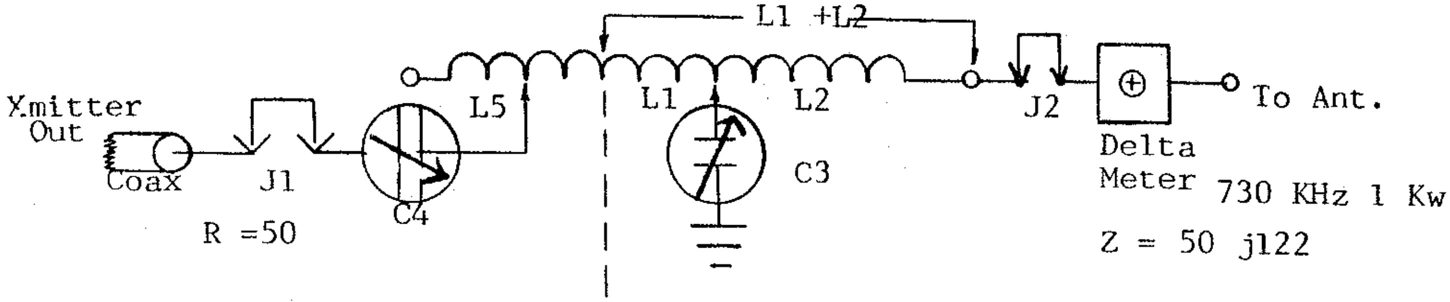



Figure 7

A computer program called SBNET[e] based on the Howard sideband technique is used to determine the bandwidth and impedance matching components shown on Figure 7.

```
***** SIDEBAND NETWORK ANALYZER [FEB 1982] *****

SELECT NETWORK MODE
(0=SB,1=LINE,2=TEE,3=RP,4=TEE/LINE,5=PI) ? 2


FREQUENCY & LOAD INFORMATION:


HIGH    FREQ(KHZ.), Ra, Xa     ? 740,52.75,114.68,
CENTER  FREQ(KHZ.), Ra, Xa     ? 730,50,121.85
LOW     FREQ(KHZ.), Ra, Xa     ? 720,44.5,127.37

POWER (WATTS) ? 1000


DESIRED INPUT RESISTANCE (OHMS) ? 50


DO AUTOMATIC SCAN (0=N,1=YES) ? 1
```

The next part of the program will scan the sideband impedances already entered and come up with the best phase shift at the lowest VSWR for a T network.

TEE NETWORK MODE

| PHASE (DEG.) | INPUT Z (HI/LO) R | SB X | POWER (HI/LO) | RATIO (POWERS) | SB VSWR (HI/LO) | SB DB (HI/LO) | SB FFS (HI/LO) |
|---|---|---|---|---|---|---|---|
| * -20.050 | 48.37 | -5.91 | 254.61 | 1.00 | 1.13 | 0.08 | 0.50 |
| | 48.10 | 6.87 | 254.66 | | 1.16 | 0.08 | 0.50 |

INPUT (L1)= 1.9 UH SHUNT (C3)= 1494.9 PF OUTPUT (C2)= 1929.2 PF
( 8.839) ( -145.840) ( -113.011)

We note that the T network results give a maximum VSWR of 1.16 in the upper sideband. This is a good VSWR, but it can be improved. The sideband power is approximately equal and slightly over the expected standard of 1/4 power in each. The matching components are all reasonable.

Although the phase shift is quite low ($-20.05^{\circ}$) there is no reason this network could not be used. It will be seen that component values are shown for L1, C3, and C2, whereas C4 and L5 are not given. The later two components make up the L portion of the network. We next sweep the data assuming a phase shift of $-20.05^{\circ}$ to obtain the L portion of the T network:

FOR USING A SERIES NETWORK,
SELECT A PHASE SHIFT FROM ABOVE ? -20.05

TEE NETWORK MODE

| PHASE (DEG.) | INPUT Z (HI/LO) | SB POWER (HI/LO) | | RATIO (POWERS) | SB VSWR (HI/LO) | SB DB (HI/LO) | C4 (PF) | L5 (UH) |
|---|---|---|---|---|---|---|---|---|
| -20.050 | 48.37 | 0.44 | 258.39 | 0.99 | 1.03 | 0.14 | 934.8 | 50.8 |
| | 48.10 | 0.44 | 259.83 | | 1.04 | 0.17 | | |

TOTAL INDUCTANCE REQUIRED (L1+L5) :

The addition of the L network has reduced the sideband VSWR from 1.13 and 1.16 to 1.03 and 1.04 respectively. this is a helpful improvement at a small cost.

The components called out for the L network are available but we would like to reduce the size of L5, so we go one step further and request a printout showing what happens if we vary the value of L5 between 1000 to 1500 PFD in 100 PFD steps. (Inductance of L5 will go down as capacitance of C4 increases.) We select the printout where the capacity is set to 1300 PFD which reduces the inductance to 36.6 microhenries. The resulting values are:

| PHASE (DEG.) | INPUT Z (HI/LO) | SB | POWER (HI/LO) | RATIO (POWERS) | SB VSWR (HI/LO) | SB DB (HI/LO) | C4 (PF) | L5 (UH) |
|---|---|---|---|---|---|---|---|---|
| -20.050 | 48.37 | -1.35 | 258.21 | 1.00 | 1.04 | 0.14 | 1300.0 | 36.6 |
| | 48.10 | 2.24 | 259.29 | | 1.06 | 0.16 | | |

TOTAL INDUCTANCE REQUIRED (L1+L5)

Although this is a slight increase in VSWR, that is 1.04 and 1.06 from 1.03 and 1.04, it is worthwhile because it allows L5 to have lower inductance.

Fixed capacitors could be used for the network of Figure 7 and two coils could be substituted in place of the larger coil which is divided into three parts [L1 + L2 + L5] and obtain the same net results.

The equivalent $Q^{(f)}$ of the system with 10 KHz of modulation is 1.78. This is determined from the expression:

$$Q_e = \frac{f_c}{2\Delta f} \quad VSWR - 1\sqrt{VSWR} \qquad (15)$$

Where:

$Q_e$ = Eqivalent Q of network at sidebands

$F_c$ = Carrier frequency

$\Delta f$ = Sideband modulation

VSWR = Geometric means sideband VSWR

The method of tune-up is straight forward, but for those interested in more details on the tuning procedure where it is desired to adjust bandwidth reference is made to the Consulting Radio Engineers Notebook.(g)

(C) Additional Folded-Unipole Designs:

UNIPOL is a rather flexible program and allows the user to locate a specific resistance, sweep the stub height for analysis of bandwidth, and display the antenna drive point as a function of the stub height. Figure 6 illustrates its use for determining the antenna drive point as a function of the stub height. We have found the program is quite accurate. The program does not take into account the lead in inductance so depending upon the location of the antenna termination point in relation to the folds will determine the accuracy of the base impedance reading. It is accurate enough to get one well within the ball park when setting up a folded unipole antenna system.

In order to better illustrate the various impedances that can be obtained for various height antennas, we have run a series of computations for these different antenna heights (physical height). The heights are: $80^{\circ}$, $100^{\circ}$ and $120^{\circ}$. We have assumed:

1. that the fold wires are near the sides of the tower. (Option 2)

2. a fold wire radius of 0.125 inches.

3. a loss resistance of 2 Ohms.

4. that the antenna system was formerly a series-fed type and we therefore are shorting out the base insulator with three pieces of 4 inches wide copper strap having a total inductance of 2 microhenries.

5. the operating frequency is 1000 KHz. Therefore, tower heights for $80^{\circ}$, $100^{\circ}$ and $120^{\circ}$ are 220', 273' and 328' respectively.

The program then computes the location of the stub to obtain a 50 Ohm base resistance and prints out the computed current transformation ratio and characteristic impedance of the transmission line. A user can try various combinations of the spacing, fold wire size, base inductance, loss resistance, etc.

Figures 8 through 10 are a summary of various combinations for these three different tower heights referenced above using the program UNIPOL.

**FIGURE 8**

COMPARISON OF 80° FOLDED UNIPOLE PARAMETERS:

| Height (Deg.): | Tower Width (Inches): | Spacing (Inches): | $Z_{o1}$: | N: | Stub Height From Top of Twr.(Feet): | R: | X: |
|---|---|---|---|---|---|---|---|
| 80 | 48 | 48 | 714.70 | 3.699 | 181.68 | 50.08 | j76.68 |
| 80 | 48 | 36 | 680.39 | 4.087 | 177.54 | 50.09 | j81.31 |
| 80 | 48 | 24 | 632.14 | 4.790 | 170.06 | 50.09 | j89.48 |
| 80 | 48 | 18 | 598.03 | 5.431 | 163.22 | 50.09 | j96.78 |
| 80 | 36 | 48 | 714.70 | 3.225 | 183.71 | 50.09 | j76.75 |
| 80 | 36 | 36 | 680.39 | 3.521 | 180.12 | 50.08 | j80.51 |
| 80 | 36 | 24 | 632.14 | 4.05 | 173.70 | 50.09 | j87.13 |
| 80 | 36 | 18 | 598.03 | 4.53 | 167.88 | 50.09 | j93.01 |
| 80 | 24 | 36 | 680.39 | 2.912 | 182.55 | 50.10 | j81.12 |
| 80 | 24 | 24 | 632.14 | 3.27 | 177.25 | 50.08 | j86.14 |
| 80 | 24 | 18 | 598.03 | 3.59 | 172.51 | 50.10 | j90.52 |
| 80 | 18 | 24 | 632.14 | 2.851 | 179.00 | 49.92 | j86.52 |
| 80 | 18 | 18 | 598.03 | 3.092 | 174.77 | 50.08 | j90.16 |

## FIGURE 9

### COMPARISON OF 100° FOLDED UNIPOLE PARAMETERS:

| Height (Deg.): | Tower Width (Inches): | Spacing (Inches): | $Z_{o1}$: | N: | Stub Height From Top of Twr.(Feet): | R: | X: |
|---|---|---|---|---|---|---|---|
| 100 | 48 | 48 | 714.70 | 3.699 | 123.00 | 50.02 | j197.28 |
| 100 | 48 | 36 | 680.39 | 4.087 | 118.02 | 50.10 | j209.47 |
| 100 | 48 | 24 | 632.14 | 4.790 | 110.23 | 50.09 | j231.10 |
| 100 | 48 | 18 | 598.03 | 5.431 | 104.00 | 50.09 | j250.74 |
| 100 | 36 | 48 | 714.70 | 3.225 | 122.00 | 49.93 | j187.84 |
| 100 | 36 | 36 | 680.39 | 3.521 | 117.52 | 50.09 | j197.59 |
| 100 | 36 | 24 | 632.14 | 4.05 | 111.00 | 50.09 | j415.01 |
| 100 | 36 | 18 | 598.03 | 4.530 | 105.38 | 50.10 | j229.63 |
| 100 | 24 | 36 | 680.39 | 2.912 | 115.50 | 50.10 | j185.47 |
| 100 | 24 | 24 | 632.14 | 3.27 | 110.00 | 50.02 | j197.19 |
| 100 | 24 | 18 | 598.03 | 3.590 | 105.47 | 50.10 | j207.94 |
| 100 | 18 | 24 | 632.14 | 2.851 | 108.37 | 50.10 | j188.64 |
| 100 | 18 | 18 | 598.03 | 3.092 | 104.46 | 50.10 | j196.87 |

## FIGURE 10

### COMPARISON OF 120° FOLDED UNIPOLE PARAMETERS:

| Height (Deg.): | Tower Width (Inches): | Spacing (Inches): | $Z_{o1}$: | N: | Stub Height From Top of Twr.(Feet): | R: | X: |
|---|---|---|---|---|---|---|---|
| 120 | 48 | 48 | 714.70 | 3.699 | 147.00 | 50.07 | j379.52 |
| 120 | 48 | 36 | 680.39 | 4.087 | 142.37 | 50.09 | j401.78 |
| 120 | 48 | 24 | 632.14 | 4.790 | 135.49 | 50.09 | j441.70 |
| 120 | 48 | 18 | 598.03 | 5.431 | 130.36 | 50.09 | j478.15 |
| 120 | 36 | 48 | 714.70 | 3.225 | 147.00 | 50.04 | j366.03 |
| 120 | 36 | 36 | 680.39 | 3.521 | 142.81 | 50.09 | j383.70 |
| 120 | 36 | 24 | 632.14 | 4.05 | 136.61 | 50.09 | j415.01 |
| 120 | 36 | 18 | 598.03 | 4.53 | 132.00 | 50.04 | j443.14 |
| 120 | 24 | 36 | 680.39 | 2.912 | 142.57 | 50.09 | j366.00 |
| 120 | 24 | 24 | 632.14 | 3.27 | 137.18 | 50.09 | j388.29 |
| 120 | 24 | 18 | 598.03 | 3.59 | 133.15 | 50.10 | j408.24 |
| 120 | 18 | 24 | 632.14 | 2.851 | 137.01 | 50.09 | j375.17 |
| 120 | 18 | 18 | 598.03 | 3.092 | 133.35 | 50.09 | j390.70 |

(D) Tall Tower Folded Unipole Antenna Systems:

Unfortunately, in the authors original article on Folded Unipole Antennas a caution was not given about the use of Folded Unipoles on tall towers. Tall towers means anything over $130^{\circ}$.

The fact that one can obtain 50 Ohms or some other usable drive point on a tall tower does not necessarily make it an efficient radiator.

Generally, an AM station who increases their tower height by locating on an FM tower is not allowed to operate with the efficiency one would expect to obtain from the taller tower. The FCC requires that the station reduce the input power to the antenna so that it will produce the same unattenuated or field efficiency it presently is licensed for. At this point the station and FCC assume that the stations efficiency has not changed. Unfortunately, in a majority of the cases where this is done the station finds that they have probably increased their bandwidth but a noticeable reduction in signal is noted. Some instability in certain cases also results. Some even note that the AM signal has also appeared on the FM carrier plus or minus the AM frequency. Most of these problems can be traced to:

1. The folds have been run to the top of the antenna or immediately below the FM antenna and tied into the tower. Stubs are used to tune the base impedance, but nothing else is done to the folds.

2. The folds are handled the same as above but no stubbing is used, and the antenna is matched to the resulting impedance.

3. The antenna is tuned to the reactive side of resonance, that is, a usable resistance is found by stubbing but the antenna is set on the negative reactance side of resonance.

4. Where tower lights exist, the neutral wire is not bonded to the tower at the beacon, twin lights and the base. the lighting wires are not in conduit and act as closely coupled folds.

5. The FM transmission line and any other coaxial lines are not bonded to the tower at least every 20 feet, again causing out of phase currents to flow on the coaxial line or lines.

6. Where tower lights were used the old lighting chokes have not been taken out of the circuit so the lighting system attempts to base load the Unipole.

7. Inadequate field intensity measurements were made to determine exactly how much gain or loss took place after the new installation. In such cases only a few spot checks were made; so a realistic evaluation of what the antenna previously did vs what it is doing now cannot be made.

The station now finds itself operating its AM station with less power, apparently poor coverage, and possibly some intermod problems, etc. Its FM is probably working fine, so if the Unipole can be corrected the station would be whole again.

What to do? Many of the stations clean up any intermod by the bonding routine, horsing around with the base network to try and obtain better bandwidth, and re-working the grounding in the transmitter building and around the tower. Sometimes this is acceptable. Some went back to a series-fed if they formerly were series-fed and used a $90^{o}$ stub or isolation coupler to get across the base insulator with their FM and other lines, while some moved the AM to another tower.

What would we recommend? First a careful study of what the problems are should be made. This would require an analysis of the tower and unipole parameters, transmission lines, base network, and any lighting or other items on the tower. Based on that information we would then recommend a method to de-tune the upper section of the tower to keep it from cancelling out a portion of the lower towers radiation. Next we would design a network to obtain the best bandwidth possible.

Lets us run an example of a station that operates on 1310 KHz with 1 KW daytime using a 400 foot tower. They side mounted a two bay FM antenna at the top of the tower. They installed a Folded Unipole having three folds on the side and ran the folds the entire length of the tower. The fold wire had a radius of 0.125 inches, the folds were spaced 48 inches and the tower face was 48 inches. The folds were shorted at approximately 145 feet from the top of the tower. A ground loss of 2 Ohms was assumed. Using that data we determined as follows:

```
OPTION DESIRED ? 2

SIDE OF TOWER IN INCHES ? 48
SEPARATION OF FOLDS FROM TOWER IN INCHES ? 48
RADIUS OF FOLD IN INCHES ? 0.125
HEIGHT OF TOWER IN FEET ? 400

FREQUENCY IN KHZ ? 1310
LOSS RESISTANCE OF TOWER IN OHMS ? 2
BASE INDUCTANCE IN MICRO HENRIES ? 0

CURRENT TRANSFORMATION RATIO IS     3.699

CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINE IS   714.701 OHMS
        DRIVE POINT IMPEDANCE
      RESISTANCE    49.903 OHMS
      REACTANCE    742.133 OHMS

DISTANCE OF STUB FROM TOP OF TOWER    249.000 FEET
```

Next we sweep the antenna from 1300 to 1310 KHz in 5 KHz steps:

| FREQUENCY | RESISTANCE | REACTANCE |
|---|---|---|
| 1300 | 34.606 | 717.706 |
| 1305 | 41.777 | 729.586 |
| 1310 | 49.903 | 742.133 |
| 1315 | 59.052 | 755.433 |
| 1320 | 69.292 | 769.569 |

We then compare the measured base impedance at the input of the antenna coupling network vs the predicted using a Folded Unipole with the stub at 249 feet from the top of the tower.

MEASURED

| FREQUENCY | RESISTANCE | REACTANCE |
|---|---|---|
| 1300 | 10.5 | -398.00 |
| 1305 | 11.6 | -380.00 |
| 1310 | 13.2 | -360.00 |
| 1315 | 14.0 | -370.00 |
| 1320 | 26.8 | -350.00 |

A comparison shows almost a 4:1 difference in resistance and about a 2:1 difference in reactance with a change in sign of the reactance. The difference in stub height was 145 feet for the station and 249 feet for the program, a difference of 104 feet. Looking at figure 11, the antenna coupling unit we note it consists of a coil having a reactance of 238 Ohms shunted across the feed point to the ground. In series with this was a variable vacuum capacitor set to -j699. The impedance was then 50 j0 at the network input. Figure 11 illustrates the network.

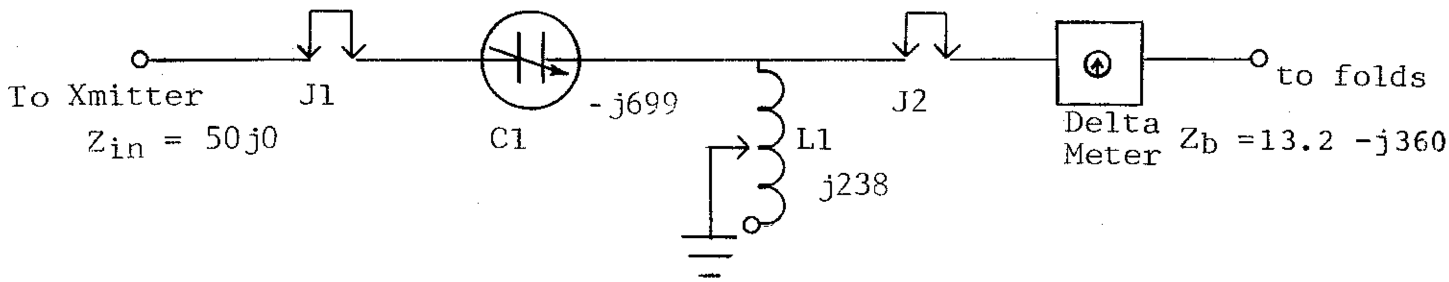



Figure 11

The reason for the difference in base impedance is not apparent so we will sweep the 400 feet antenna between the top [400 feet level] and the 350 feet distance from the top in 10 feet steps to determine what the overall antenna looks like. The following is a tabulation of this sweep:

| DISTANCE OF STUB FROM TOP | BOTTOM | RESISTANCE | REACTANCE |
|---|---|---|---|
| 0.000 | 400.000 | 0.218 | 49.140 |
| 10.000 | 390.000 | 0.074 | 28.684 |
| 20.000 | 380.000 | 0.007 | 8.632 |
| 30.000 | 370.000 | 0.012 | -11.303 |
| 40.000 | 360.000 | 0.089 | -31.402 |
| 50.000 | 350.000 | 0.243 | -51.954 |
| 60.000 | 340.000 | 0.484 | -73.276 |
| 70.000 | 330.000 | 0.827 | -95.729 |
| 80.000 | 320.000 | 1.294 | -119.751 |
| 90.000 | 310.000 | 1.920 | -145.889 |
| 100.000 | 300.000 | 2.759 | -174.858 |
| 110.000 | 290.000 | 3.890 | -207.624 |
| 120.000 | 280.000 | 5.441 | -245.553 |
| 130.000 | 270.000 | 7.625 | -290.647 |
| 140.000 | 260.000 | 10.809 | -345.996 |
| 150.000 | 250.000 | 15.680 | -416.646 |
| 160.000 | 240.000 | 23.647 | -511.468 |
| 170.000 | 230.000 | 37.964 | -647.643 |
| 180.000 | 220.000 | 67.643 | -863.335 |
| 190.000 | 210.000 | 145.860 | -1263.248 |
| 200.000 | 200.000 | 483.036 | -2263.146 |
| 210.000 | 190.000 | 6911.116 | -5371.794 |
| 220.000 | 180.000 | 1033.493 | 3223.300 |
| 230.000 | 170.000 | 218.168 | 1539.842 |
| 240.000 | 160.000 | 89.292 | 990.936 |
| 250.000 | 150.000 | 47.151 | 721.463 |
| 260.000 | 140.000 | 28.373 | 560.130 |
| 270.000 | 130.000 | 18.425 | 451.589 |
| 280.000 | 120.000 | 12.541 | 372.668 |
| 290.000 | 110.000 | 8.786 | 311.969 |
| 300.000 | 100.000 | 6.254 | 263.233 |
| 310.000 | 90.000 | 4.477 | 222.731 |
| 320.000 | 80.000 | 3.192 | 188.095 |
| 330.000 | 70.000 | 2.245 | 157.744 |
| 340.000 | 60.000 | 1.538 | 130.573 |
| 350.000 | 50.000 | 1.009 | 105.780 |

Two arrows are shown on the tabulation.

The first one is between 140 feet and 150 feet from the top. The base impedance would measure between about 11 to 16 Ohms resistance and the reactance would vary between -j346 to -j417 Ohms. The measured impedance falls nicely between these values with 13.2 -J360 with the stubs at 145 feet from the top of the tower.

The second arrow is between 240 feet and 250 feet from the top and this represents the location the stub should be at to obtain 50 j792.

The tabulation clearly shows that for a 400 foot [191.7$^{O}$] Folded Unipole the sign of the reactance changes three times.

In tuning the folds the station would have done better if they had brought the folds down in the positive reactance region around 250 feet. This alone would not be the best solution. Instead we would break the folds into two sections. One set starting at the base and going up approximately 180 feet [under 90$^{O}$] where the folds would be bonded to the tower.

The second set of folds would start at the top and go down approximately 210 feet [100.6$^{O}$]. At this point the three top folds would be connected together and tuned through a variable vacuum capacitor to the tower. It is not difficult to remotely control this capacitor from the base. The simplest way to adjust this capacitor would be to use a field intensity meter and with power in the antenna adjust it for maximum field at several remote locations. The upper section will tend to couple into the lower Folded Unipole so some adjustment will be required.

The tuning capacitor for this upper section is best determined by experiment but in general a value of approximately 6.5 PFD per meter should be sufficient.

Once maximum field intensity is obtained, the station power can then be adjusted to conform to the C. P. unattenuated field intensity.

As a final note on tall tower Folded Unipoles, they can be used to de-tune towers where re-radiation is a problem. Reference is made to The Consulting Radio Engineers Notebook for detailed information.[g]

## IV. SUMMARY:

A review of the Folded Unipole principle has been given. A method for computing expected base impedances has been presented along with examples. Certain cautions have been expressed on the use of this type of antenna system, and methods of coupling and bandwidth control have been discussed. the Folded Unipole Antenna is equivalent to or better than an identical height series fed antenna.

In many installations because of its ability to radiate better with a restricted ground system, support other VHF or UHF antennas without isolation problems it has proved to be a worthwhile method of feeding an antenna.

## ACKNOWLEDGMENT

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John H. Mullaney, P. E.

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