COMPUTER ASSISTED DESIGN OF CATV
ANTENNA-TOWER/ANTENNA-ARRAYS

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ABSTRACT

Most CATV engineers are well aware of the difficulties in producing functional, interference repellent, and cost-effective antenna-tower/antenna-array designs, and in completing the project on time. The Computer Assisted Design (CAD) program, developed by Biro Engineering, optimizes array configurations, their dimensions, and proper location on the tower.

The paper will discuss the major benefits of the program, such as improved co-channel, adjacent channel and second harmonic FM interference rejection, as well as the advantages of a computer drafted and printed tower/array design, as applied to a 400' guyed CATV antenna tower project.

Most CATV engineers are well aware of the difficulties in producing functional, interference repellent, and cost-effective antenna-tower/antenna-array designs, and in completing the project on time.

For those who consider the array design a simple task, just take into account the different VHF-UHF antenna models on the market, their gain, beamwidth, Front/Back ratio specifications, the different shape and physical size of the radiators, mounting features, the length of the antenna boom or the diameter of the parabolic dish, and last but not least, the antenna manufacturer. Then, focusing on the tower design, one must choose between selfsupporting and guyed antenna towers, deal with tower height and/or guy-wire layout restrictions, reserve space for microwave dishes or two-way radio radiators, the mounting of the arrays on tower-legs, crossarms or V-Gate structures, vertical and horizontal separation between arrays,--just to mention a few variations.

In effect, the design may involve a vast number of possibilities, too many to be chosen by intuition or experience, and too many to be analyzed in an ordinary way.

Off-air TV receiving antennas have to fulfill two distinctive functions. First, to provide maximum gain in the direction of the desired signal. Second, to repell signals arriving from the undesired (interference) directions.

CATV receiving antennas cannot operate in open space. They are mounted on gates, crossarms, or on the tower legs of massive steel towers. Or, by choice, the antenas are co-located on the tower. Nearby reflecting surfaces may destroy the radition pattern of the arrays, and any such interference should be avoided or reduced to a tolerable level. That formulates a third objective: to generate a "clean" tower and antenna-array design. No matter whether the engineer follows the old fashioned "manual design", or applies the recently developed Computer Assisted Design program, he needs design specifications, such as:

1. Listing of the desired VHF-UHF stations to be carried on cable.

2. Projected or actual signal levels of the desired stations.

3. Predicted or measured interference levels, such as:

   a. Co-channel interference
   b. Adjacent channel interference
   c. Second harmonics of local FM stations
   d. AC interference sources

4. The direction of reflections (ghosting)

5. Type of tower.

6. Tower height limitations.

7. Microwave dish allocations

8. Preference of antenna-type and/or antenna manufacturer.

To comply with the signal level and interference protection requirements of the design specifications, the design must be preceeded by an on-site Signal Survey or by a Computerized TV Reception Study. Both require the exact coordinates of the proposed antenna site. They can be obtained either from 7 1/2' U.S. Geological Survey Maps (Topo-Maps), or with the aid of a LORAN receiver during the on-site Signal Survey.

The printout of a Computerized TV Reception Study (Fig.1) lists all major technical and program parameters of all desired and most of the undesired TV stations, including computer calculated great circle distances and directions. The computer projected signal levels should provide a reasonable basis for antenna-size and antenna height calculations, as well as for co-channel and adjacent channel considerations.

*** COMPUTER AIDED TV RECEPTION STUDY ***

BIRO ENGINEERING
PRINCETON,NEW JERSEY

LOCATION = TUCSON, AZ

COORDINATES = 32/12/52 110/56/57

THIS IS A LISTING OF ALL VHF AND UHF STATIONS WITHIN 250 MILES

| DIST | CHAN | CALL | LOCATION | STATE | NETWK | POWER | OFST | HAAT | AZIMUTH | LEVEL |
|---|---|---|---|---|---|---|---|---|---|---|
| 10.06 MI | 40 | KPOL | TUCSON | ARIZ | IND | 1534. | 0 | 2029. | 283.9 | 18.8 |
| 19.41 MI | 9 | KGUN | TUCSON | ARIZ | ABC | 110. | - | 3720. | 44.3 | 9.5 |
| 19.48 MI | 6 | KUAT | TUCSON | ARIZ | ED | 36. | + | 3630. | 44.5 | 9.7 |
| 19.56 MI | 13 | KOLD | TUCSON | ARIZ | CBS | 110. | - | 3610. | 44.6 | 8.8 |
| 19.56 MI | 4 | KVOA | TUCSON | ARIZ | NBC | 35. | - | 3680. | 44.6 | 10.8 |
| 35.23 MI | 11 | KMSB | NOGALES | ARIZ | IND | 150. | 0 | 1570. | 177.6 | 5.4 |
| 48.75 MI | 18 | KDTU | TUCSON | ARIZ | REL | 2490. | - | 1966. | 86.8 | 8.7 |
| 61.46 MI | 2 | XHFA | NOGALES | ARIZ | IND | 8. | | 231. | 179.9 | -20.3 |
| 100.67 MI | 45 | KUTP | PHOENIX | ARIZ | IND | 3020. | 0 | 1792. | 320.6 | -35.6 |
| 100.77 MI | 5 | KPHO | PHOENIX | ARIZ | IND | 100. | - | 1770. | 320.6 | -23.7 |
| 100.79 MI | 21 | KPAZ | PHOENIX | ARIZ | IND | 251. | 0 | 1600. | 320.6 | -45.6 |
| 100.79 MI | 10 | KTSP | PHOENIX | ARIZ | CBS | 316. | - | 1700. | 320.6 | -28.8 |
| 100.80 MI | 12 | KPNX | PHOENIX-MESA | ARIZ | NBC | 316. | - | 1780. | 320.5 | -28.6 |
| 100.81 MI | 3 | KTVK | PHOENIX | ARIZ | ABC | 100. | + | 1670. | 320.6 | -22.4 |
| 101.39 MI | 33 | KTVW | PHOENIX | ARIZ | SP | 2290. | 0 | 1710. | 320.8 | -37.1 |
| 101.39 MI | 15 | KNXV | PHOENIX | ARIZ | IND | 524. | - | 1710. | 320.8 | -40.0 |
| 101.42 MI | 8 | KAET | PHOENIX | ARIZ | ED | 316. | + | 1756. | 320.8 | -28.0 |
| 184.72 MI | 7 | KUSK | PRESCOTT | ARIZ | IND | 9. | 0 | 2810. | 339.1 | -103.8 |
| 192.97 MI | 2 | KNAZ | FLAGSTAFF | ARIZ | NBC | 100. | 0 | 1540. | 350.6 | -76.8 |
| 232.14 MI | 22 | KRWG | LAS CRUCES | N.M. | ED | 1450. | - | 450. | 87.6 | -269.0 |
| 232.88 MI | 13 | KYEL | YUMA | ARIZ | NBC | 316. | + | 1560. | 286.1 | -162.7 |
| 232.91 MI | 9 | KECY | EL CENTRO | CAL | CBS | 316. | + | 1601. | 286.1 | -154.6 |
| 243.67 MI | 48 | KASK | LASCRUCES | N.M. | IND | 79. | + | 25. | 86.8 | -395.0 |

OUR SIGNAL LEVEL CALCULATIONS ARE BASED ON SINGLE YAGI ANTENNAS AT 30 FEET ABOVE GROUND EXHIBITING 6 DB GAIN ON VHF AND 9.5 DB GAIN ON UHF.

**FIG. 1**

But the computer cannot take into consideration:

a. Terrain features, affecting desired and undesired signal levels

b. Reflections, causing ghosting

c. The intensity and direction of any AC or RF interference.

Therefore, the efficiency and reliability of the tower/antenna-array design can be significantly improved if it is followed by an on-site ground or helicopter survey, confirming signal level projections, as well as the direction and level of interference transmissions.

## THE SYNTHESIS PROCESS

There are as many approaches to meet a set of specifications as there are design engineers. Given plenty of time, paper, patience, and a scientific calculator, an expert could produce all the unique solutions that meet the design specifications. However, there must be a better way. A computer can perform repetetive operations with ease. While not the ultimate solution, computerized synthesis is still the best tool to satisfy the complexities of the tower/array design.

Synthesis has been widely used in connection with filter designs. The "G" or "K" parameters, often applied in "cookbook type" filter designs, represent no more than tabulation of solutions for a number of synthesis possibilities.

The CAD program for towers and antenna-arrays, as a matter of fact, uses the same procedures in the computer aided mode that the experts use in the manual mode. The difference is that the computer constantly monitors many aspects of the design process and adapts ifself to changing specifications. Then, when a single or a set of specifications are judged inconsistant, the program may refuse to accept the input. Or, in the case of potential inaccuracy, the program flashes a warning note on the screen.

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SUBROUTINE
FOR
ADJACENT CHANNEL PROTECTION

TOWER:   GUYED TOWER
DESIRED CHANNEL: CHANNEL 12
UNDESIRED CHANNEL: CHANNEL 13

ANTENNA: YAGI                    NUMBER OF ELEMENTS:12

DIRECTION OF DESIRED: 74° AZIMUTH
DIRECTION OF UNDESIRED:138° AZIMUTH

TWO-BAY:  YES                            FOUR-BAY: NO
DIAMOND ARRAY: NO

LIMITATIONS

HORIZONTAL CLEARANCE  :  2 METERS
VERTICAL CLEARANCE    :  5 METERS
GUYED TOWER           :  YES
SELFSUPPORTING        :  NO
GUY WIRES             :  AT 180'
STAR-MOUNT            :  NO
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**FIG. 2**

Fig. 2 shows the synthesis display for the ADJACENT CHANNEL PROTECTION subroutine. The upper display is the "SPEC.PANEL", while the bottom lines are a list of "COMMAND PARAMETERS", obtained from the preliminary specifications.

Once the minimum parameters have been selected, the designer has to enter only the "PFMPRES" command to synthesize all possible array configurations and antenna types that match the specifications.

The usefulness of the CAD program extends beyond the basic tower/array design function. There are powerful diagnostic tools built into the program, which allow the designer to investigate the effects of certain components. For example, the designer can probe Front/Back ratio conditions while switching from Yagis to Log-Periodics, or from a horizontally stacked, phased-array configuration to the vertical stagger stacking approach.

## ARRAY SYNTHESIS SUBROUTINE

This subroutine of the CAD program focuses on one of the array synthesis techniques which has proven useful in determining the excitations of arrays that are to generate the desired radiation patterns.

To force a deep radiation pattern null into the direction of an interference source is a common practice in antenna engineering. Less frequently analyzed, however, is the protection capability of the phased array into a number of other directions, namely into the directions of the secondary interference sources.

The radiation pattern of any array is the product of the individual antenna pattern, multiplied by the ARRAY FACTOR.

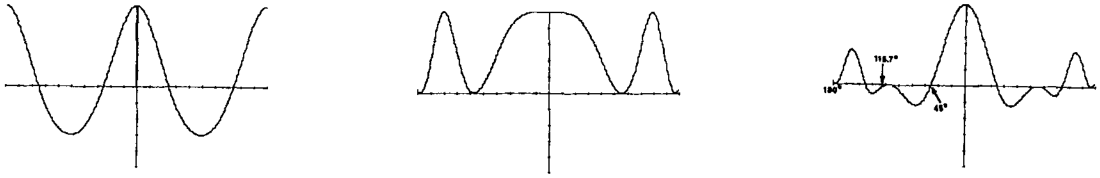
In the simple case of two, horizontally stacked antennas, fed by equal amplitude and phase currents, the array factor is:

$$\frac{\sin(S\sin\Theta)}{2\sin(S/2\,\sin\Theta)}$$

where S is the electrical spacing between the antennas in radians.

The radiation characteristics of a short Yagi antenna can be described by the following equation:

$$Y = \cos\left(\pi/2\,\sin 0.5\,\Theta^{2}\right)$$



**ARRAY FACTOR times YAGI PATTERN = ARRAY PATTERN**

**FIG. 3**

FIG. 3. shows the forming process of the radiation pattern. The phased-array was designed to create a deep null into 45° AZIMUTH, the direction of the identified co-channel offender, as well as at 115.7° AZIMUTH, the direction of the nearby FM radio station.

As expected, the array exhibits nulls at +/-45° of the main beam, as well as at +/-135°.

Note the excellent Front/Back ratio of the pattern (28.6 dB), not only exactly at 180°, but in the wide range of 171° to 189°.

At 115.7° , which is the direction of the secondary (local FM station) interference source, the two-bay array is ascertaining 23 dB protection.

The Computer Aided Design provided a fast solution and enhanced protection against a multitude of interference sources.

## TOWER DESIGN SUBROUTINE

For the tower design portion of the program an iteration algorithm was developed which takes into account the following tower geometry parameters.

1. The width and shape of the tower.
2. The position (height above ground) of the guy-wires and star-mounts.
3. The height, width and vertical separation between the antenna crossarms (gates).
4. The separation between the inner tip of the antenna elements and the tower.
5. The minimum vertical separation between adjacent antenna-arrays.
6. Partial or total blockage caused by guy-wires and startmounts.
7. Minimum clearance between microwave dishes and antenna-arrays.

The program's interactive data-base manager provides a flexible means of manipulating and examining very large amounts of input data. The data-base manager also lets the designer create, delete and revise critical parameters, provided that the revisions do not alter excessively the number of radiating elements, the size of the array or the antenna-gate configuration. For example, one may change the size of the side-mounted gate from 14'x4' to 20'x4', but not to a V-GATE configuration with 10'x4' side arms.

When the computer program requires more information to continue a routine, it will prompt the operator a new table on the screen that must be edited and completed. These tables contain default warnings on tower/array configurations, in order to prevent the designer from wasting time with unacceptable architectural formations.

Once the designer is satisfied with the results, the program automatically recomputes antenna gains, array factors, radiation pattern nulls and beamwidths, as well as the critical horizontal/vertical clearances, and reopens the program options for a printout record or canceling the data, making additional changes or exiting the program.

## DRAWING ERRORS, DRAWING MODIFICATIONS

The computer generates error-free drawings. It shows the tower and antenna-array layouts exactly as they were designed.

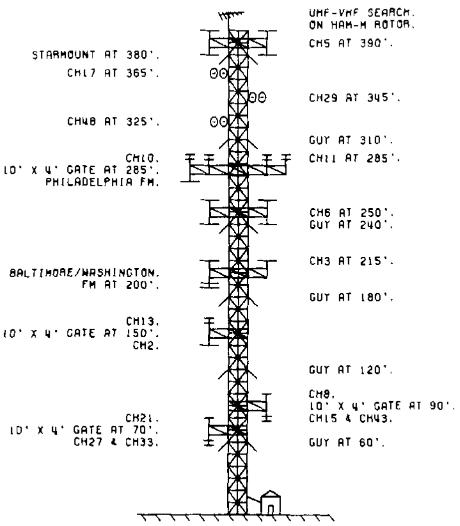
Not only is the time required for a complete printout (drawing) many-many times shorter than the customary manual drafting, but any later modifications or changes, provided these were properly fed into the program, will produce precise and instant new printouts.

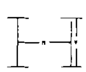
Since there is no human element introduced into the drafting process, there is little room for human mistakes. The customary checking and double-checking of the drafted product has been also eliminated, representing an additional savings in time and costs.

## A DESIGN EXAMPLE

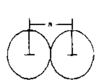
### 400' GUYED CATV ANTENNA TOWER

### FOR HERSHEY, PA.

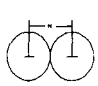


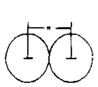
CH5. WRC. WASHINGTON. IND. - OFFSET
92.85 MI. 194.0 AZIMUTH ANGLE
H=261" V=145"
ARRAY PHASED FOR CO-CHANNEL PROTECTION
AGAINST CH5. NEW YORK. 144.68 MI.
USE 4 PCS OF LINDSAY MODEL 9AY-5 YAGIS.



CH17. WPHL. PHILADELPHIA. IND
76.73 MI. 100.8 AZIMUTH ANGLE
H=54.4"
ARRAY PHASED FOR PROTECTION
AGAINST LOCAL CH15. LANCASTER. 10.7 MI.
USE 2 PCS OF JERROLD 4' PARABOLIC DISHES.

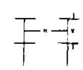


CH29. WTAF. PHILADELPHIA. IND
76.80 MI. 100.9 AZIMUTH ANGLE
H=57.25"
ARRAY PHASED FOR PROTECTION AGAINST
ADJACENT CHANNEL 28. WILKES-BARRE. 76 MI.
USE 2 PCS OF JERROLD 4' PARABOLIC DISHES.

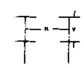


CH48. WKBS. PHILADELPHIA. IND
76.58 MI. 100.8 AZIMUTH ANGLE
H=83.3"
ARRAY PHASED FOR PROTECTION AGAINST
ADJACENT CHANNEL 49. RED LION. 22.9 MI.
USE 2 PCS OF JERROLD 6' PARABOLIC DISHES.

BALTIMORE/WASHINGTON FM ARRAY
63.92 MI. 186 AZIMUTH ANGLE
V=120"
VERTICAL SPACING CALCULATED FOR MAXIMUM GAIN.
USE 2 PCS OF LINDSAY MODEL 10AY-FM YAGIS.

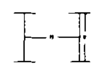


CH10. WCAU. PHILADELPHIA. CBS. 0 OFFSET
76.88 MI. 100.7 AZIMUTH ANGLE
H=83" V=60"
ARRAY PHASED FOR CO-CHANNEL PROTECTION
AGAINST ALTOONA. PA. 95.87 MI.
USE 4 PCS OF LINDSAY MODEL 12AY-10 YAGIS.

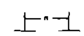


CH11. WBAL. BALTIMORE. NBC. - OFFSET
63.99 MI. 179.3 AZIMUTH ANGLE
H=91.6" V=58"
ARRAY PHASED FOR CO-CHANNEL PROTECTION
AGAINST CH11. NEW YORK 144.68 MI.
USE 4 PCS OF LINDSAY MODEL 12AY-11 YAGIS.

PHILADELPHIA FM ARRAY
77 MI. 100.8 AZIMUTH ANGLE
V=120"
USE 2 PCS OF LINDSAY MODEL 10AY-FM YAGIS.



CH6. WPVI. PHILADELPHIA. IND
76.67 MI. 100.7 AZIMUTH ANGLE
H=213" V=135"
APPLY VERTICAL STAGGER STACKING FOR PROTECTION
AGAINST JOHNSTOWN. PA. 122.27 MI.
USE 4 PCS OF LINDSAY MODEL 9AY-6 YAGIS.



CH3. KYW. PHILADELPHIA. NBC
76.69 MI. 100.8 AZIMUTH ANGLE
H=251"
ARRAY PHASED FOR PROTECTION AGAINST
CH3. CLEARFIELD. PA. 110.21 MI.
USE 2 PCS OF LINDSAY MODEL 9A6-3 YAGIS.

## REFERENCES

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2. J.A. GREENFIELD, S.E. HANSEN & R.W. DUTTON, "TWO-DIMENSIONAL ANALYSIS FOR DEVICE MODELING", STANFORD UNIVERSITY PRESS, STANFORD, CA., 1980

3. STEVEN I. BIRO, ADVANCED DISTANT SIGNAL RECEPTION TECHNIQUE, TV COMMUNICATIONS, OCT. 1979.

4. THE BIRO TECHNIAL BULLETINS, JULY, 1986.