The Slant Wire Shunt Fed Monopole:
A Neglected but Invaluable Technique

Benjamin F. Dawson III
Hatfield & Dawson Consulting Engineers, LLC
Seattle, WA, USA
dawson@hatdaw.com

Abstract
Antennas which are fed by a "shunt" or other method in which a part of the antenna comprises a portion of an electrically small one-turn loop, so that the feed is in essence a sort of autotransformer, are quite common, particularly at frequencies above 10 megahertz. Shunt feed arrangements for grounded vertical tower radiators, such as those used for medium wave broadcasting, are less common. A grounded vertical radiator can be arranged with a skirt-wire or coaxial feed, but a much less complex although far less common method is by a "slant wire," arranged to feed an elevated point on the vertical radiator by a conductor from a location at a modest distance from the tower base, so that the input to the feed arrangement exhibits a convenient resistive impedance term. Such systems are described in the historical literature, but are not commonly employed in the U.S. in particular, apparently because of largely erroneous assumptions about the distortion of both vertical and horizontal radiation patterns caused by the non-symmetrical feed geometry. This misinformation has led to the prohibition of their use for nighttime antenna operation in the U.S. by FCC for at least the last 30 years. A brief survey of the technical literature discloses that the actual circumstances of current distribution and radiation pattern geometry for these antennas has been well known since the 1930's. Analysis using modern numerical analysis techniques both confirms the early work and demonstrates that for radiators of the usual height employed by the vast majority of MF broadcasting stations the pattern distortions are trivial. The impedance bandwidth of slant wire shunt fed vertical radiators is also analyzed and numerous examples are shown demonstrating good bandwidth. Slant wire shunt fed antenna elements in directional antenna arrays are also practical in some situations, and examples are described. Slant wire feeds are simpler electrically than other types of feeding grounded base vertical radiators, and impose far less structural load and are less susceptible to weather related damage in hostile climate conditions

HISTORICAL LITERATURE ON THE SLANT WIRE FEED

Morrison & Smith describe the basic characteristics of slant wire feed systems, and provide extensive measured data for both impedance and current distribution on a typical vertical radiator when excited by a slant wire feed. [1] This very thorough paper has been used as the basis for the design of many such shunt feed systems, although it's likely an equal or even greater number of these systems have simply been constructed and tuned entirely empirically.

Graphs of the current distribution and horizontal plane radiation patterns of the test antenna for both series and slant wire shunt excited conditions are shown in the Morrison & Smith paper. The horizontal plane radiation patterns show noncircularity for both conditions, and the pattern for the shunt excited condition is only very slightly less circular than that for the series fed condition. The difference is probably less than the measurement error of the method used. However, the current distribution graphs for the condition where the tower was well over 1/3 wavelength in height are easily misinterpreted. The shunt excitation produces currents in the section of the tower below the feed point that are quite large compared to those above the feedpoint, or compared to the currents at the same height on the series fed tower. These currents might be thought to produce large differences in radiation at various azimuths, particularly in the vertical plane pattern, although the graph in the Morrison and Smith paper doesn't show the currents in the feed wire or the effect of the complete loop on the vertical radiation pattern. Weeks provides some methods for impedance calculations for slant wire feeds. [2] Griffith also briefly discusses practical aspects of the slant wire shunt feed. [3] Baudoux, in another early paper, provided a study of current distribution and impedance in a slant wire fed monopole. [4] Another 1940's era study was a comparison of the radiation characteristics of slant wire versus base fed tall monopoles by MacKinnon. [5]

In an unpublished study discussed in Laport, Brown and Epstein made scale model measurements which showed fairly substantial distortion of the vertical radiation pattern of a test model, related to the plane of the slant wire feed. [6] Laport notes that the taper of the model tower (nearly 5%) also contributed to the distortion of the current distribution. The model antenna was close to one-half wavelength tall. The graph of the vertical pattern data is also reprinted by Head in Jasik, Ed, [7] The current distribution graph information allows confirmation of the approximate height.

Morrison and Smith were employees of Bell Laboratories. Its affiliate, the Western Electric Company, appears to have promoted the use of slant wire feeds. Brown, Epstein and Laport were all employees of Radio Corporation of America, Western Electric's rival in the manufacture of broadcast equipment, which may explain the negative emphasis of their discussion. This emphasis on the pattern distortion effects of slant wire feeds, though confined to a single poorly defined example, appears to have been unduly generalized. Since as early as the 1960's the U.S. regulatory agency, the Federal Communications Commission, has discouraged (and in recent times has simply prohibited) the use of slant wire fed antennas for operation during nighttime hours (sunset to sunrise) because of the purported unpredictability of the vertical radiation patterns from these antennas.

Although vertical tower antennas with lengths of around one-half wavelength are not uncommon, the vast majority of medium wave transmitting stations employ antennas that are on the order of one-quarter wavelength in height. These lower heights are dictated by economy and by the fact that the anti-fading benefits of taller antennas are wasted in circumstances where incoming interference levels limit service to the high values of groundwave signal strength in the immediate area of the antenna. Therefore the emphasis of the analysis in this paper is on antennas in the range from 60 to 120 electrical degrees in height

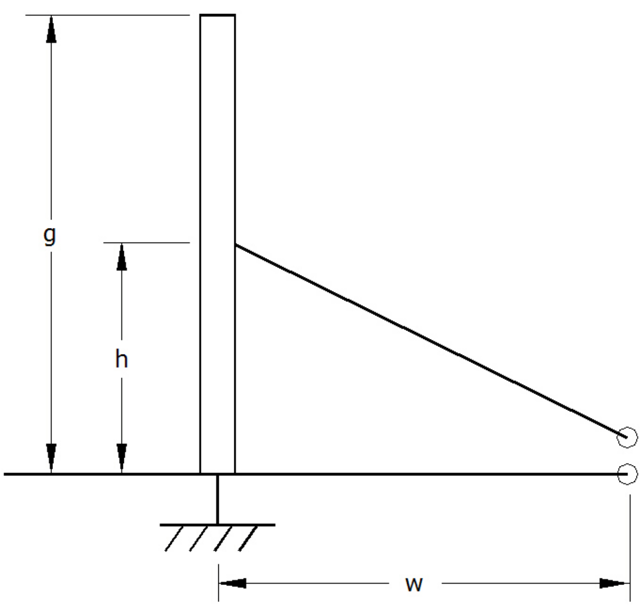

Figure 1: The Slant Wire Shunt Fed Antenna

MOMENT METHOD ANALYSIS OF SLANT WIRE FEED SYSTEMS

Scale model measurements, particularly of impedance and current distribution, are notoriously troublesome to make and to interpret. Scale modeling as a method of impedance and current distribution determination for "wire" antennas has fallen out of favor with the advent of moment method analysis. Computerized moment method techniques have proven to be so fruitful and dependable for analysis of series-fed and skirt-fed vertical tower antennas and arrays of such antennas that the FCC now allows their use for some directional antenna performance verification. Similar computer modeling techniques have been used to investigate slant wire shunt fed vertical antennas for this study.

The work of Brown and Epstein was analyzed using the program MININEC, assuming a frequency of 615 kHz, where the 800 foot tower would be 180 degrees tall, replicating their model measurements. The data as reported by Laport and Head does not contain a horizontal plane pattern, but includes current distribution data and normalized vertical plane pattern data. A similar analysis was made of the Morrison and Smith data for the case where the antenna is well over 180 degrees in height. They provide extensive current distribution and horizontal plane pattern data, but do not report the vertical radiation pattern of the full scale antenna they measured. In both cases if some simplifying assumptions are made, the results obtained from a moment method analysis compare reasonably well. Neither of the studies report the discontinuity in magnitude of the current at the slant wire attachment point that one would anticipate from Kirchoff's law, probably as a result of the measurement technique, but the current shown by the moment method analysis compares well above and, if normalized, reasonably well below the feed point in both cases. Additionally, the radiation pattern data of both studies is also verified by the moment method analysis.

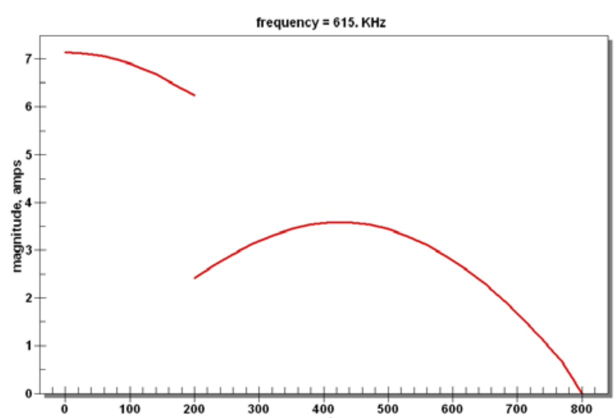

Figure 2; Lower and Upper Section Current Distribution on Model of Brown & Epstein Example

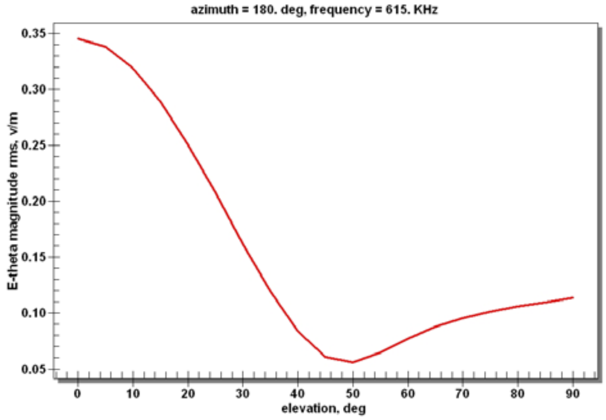

Figure 3: Vertical Pattern in Plane of Slant Wire for Brown & Epstein Example

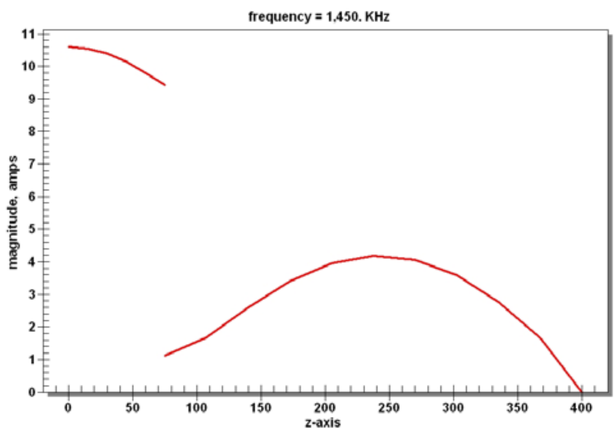

Figure 4: Lower and Upper Section Current Distribution for Morrison & Smith Example

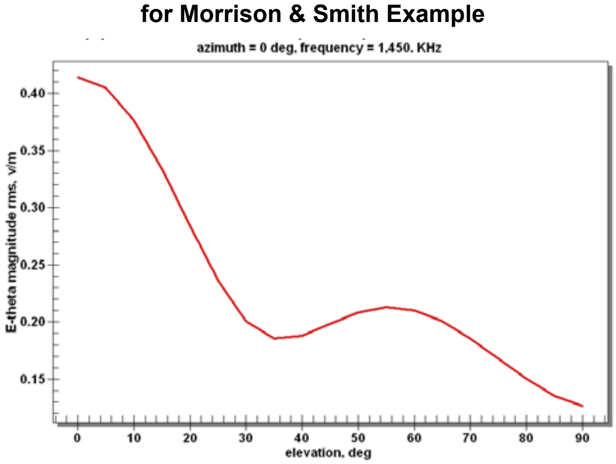

Figure 5: Vertical Pattern in Plane of Slant Wire Feed for Morrison & Smith Example

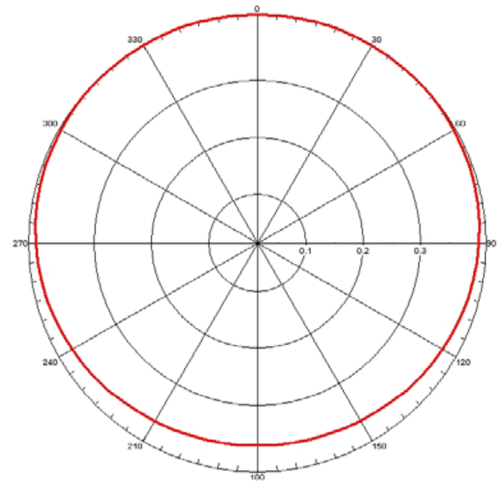

Figure 6: Horizontal Plane Pattern at 1450 kHz for Morrison & Smith Example

In both cases the horizontal plane radiation pattern data is modestly non-circular, with a directionality of about 1.0 dB, and the vertical plane pattern in the plane which includes the tower and the slant wire is modestly distorted, with the minimum occurring at about 40 to 45 degrees elevation in the plane of the feed, rather than at the zenith as would occur for a perfectly symmetrical infinitely thin base fed radiator.

However, the use of the Brown and Epstein example as an illustration in both Jasik and Laport appears to have had the unfortunate effect of condemning the feed method for all heights of towers and slant wire feed arrangements.

Towers of the more modest electrical heights normally employed give quite different results. This is also clear from Morrison and Smith's 550 kHz data, where the antenna they measured was 80 degrees in height. The example below is for a 60 degree tower fed by a steeply sloping slant wire to a fairly high location on the tower in order to obtain an impedance with 50 ohms resistance. This feed is similar to that employed in the KOAC antenna described below. The pattern circularity is $\pm$ 0.33 dB, and the vertical plane pattern is essentially indistinguishable from the pattern of a base fed antenna of the same height. It does not go to zero at the zenith in the plane of the slant wire, but neither would that of a base-fed antenna of finite cross section.

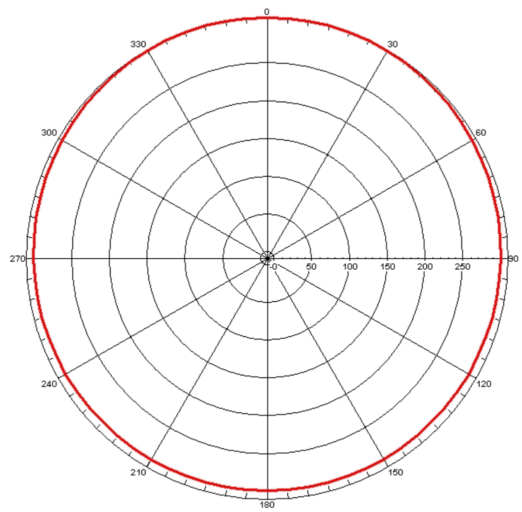

Figure 7: 60 Degree Tower Slant Wire Fed Example

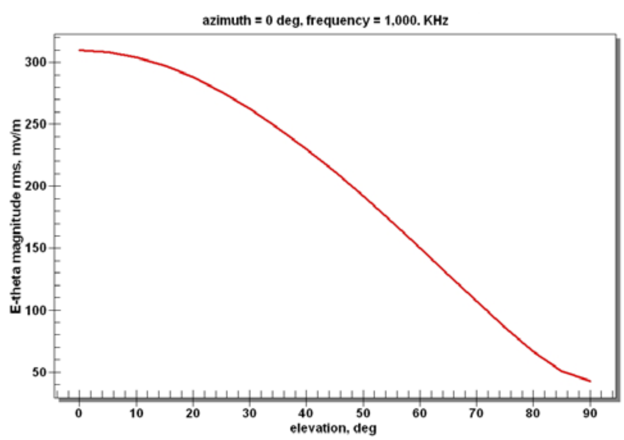

Figure 8: 60 Degree Tower Vertical Pattern in Plane of Slant Wire Feed

Another example is a relatively thin uniform cross section tower 90 degrees in height, fed with a slant wire at a 45 degree incline to the point where an input impedance with 50 ohms resistance is obtained at the feed point on the lower end of the slant wire.

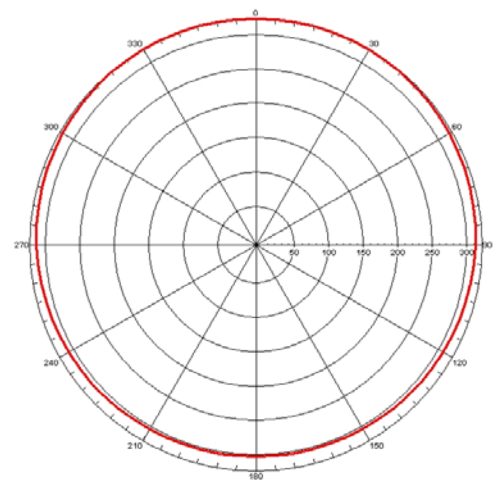

Figure 9; 90 Degree Tower Slant Wire Fed Example

Like the 60 degree example, this antenna has a quite acceptable circularity, $\pm$ 0.6 dB, and a vertical pattern which is virtually identical to a base-fed antenna of the same height, except for a very small amount of radiation at the zenith in the plane of the slant wire feed.

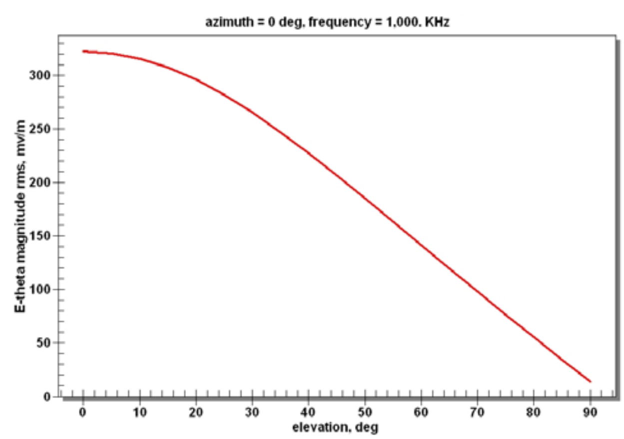

Figure 10: 90 Degree Tower Vertical Pattern in Plane of Slant Wire Feed

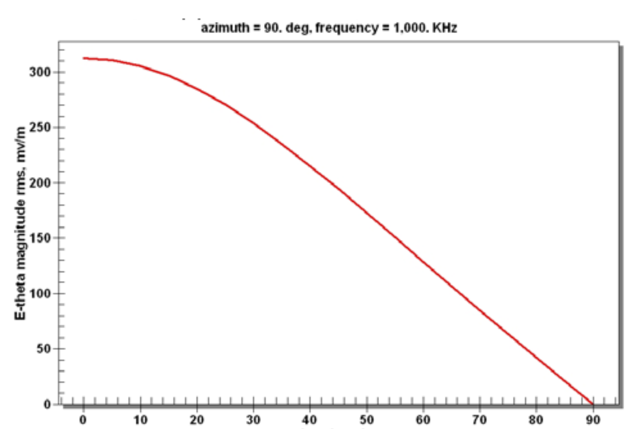

Figure 11: 90 Degree Tower Vertical Pattern Orthogonal to Plane of Slant Wire Feed

The antenna height where the use of the slant wire feed begins to produce a very modest departure from the ideal (and physically impossible) sinusoidal assumption for vertical radiators in the broadcasting services is about 120 to 135 degrees. The following example is a 120 degree large cross-section tower, whose slant wire feed is also at a 45 degree incline to the elevation which produces a resistive input of 50 ohms at its feed point.

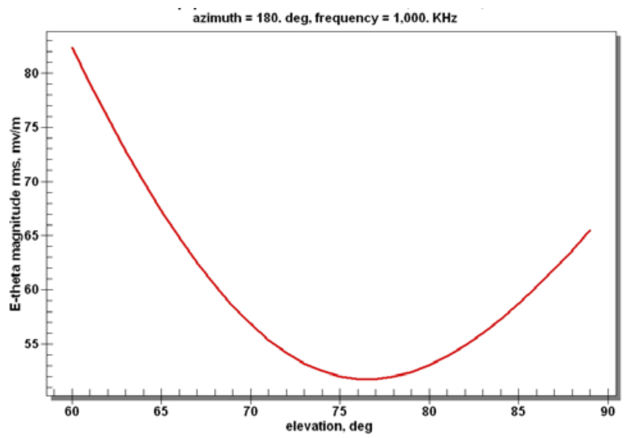

Figure 12: 120 Degree Tower Expanded Scale Vertical Pattern in Plane of Slant Wire Feed

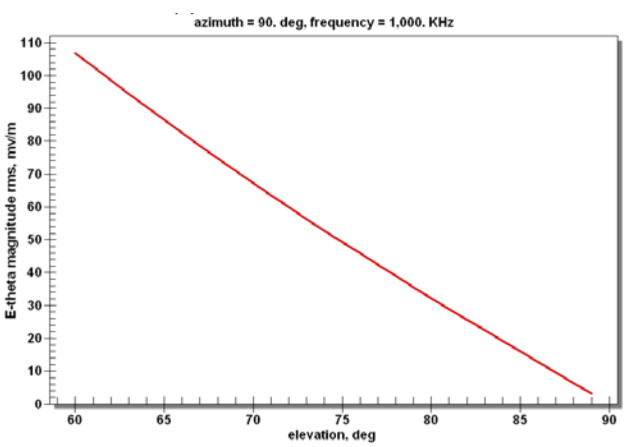

Figure 13: 120 Degree Tower Expanded Scale Vertical Pattern Orthogonal to Plane of Slant Wire Feed

THE HISTORICAL USE OF SLANT WIRE FEEDS

The two decades which followed the end of World War II experienced a great increase in medium wave broadcasting. A great many of these new broadcasting enterprises were designed to serve local areas in close proximity to the transmitting site, and, particularly in North America, many of them were authorized for operation only during daytime hours. The economics of many of these newly established facilities called for equipment installations which were as simple and economical as possible. In this situation, the low cost of a slant wire feed was attractive and the majority of slant wire feed systems in the U.S. were probably installed during this period. New broadcasting stations in less developed parts of the world proliferated, and while antenna towers were easily fabricated from simple steel components, compression base insulators were an exotic and expensive luxury, leading to the use of slant wire feeds because of their inherent simplicity and economy.

Very straightforward domestic examples of these date from the 1940's and 1950's.

Figure 14: Base Area of KLOO Antenna

This antenna dates from sometime in the 1940's and was in use until 2002. It was a straightforward wide face square free-standing tower similar to a power transmission tower, fed with a single wire from a matching unit enclosed in a cabinet at a distance of about 40 feet (12 meters) from the antenna tower.

Figure 15: Slant Wire Feed and ACU Enclosure at KBKR

This is also an installation where the antenna tower and the slant wire feed date from the 1940's, although the matching network installation is more recent.

Figure 16: Monopole and Slant Wire Lower Termination at Triplexed Antenna in Santa Barbara, CA.

In this unusual installation, three (of the total of 5) medium wave stations in this California coastal city are all "tri-plexed" into a monopole antenna, which is fed with a slant wire. It is just over one-quarter wavelength in height at the lowest of the three frequencies.

THE SLANT WIRE FEED IN DIRECTIONAL ARRAYS

Providence, RI WEAN 780/790 kHz

The best documented early use of slant wire feeds in a directional antenna array is the system used at WEAN (now WSKO) at Providence, Rhode Island. This antenna, which was originally on 780 kHz, was modified to 790 kHz as a result of the comprehensive North American Regional Broadcast Agreement ("NARBA"). It was a very closely spaced (45 degrees) two element array. It was slant wire fed from two feed points located on the line between the towers. The phase angle and modest field difference between the two feeds produced a "filled cardioid" pattern. The same pattern is still employed by this station, but the system has been a conventional series-fed arrangement since being rebuilt after a hurricane destroyed the original antenna towers in the mid-1950's. Two photographs of the original WEAN slant wire feed are contained in Sterling. [8] It is also described in some detail in a paper by Morrison. [9]

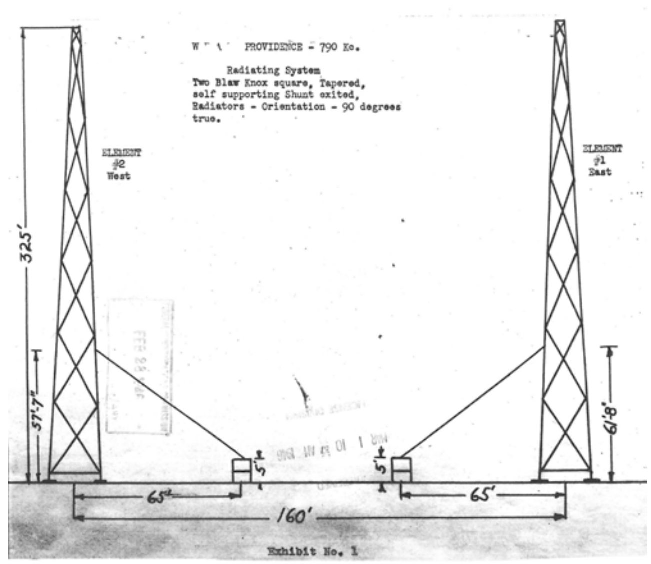

Figure 17: Drawing of WEAN Antenna System from FCC Archive Files

Dallas, TX KRLD 1040 kHz

The second example was in use for a much shorter period. This was the two element cardioid pattern employed by KRLD on its pre-NARBA frequency 1040 kHz. The history of this installation is somewhat murky. It was evidently installed about 1938, but rebuilt to a standard base-fed configuration within two or three years. The system was base-fed at the time of the NARBA frequency change to 1080 kHz in 1942, but it is not known if the change was made at that time or earlier. The reason for the change is also not known.

The system was unusual because the towers were tall, 180 degrees at 1040 kHz, and the slant wire feed was not direct. The slant wire system consisted of two parallel pairs of wires, one fed at the bottom but insulated at the tower end, the other connected to the tower but insulated at the lower end, so that they formed a capacitor, with the dimensions (and thus capacitance) "determined at the time of installation" (Bell Laboratories Dwg. ESXX614623). Since the input impedance of slant wire feeds is normally inductive and since the KRLD slant wire was directly fed from the 2 5/8 inch 65 ohm line, the "feed wire capacitor" was evidently designed to be the conjugate reactance.

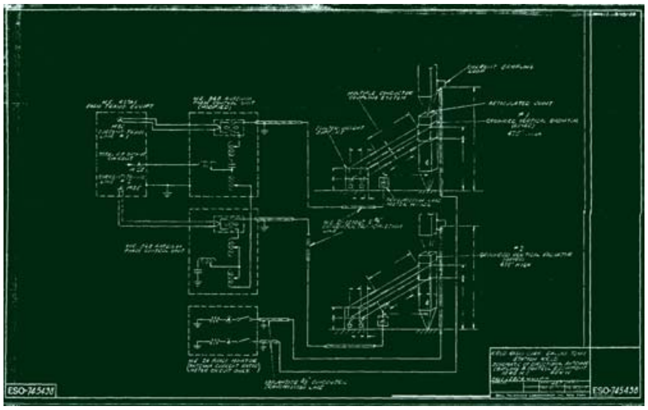

Figure 18; Bell Labs Drawing ESO-745498 for KRLD

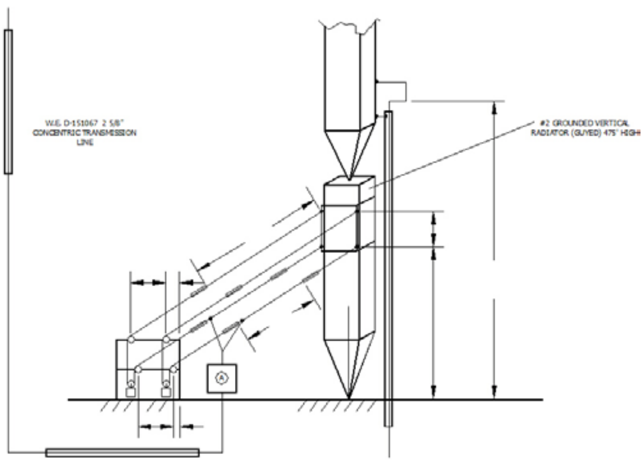

Figure 19: Detail of KRLD Feed and Parallel Wire Capacitor (Redrawn)

The complete feed system is shown in the Bell Laboratories drawing ESO-745498. A feed system of this same type, evidently also a WECO design, was employed for the 192 degree tall omnidirectional antenna system of KSL, Salt Lake City, until September, 1977.

Corvallis, OR KOAC 550 kHz

The oldest known continuously operating slant wire fed directional array is the two-pattern two-element system operated by Oregon Public Broadcasting (originally Oregon Agricultural College, now Oregon State University, hence the call letters), implemented in 1937. This system consists of two rather short (65.5 degree) self-supporting towers spaced 135 degrees. The system was originally a single pattern, employed with 5 kilowatt operation daytime and 1 kilowatt nighttime, but in 1947 was modified to employ two different patterns with 5 kw operation at all times. It has always operated on 550 kHz. The matching networks at the feed points of the slant wires are not switched between the two patterns, but the system is designed to accommodate the modest VSWR that results from inexact matching of the feed lines for the two feed conditions. The slant wire feeds are in the plane of the line of towers, but the feed points are outside rather than between the towers. Like the Zyyi BBC antenna described below, and the analysis example for an electrically short tower, the feed is to a fairly high point on the towers.

Figure 20a & b: Slant Wire Feed at KOAC

The towers in the KOAC array are fed very similarly to the short tower example given above. Here is the result of a model of the KOAC array. The horizontal plane pattern of the KOAC array is essentially the same as if it were base driven and the vertical plane pattern is also essentially identical.

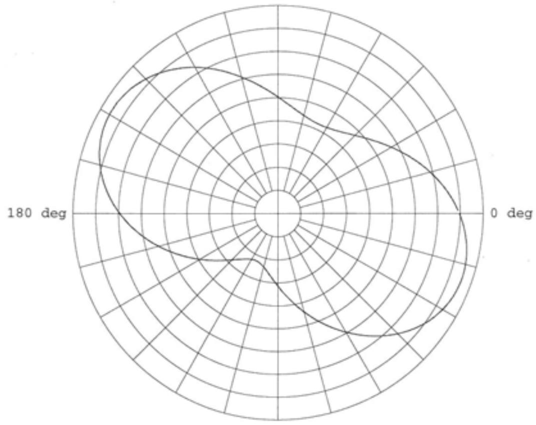

Figure 21; KOAC Horizontal Plane Night Pattern

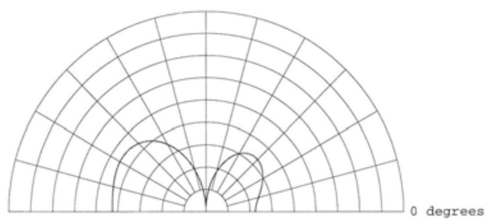

Figure 22: KOAC Vertical Plane Pattern in Azimuth of Minima (Orthogonal to Tower Line and Slant Wire Feeds)

Zyyi, Cyprus, BBC 1323 KHz

A more recently implemented use of a slant wire feed in a directive array is the 1323 kHz operation of the BBC at Zyyi, Cyprus. This 200 kW installation has a single driven radiator, with an elegant slant wire feed, and a parasitic second element. It is, so far as the author is aware, the highest power slant wire feed system in operation. It employs a multiple parallel wire feed to produce a favorable impedance condition at the feed point, and to reduce the surface voltage gradients on the feed. This antenna is used to provide the English language BBC World Service coverage well known throughout the Middle East.

Figure 23: ZYYI BBC Antenna

Figure 24: Slant Wire Feed and ACU Enclosure

INPUT FEED SYSTEM ARRANGEMENTS

Most antenna towers equipped with a slant wire feed have employed a feed system geometry constructed so that the resistive portion of the input impedance as measured at the transmission line or matching network connection is a convenient value, frequently the same value as the characteristic impedance of the coaxial feeder. In the latter case, the matching network can be a simple series capacitor whose reactance is the conjugate of the measured feeder input reactance, which is, for all practical cases, inductive. The use of a parallel but insulated feeder/capacitor arrangement, such as that shown in the KRLD example, can provide a so-called "self-tuned" antenna far more simply than the elaborate cobweb of cabling and distributed inductors used in skirt-fed arrangements which are described as "self-tuned." Optimum bandwidth may often be obtained, however, by selection of a feed point which does not match the feed line impedance. If selection of an exact input resistance is not considered necessary, one of the lower guys on a conventionally guyed tower may be used as the feeder by proper arrangement of the guy insulators. A conventional "T" or "π" network may be used to provide "line-stretching" for bandwidth improvement, a specific phase shift in a directional array, or so that one of the network arms may be used as a filter for intermodulation or harmonic suppression, as is done with base fed radiators. A feed system using two slant wires, one extending out from the tower attachment connected to the lower one which extended back to the tower base, was used to obtain a non-reactive input impedance for a facility formerly used in Germany. [10]

INPUT IMPEDANCE OF THE SLANT WIRE FEED

In general, the input impedances for slant wire fed systems for radiators in the range of heights from about 75 to 145 degrees exhibit very satisfactory VSWR over the range ±10 kHz. As is the case with very short base-fed radiators, the ±10 kHz VSWR deteriorates for very short towers. Typical examples measured at the slant wire input are:

Tower	VSWR	VSWR	Type of Tower
Height	+10 KhZ		-10 kHz
145°	1.18:1	1.19:1	Tapered Self Supporting
123.5°	1.05:1	1.04:1	Guyed Uniform Cross Section.
106.1°	1.06:1	1.09:1	Tapered Self Supporting
90.5°	1.04:1	1.04:1	Guyed Uniform Cross Section
73.6°	1.09:1	1.13:1	Tapered Self Supporting

These values are essentially indistinguishable from those of many base-fed or skirt-fed towers of the same general geometry.

The input bandwidth of the feed system of directional arrays is highly dependent upon the feed system design, so it's not possible to generalize about array input impedance bandwidth beyond noting that the mutual impedances among elements in a directional array are not dependent upon the feed system, and that therefore a well designed array of shunt fed elements should exhibit good input impedance characteristics, just as series fed systems often can be designed to do. The one set of comparison data available is for the original shunt fed WSKO (WEAN) array versus the replacement series-fed system. The replacement array used the original phasing and branching equipment with the addition of new networks for impedance matching at each of the tower feeds. The original system had a 10 kHz lower sideband VSWR of just under 2:1 and a 10 kHz upper sideband VSWR of 1.15:1. The characteristics of the replacement series fed system were substantially less favorable, with sideband VSWR's of 2.34:1 and 1.78:1 respectively. Given the tight (45 degree) spacing of the elements in this array, these are not remarkable for the time and for the type of phasing and branching equipment which was used.

ADVANTAGES OF THE SLANT WIRE FEED SYSTEM

The major advantage of a slant wire feed system is its mechanical simplicity. Because the antenna structure can be grounded no base insulator is necessary. But, unlike skirt feed systems, the use of a slant wire feed does not require substantially greater tower strength just to accommodate the feed. Additionally, skirt fed systems are vulnerable to the effects of adverse weather in both hot and cold climates. Any skirt fed system that which is located in an area of tropical or even temperate zone storms must be constructed with high mechanical tension on the skirt wires or many skirt-wire support insulators, or a combination of both, and in areas of ice formation in winter the total structure must resist not only the weight of ice but its substantial additional windload. These mechanical considerations can result in very substantial additional cost for towers designed for use with for skirt feeds, costs which may exceed the substantial cost of high quality base insulators. In marked contrast, slant wire feeds result in trivial additional mechanical load on antenna towers, allowing many existing structures to be used as medium wave radiators at little or no additional cost, or allowing original installation and use of economical but fully mechanically adequate structures as medium wave antennas

CONCLUSION

The use of slant wire shunt feed arrangements for driving grounded vertical radiators has fallen into disuse and even disrepute for historical reasons that are shown to be invalid for most situations. Many long established systems of this type have provided excellent performance and reliability. In situations where the antenna tower height is modest, less than about 135 or 140 degrees, and where insulator and structural costs for a base fed or a skirt fed system would contribute substantial cost, a slant wire feed should be considered. This includes situations where a self-supporting tower would require multiple base insulators, and those where severe weather would impose substantial additional strength requirements on a tower fed by a skirt system. The informal regulatory prohibition of use of slant wire feeds for nighttime operation in the U.S. should be rescinded for antenna heights less than 120 degrees, or for taller radiators where accurate numerical modeling shows compliance with allocation standards. Slant wire feeds should also be considered for use with simple directional arrays where numerical modeling shows they would be practical and capable of adjustment to meet allocation standards.

ACKNOWLEDGMENTS

The assistance of various colleagues in gathering obscure data and helping in analysis of it was essential to the preparation of this paper. Paul W. Leonard, P.E, performed much of the MININEC analysis, and Jack Sellmeyer, P.E., and Robert McClanathan, P.E. provided historical data from their files. John Webber of Merlin Communications provided photographs and data for the BBC Zyyi antenna

and John Sykes of BBC graciously consented to their use. The Pacific Northwest states have or have had a relatively large number of slant wire fed antennas due to their extensive use in the 1940's and 1950's by Grant Feikert, P.E.; Harold Singleton, P.E.; and J. B. Hatfield (Sr.), P.E.

REFERENCES

[1] The Shunt-excited Antenna, John F. Morrison and Phillip H. Smith, Proceedings of the IRE, vol. 25, pp. 673-696, June 1937.

[2] W. L. Weeks, Antenna Engineering, New York, McGraw-Hill, 1968, pp. 164-167

[3] B(enjamin) Whitfield Griffith Jr., Radio Electronic Transmission Fundamentals. New York, McGraw-Hill, 1962 and Atlanta, Noble Publishing, 2000.

[4] Current Distribution and Radiation Properties of a Shunt-Excited Antenna, Pierre Baudoux, Proceedings of the IRE, pp. 271-275, June 1940

[5] Experimental Comparison of Shunt- and Series - Excitation of a High, Uniform Cross-Section, Vertical Radiator, K. A. MacKinnon, Canadian Journal of Research, Vol. 17, pp. 227 - 236, December, 1939.

[6] Edmund Laport, Radio Antenna Engineering, New York, McGraw-Hill, 1952

[7] Howard Head, Chapter 20, "Medium Frequency Broadcast Antennas" in Jasik, Henry, ed. Antenna Engineering Handbook, New York, McGraw-Hill, 1961

[8] George E. Sterling, The Radio Manual, 3rd Ed., Van Nostrand, New York, 1938

[9] Simple Method for Observing Current Amplitude and Phase Relations in Antenna Arrays, John F. Morrison, Proceedings of the IRE, vol. 25, no. 10, pp. 1310-1326, October, 1937.

[10] http://www.waniewski.de/MW/Bremen/bremen_mw_1en.htm

[11] Relative Tower Currents and Fields in an AM Directional Array, James B. Hatfield, IEEE Transactions on Broadcasting, vol. 35, No. 2, June 1989.

[12] CCIR Report 1015, 1986.

APPENDIX: Radiation pattern "distortion" by slant wire feeds and the resulting effects on interference calculation for allocation purposes.

As the historical authorities and the moment method modeling results described in this paper show, the horizontal plane patterns of typical slant wire fed antennas of modest height are essentially indistinguishable from those of base-fed radiators of the same geometry.[1]

The current in the slant wire feed which produces modest horizontal plane pattern non-circularity also results in very minor distortion of the vertical plane radiation pattern, particularly when compared to the fictitious results from assumed sinusoidal current distribution. This distortion, shown in the plotted data, is significant only at very high vertical angles and for relatively tall towers or for slant wire feeds that have a quite elevated feed point and substantial angle to the vertical. But this vertical pattern shape is unusual only by comparison to the cosine pattern which is assumed in allocation policies to be the result of sinusoidal current distribution in vertical radiators. The current distribution in vertical radiators is not sinusoidal (if it were they would not radiate!) a fact that can be demonstrated easily by measurements. Current distribution in the elements of typical directional arrays is shown, for example, in a study by Hatfield. [11]

A further deficiency of the assumption of sinusoidal current distribution for allocation purposes is the detuning of unused elements in a directional array by conjugate reactance loading. While this can reduce horizontal plane reradiation to very low values, it can have substantial adverse effects on vertical patterns from the array, often resulting in actual fields far in excess of those predicted by the usual sinusoidal assumptions.

An additional concern is the very small amount of horizontally polarized radiation caused by the current in the slant wire's horizontal aperture. This too is trivial from an allocation standpoint. In the KOAC night array, for example, the broadside V polarized radiation is maximum in the horizontal plane and diminishes to essentially zero at the azimuth. The H polarized component is so far less except for the one or two degrees from vertical as to be unimportant. And the skywave allocation implications of the radiation above 75 degrees extend only to a distance of about 50 km, a distance important only for fade zone calculations and not allocation conditions. Further, in the latitudes of North America (and Europe) the effects of excess polarization coupling loss reduce the implications of H polarized signals by at least 10 dB and often more. [12][2]

[1] Omnidirectional radiators which are one element of a directional array frequently exhibit as much as +/- 2 dB of non-circularity

[2] My appreciation to Dr. Phillip Knight for pointing this out