Generalized CoCo Antennas

Branislav M. Notaroš,[1] Miroslav Djordjević,[2] and Zoya Popović[3]
[1]Colorado State University, ECE Department, notaros@colostate.edu
[2]University of Massachusetts Dartmouth, ECE Department, miroslav@ieee.org
[3]University of Colorado at Boulder, ECE Department, zoya@colorado.edu

Abstract – This paper presents recent contributions to the theory and design of generalized colinear (GeCo) transmission-line antennas. The main feature of these narrowband antennas, which radiate essentially as colinear arrays of wire dipoles driven in phase, is their extremely simple feed. They are excited at a single port, but behave as if excited at a number of ports. This is achieved by making the antenna in the form of series-connected segments of asymmetric two-conductor lines, with alternating 180-degree phase shifts at the series connections. The classical coaxial collinear (CoCo) antenna, made of sections of coaxial cable, is a special case of this new, much broader, antenna class. The paper presents generalized colinear antennas implemented in a multitude of forms, and some designs have properties that cannot be achieved with conventional CoCo antennas. Examples include antennas made of different combinations of asymmetric strip lines and two-wire lines with "inverse connections" between the segments, as well as printed antenna arrays based on the CoCo concept. The analysis of GeCo antennas is carried out using the method of moments. Numerical and experimental results are shown to be in reasonable agreement.

1. Introduction

The coaxial colinear (CoCo) antenna, introduced in 1956 by H. A. Wheeler [1], has been used over the past few decades mostly in atmospheric and ionospheric radar applications, e.g., for wind profilers, as well as in commercial communication applications. The CoCo antenna is inherently narrowband, and as such intended for practically single-frequency operation. It radiates essentially as a colinear array of wire dipoles driven in phase, providing a narrow broadside beam and an omnidirectional pattern in the plane perpendicular to the antenna axis. It is used both as an isolated antenna element and in large arrays [2-10].

The CoCo antenna consists of a sequence of colinear sections of a coaxial cable that are half-wave long (measured in terms of the guided wavelength). The antenna has a single simple feed, but the driving voltage is transmitted to the secondary "ports" of the assembly (ports between adjacent segments of the antenna) via cable segments, which are half of a guided wavelength long. The inner and outer conductors of one segment are connected to the outer and inner conductors of the next segment, respectively. With this, approximately cophasal current distribution along the outer surface of the coaxial-cable segments (the antenna radiating current) is obtained.

In 1996-1998, based on a new understanding of the physical basis of operation of the CoCo antenna, we proposed a new wide class of cophasal antenna arrays with simple compact feeds, with the classical CoCo antenna being just a special case and one of many realizations, not at all based on the coaxial-cable geometry [11-13]. Since such antennas are excited at a single port, but behave as if excited at a number of ports, we refer to them as OPOMEX (One-Port-Multiply-Excited) antennas, or simply as generalized colinear (GeCo) antennas. The OPOMEX antenna concept has subsequently been used by other authors [14, 15]. It is important to have in mind that, in all applications, the main advantage of using both classical and generalized CoCo antennas for narrowband operation is their extremely simple feed. For example, it was shown that an electronically reconfigurable OPOMEX antenna for diversity wireless communications can exploit spatial diversity in a multipath channel using only a single simple feed (which is not a lossy dispersive corporate feed) and a single low-noise amplifier [16].

This paper presents several forms of generalized colinear antennas, using segments of transmission lines of several types, with the two conductors in a segment having different equivalent electrical radii. Examples include antennas made of different combinations of asymmetric strip lines and two-wire lines with "inverse connections" between the segments, as well as printed antenna arrays based on the CoCo concept. The analysis of GeCo antennas is carried out using the method of moments (MoM). In particular, we use WireZeus, a computer program for analysis of wire antennas and related radiating structures [17]. WireZeus can very effectively analyze a number of forms of OPOMEX antennas, including narrow-strip versions, possibly printed on a thin dielectric substrate. We present two independent techniques, based on using WireZeus, for the analysis of GeCo antennas: (i) a direct numerical method (direct use of WireZeus to model GeCo antennas as wire antennas) and (ii) a multiport-network method (with a use of WireZeus to compute the admittance matrix of the antenna multiport network) [13]. Numerical and experimental results are shown to be in reasonable agreement in all cases.

We show that GeCo antennas can have properties that cannot be achieved with CoCo antennas. For example, numerical optimum of sidelobe levels for a 2 × 5-element free-space CoCo antenna appears to be at the most –14 dB. A 2 × 5-element GeCo antenna is described in the paper, obtained by numerical optimization, for which all sidelobes are at a level of –25dB or less. As another example, it is possible to design GeCo antennas having very high and approximately real impedance (over 1 kΩ), which does not appear possible with CoCo antennas. Such high values of impedances are of interest when feeding several GeCo antennas in parallel in a two-dimensional aperture.

2. Principle of Operation of Generalized CoCo Antennas

Consider first the classical CoCo antenna, consisting of a sequence of collinear sections of a coaxial cable (Fig.1). The lengths of segments are approximately half a wavelength along the line. The segments are transposed, i.e., the inner and outer conductors of one segment are connected to the outer and inner conductors of the next segment, respectively. We will refer to the cable interconnections as "ports". The last cable segment is short-circuited at a distance of about a quarter-wavelength (along the line) from the interconnection with the preceding segment. The last port along the collinear antenna then sees an open circuit in that direction. Since all the preceding segments are (approximately) half-wave long, this high impedance as seen by the line towards the ends of the antenna arms will be transmitted to the generator. As can be observed from Fig.l, all the ports then have a voltage of amplitude and phase (with respect to the indicated reference direction) close to the antenna driving voltage. Approximately cophasal current distribution along the outer surface of the coaxial segments (the antenna radiating current) should therefore be expected. Of course, the same effect can be obtained if the last segment is half a wavelength long (along the line) and open-circuited.

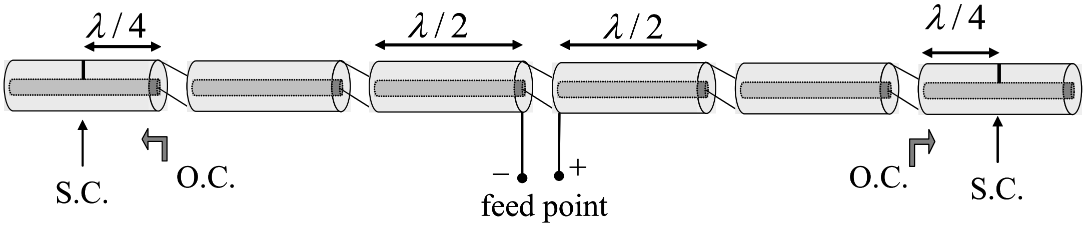

Figure 1. *Sketch of a classical CoCo antenna. The excited port is referred to as the feed port, while the places where the cable sections are connected are referred to as "ports".*

In order to answer a simple question—why an antenna made of a cable would radiate at all—we first realize that it consists, in fact, of two antennas, one within the other (the inner and outer coaxial-line conductors), connected to the same feed point and source. The currents in the two antennas are in opposite directions. Transposition of the coaxial-line conductors at certain intervals does not change the propagation along the line, and is intended to produce proper voltages across the gaps between adjacent line segments. It is a simple matter to conclude that if the characteristic impedance of the coaxial-line sections were made to approach zero (i.e., the radius of the inner conductor to approach that of the outer conductor), the CoCo antenna would not radiate any more. This indicates that the CoCo antenna radiates because the two parallel antennas which make it have different current magnitudes at the feed, i.e., the feed-port currents are unbalanced.

Consequently, antennas of the form shown in Figs.2(a) and (b), made of close segments of wires of different radii, will have properties similar to those of a CoCo antenna [13]. Indeed, the antenna in Fig.2(a) can be considered as obtained from that in Fig.1 by "pulling out" the inner line conductors and placing them outside and parallel to the outer conductors. Voltages will therefore appear between the two thicker (and two thinner) conductors at the ports. The antenna will behave as if excited not only by the actual generator, but also by concentrated voltage generators at all the ports.

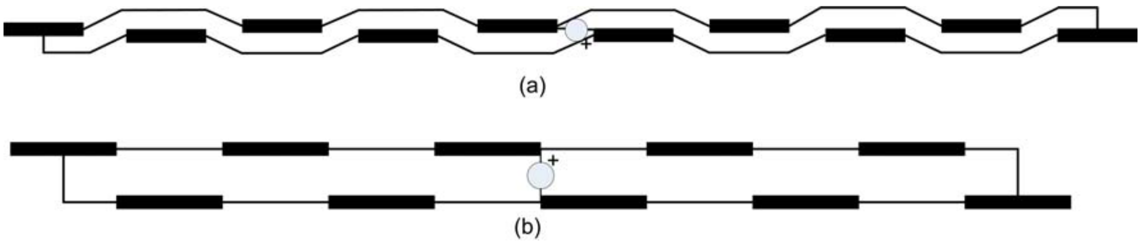

Figure 2. *Two possible forms of the GeCo antenna. Both forms (a) and (b) are constructed of segments of two-wire lines with conductors of different radii or with strips of different widths.*

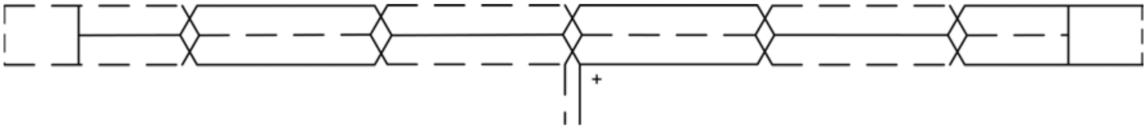

Figure 3. *Another possible form of the GeCo antenna. The antenna is constructed of wire segments of the same radius. The planes of the two antenna parts (indicated in solid and in dashed lines) are separated by a small distance.*

This in turn means that the GeCo antennas can be constructed in a multitude of forms, which only must comply with the general philosophy mentioned. For example, another antenna of this type, constructed entirely of the same wire, is sketched in Fig.3. With the GeCo antennas we have a number of relatively easily adjustable parameters. For example, if the conductors in Fig.2 or Fig.3 are wires, there is a wide range of available wire radii, and we can choose the distance between them in a relatively wide range. Further, the GeCo-antenna conductors need not be round wires. For example, one conductor may be tubular (of any cross-section, not necessarily circular), and the other a thin wire running parallel to the tube, outside it or inside it. If placed inside the tube, it need not run along the tube axis, as it does in CoCo antennas. The two conductors may also be strips of different widths, which is very simple to obtain. The strips can be glued onto a styrofoam support, on the same side or on the opposite sides of the support, with the propagation coefficient of the equivalent line being very nearly that for air. Alternatively, they can be printed on a thin dielectric substrate, in which case the propagation coefficient may also be a parameter for design. The strips can be printed on the same side or on the opposite sides of the substrate; in the latter case, the strips need not be staggered, but may be one above the other.

3. Modeling and Analysis of GeCo Antennas

In principle, generalized coaxial colinear antennas of the forms shown in Figs.2 and 3, as well as of some other suggested forms (including printed versions), can be analyzed as wire structures, using the method of moments. However, one should be aware of the fact that most wire-antenna MoM analysis programs, assume a uniform current distribution around the wire circumference. For GeCo antennas this is not a good assumption, since the thick and thin wires of any GeCo segment are quite close (axis-to-axis distance on the order of the diameter of the thick wire). In addition, we have interconnections of wires with greatly differing radii, which is difficult to accurately take into account. Finally, the radius of the short segment with the generator influences significantly the antenna susceptance. Consequently, although techniques for direct analysis of wire antennas can be used for approximate analysis of GeCo antennas, one cannot expect very accurate results, in particular for the antenna impedance.

On the other hand, we can perform a modified wire-antenna analysis of GeCCo antennas based on the multiport-network theory [13]. To this end, we first realize that the thick and thin wires (or wide and narrow strips, etc.) form an (asymmetrical) transmission line. The principle of superposition can then be applied to decompose the current in thick wires (I_{thick}) as follows:

$$I_{\text{thick}} = -I_{\text{thin}} + \Delta I \, . \tag{1}$$

The first component ($-I_{\text{thin}}$) is equal to the current in the adjacent thin wire, but in the opposite direction. This is a transmission-line current, and since the line conductors are very close, it practically does not radiate. The other component (ΔI), i.e., the unbalanced part of the total current in the thick wires is the actual radiating current.

We next note that in both Figs.2 and 3 the points of the wire transposition can be considered as additional ports, with unknown voltages. We also note that these voltages are "connected" (measured) between the antenna segments (i.e., thick-wire segments) on one hand and between the transmission-line conductors on the other hand. This is sketched in Fig.4. The transmission-line assembly and the antenna assembly of a GeCo antenna can be considered as two multiport networks connected in parallel. This parallel connection can, in turn, be considered as a single equivalent multiport network. It is evident from Fig.4 that in the ports of the equivalent network there is current only in the actual excitation port (labeled 1), while the other (additional) ports of the equivalent multiport network are open-circuited.

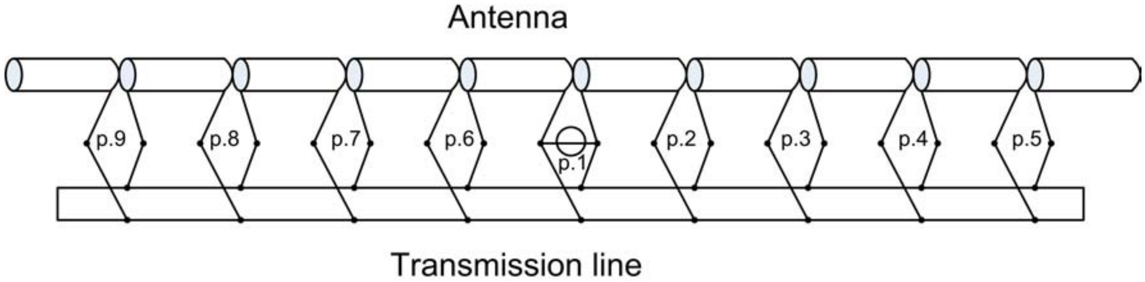

Figure 4. *The GeCo antenna represented as a parallel connection of two multiport networks, with common ports (p.1, p.2, ...). If this combination is considered as a single equivalent multiport network, all ports of the equivalent network except p.1 are open-circuited.*

Based on this reasoning, it is possible to develop another approximate method for the analysis of GeCo antennas (which can also be used for the analysis of CoCo antennas). Briefly, the currents at the transmission-line multiport-network assembly can be represented as

$$\left[I_{\text{line}}\right]=\left[Y_{\text{line}}\right]\left[V\right] , \tag{2}$$

where $[Y_{\text{line}}]$ is the transmission-line admittance matrix. The elements of this matrix can be calculated with relative ease from the transmission-line equations. The left-hand side of Eq.(2) is a single-column matrix of currents at the transmission-line ports, and $[V]$ is the matrix of voltages at these ports.

The currents at the ports of the antenna multiport network can likewise be expressed as

$$\left[I_{\text{antenna}}\right]=\left[Y_{\text{antenna}}\right]\left[V\right] . \tag{3}$$

The admittance matrix of the antenna multiport network, $[Y_{\text{antenna}}]$, can be obtained only numerically, and requires a full numerical analysis of the antenna. The evaluation of $[Y_{\text{antenna}}]$ is therefore incorporated in the method-of-moments analysis (an in-house code WireZeus). Here, we need to determine the antenna-assembly equivale.nt radius prior to the analysis. It is not difficult to conclude that, by decomposing the total current into the transmission-line current and the antenna current, we are left with the thick-wire assembly as the antenna. Therefore, the equivalent radius of the thick wire should be used as the antenna wire radius [17].

Referring to Fig.4, the total currents at the ports of the equivalent multiport network are obtained from the following matrix equation:

$$[I] = ([Y_{\text{line}}] + [Y_{\text{antenna}}])[V] = [Y_{\text{equivalent}}][V] \ , \tag{4}$$

where the sum of two admittance matrices represents the admittance matrix, $[Y_{\text{equivalent}}]$, of the network obtained as the parallel connection of the transmission-line and the antenna multiport networks. As explained, all ports except p.1 of the equivalent network are open-circuited, so that all the elements of the column matrix $[I]$ are zero except the first one,

$$[I] = [I_1 \ 0 \ 0 \ \cdots \ 0]^{\mathrm{T}} \ , \tag{5}$$

and that is the total current in the generator. We can assume any current I_1 in port 1, and solve for voltages $V_1, V_2, \ldots, V_{N+1}$ (N+1 is the total number of ports). The GeCo-antenna impedance is then obtained as

$$Z_{\text{GeCo}} = \frac{V_1}{I_1} \ . \tag{6}$$

Note that this impedance is, in fact, the parallel connection of the impedance of the antenna proper and the transmission-line assembly. This impedance is observed by the generator.

If the relative port voltages are known, the voltages that drive the antenna proper are known as well. We can assume any voltage at the input antenna port, scale the other voltages accordingly, calculate the antenna current distribution, and hence the antenna radiation field. [Note that the impedance of the antenna proper calculated in this manner is not the impedance of the GeCo antenna from Eq.(6).]

To make a qualitative comparison between the two presented methods for the analysis of GeCo antennas in terms of the accuracy of the simulation, we note that the excitation zone in the two models is quite different. In the direct method (direct use of a numerical solver, in this case MoM WireZeus program), a delta-function generator is connected at the starting point of a short segment of the thin wire. This segment, in turn, is connected in a complex way to the adjacent thin and thick antenna segments. In the multiport-network approach, the antenna proper is excited between two thick wire segments by a delta-function generator. The excitation mechanisms being so different, we cannot expect excellent agreement in the antenna impedance obtained by the two methods. We can expect, however, relatively good agreement of the radiation patterns. We can also expect that both methods should predict the antenna operating frequency with reasonable accuracy.

Finally, note that the GeCo antenna general philosophy is intuitive and can easily be exploited in different practical realizations also starting from the network model of a standard antenna array feed shown in Fig.5(a). In this model, an *N*-port antenna array is excited by an (*N*+1)-port feed network with a generator at one port. However, we can add one port to the antenna array to make it a (*N*+1)-port network as indicated in Fig.5(b), and then, to make it as simple as possible, open-circuit all other ports – this is a GeCo or OPOMEX antenna (see Fig.4). So, the antenna indeed does not have to be based on the coaxial-line geometry, but on any other structure that allows this type of network-feed interconnect.

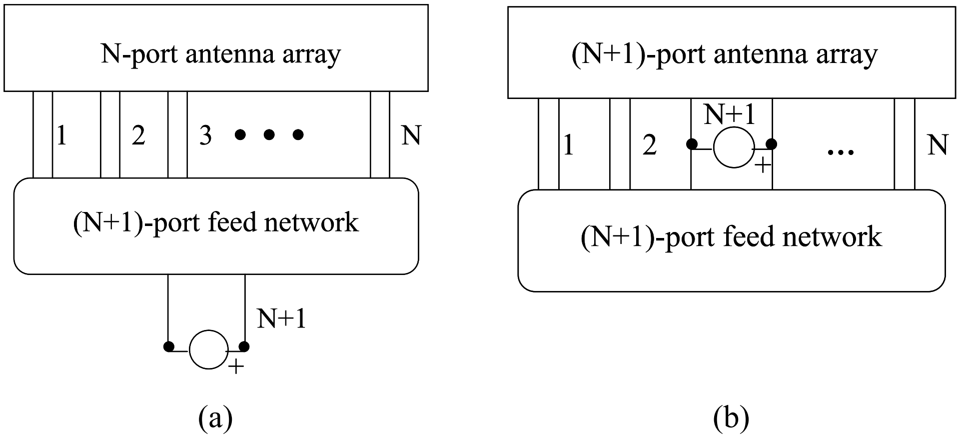

Figure 5. *Principle of operation of generalized coaxial colinear antennas based on the network model of a standard antenna array feed with a generator at one of the ports of the feed network (a), which can be transformed into a GeCo or OPOMEX antenna by adding a generator port to the antenna array network and open-circuiting all other ports for simplicity (b).*

4. Specific GeCo Antenna Designs

4.1. Two-Wire-Line Colinear Antenna

The first example of a GeCo antenna design is a two-wire-line colinear antenna of the form shown in Fig.2(b). The antenna is composed of 2 × 5 segments, radii of the thick and thin wires are 0.9 cm and 0.5 mm, respectively, and the distance between the wire axes is 2 cm. The characteristic impedance of the two-wire-line segments is about 255 Ω, which cannot be implemented with a coaxial cable. The design objective is to obtain an antenna that operates at 300 MHz, matched at 200 Ω, and with a high gain in the E-plane.

Interactive optimization is used in conjunction with each of the two methods for analysis of GeCo antennas described in the previous section, with the segment lengths (including that of the last, short-circuited segment) as the optimization parameters. The optimal antennas obtained by the two methods are of somewhat different dimensions. The direct method (full-wave analysis) results in the first four segment lengths of 48.5 cm, the length of the last segment 42 cm, and the length of the short-circuited segment of 20 cm. With the indirect method (the use of multiport-network approach), these lengths are 45 cm, 45 cm, and 24 cm, respectively. The simulation results for the two optimal antennas are summarized in Fig.6. It is seen that the two antennas have similar VSWR's and gains. This indicates that the results obtained by the two methods are in a reasonable agreement, and that, in general, both methods should be used in the CAD of GeCo antennas, to get an insight into possible errors in each of the methods.

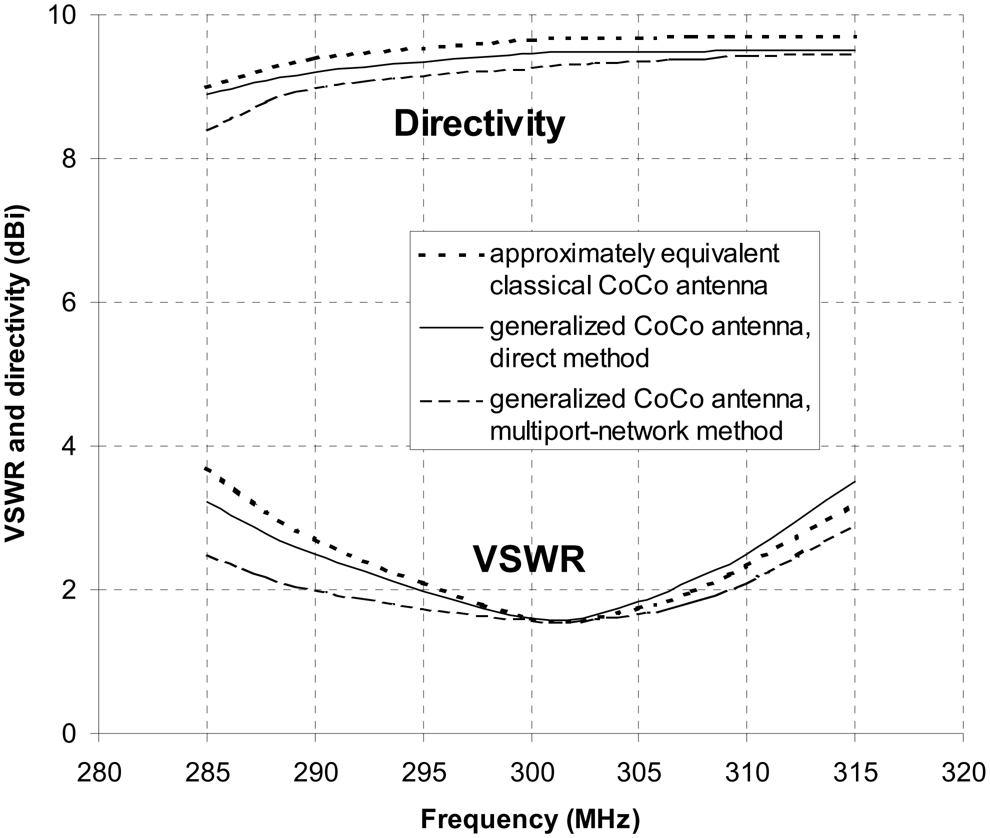

Figure 6. *Directivity and VSWR (with respect to 200 Ω) of the 300-MHz optimized GeCo antennas described in the text using the direct method and multiport-network method, respectively. Also shown are directivity and VSWR (with respect to 50 Ω) for an approximately equivalent classical CoCo antenna, made of commercial coaxial-line segments and described in Subsection 4.2.*

Fig.7 shows the co-polarized E-plane radiation pattern of the GeCo antenna obtained by the direct analysis method. Note that the largest sidelobe is about −13 dB below the main lobe. The antenna is bi-directional.

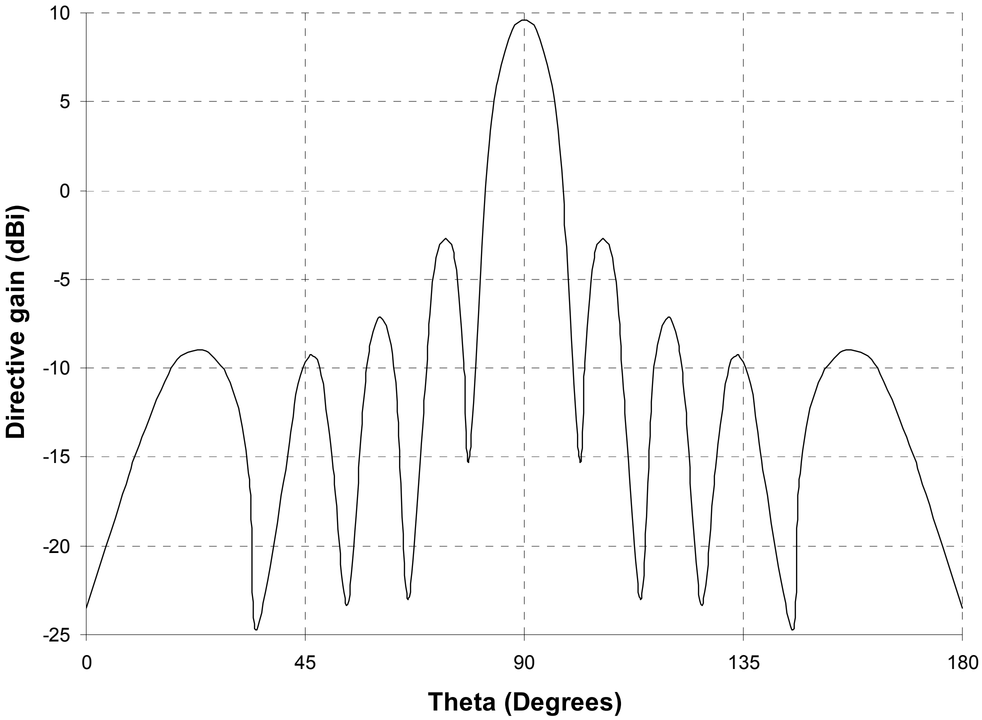

Figure 7. *Radiation pattern in the plane containing the long axis of the 300-MHz GeCo antenna described in the text, calculated by the direct analysis method.*

4.2. Comparison of GeCo and Classical CoCo Antennas

It is of considerable interest to compare the results of the preceding example with those for a true CoCo antenna (made of sections of a realistic coaxial line). Note that the results of the multiport-network method in the preceding example correspond to those for a CoCo antenna made of line segments with a characteristic impedance $Z_0 = 255\ \Omega$ situated in air. This can, in principle, be also a coaxial line. However, such a high characteristic impedance is obtained for the ratio of radii of outer and inner coaxial-line conductors of about 70, which is not commercially available and is quite difficult to realize. Our goal is to design a CoCo antenna made of sections of an available coaxial line. Therefore, the following coaxial-line parameters are adopted: $Z_0 = 75\ \Omega$, $v/c = 0.67$, and the line attenuation constant $\alpha = 0.03$ dB/m.

Since the wavelength along this coaxial line is only 0.67 that in free space (assumed in the preceding example), to obtain approximately the same gain it is necessary to adopt the length of the CoCo antenna to be about the same as before, i.e., about $2 \times 5 \times 45$ cm = 450 cm. Therefore the CoCo antenna is adopted with 2×7 segments, each 33.5 cm long (i.e., half a wavelength along the line at 300 MHz), making a total length of 469 cm. The length of the short-circuited line segments is adopted to be half this length (16.7 cm).

The computed VSWR (with respect to 50 Ω) and gain of this antenna are shown in Fig.6 along with the results for the two optimized GeCo antennas described in Subsection 4.1. It can be observed from the figure that this approximately equivalent CoCo antenna has very nearly the same properties as the GeCo antennas. This conclusion is found to be true in many other cases of parallel analysis of CoCo and GeCo antennas. However, GeCo antennas not only can be made of lines having practically arbitrary characteristic impedance, but this impedance can also be varied very easily between the segments of an antenna if desired. For example, this is a valuable tool for controlling sidelobe levels, as the next example will demonstrate.

4.3. GeCo Antenna with Minimized Sidelobes

As explained, the two-wire-line colinear antennas in Figs.2(a) and (b) will practically not radiate if made of conductors of the same radius; a difference in radii of the line conductors is essential for the GeCo-antenna operation. One can expect, therefore, that the antenna current component along the GeCo antenna can be tapered if the difference in the conductor radii (or in strip widths) is decreased towards the antenna ends. The following numerical example will show theoretically that this is indeed true. In Subsection 4.5, a fabricated printed GeCo antenna of this type will be described and it will be shown that the measured results also confirm this reasoning.

A printed antenna for 3 GHz is considered using the direct method, with the objective to design an antenna with minimized sidelobes. The antenna shown in Fig.2(b) can also be considered to be made of strips printed on a thin dielectric substrate. This type of GeCo printed antenna is optimized interactively using WireZeus, in order to obtain the best possible match, possibly with added narrow-band matching network, and as low sidelobes as possible. The antenna is assumed to be printed on a 0.508-mm substrate with $\varepsilon_r = 2.17$, having 2 × 5 sections. The distance of the axes of the printed strips is adopted to be 5 mm, and their lengths 44 mm. The distance of the short circuit from the last interconnection is 22.2 mm, and the distance from the short circuit to the array end 24 mm. The width of all the narrow strips (including the ones that contain the generator) is 0.3 mm. The optimization of the widths of the wider strips results in widths of 3 mm, 2.8 mm, 2.3 mm, 1.5 mm, and 0.5 mm, starting from the feed point. The antenna matching network is simultaneously optimized, with the objective that at 3 GHz the antenna is well matched to 50 Ω.

The optimized antenna radiation pattern in the plane containing the long antenna axis is shown in Fig.8. Comparing the sidelobe levels in Figs.7 and 8, it is concluded that the sidelobes in Fig.8 are more than –25 dB below the main beam, while in Fig.7 they are only about –13 dB below the main beam. Note that the latter result corresponds approximately to that for the classical CoCo antenna, where it is practically impossible to suppress the sidelobes by more than about –14 dB. The compensated optimal antenna VSWR is about 1.14 at 3 GHz, and below 2.2 in the frequency range (3.00 ± 0.02) GHz.

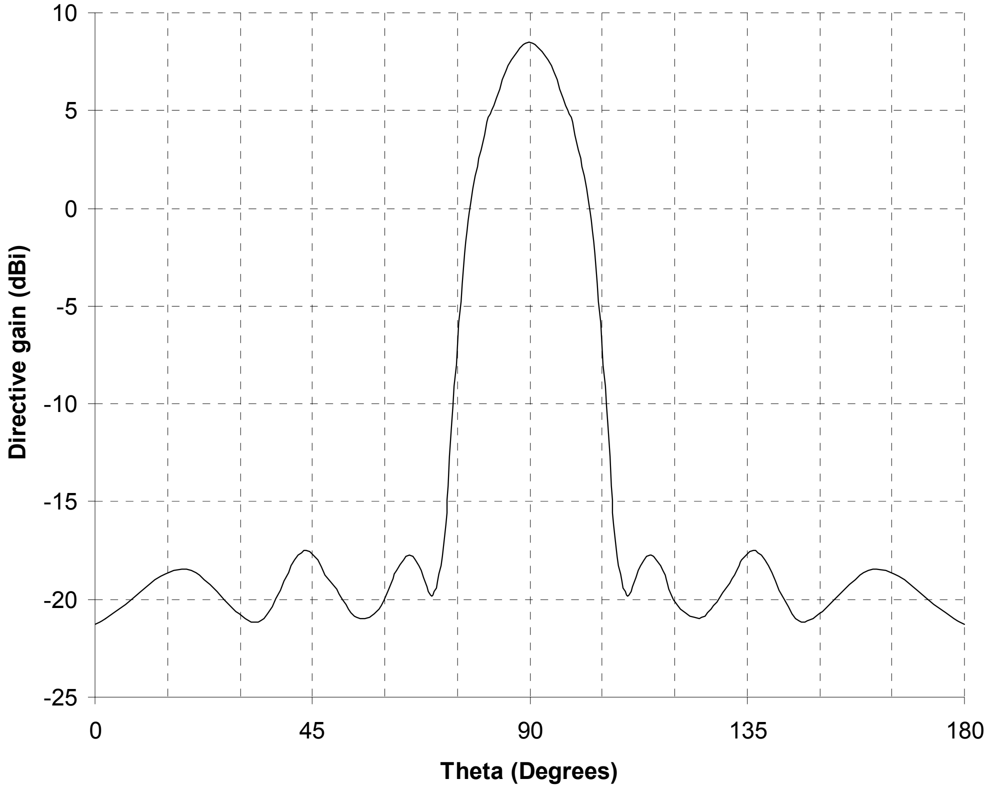

Figure 8. *Directive gain of the 3-GHz printed GeCo antenna optimized for low sidelobe levels, calculated by the direct method.*

4.4. Quasi-GeCo Strip Antenna

As the next example and another check of the accuracy of the direct analysis method, consider the structure sketched in Fig.9, which represents a half of the antenna in Fig.2(b), mounted above a ground plane. The structure is manufactured from thin wires and thin rectangular strips. It is glued on a styrofoam support, and the thin-wire conductor is connected to the inner coaxial line conductor protruding through the ground plane. Note that this is not a GeCo antenna, since the image of the wide conductor in the ground plane is also a wide (instead of a narrow) conductor, and the image of the thin conductor is also a thin (instead of a wide) conductor. However, this configuration enables measurement of the impedance for a structure that is very similar to the GeCo antenna.

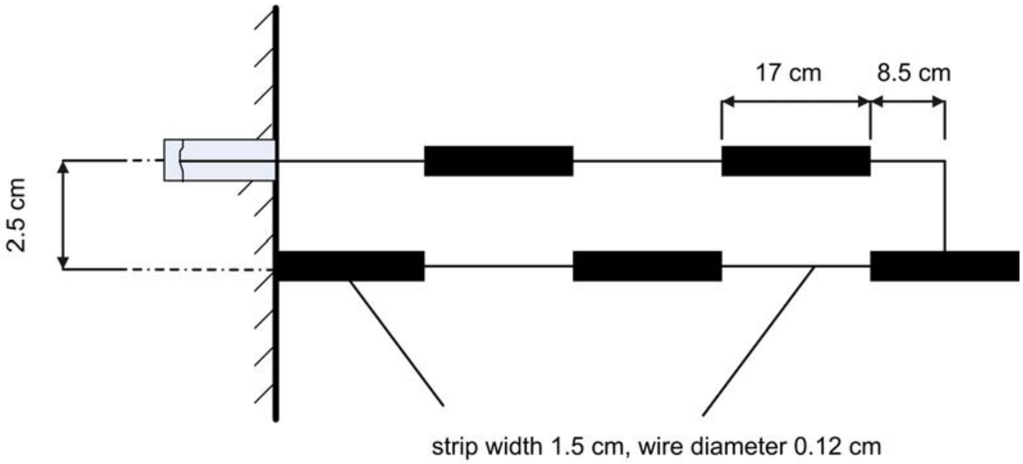

Figure 9. *Sketch of a half of the GeCo antenna in Fig.2(b) (with dimensions), mounted on a ground plane.*

Fig.10 shows the theoretical and measured VSWR of the antenna, with respect to 50 Ω. The theoretical results are obtained using the direct method, and are corrected for the estimated difference in the capacitance between the generator model (delta-function generator) and the actual N-connector used in measurements. Good agreement between the two sets of results can be observed.

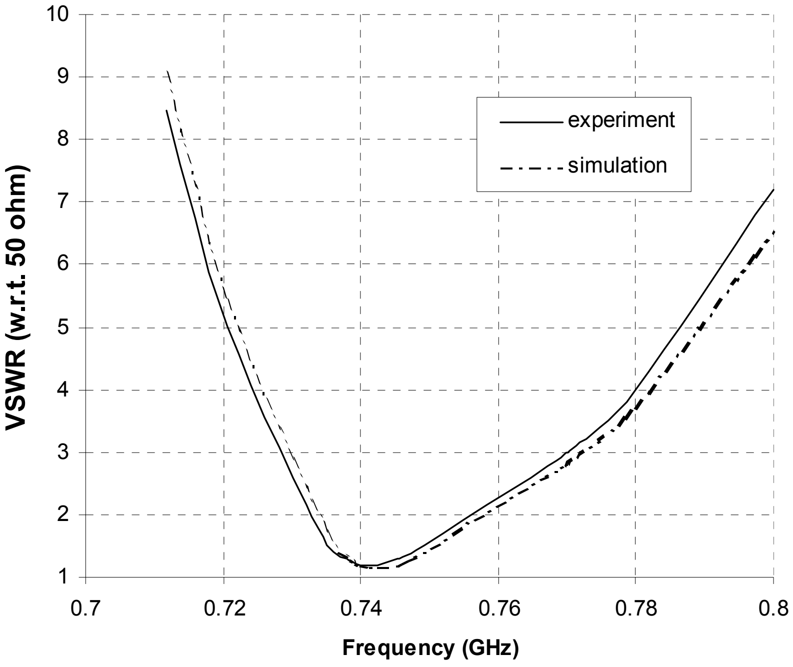

Figure 10. *Experimental and theoretical VSWR, with respect to 50 Ω, of the antenna in Fig.9, versus frequency.*

4.5. Printed GeCo Antenna

The last example is a printed 3-GHz GeCo antenna of the type shown in Fig.2(b), with the number of segments and their lengths as described in Subsection 4.3. The antenna is fabricated on a substrate of thickness $t = 0.508$ mm and relative permittivity $\varepsilon_r = 2.17$ (produced by "Arlon"). The strip widths after etching differ from those in Subsection 4.3 due to fabrication limitations. The thin strip width is about 0.7 mm (instead of 0.3 mm), and the widths of the wider strips, from the feeding point towards the antenna arm ends, are 4.0 mm, 3.0 mm, 2.5 mm, and 1.0 mm (instead of 3.0 mm, 2.8 mm, 2.3 mm, 1.5 mm, and 0.5 mm), respectively. The antenna is matched to the 50 Ω feeder by a 200 Ω two-wire line quarter-wave matching section followed by a coaxial balun. Note that, although the difference in desired and actual strip widths is relatively large, the strip-width tapering rates in the two cases are almost the same, which should imply that the sidelobe levels should not be dramatically different.

Fig.11 shows the normalized measured antenna E-plane copolarized power pattern. The crosspolarization level for all angles is at most –16 dB with respect to the main lobe copolar power. Note that the level of the first sidelobe is about –21 dB, in spite of the relatively crude experimental model when compared to the mathematical model, indicating that the design has good tolerance.

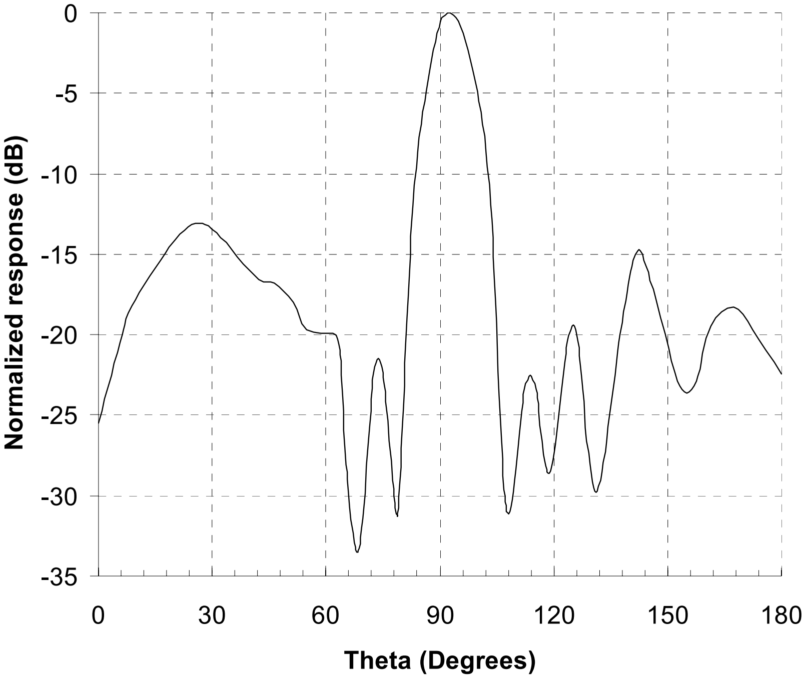

Figure 11. *Normalized measured copolarized E-plane power pattern of the experimental 3-GHz printed GeCo antenna described in the text. The H-plane pattern has no gain, as the antenna is a linear array. The cross-polarization is better than –16 dB for all angles.*

Finally, shown in Fig.12 is the measured reflection coefficient of the antenna with its matching network. Note an excellent match of the antenna to 50 Ω at about 2.92 GHz with a return loss of –31 dB. Theoretically, it should have the reflection coefficient of 0.064 (i.e., –24 dB) at 3.0 GHz. The deviation from the predicted operating frequency is less than 3%.

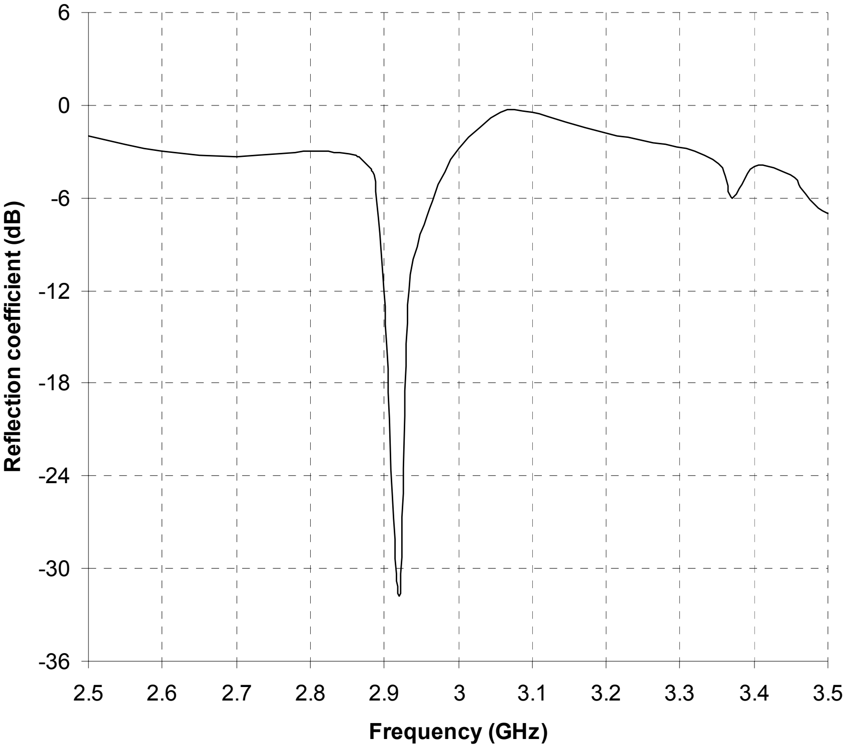

Figure 12. *Measured reflection coefficient of the experimental 3-GHz printed GeCo antenna.*

5. Conclusions and Discussion

This paper has presented recent contributions to the theory and design of generalized colinear antennas. The main feature of these antennas, which radiate essentially as colinear arrays of wire dipoles driven in phase, is their extremely simple feed. They are excited at a single port, but behave as if excited at a number of ports. Effectively, the feed network is integrated with the antenna itself and requires no additional real-estate. This is achieved by making the antenna arms in the form of segments of asymmetrical two-conductor lines, with exchanged places of the conductors at certain (regular or irregular) intervals. The classical CoCo antenna is a special case of this new class of narrowband antennas.

The GeCo antennas offer greater design flexibility than classical CoCo antennas, which have been made only of segments of coaxial lines. In contrast, the GeCo antennas can be made in a wide variety of forms, using segments of any two-conductor transmission line with conductors of different equivalent electrical radii. For example, a strip-line with strips of different widths, a two-wire line with wires of different radii, and two strips of different widths on the two sides of a dielectric substrate are possible building-blocks for a GeCo antenna. Finally, the GeCo antenna can be made of successive segments of different lines, resulting in a further possibility to modify the current distribution along the antenna, and thus the radiation pattern. Specifically, tapering of the current amplitude can result in sidelobe reduction.

The paper presents two methods for the analysis of GeCo antennas. According to the first method, the structure is analyzed as a wire antenna. The other method uses the principle of superposition and the basics of the multiport-network theory, combined with the numerical analysis of wire antennas. We show results using an in-house MoM code (WireZeus), but simple and fast CAD tools such as MiniNEC can also be used. Numerical and experimental results are presented for several GeCo antennas, and are shown to be in reasonable agreement in all cases.

The main published applications of CoCo arrays have been at lower MHz frequencies for meteorology and weather prediction. The limitations in available impedances of coaxial cables, and the parasitic reactance associated with the interconnection of the cable sections have made high-frequency applications difficult. However, these antennas may have large advantages at higher frequencies, where a narrow percentage bandwidth is still several hundred MHz, and where feed networks become lossy. Recently, revolutionary planarized wafer-scale fabrication technology advances have made it possible to fabricate air-filled micro-coaxial cables with square and rectangular cross-sections on the order of 200 μm on the side [18-20]. The loss of these quasi-planar micro-coaxial cables is below 0.1 dB/cm at Ka-band, and the TEM mode is dominant up to around 400 GHz. In addition, parasitic reactances associated with interconnections are greatly reduced. GeCo antennas with varying characteristic impedances of sections between 20 and 120 Ω are possible, thus enabling sidelobe reduction. In addition, several such linear antennas can be fed in parallel with an integrated micro-coaxial feed. The design of GeCo antennas in this new technology, as well as in different printed-circuit technologies, are topics of current and future work.

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