Sensor and Simulation Notes

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Symmetry in Low-Impedance Magnetic Antennas

Carl E. Baum
Air Force Research Laboratory
Directed Energy Directorate

Abstract

Segmented loops form an appropriate array for a low-impedance magnetic antenna. This paper considers the symmetries of such antennas and the inclusion of pulse-power sources in the total configuration.

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1. Introduction

A previous related paper [1] gives the basic geometry of the segmented-loop antenna. Several possible geometries were considered. The case of a four-loop array fitting in a rectangular parallelepiped is shown in Fig. 1.1. The symmetry provides equal currents (at low frequencies) in the four loops.

Not considering the connection near the coordinate origin to the source, this loop structure has three symmetry planes: $x = 0$, $y = 0$, $z = 0$. We can also note that the three coordinate axes are also two-fold rotation axes. If we constrain $a = b$ then there are two additional symmetry planes: $x = \pm y$. Also the z axis becomes a 4-fold rotation axis and we now have four two-fold axes: x, y, and bisectors of those two axes.

In the present paper we extend the previous results to include the geometry near the coordinate origin. This is followed by the inclusion of some of the pulse-power equipment.

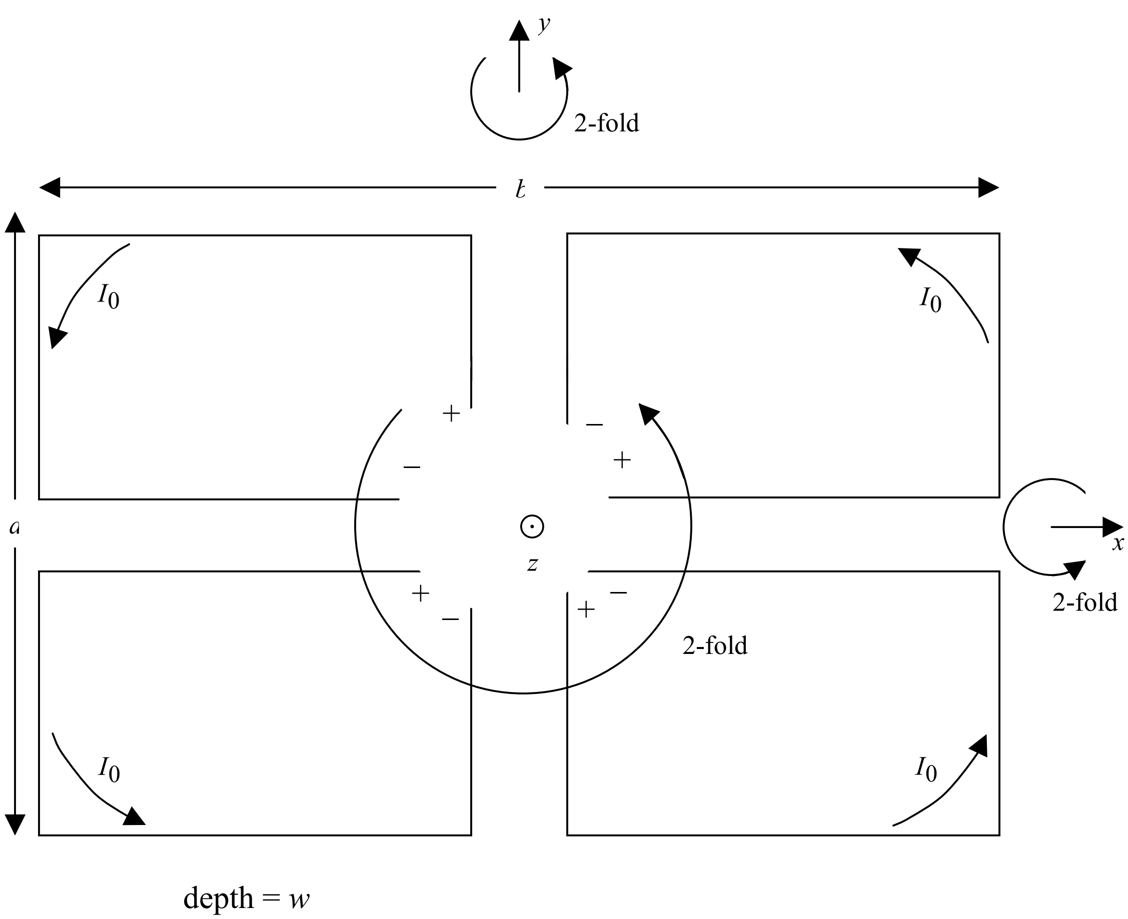

Fig. 1.1 Four-Loop Array

2. Connections Near Center

The loop conductors need to be connected together so that the positive terminals are all connected together, as are all the negative terminals. (See Fig. 1.1.) Furthermore, the positive sides need to pass the negative sides without touching. One solution for this connection arrangement is given in Fig. 2.1.

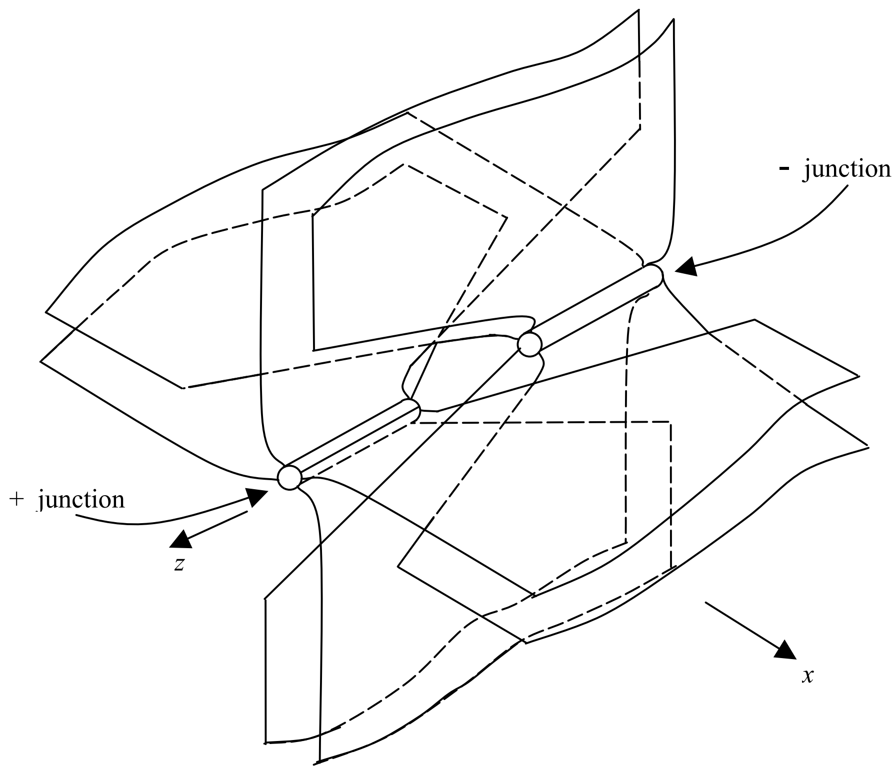

Fig. 2.1 Loop Junction

3. Dihedral Symmetry

Now we have two terminals on the *z* axis, just inside $z = \pm\, w/2$. This is inconsistent with the symmetry planes discussed in the previous section. However, the 2-fold rotation axes in Fig. 2.1 (*x*, *y*, and *z* axes) are still applicable. Rotation about the *z* axis by π reproduces the geometry exactly, while rotation about the *x* and *y* axis merely interchanges the labels + and – in Figs. 1.1 and 2.1.

This is an example of dihedral symmetry [4]. The general case D_N has N 2-fold axes perpendicular to one N-fold rotation axis, typically taken as the *z* axis. The case here is D_2. However, if $a = b$, this becomes D_4.

4. Neutral Conductor Placement in Segmented Loops

Now let us introduce other conductors in the loop geometry. This will aid in the inclusion of the pulse-power equipment.

Referring to Fig. 4.1, there are various possible placements for neutral conductors. One could use the symmetry planes: $x = 0$ and $y = 0$. However, since we will be later adding high-voltage equipment near such conductors this could push the loop conductors farther apart near these neutral conductors, thereby reducing the loop area (and, hence, magnetic-dipole moment).

Another interesting possibility considers the loop bisectors as indicated in Fig. 4.1. Except for the small region near $\vec{r} = \vec{0}$, the 4-loop array has three symmetry planes, as discussed previously. The currents are symmetric with respect to the $z = 0$ plane, making the magnetic field perpendicular to this plane on the plane (except near the origin) [4]. Thin conductors on this plane which curry no net current do not interfere with the loops. For there to be no current (net) the voltages between the plus junction (Fig. 4.2) and neutral, and minus junction and neutral must balance.

If the array had C_{4a} symmetry, then $a = b$ and the diagonals are also symmetry planes. The neutrals could then be placed on these diagonals and connected to the loops at the corners, without producing net currents on these neutrals. If $a \neq b$ then the neutral paths could be altered (perhaps using numerical calculations) to achieve the balance. Alternately the neutral conductors need not be connected to the loops at the corners.

5. Inclusion of Differential Marx Generator and Other Equipment with Neutral Conductors

A differential Marx generator [3] is appropriate for inclusion with the previously discussed neutral conductors. Taking such conductors as a metal tube we could have the cross-section geometry as shown in Fig. 5.1. Here we have the two halves (+ and −) parts on opposite sides of the tube. Each represents a source connected to the $\pm$ junctions as indicated in Fig. 4.2. Note that the Marx columns are approximately parallel to the neutral tube, and connect to this tube at some distance away from the junctions. They also have a source impedance to be included in the calculations.

As discussed in [2] there are appropriate charging networks for fast charging of Marx generators. Charging bases (+ and −) could be included inside the tube (perhaps internally segmented) as in Fig. 5.1. The RL networks lead out from these buses for + and − charging of the elements in both Marx halves.

Other electrical conductors (power, trigger signals, etc.) can also be included inside the neutral tube. Batteries can also be included inside or adjacent to the neutral tube at the end opposite to the Marx generator.

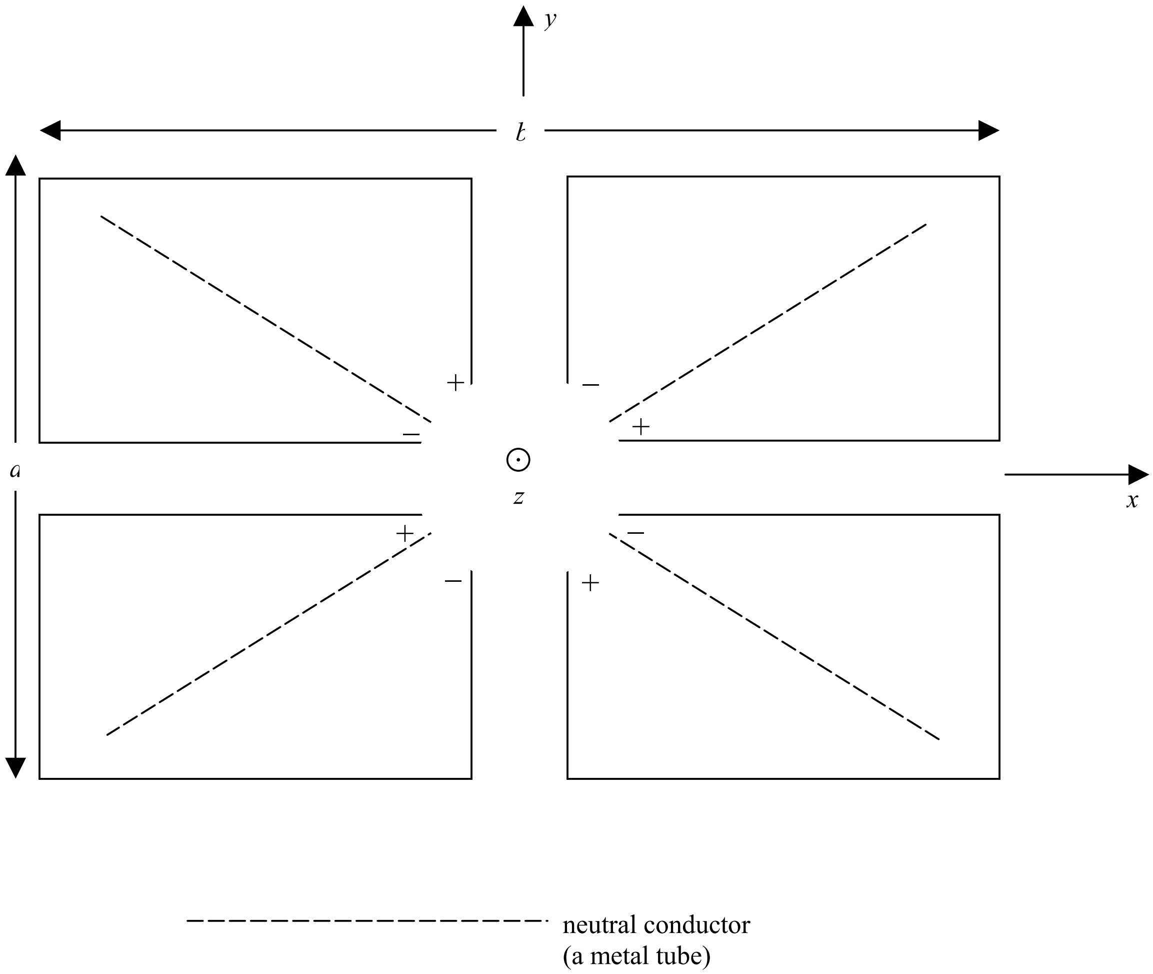

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Fig. 4.1 Placement of Neutral Conductors

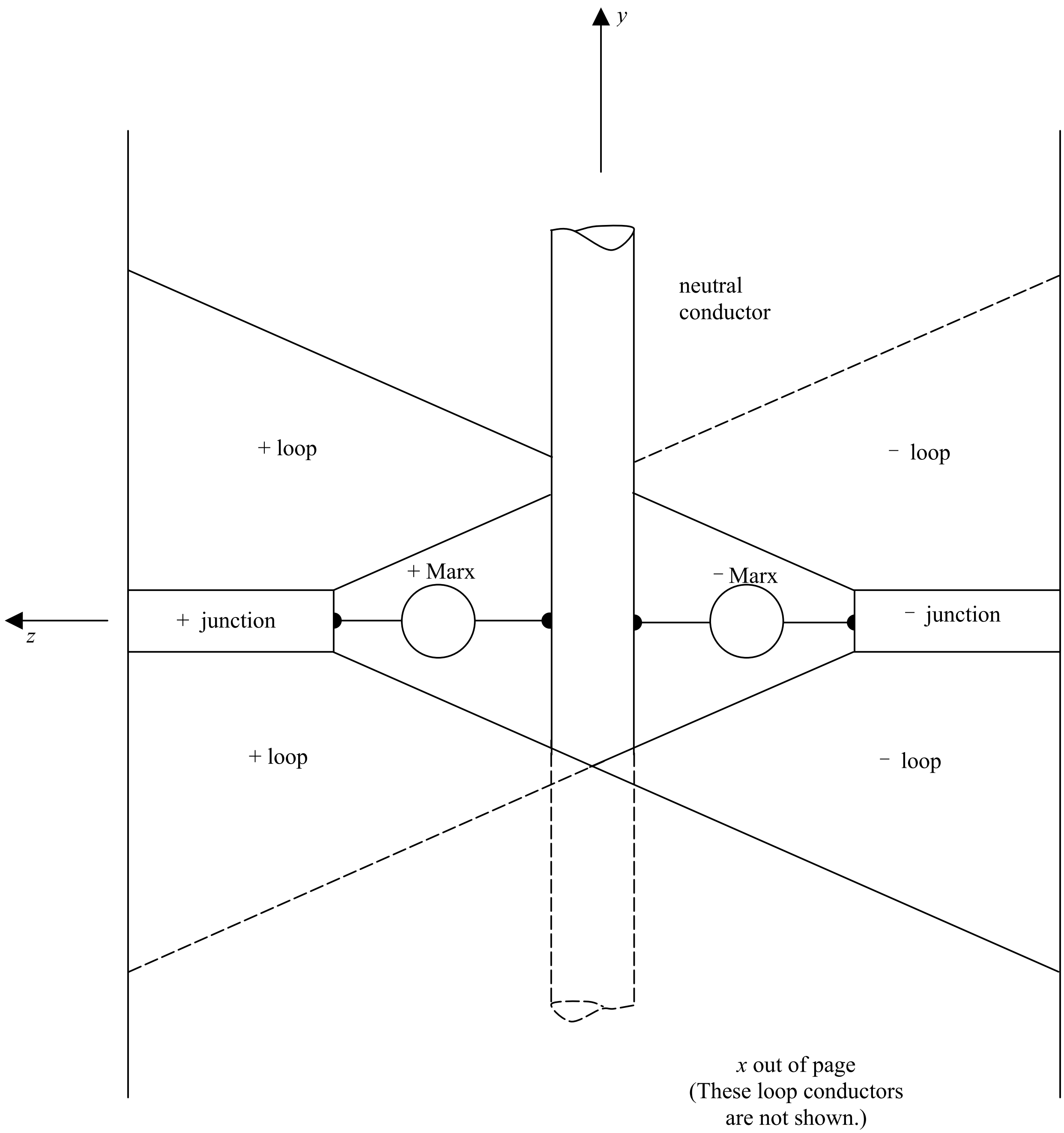

Fig. 4.2 Neutral Conductors Near Origin

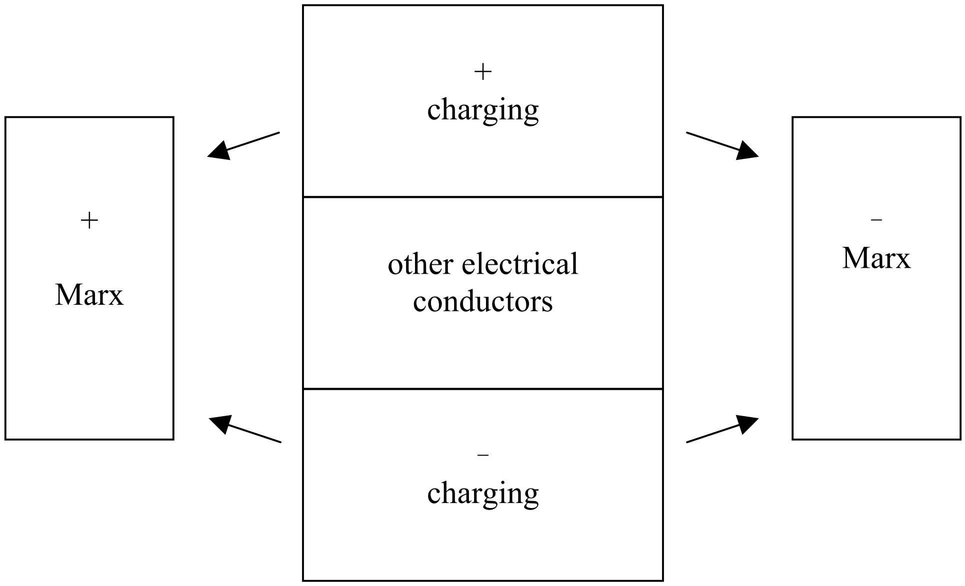

Fig. 5.1 Geometry Near Neutral-Conductor Tube

6. Inclusion of Single-Ended Marx Generator with Antenna Conductors

With a single-ended Marx generator we can mount it on one of the loop conductors for reference. Using one of those marked + in Fig. 4.1 we can have a configuration as in Fig. 6.1. The Marx needs to feed a negative voltage to the negative junction. In Fig. 6.1 the inclusion of a possible transfer capacitor is indicated.

The neutral tube is now replaced by an electrical distribution tube bonded to the positive loop conductor. It can extend (as indicated) to other positive loop conductors by passing through or over the positive junction.

7. Inclusion of Two Single-Ended Marx Generators with Antenna Conductors

The configuration of the previous section can be extended to two Marx generators configured so as to give a differential voltage to the loop array as indicated in Fig. 7.1. Note the use of a single closing switch to connect both Marx generators to the loop array. The negative Marx is mounted on a positive loop conductor and the positive Marx is mounted on a negative loop conductor to achieve the differential configuration for higher voltages to be applied to the loop array.

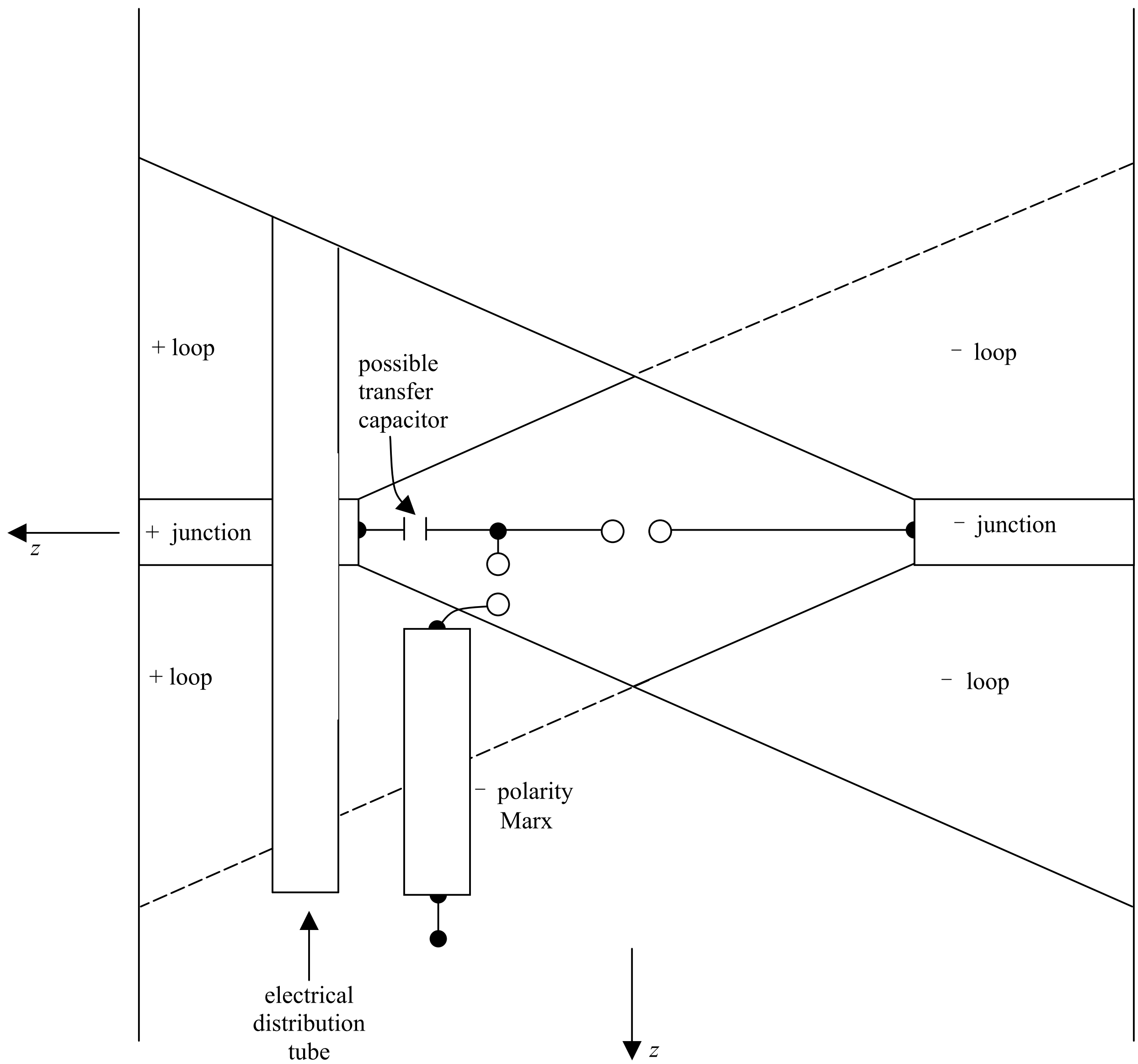

Fig. 6.1 Single-Ended Marx Generator Mounted on Loop Conductor

Various $\pm$ loop conductors as in Fig. 4.1 can be used for this purpose. They can be oppositely positioned, as both near the *x* axis, or adjacently positioned as one near the *x* axis and one near the *y* axis. The neutral tubes are now replaced by conducting tubes bonded to the appropriate loop conductors. Noting that each loop has both a + and a – terminal, the electrical distribution tube can be topologically connected to both Marx generators by following a path (bonded) on one of the loops between + and – terminals. This allows for a single electrical trigger signal for the two Marx generators.

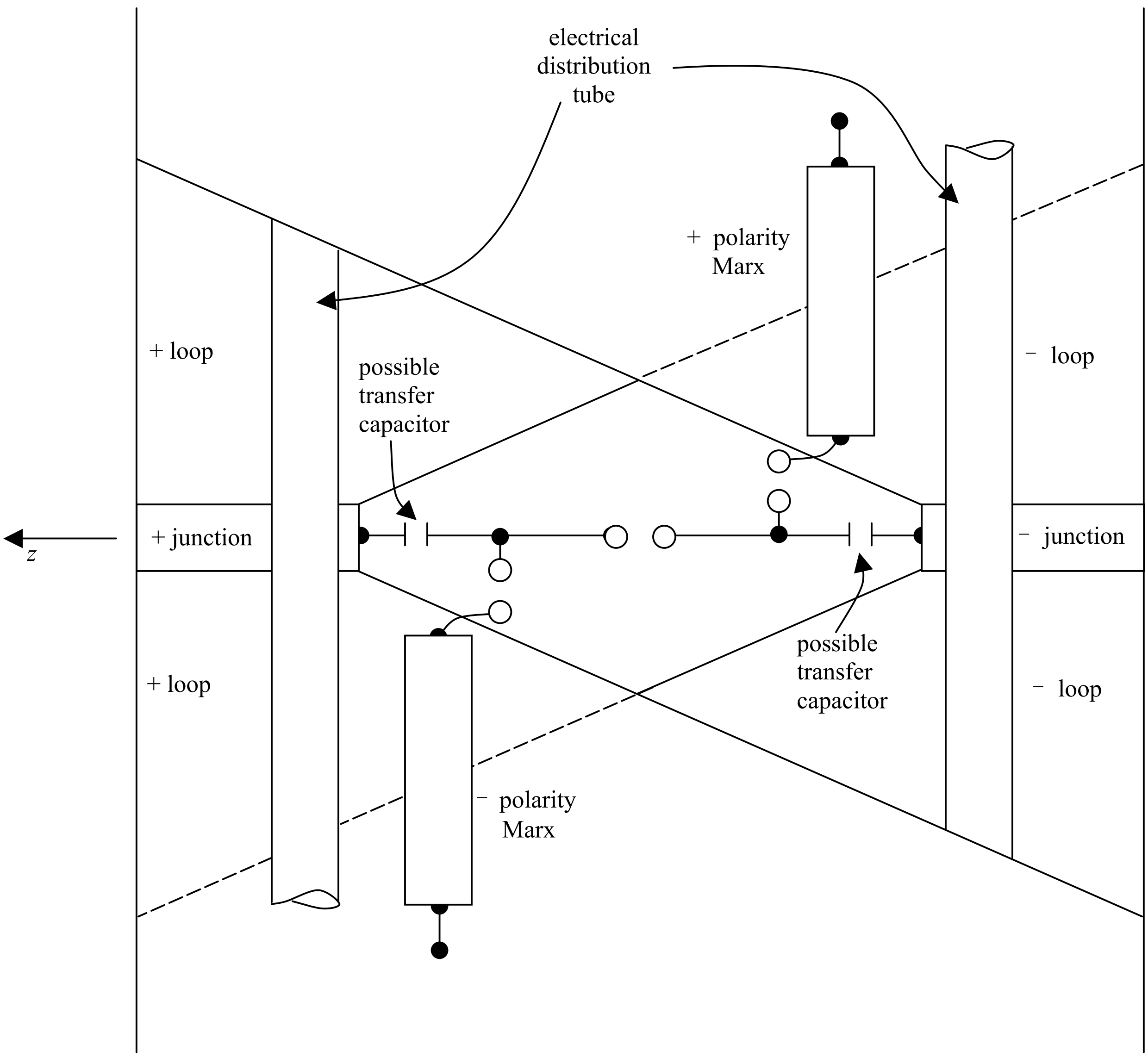

Fig. 7.1 Two Single-Ended Marx Generators Mounted on Loop Conductors

8. Concluding Remarks

Dihedral symmetry is then appropriate for the loop array. Introduction of Marx generators and associated equipment makes the real configuration somewhat different, but ideally only slightly so. This paper has given various choices for such configurations.

Here we have assumed a 4-loop array. The same symmetry configurations apply to a 2-loop array. In this case one of the symmetry planes ($y = 0$ or $x = 0$) can be used as a neutral conductor for the case of a differential Marx generator.

References

1. C. E. Baum, “Compact, Low-Impedance Magnetic Antennas”, Sensor and Simulation Note 470, December 2002.

2. C. E. Baum and J. M. Lehr, “Charging of Marx Generators”, Circuit and Electromagnetics System Design Note 43, September 1999.

3. C. E. Baum, “Differential Marx Generators”, Circuit and Electromagnetic System Design Note 49, April 2004.

4. C. E. Baum and H. N. Kritikos, “Symmetry in Electromagnetics”, ch. 1, pp. 1-90, in C. E. Baum and H. N. Kritikos (eds.), *Electromagnetic Symmetry*, Taylor & Francis, 1995.