What's Wrong with the Cross Field Antenna?

Paul Zander AA6PZ

Let me start by saying I am not especially pleased with writing this report. I would be much happier writing a paper about how to make a really small and efficient antenna. However, having spent a lot of time and effort over a period of years, I reached the conclusion that the Cross-Field Antenna or CFA, does not work as claimed. Science does not always lead us to the conclusions we wish for. Scientific advancement comes from discovering what does not work as well as from what does work. Hopefully the reader will learn something about electromagnetic fields, and how to conduct experiments on antennas in general.

I also have no reason to think that the originators of the CFA did anything more than become a bit too enthusiastic about some of their early experiments which gave very encouraging results. I exchanged correspondence with Dr. Hately, GM3HAT. I also had a delightful and interesting personal conversation with Mr. Kabbary at a technical conference. I was all smiles when he signed my copy of the conference proceedings.

Why Consider the Cross Field Antenna?

There are two stated advantages of the CFA. First it can be very small size. Conventional antennas have dimensions of ¼ to ½ wavelength. In contrast the CFA is said to work with dimensions of .1 to .01 wavelength. This is a big deal on the 40, 80 and 160 meter bands.

Secondly CFA is said to tunable over a very wide frequency range. Presumably one antenna might be used on 160, 80 and 40 meters, with a rather simple tuning adjustment.

Basic Appearance

The most common implementation of the CFA can be called a top hat, because it looks like a very large men's hat made from metal. There is a horizontal sheet of metal which goes under the area of the antenna to form a ground plane. Spaced above the ground plane is a horizontal disk called the D-electrode. Above the D-electrode is a large vertical cylinder, called the E-electrode. If the D-electrode is, for example, 4 ft in diameter and 6 inches above the ground plane, the E-electrode might be 3 ft in diameter, 4 ft high and spaced 6 inches above the D-electrode. For reasons which will be explained later, the E-electrode is sized and positioned to achieve capacitance with ground plane, but not the D-electrode.

Theory of CFA

The next paragraphs are a summary, with a minimum of mathematics, of how the CFA is said to work..

When transmitting, some of the power is applied as a voltage to the E-electrode, and hence an electric field between the E-electrode and the ground. So the E-electrode generates an electric field.

The rest of the power is applied to the D-electrode. Recall that the D-electrode has a large capacitance to ground. Therefore this portion of the antenna and its drive can be considered as a source connected to a capacitor. An RF voltage causes a current to flow in a capacitor. One of the concepts of electrical circuits is that current flow around a loop must be continuous. But what about the gap in the capacitor? To solve this apparent “inconsistency”, electronics engineers invoke something called “displacement current” or “displacement field”. The voltage, spacing between the plates, and the material between them (air in this case) are used to compute a displacement field which is analogous to a current flowing between the plates. Add up the portion of the displacement field at the edges and the middle, and the total is exactly the same as the current flowing in the leads. Actually the spacing of the plates, the area of the plates and the material between them also is used to compute the capacitance, which in turn can be used to compute current from voltage. It is just the same factors combined in different ways. Anyway, D fields and displacement current is a topic which is routinely taught in college course. It is also something that is seldom of importances. The CFA is one such case.

So to summarize, the power applied to the D-electrode which generates a field called the displacement current, which has all the properties of a real current flowing in a conductor. Anytime there is a current, there is a magnetic field around it. The displacement current flowing vertically between the D-electrode and ground will generate a horizontal magnetic field that forms a ring surrounding the antenna structure.

Now we get to the last step in the explanation of the CFA. There is a horizontal magnetic field created by the D electrodes and a vertical electric field generated by the E-electrodes. A traveling radio field can be described as an electric field and a magnetic field at right angles to each other. The fields are said to be “crossed.” If the D and E electrodes have the proper phase relation, the magnetic and electric fields have the properties needed to create a radio signal which can radiate. Achieving the correct phase is done by the circuit which divides the transmit power between the two electrodes. The operating frequency of the antenna is determined by the adjustment of the driving circuit. Unlike a dipole, the size of the antenna does not have to be adjusted to set the operating frequency.

Pretty neat, if it works.

My Experiments.

When I first heard of the CFA, I thought about building one. The first problem was materials. As a long time ham, I have a stock of wire and metal tubing. Pieces of sheet metal big enough to build a CFA was a problem. Eventually I put together something that looked like a small version the published pictures. Since it was small, I figured I could test it on 10 or 15 meters before buying bigger material to make an 80 meter version. Well I couldn't get it to work. After a couple weekends of unsuccessful experiments, I wrote to the inventor, GM3HAT. The most likely problem with my experiment was that the long cables running from my shack to the antenna outside had more capacitance than the antenna. The suggestion was to make the antenna bigger and the cables shorter.

Making a bigger CFA turned out to be easier said than done. The printed descriptions showed the basic concept, but not a dimensioned drawing with construction details. Rather than buying big pieces of sheet metal and spending a many hours fabricating the shapes as well as mechanical mounting supports, I had a clever idea. I would build an experimental antenna out of materials that were easy to work with until I had some confidence that the dimensions were correct. My material of choice was cardboard covered with aluminum foil. I came up with this idea just after discarding some very large cardboard boxes. It took a long time before I found more suitable boxes.

Another problem with the first antenna was the feed network. The published design used a large toroid core. Something else I didn't just happen to have. I found several large, unlabeled toroids at the electronics flea market. When I tried to make RF transformers, the cores turned out to be very lossy. It took more scrounging until I found some cores which were useful for RF.

Once a project gets on the back burner, it can stay there a long time. Building an antenna from cardboard meant it wasn't a good idea to work on the project during the rainy season. Furthermore, this was in the mid to late 1990's when summers meant good DX on 10 during the day and all night long on 20. Why waste time on an 80 meter antenna when the other bands were good?

Eventually I gathered the materials and built a small antenna for preliminary experiments, I put it inside the shack where it was balanced on top of the transmitter and the oscilloscope. I also made adapters to sample the voltage on the D and E electrodes use the oscilloscope to see when the phases were correct.

Now an amazing thing happened. When the phase was of the electrodes was 90 degrees, the SWR dropped way down. The antenna was obviously accepting power. This is just as claimed by the inventors. Being inside a building, it was not a good situation to test radiation. At least I felt like I was making progress. I also learned that the prototype was too fragile. I would have to build another one with wooden stiffeners and better glue.

Finally I found some time, in the summer, and after Field Day and well before the family vacation to resume the experiments. I assembled my latest creation on the patio table with the oscilloscope under the table. For the number of trips to the transmitter and back, I would have been better off to make a 25 ft cable for the T/R switch, but I was too focused on the antenna to think of that at the time.

As with the indoor experiments, once I had the relative phases correct, the SWR dropped. I could achieve an SWR less than 1.2 at any frequency on 40 meters. I could increase the transmit power to 100 watts with no obvious problems with arcing, etc. So now I am feeling like I have finally made a real antenna. How good is it?

One thing I had learned in previous antenna projects is to always use a reference antenna. With only one antenna, it is impossible to tell if conditions are unusually good or bad on a given day. With a different antenna as comparison, one can sort out what is antenna and what is conditions.   I had a commercially made 40 meter trap vertical on the garage roof which had survived several previous attempts at a replacement.

Another key antenna concept is the reciprocity theorem. With very few exceptions, if a transmitter has a certain gain and directional pattern on transmit, it will have the identical pattern on receive. So rather than calling CQ and making a couple QSOs, I could tune the band on receive, switch between the vertical and the CFA and get quite a few data points in a short time.

I hoisted the CFA to a flat portion of the house roof, and verified that it was still tuned up. Then I went back to the receiver and started tuning around. The vertical definitely had much stronger signals than the CFA. Maybe the CFA had a lower radiation pattern and would come into its own at night when the skip is longer.   No such luck. The signals on the CFA were consistently 3 S units weaker.   I checked and re-checked everything but could not get it to be a good antenna. I carefully dismantled the prototype and stored it inside before too many damp evenings caused it to warp beyond repair.

Other Publications of CFA

Although it had been a number of years since the first publication of the CFA concept, the amateur radio magazines rarely had any mention of the topic.   This should have been a big clue. If other people were having great success, there would be growing interest. The few articles I did see had photographs and drawings of how the antenna was built. As to how well it worked in practice, they basically said, I built this antenna, and made some contacts so it must be a good antenna. I don't recall seeing any article which actually compared the CFA with a conventional antenna except for the original CFA at a broadcast station in Egypt.

World Radio Magazine has a regular column on Aerials by Kurt N. Sterba. He was determined that the CFA couldn't possibly work, but didn't offer an explanation beyond repeating that other attempts to make small antennas hadn't worked. While that column often has good information, I was not satisfied with the coverage of the CFA.

Looking back, its hard to believe that the years of my CFA dreaming had overlapped the widespread use of the Internet. I first read about the CFA, from photocopies of a couple articles supplied by a co-worker.   Correspondence with GM3HAT required a trip to the post office for overseas stamps. Today there are many web pages discussing the CFA. Most of them are on sites devoted to experimental antennas.

Well Behaved Antennas

I did find a most interesting web page called, The **Well-behaved Antenna** (www.ee.surrey.ac.uk/Personal/D.Jefferies/antennexarticles/behave.htm) by Dr. Jefferies at the University of Surrey. A well-behaved antenna is one which is straightforward to get to work.

For example, the dipole antenna is “well behaved”. You cut some wire or tubing to the length given by a formula. You put the antenna as far as you can from the ground and metal objects. You check the SWR. Sometimes it is working immediately; sometimes a small adjustment is needed to tune it to the desired frequency.

In contrast, despite numerous attempts, I could not get the CFA to function as a good antenna. The CFA is obviously not well behaved.

To be fair there are many antennas which are not well behaved. For example, trying to tune a 10 element beam for maximum gain can be a very tedious process. The 10 element beam can be a useful antenna.

Engineering Analysis of Feed Point

The early articles had me so concerned with field theory and mechanical construction, that I failed to do any numeric estimate of the currents, voltages and impedances at the electrodes. In hind site, I should have done that much earlier.

The following is not mathematically rigorous, but it does give an estimate of what is needed to drive an antenna.

Consider a 40 meter dipole, 65 feet long. A dipole has 72 ohms input impedance. 100 watts power gives a current of 1.15 amps (87 volts) at the terminal. The current diminishes to 0 at the ends. To keep the numbers simple, estimate .5 amps average current over the length of the antenna. We know the dipole efficiently creates an RF field at a distance. (If you insist on a detailed analysis, use a program like EZNEC which does includes a more sophisticated computation including the variation of current over the length of the wire.)

A quarter wave vertical has half the length of a dipole and also half the impedance. So twice as much current flows over half the distance to give the same radiation.

Now consider the CFA with the D-electrode 4 feet in diameter and 6 inches above the ground plane. To get the same combination current and length takes 130 Amps. The capacitance is 68 pF. At 7 MHz, the reactance is 340 Ohms. It will take 44kV to force 130 Amps through the capacitor. If the spacing is increased, the needed current is reduced, but the capacitance is also reduced. It still takes 44kV to force the current needed for the magnetic field.

Meanwhile it will take a high voltage on the E electrode to create the E field of the proper strength to match the magnetic field. Obviously creating the high voltages could cause some practical problems with insulation.

None of the articles about the CFA do mention such extreme voltages or currents. The drawings of the matching networks suggest that the impedances are low.

However, the articles do mention the high voltage on the ends of a conventional dipole and the intense fields close to dipole. They claim the CFA is much better because the near fields are less.

While this is admittedly a simplified analysis, the only way it could be way off is if there is significant interaction between the D and E electrodes. None of the descriptions of the CFA mention coupling between the D and E electrodes. Typically, the E electrode is of a size and position to minimize coupling.

What I Think is Missing from the Stated Theory of the CFA

Consider the earlier description about the D-electrode generating a magnetic field. The concept of the D-field ties to the concept that current always flows in a complete circuit. If there is to be a displacement current in the space surrounding the D electrode, there must also be a real current of electrons flowing into the D electrode. The complete picture has a cable from the transmitter with one side connected to the D-electrode and and the other to ground. When there is a D field pointing down from the D-electrode, there must be a current flowing up the wire. The drive current will also generate a magnetic field which will cancel the magnetic field of the D-electrode.

The cancellation of the magnetic field also cancels the stated theory of the CFA.

Why the CFA Sometimes Appears to Radiate.

The schematic of the feeding network for the CFA looks something like this. There is a transformer which splits the transmitter power into two branches, one going to each electrode. One of the branches has a short feedline; the other has a feedline approximately quarter wave long to achieve the desired phase between the D and E fields.

So lets look at this circuit. The short feedline is connected to one of the electrodes, which is a capacitor. Since the feedline is short, it presents a capacitance to the power splitter. The second feedline is also connected to a capacitor. Since the second feedline is a quarter wavelength, it presents not a capacitance, but an inductance to the power splitter. The inductance resonants with the capacitance. With assorted lengths of cable and other metal parts, the power does find some way to radiate, but the radiation is not “well behaved”. Two antennas may be built which are superficially the same. However the lengths and placements of the cables is different. One of the antennas might actually appear to be working.

The first large CFA was built on a building specially made to house broadcast transmitter. The construction includes many copper straps. When the transmitter power couples into the building framing, there could indeed be efficient radiation. However the actual radiating antenna is not just the CFA structure on the roof, but the entire building. The “real” antenna is much larger than the CFA and maybe it works quite well.