Collinear and Coparallel Principles in Antenna Design

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Abstract— The paper summarizes collinear principle (CollP) used for the design of enhanced directivity collinear arrays (CollAr) first. Various types of collinear arrays starting from historical wire design introduced by Franklin, going through coaxial collinear arrays as far as to the most recent CollAr implemented in microstrip line and patch technology are mentioned. Further supplementary principle of parallel line up arrangement of in-phase current sources to form coparallel array (CopAr) in presented. Two examples of CopAr based on planar extension of collinear microstrip patch antenna (PCoMPA) and branched F-type antenna are described in more details.

1. INTRODUCTION

Antenna arrays known as collinear arrays (CollAr) are based on in-phase feeding of radiating elements that are lined up serial and their radiation is typically omnidirectional perpendicular to the longitudinal axis of elements. The original idea has been introduces by Franklin [1]. He first designed CollAr from long wire that had $\lambda/4$ U-shaped sections to provide phase shift to maintain in-phase feeding of straight $\lambda/2$ parts of wire, see Fig. 1(a). Instead of U-shaped sections small inductors to ensure phase shift can also be used. The principle has been then applied by several researches in either coaxial [2], or microstrip line antenna technology [3, 4], see Figs. 1(b), (c), (d). These linear versions of collinear antenna arrays have nearly omnidirectional radiation pattern due to more or less longitudinal axis symmetry. However collinear microstrip patch antenna (CoMPA) first introduced in [5] has directive character as the ground plane is present as necessary part of patch type antennas.

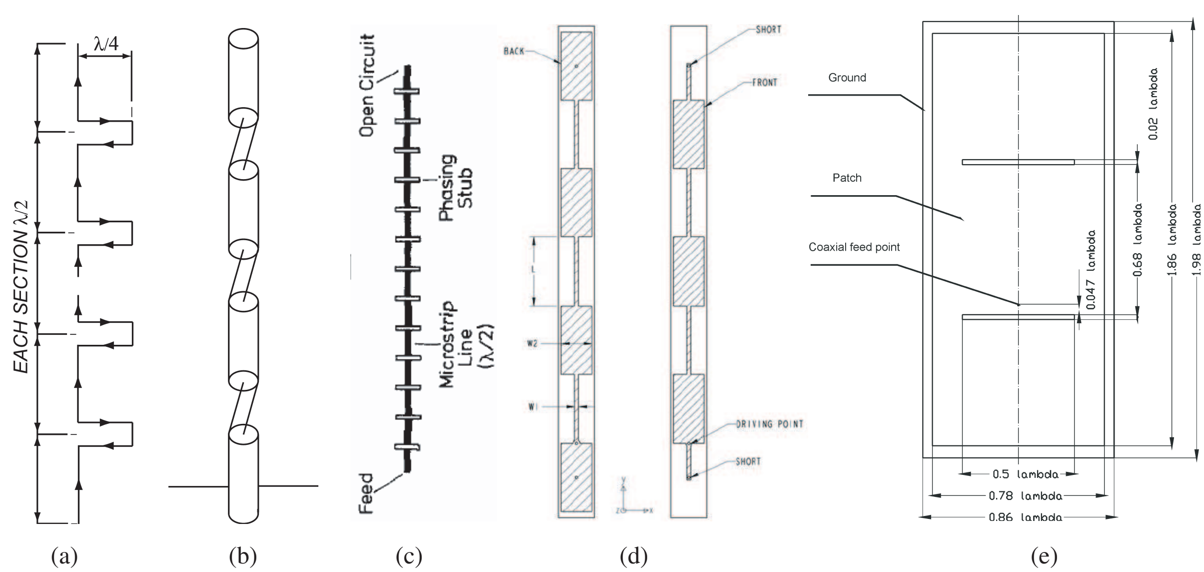


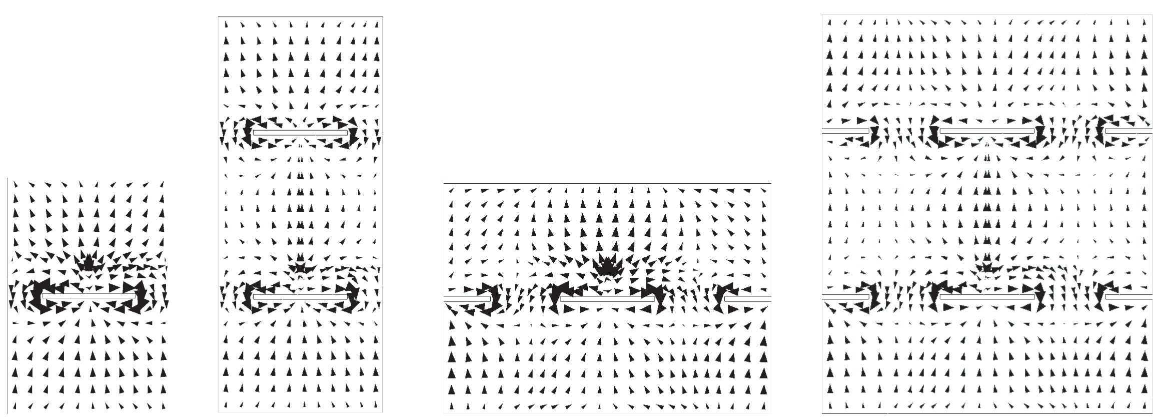
Figure 1: Geometry of several collinear arrays: (a) original Franklin dipole [1], (b) coaxial collinear [2], (c) microstrip line with a flat O shaped sections [3], (d) thin/thick section microstrip line [4], (e) collinear microstrip patch antenna [5].

If the line up of the radiating elements is parallel, the character of radiation is not omnidirectional but directional. The optimal distance between two elements to achieve highest directivity is approx. $\lambda_0/2$ supposing in-phase feeding. The directivity is again higher in dependence on the number of elements but in this case the radiation is provided through two beams backward and forward, perpendicular to the axis of the array, broadside with two beams. The antenna radiating in two opposite directions is not practical, hence the reflection plane is often used. This plate prevents backward radiation and provides approx. 3 dBi directivity enhancement. This arrangement of in-phase radiating elements that are lined up parallel to the element axis is here called coparallel array (CopAr). The two designs of CopAr are presented here.

The first example of CopAr is a planar extension of collinear microstrip patch antenna (PCoMPA) that operate with TM_{03} and TM_{05} mode. Modular principle can be used to extent either longitudinal or lateral dimensions and consequently the directivity of an antenna. This antenna combine both collinear and coparallel principles. The second example of CopAr is a coparallel branched F-type antenna (CopFA) that use two and three parallel in-phase current source areas formed by monopole heel stubs perpendicular to the ground plane. It is an extension of classical wire F antenna realized in planar technology. Operational principle, and corresponding radiation properties of particular implementation of both CopArs for 2.4 GHz frequency band together with main advantages and drawbacks are described.

2. COLLINEAR/COPARALLEL PLANAR MICROSTRIP PATCH ANTENNA

As it is well-known that microstrip patch antenna (MPA) can be designed to operate with higher order modes. However radiation properties of higher order modes of simple rectangular or circular shaped MPA exhibit nulls in radiation pattern due to the presence of out-phase current density areas on patch surface. Using suitable patch shape modification that employs slots and notches to redistribute current density to form several in-phase source areas these nulls can be suppressed and enhanced gain can be achieved. Here TM_{0x} mode (where x determine the number of half current wavelengths in the resonant longitudinal dimension of the patch) of MPA is used. PE in the shape of inner slots and edge notches are then applied to the patch in such a way that they eliminate radiation from even out-phase half current wavelengths. Specific topology of the patch shape modified patch thus arise. The simplest example of the usage of described principle is MPA operating with TM_{03} mode with one central narrow slot placed in the middle of the patch. The slot of the length approx. $\lambda_g/2$ and width of a fragment of λ_g causes that second/even current wavelength flow around the slot, see Fig. 2(a). Currents in the vicinity of the slot circumference thus cancel their contributions to the radiated fields due to the out-phase orientation on opposite sides. Vector current distribution of longitudinally extended MPA operating with TM_{05} mode with two slots is illustrated in Fig. 2(b). The same effect of even half current wavelength flowing around both slots as in case of a patch operating with TM_{03} mode with one slot can be seen.



(a) (b) (c) (d)

Figure 2: Vector surface current distribution on the CoMPA with (a) TM_{03} and (b) TM_{05} modes and PCoMPA with (c) TM_{03} and (d) TM_{05} modes (modeled in IE3D MoM simulator with infinite ground plane), (e) PCoMPA with TM_{05} mode separated into basic modules.

Further these radiators forming CollAr in microstrip patch technology can be laterally extended and complemented by a pair(-s) of approx. $\lambda_g/4$ edge notches perpendicular to the patch border to introduce coparallel principle, see Figs. 2(c), (d). The current distribution of TM_{03} and TM_{05} modes remains the similar and phenomenon of current flow around the slots and notches is maintained. As a result the $|J_y|$ current density component is dominant at the surface of the patch and the radiator exhibits broadside linearly polarized radiation with directivity enhancement. Domination of the $|J_y|$ component on the most of the patch surface is actually a necessary condition for reasonable low cross-polar level. Advantage of a such arrangement compared to classical array is simple structure without separate feeding network. Disadvantage is of course unavailability to control amplitude distribution and phase of source currents on the structure and increased cross-polar ratio.

Figure 3 shows the CoMPA motif from Fig. 2(d) separated by dashed lines into basic building modules previously discussed arrangements. A hypothesis of further longitudinal and lateral extension based on these building blocks with appropriate number and position of inner slots and a pairs of lateral edge notches to further enhance directivity and gain can be stated.

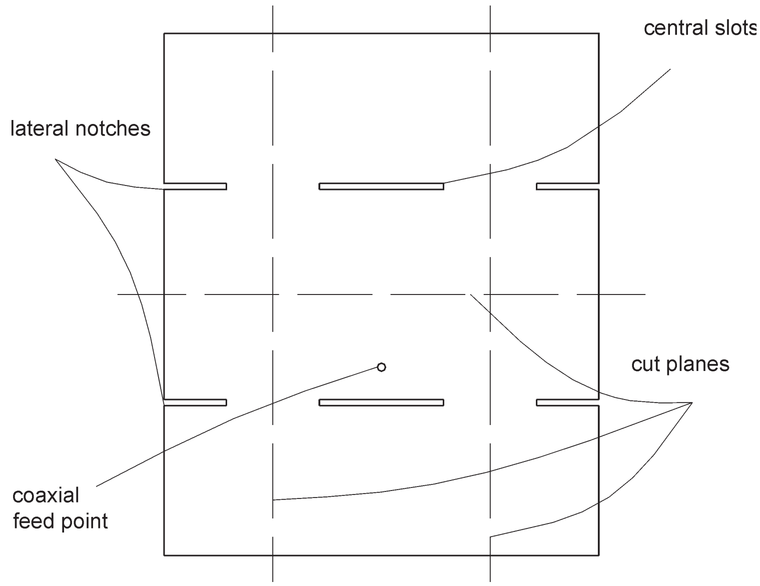
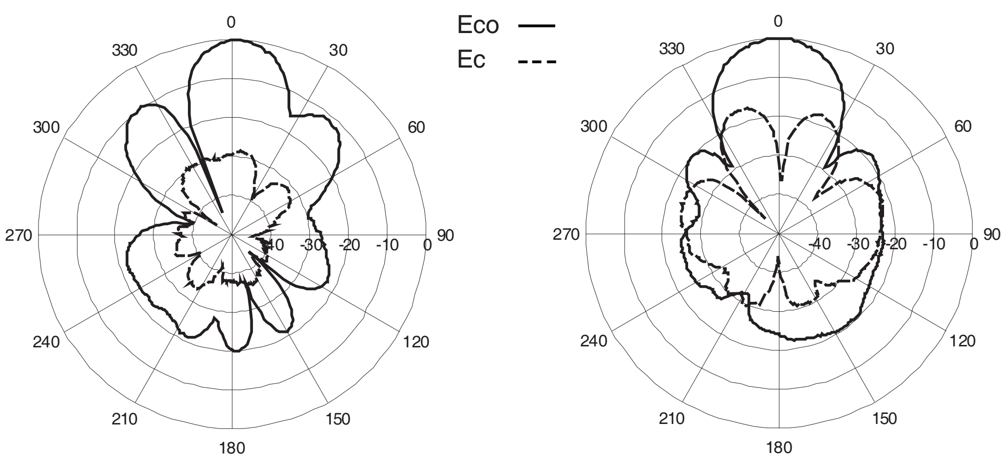


Figure 3: Schematic view of PCoMPA with TM05 mode separated into basic modules that can form independent CollAr and/or CopAr.

Radiation pattern of realized PCoMPA operating with TM_{05} [6] in 2.4 GHz frequency band with directivity 15.4 dBi and sidelobe level -10 dB can be seen in Fig. 4.



(a) (b)

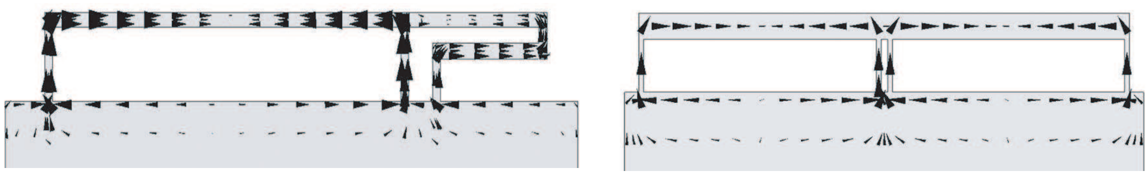
Figure 4: Measured co-polar (Eco) and cross-polar (Ex) components in dB of radiation pattern of PCoMPA operating with TM_{05} mode with two central slots and two pairs of lateral edge notches in (a) E-plane, (b) H-plane.

3. COPARALLEL BRANCHED F-TYPE F ANTENNA

Classical F antenna is a variant of monopole, where the top section has been folded down so as to be parallel with the ground plane. This is done to reduce the height of the antenna, while maintaining a resonant trace length. This parallel section introduces capacitance to the input impedance of the antenna, which is compensated for by implementing a short circuit stub. The main radiating source area is the current density of the heel of monopole.

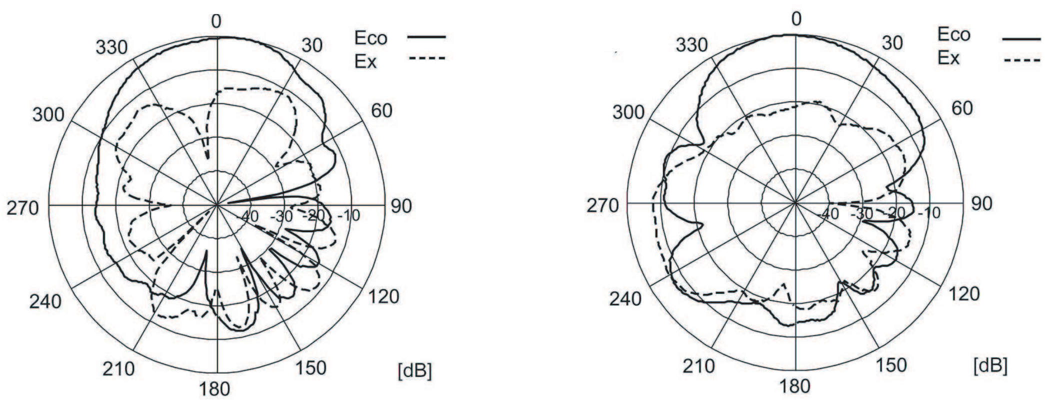
Directivity of such a structure is about 2.2 dBi and the radiation has an omnidirectional character, perpendicular to the vertical stub.

To implement coparallel principle to enhance directivity into the F antenna design two and three parallel stubs connecting with approx. $\lambda_g/2$ line conductors are introduced, see Fig. 5. As it can be seen by proper setting of connecting wire length in-phase parallel orientation of current density on stubs perpendicular to the ground plane can be excited. To further enhance directivity the reflection plane in the distance of $\lambda_g/4$ can be used [7]. The resulting measured radiation patterns can be seen in Figs. 6 and 7.



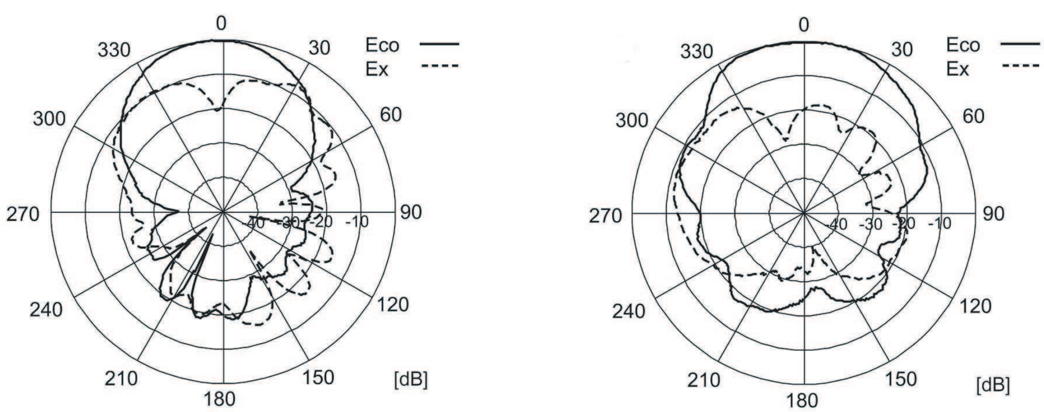
(a) (b)

Figure 5: Vector surface current distribution of (a) two element (b) three element branched F-type antenna.



(a) (b)

Figure 6: Measured radiation pattern of two element branched F-type antenna, (a) H-plane, (b) E-plane.



(a) (b)

Figure 7: Measured radiation pattern of three element branched F-type antenna, (a) H-plane, (b) E-plane.

Two and three element branched F-type antennas with reflecting plane has provided directivity up to 10.7 dBi, see Table 1. The advantage of such an arrangement is a simple structure and relatively small dimensions. The drawback is a low front-back ratio which can be enhanced by larger dimensions of the reflection plane.

Table 1: Comparison of simulated directivities and impedance bandwidth for VSWR = 2 of classical single element F antenna, and two and three element branched F-type antennas with and without reflector plane.

Antenna	D [dBi]	B [MHz]	B [%]
F-antenna	2.2	240	9.8
2 elements F-antenna	4.75	245	10
3 elements F-antenna	6	100	4.1
2 elements + reflector	9.5	250	10.25
3 elements + reflector	10.7	97	3.7

4. CONCLUSIONS

Collinear principle in antenna design has been summarized based on historical development. Supplement principle denoted as coparallel principle has been presented on recent authors designs of collinear and coparallel arrays implemented in microstrip patch and F-type planar antenna technologies. Vector current distribution has been used to explain antenna operational principle. Main advantages and drawbacks of presented individual designs has been discussed.

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