New class of printed antenna structures

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Summary

In this paper printed antenna structures with dipoles at second resonance (antiresonance) fed by coplanar striplines (CPS) are described. Complementary structures, that is, slots fed by coplanar waveguides (CPW) as well as active antenna structures based on slots fed by coplanar waveguides are also shown. Presented structures have many advantages over conventional microstrip antennas with patches: wider bandwidth, lower losses in feeding waveguides, greater possibilities in designing antenna arrays with tapered distributions, higher suppression of cross-polarisation and greater possibilities of application in integrated antenna structures. Methods for analizing these structures are also described.

Introduction

Investigation, development and application of printed antennas, where so called microstrip antennas also belong, are in tremendous growth in last fifteen years. Reasons are numerous:

- expensive and complicated production of conventional antennas is replaced with cheaper, more accurate photolitographic process which provides better reproducibility;
- lesser weight;
- smaller dimensions - planar structures of minimal thickness;
- suitability for integration with microstrip and other planar microwave circuits;

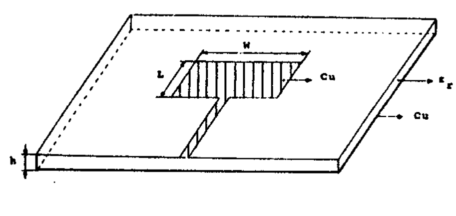

Fig. 1 Microstrip patch-antenna.

The mostly used type of printed antennas are microstrip patch-antennas, figure 1, which, however, have significant disadvantages:

- narrow bandwidth;
- high losses in feeding networks (especially in large arrays);
- high crosspolarisation;
- narrow bandwidth;
- poor tapering possibilities, that is, smaller possibilities of designing antenna arrays with higher sidelobe suppression.

Antenna Structures with Printed Dipoles

At the end of seventies and beginning of eighties, in former Institute of Applied Physics, we have been working on investigation of new printed antenna structures, i.e. antenna arrays, in order to overcome the disadvantages of conventional patch antennas. The results of these investigations were structures that have never been used before: the arrays of printed dipoles operating on second resonance and fed by coplanar strips[1].

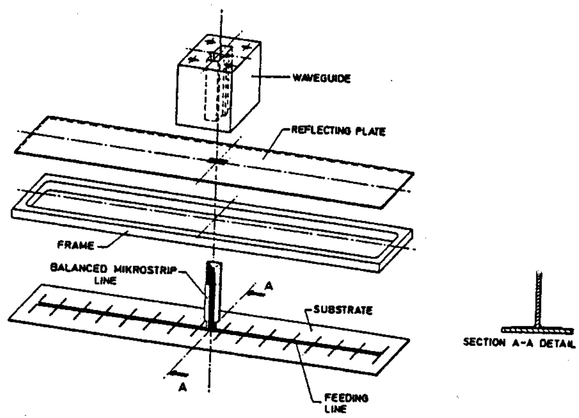

Fig. 2 Array of printed dipoles fed by coplanar strips.

Coplanar strips are fed by a waveguide-balanced microstrip transition in the middle of the array, figure 2. There is a reflector plate behind the array. In this structure almost all of the disadvantages of conventional patch antennas are avoided:

- bandwidth is widened, since dipoles at the second resonance have relatively slow impedance variation versus frequency;
- losses in coplanar strips are significantly diminished (especially the losses in dielectric substrate) in comparison with those in microstrips;
- a lower crosspolarisation is achieved due to ideally balanced symmetrical structure;
- characteristic of dipoles operating at second resonance to have impedance that can be easily variated with the variation of strip width is used to design printed dipole arrays with relatively high tapering ratio, that is, high sidelobe suppression.

Besides linear arrays of printed dipoles at second resonance fed by coplanar strips, two-dimensional arrays with uniform distribution, as well as two-dimensional arrays with tapered distributions were realized[2], figure 3.

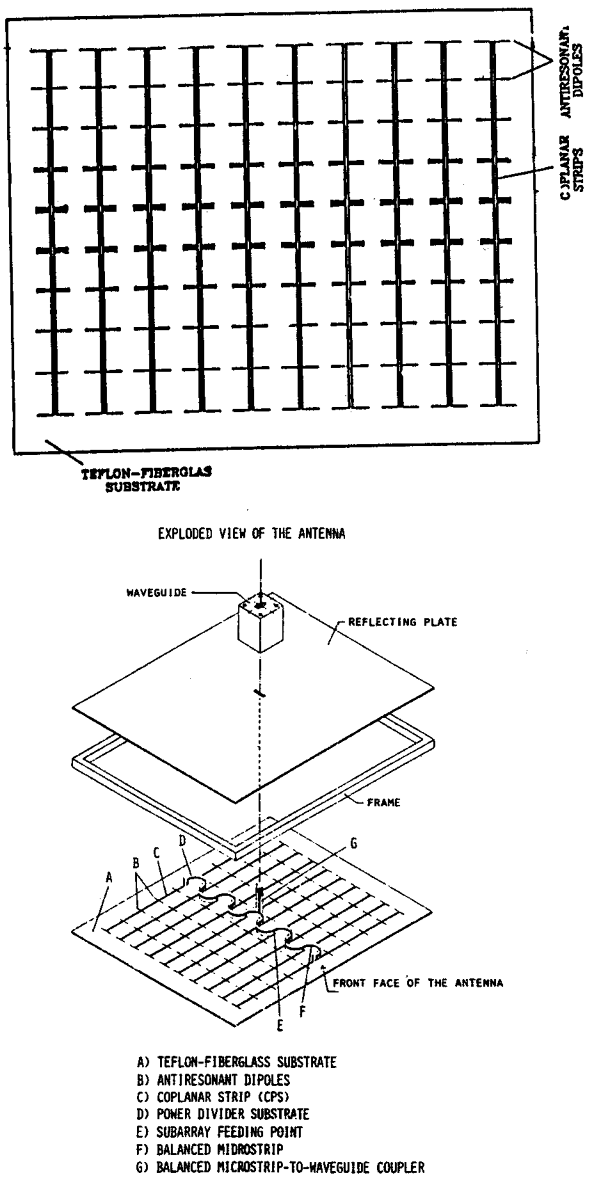

Fig. 3 Two-dimensional array of printed dipoles with tapered distribution: a) printed board; b) exploded view of the antenna.

The first arrays were designed using approximative methods in which the dielectric substrate influence was not taken into account in evaluating printed dipole characteristics. In order to determine characterictics of dipoles on dielectric substrate, it was necessary to introduce experimentally obtained corrections.

At the beginning of eighties, a theory of cylindrical antenna equivalence, in this case - theory of printed dipoles transformation into equivalent dipoles of circular cross-section with dielectric or magnetic cover was developed in our Institute[3,4,5], figure 4. Obtained structures can be analized using well-known methods.

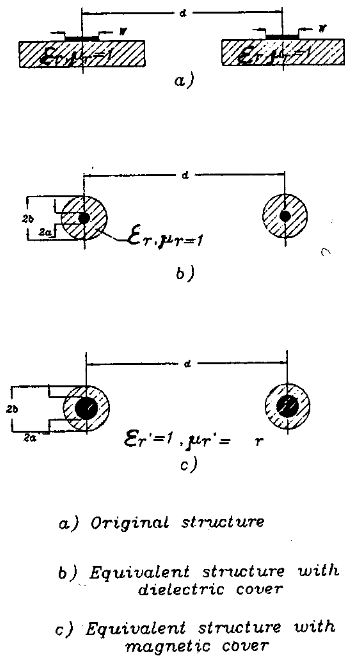

Fig. 4 Transformations of printed dipoles into equivalent dipoles of circular cross-section with dielectric or/and magnetic cover.

In the middle and late eighties, a large number of original antenna structures based on dipoles operating at second resonance and fed by coplanar strips, were designed.

Figure 5 shows monopulse antenna array with 2.2° beamwidth in H plane in Σ mode, with -45 dB depth in Δ mode and 28.5 dB gain.

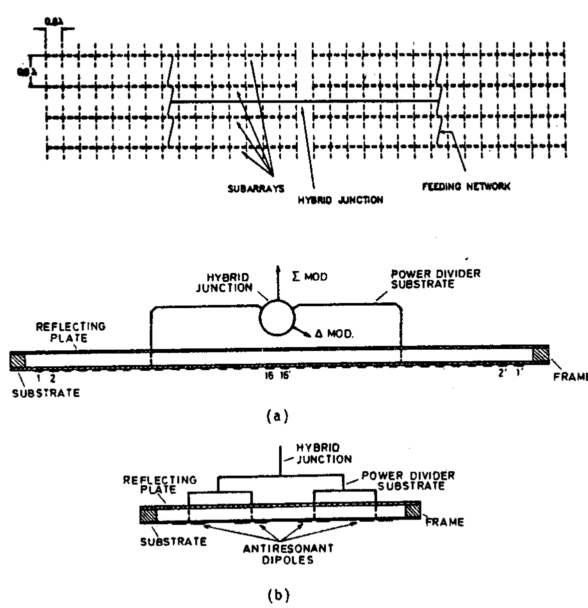

Fig. 5 Monopulse antenna array with feeding network: a) cross-section of the longer side; b) perpendicular cross-section.

In addition to printed dipoles, triangular, triangular with cap and trapezoidal dipoles were also investigated[7,8], figure 6. The best results, meaning the widest bandwidth, were achieved with trapezoidal dipoles fed by coplanar strips.

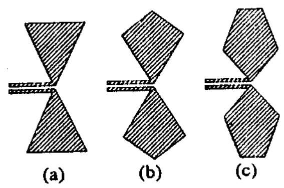

Fig. 6 Different types of printed dipoles: a) triangular; b) triangular with cap; c) trapezoidal.

In late seventies, active integrated antenna structures with integrated modulators and detectors operating up to 40 GHz were realized[9], figure 7.

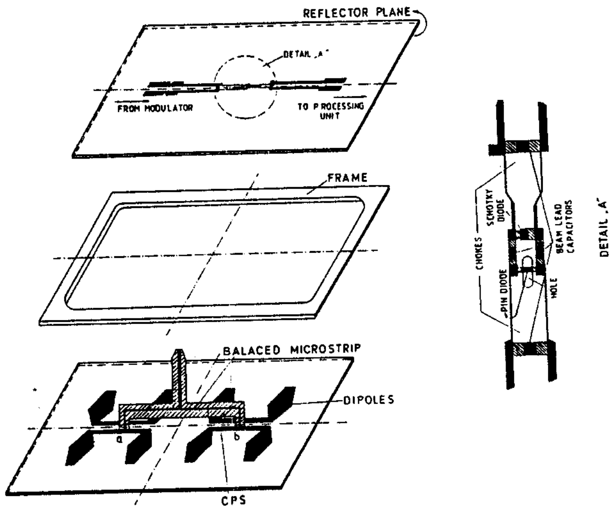

Fig. 7 Antenna array integrated with modulator and detector for 8 GHz to 40 GHz frequency range.

Antenna structures with printed slots

In the same time with investigating the antenna structures with dipoles, the complementary structures - printed slots, were researched.

Until 1982 printed slots and arrays with slots were excited with microstrip on the other side of the dielectric substrate, figure 8.

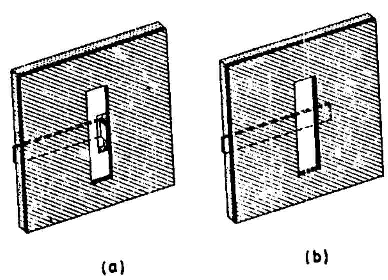

Fig. 8 Slot excited by microstrip on the other side of dielectric substrate.

We can notice that the structure complementary to dipole fed by coplanar strips is the slot fed by coplanar waveguide[10,11], figure 9.

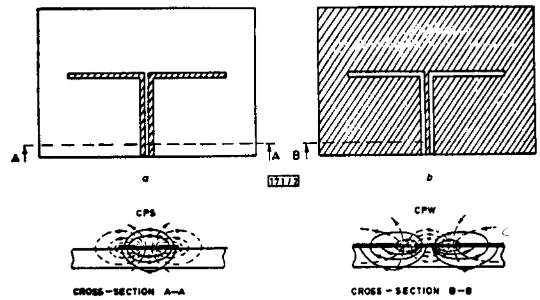

Fig. 9 a) Printed dipole fed by coplanar strips; b) slot fed by coplanar waveguide.

Based on this idea, the possibility of feeding a slots with CPW on the same side of the substrate was discovered in 1982. Also, the structure complementary to array of dipoles fed by CPS, figure 10, is an array of slots fed by CPW[10,11], figure 11.

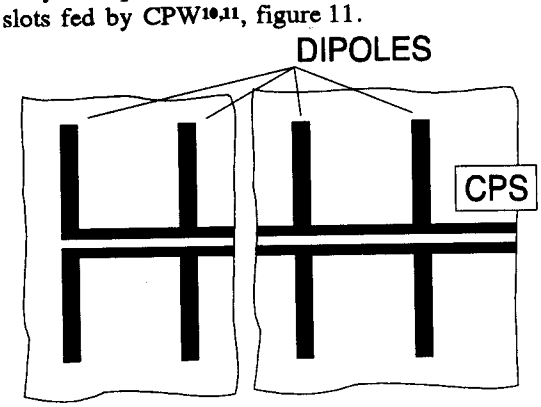

Fig. 10 Printed dipole array excited by CPS.

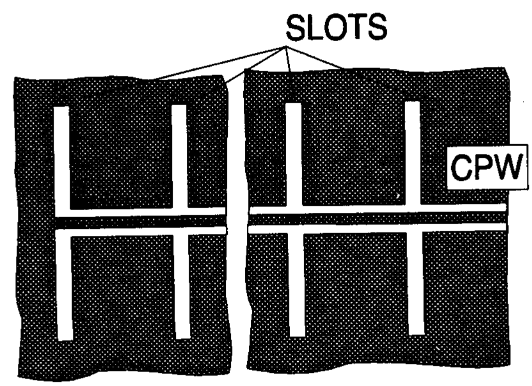

Fig. 11 Printed slot array excited by CPW.

Presented structures are uniplanar (entire structure is on the same side of dielectric substrate). This characteristic is specially important for active integrated-monolithic antenna structures researched from in the beginning of nineteens.

The first experimental models (in the beginning of 1982) were designed using approximative methods with the experimentally obtained corrections in order to take into account the dielectric substrate influence.

In the period between 1982 and 1984 the Booker's concept of complementary electromagnetic structures was extended to inhomogeneous electromagnetic structures. Namely, it is shown that the well-known Booker's relation

$$Z_{dipole} \cdot Z_{slot} = \frac{Z_0^2}{4},$$

is also valid for inhomogeneous structures if they are complementary-dual which means that they are geometrically complementary and on the substrates with relative permeability and relative permitivity interchanged ($\mu_r'=\varepsilon_r$; $\varepsilon_r'=\mu_r$)[4,12].

The paper in which the mentioned theory was presented has been awarded the Maxwell's prize of IEE for 1986[12].

The essential approach in analysis is transformation of an array of slots on dielectric substrate into complementary-dual structure, that is, into an array of printed dipoles on the magnetic substrate, excited by CPS[13]. Obtained structure is, after that, applying the theory of cylindrical antenna equivalence[5], transformed into an array of dipoles of circular cross-section with magnetic cover and analized with well-known methods.

The mentioned method is applied to design of numerous arrays of printed slots excited by CPW. Experimental results have shown very good agreement with theoretical expectations.

In 1990 has been investigated and realized uniplanar antenna-mixer with LO based on slots excited by CPW[14,15], figure 12.

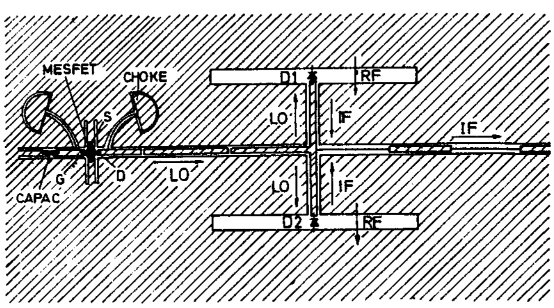

Fig 12. Integrated uniplanar antenna-mixer and local oscillator.

These structures have many important advantages over other active-integrated antennas. The main are:

- direct matching of microwave components impedance to slot impedance is easily realizable by varying dimensions of slots (length and with) which operates near second resonance;
- since structure is uniplanar, all components of the integrated structure are placed on the same side of the substrate, so it is not necessary to make holes in the substrate to provide connection between components or to make the connection between components and ground.

Conclusion

Chronology of the research and development of the new printed structures: printed dipoles excited by coplanar strips and printed slots excited by coplanar waveguide, with many advantages over conventional microstrip antennas, has been presented. Examples of linear, two-dimensional, tapered, monopulse and active antenna arrays in which the mentioned structures has been applied, has also been shown, including simple methods derived for analysis of mentioned structures.

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