A SURVEY OF EUROPEAN ACTIVITY ON COPLANAR WAVEGUIDE

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ABSTRACT

Although early work in Europe was directed at developing closed-form analytic expressions for Z_0 and ε_{eff} of a number of variants of CPW, much of the current work is application oriented. Amongst the topics being examined are CPW filters, mixers, couplers, and wideband electro-optic modulators. Work is also in progress on developing CAD data for CPW discontinuities, whilst theoretical work continues. This paper will present an overview of current European CPW work.

I. INTRODUCTION

Coplanar Waveguide (CPW) was first proposed as an MIC transmission medium by Wen [1] at the David Samoff Research Center in 1969. CPW has several advantages over microstrip including:

* Lower Dispersion
* Less Radiation Loss
* Easy Grounding of Shunt-Mounted Components
* Lower Fabrication Cost since Via-Holes are Eliminated
* Closed-Form Expressions for the Characteristic Impedance and Effective Dielectric Constant
* Higher Directivity Couplers due to Near Equality of Even and Odd Mode Propagation Constants.

Wen's form of CPW, shown in Fig. 1(a), requires an infinitely thick and an infinitely wide substrate. This fact, together with the absence at that time of any CAD data for discontinuities, undoubtedly hindered the widespread application of CPW despite its advantages.

European work on CPW started in earnest in the early 1980's. Initially, the work concentrated on developing closed-form analytic expressions, using conformal mapping, for the characteristic impedance and phase velocity (or, equivalently, effective dielectric constant) of a number of variants of the original CPW structure in which the effects associated with finite substrate thickness, finite width ground planes, backside metallisation etc. were considered. Although theoretical work continues, much of the recent work in Europe has been application oriented. Topics under investigation include CPW single, double, and image reject mixers, filters, 3 dB couplers, and wideband electro-optic modulators.

Work is also in progress on developing CAD tools for CPW design.

This paper will present an overview of the current European CPW activity in the three main areas of theoretical analysis, development of CAD data, and practical applications.

II. THEORETICAL ANALYSIS

Closed-form analytic expressions have been obtained, using conformal mapping, for the characteristic impedance and phase velocity of a number of modified CPW structures. These structures include:

* CPW with a finite thickness substrate [2], Fig. 1(b)
* CPW with infinite thickness substrate but finite width ground planes [2], Fig. 1(c)
* CPW with finite thickness substrate and finite width ground planes [2], Fig. 1(d)
* CPW with a lower ground plane [3], Fig. 1(e)
* CPW with an upper lid and a finite thickness substrate [4], Fig. 1(f)
* CPW with an upper lid and a lower ground plane [4], Fig. 1(g)
* Asymmetric CPW [5], Fig. 1(h)
* Asymmetric CPW with a finite thickness substrate [5], Fig. 1(i).

References [2] to [5] are either IEEE publications or other widely available Journals and so the expressions for Z_0 and ε_{eff} will not be given here. In some cases the expressions for Z_0 and ε_{eff} are exact, whilst in others they are approximate, but highly accurate. These solutions have been obtained by Fouad-Hanna and co-workers at CNET in France, and by Ghione and Naldi at Turin Polytechnic in Italy.

Wen [6] extended his CPW concept to include coupled lines in 1970, Fig. 2(a). Once again, an infinitely thick substrate with infinitely wide ground planes was required. Fouad-Hanna and Thebault [7] have extended Wen's analysis to the case of a finite thickness substrate, Fig. 2(b), and Fouad-Hanna [8] has considered the case of a finite thickness substrate with a lower ground plane, Fig.2(c). Fouad-Hanna

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and Thebault [7] also re-analysed Wen's original structure and obtained alternative expressions for Z_{oe} and Z_{oo} which are substantially easier to compute than the expressions given by Wen. Also, Ghione and Naldi [9, 10] have developed a method for analysing multi-conductor CPW couplers of the types shown in Fig. 2(d)-(g), and have considered how close CPW centre conductors can be before significant unwanted coupling occurs [4].

Finally, Wolff [11, 12] and co-workers at Duisburg University in Germany are involved in numerical analysis of various CPW structures using full-wave and finite-difference techniques.

III. CAD

Sinclair *et al* from THORN EMI Electronics in the UK have developed models for steps [13], bends and T-junctions in CPW. In each case a lumped-element equivalent circuit has been derived in which the element values are explicit functions of the physical parameters of the discontinuity. These models enable real-time computation of the S parameters of the discontinuity, and are readily incorporated into any standard commercially-available CAD programme. These models have been experimentally validated up to 40 GHz for relative dielectric constants ranging from 2 to 10.

Naghed *et al* [14] have developed an extremely powerful and elegant method of determing the equivalent inductances of CPW discontinuities based on an analysis of the dual structure of coplanar strips. Sinclair made extensive use of this technique in his work.

Finally, Argumens in Germany markets a 3D finite-difference program called COPLAN specifically for the calculation of the S parameters and equivalent circuit element values for a range of CPW discontinuities including gaps, bends, steps, open and short circuits, T- and cross junctions, spiral inductors and interdigital capacitors.

IV. APPLICATIONS

This section will review the work that is underway in Europe in four specific areas, namely filters, mixers, couplers, and electro-optic modulators.

CPW should enable the realisation of filters with better stop-band rejection characteristics than can be achieved using microstrip, and it greatly facilitates the realisation of filter topologies which require short-circuit stubs or lines. The passband insertion loss, however, may be higher depending upon the aspect ratio chosen for the CPW transmission lines. Rayit and McEwan [15] at Bradford University, UK have reported preliminary results on a 5th order generalised Tchebychev lowpass filter covering DC-8 GHz. This filter was constructed in suspended CPW for low loss. In another lowpass design, Rayit [16] has achieved 40 dB rejection over 12-18 GHz using a conventional shunt stub, unit element topology.

CPW is an attractive medium for the realisation of balanced and double balanced mixers as it eliminates the need for complex three-dimensional structures. Ramboz and Fouad-Hanna [17] have reported a truly planar X-band balanced mixer with 6+/-0.5 dB conversion loss over the IF frequency range of 1.8 GHz centred on 1.8 GHz. The IF, LO, image and sum signal rejection at the RF port was better than 20 dB, and the RF port match was better than 14 dB. Fouad-Hanna [18] has reported a CPW image rejection mixer with 5.5 dB conversion loss, 20 dB image rejection and 30 dB LO/RF isolation at S band over the 100 MHz IF frequency range.

Gillick *et al* [19] from King's College, London have developed a 3 dB CPW quadrature coupler using a combination of broadside and edge coupling as an alternative to the multiple coupled-line coupler first reported in CPW by Bastida and Fanelli [20] from CISE in Italy. Gillick *et al* achieved >15 dB isolation over 12-36 GHz, with <1.1 dB insertion loss.

Finally, the Defense Research Agency at Malvern, UK have developed a DC-10 GHz Mach-Zehnder interferometer-based waveguide electro-optic modulator which uses CPW to get the RF signal on to the PIN modulator. GEC-Marconi Materials Technology Ltd at Caswell, UK have extended this concept and market commercially travelling-wave versions of the above with a 3 dB bandwidth of DC-20GHz, whilst in the laboratory they have achieved a bandwidth of DC-37 GHz [21]. Both of these devices utilise CPW/slotline for the microwave circuitry.

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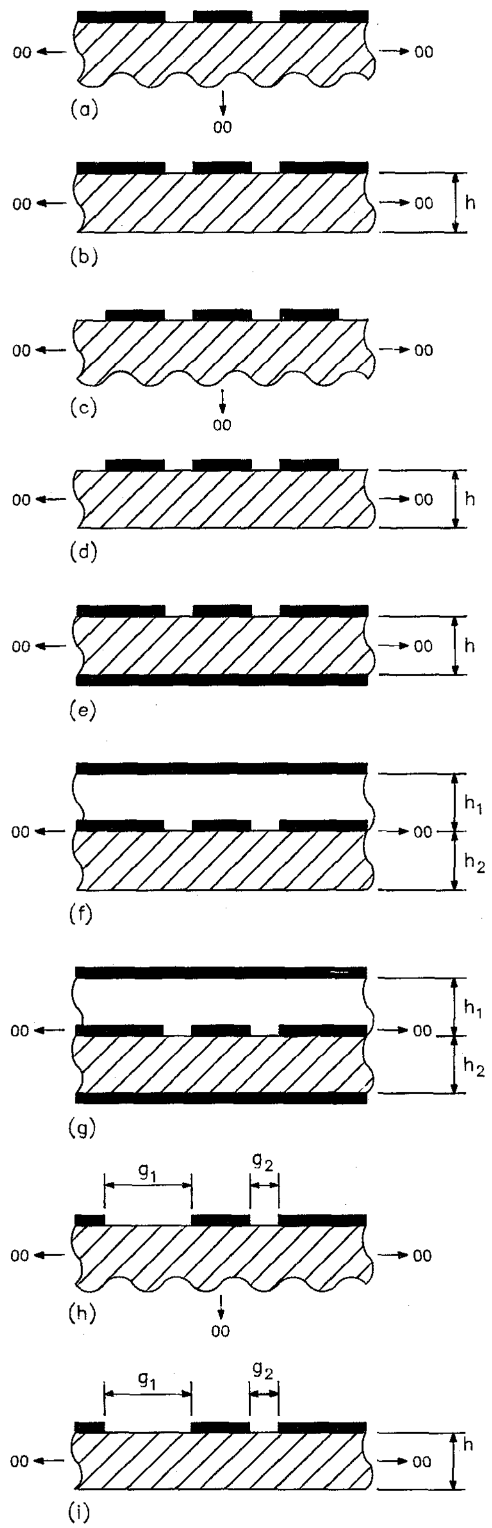
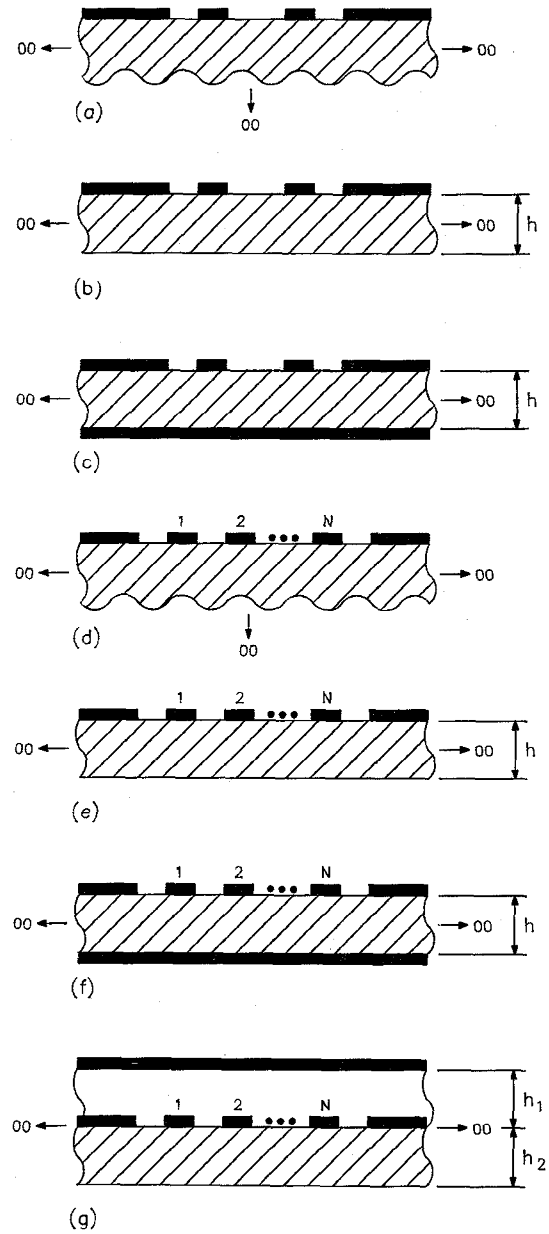


TYPES OF CPW TRANSMISSION LINE WHICH HAVE BEEN ANALYSED USING CONFORMAL MAPPING
FIGURE 1



TYPES OF CPW COUPLER WHICH HAVE BEEN ANALYSED USING CONFORMAL MAPPING
FIGURE 2