CC/NUMBER 22
JUNE 2, 1980

This Week's Citation Classic

Wheeler H A. Transmission-line properties of parallel strips separated by a dielectric sheet. *IEEE Trans. Microwave Theory* **MTT13:**172-85, 1965. [Wheeler Labs., Great Neck, NY]

A transmission line is made of a symmetrical pair of parallel thin strips, or one strip and a shield plane, separated by a dielectric sheet ('microstrip'). Its wave properties are computed to a close approximation by an application of conformal mapping to the mixed dielectric. The relation between shape ratio and wave resistance is graphed for a wide range of dielectric. [The *SCI®* indicates that this paper has been cited over 210 times since 1965.]

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May 9, 1980

"With the advent of 'printed circuits' around 1950, their microwave applications gave rise to the strip line. It was a thin strip separated from a return conductor (another strip or a ground plane) by a dielectric sheet. (It was commonly termed 'microstrip.') Its wave properties became significant and presented difficulties in computation, especially with mixed dielectric (the sheet in between and the air outside).

"First I saw a challenge to make a simple approximation by application of conformal mapping. Based on wide strips with air dielectric, I achieved this result for the range down to a rather small width. I published that in 1964.[1]

"In that exercise, I mapped the field of the strips on a rectangular area with uniform field. Then I could map the dielectric boundary as a curve in that area, so dielectric of proper shape could be inserted in the rectangular area. I introduced some unusual concepts to place the capacitance between bounds that could be made very close, especially at extremes of large or small width and large or small dielectric constant I evaluated the 'effective filling fraction' of the dielectric, which came out to be dependent mainly on the shape ratio and only weakly on the dielectric constant.

"From the capacitance in air and the effective dielectric constant, it was routine to evaluate the wave resistance and wave speed. For the convenience of the reader, I graphed on useful (log-log) scales the relation between wave resistance and shape factor for a wide range of dielectric. This became available for the first time with the publication of the subject paper in 1965.

"The methods of approximation were a culmination of 40 years of practice in developing approximate formulas for relations whose exact formulation was difficult and could not be expressed in simple terms.

"Subsequent workers on this problem have referred to my 1965 paper as a standard of comparison, while they exploited convergent numerical methods. The latter have been enabled by the fast computer, but have yielded only a few examples. These have verified the close approximation of my formulations and graphs, which were made with only the slide rule.

"The consistent citation of my 1965 paper reflects mainly its distinction as the first general evaluation of a strip line with mixed dielectric.

"That paper has now been extended in my 1977 paper[2] which was made possible by the convenience of the personal programmable calculator. I devised a simple single formula for close approximation of the 1965 relations, extended to include the strip thickness. This formula was 'reversible' for explicit analysis or synthesis. The thickness effect enabled the computation of the magnetic-field losses by numerical differentiation for my 'incremental inductance rule' of 1942.[3] The formulas were developed by testing on the HP-25 model, then all programmed on one magnetic card for the HP-97 model. The latter provides all the properties of this strip line, to a close approximation for design purposes.

"The 1965 paper was presumptively a contributing factor in my selection by the IEEE Society on MTT in 1977 as the second recipient of the Microwave Career Award."

1. **Wheeler H A.** Transmission-line properties of parallel wide strips by a conformal-mapping approximation. *IEEE Trans. Microwave Theory* **MTT12**:280-9, 1964.
2. .... Transmission-line properties of a strip on a dielectric sheet on a plane. *IEEE Trans. Microwave Theory* **MTT25**:631-47, 1977.
3. .... Formulas for the skin effect. *Proc. IRE* **30**:412-24, 1942.