PROCEEDINGS OF ISAP '85 042-6

A DIAGRAMMATIC APPROACH TO TRANSIENT SCATTERING AND COMPLEX RESONANCE CONSTRUCTION BY MULTIPLE WAVEFRONT INTERACTION

E. Heyman

Department of Electrical Engineering, Tel-Aviv University, Ramat Aviv, Israel

and

L.B. Felsen

Department of Electrical Engineering and Computer Science Polytechnic Institute of New York, Farmingdale, New York 11735 USA

Complex resonant frequencies and the associated modal fields play an important role in the theory of transient scattering. These resonant modes, which behave as damped oscillations, form the basis of the singularity expansion method (SEM) [1]. While best suited to transient field evaluation at late observation times, recent efforts to push SEM into the early time domain have highlighted difficulties that pertain to the need, or not, of including an entire function in the frequency domain representation. Of the various interpretations of the entire function [2,3], the most cogent appears to be the one based on the initial interaction of the incident wavefront with the scattering object [4,5]. The wavefront approach retains its significance, however, even at later times when the wavefront has had an opportunity to sample the scatterer by successive traversals before reaching the observer. These multiple wavefront arrivals, which now obscure the scattering process, can then be combined collectively into physically more appropriate resonant modal fields. The bilateral wavefront-resonance interplay has been exploited to construct a hybrid formulation that combines both wave types in unique proportion to optimize description of the transient response for all observation times [5,6]. A remarkable feature of the resonance construction by wavefront summation is the accuracy of the complex resonances, even including those at the lower frequency end, when high-frequency asymptotic (ray) methods are used to approximate the scattering process [7.8.9].

Since the shape and composition of a scatterer determine the resonances in the complex frequency plane, their distribution may be employed for object classification and identification. For targets comprising composite substructures (see Fig. 1), one may consider partial resonances characteristic of each substructure in isolation, and then explore the perturbation of these isolated resonances when the substructures are assembled to form the composite object. By this approach, it is possible to explore the effect on the resonance map caused by changes in a substructure, thereby providing insight into the scattering mechanisms that establish a compound resonance. The evolution of a partial resonance and its modification by other object features is explained in its most basic form by wavefront interactions taking place between identifiable scattering centers. The totality of multiple interactions can be "collectivized" in many alternative forms that highlight different aspects of the scattering process and resonance formation.

Success in this endeavor depends critically on a systematic ordering of the multiplicity of wavefront events. Here, it may be useful to employ diagrammatic techniques, which chart the individual interactions and, by the existence of various "closed loops", point the way toward their selective collective treatment. Accordingly, borrowing from system theory [10], we

introduce scattering centers as nodes, and propagation functions between scattering centers as directed branches, in a signal flow graph that models the scattering process. For complicated scatterers, the individual propagation and scattering events are described by the geometrical theory of diffraction (GTD), thereby embedding a high frequency constraint in the procedure. However, because of the remarkable accuracy of all of the complex resonance frequencies constructed in this manner for certain simple object shapes [7,8,9], it is reasonable to expect that the GTD scheme can likewise generate the resonance configuration for more complex targets.

The above-described theory of transient scattering, linking wavefronts and resonances by formal matrix manipulation and by the flow graph approach, is contained in a forthcoming publication [5]. It is briefly reviewed here and then applied to the construction of the transient field and complex resonance equation for a variety of object shapes that demonstrate different features of Emphasis is on two-dimensional structures or, the flow graph technique. equivalently, on certain phenomena on three-dimensional structures with rotational symmetry. Included are smooth convex objects, objects with edges, convex-concave shapes, and layered media (Fig. 2). For some of these, the interaction functions may involve complex ray fields, while for layered media, the identification of partial resonances is linked with the previously introduced "collective ray" [11]. The presentation stresses the options available for ordering the composite resonances according to partial subgroups, and the physical features of various groupings.

## Acknowledgment

This work was sponsored by the U.S Office of Naval Research, Electronics Branch, under Contract No. N00014-83-K-0214 and by the joint Services Electronics Program under Contract No. F49620-82-C-0084.

## References

- [1] C.E. Baum, "The Singularity Expansion Method: Background and Developments" Electromagnetics, Vol. 1, No. 4, pp. 351-361, 1981.
- [2] M.A. Morgan, "Singularity Expansion Representation of Fields and Currents in Transient Scattering", <u>IEEE Trans. Antennas Propagat.</u>, Vol. AP-32, pp. 466-473, 1984.
- [3] L.W. Pearson, "A Note on the Representation of Scattered Fields as a Singularity Expansion", IEEE Trans. Antennas Propagat., Vol. AP-32, pp. 520-524, 1984.
- E. Heyman and L.B. Felsen, "Non -Dispersive Approximations for Transient Ray Fields in a Inhomogeneous Medium", in <a href="https://doi.org/10.10/10.10/4.">Hybrid Formulation of Wave Propagation and Scattering, L.B. Felsen ed., Nijhoff Pub. Co., The Hague, 1984.</a>
- [5] E. Heyman and L.B. Felsen, "A Wavefront Interpretation of the Singularity Expansion Method", to be published in <a href="IEEE Trans. Antennas Propagat">IEEE Trans. Antennas Propagat</a>, 1985.

- [6] E. Heyman and L.B. Felsen, "Creeping Waves and Resonances in Transient Scattering by Smooth Convex Objects", IEEE Trans. Antennas Propagat., Vol. AP-31, pp. 426-437,1983.
- [7] S.U. Hwu and L.W. Pearson, "Numerically Determined Natural Resonances for an Infinitely Long Perfectly Conducting Strip", presented at International IEEE/AP-S Symposium National Radio Science Meeting, Boston, MA, USA, 1984.
- [8] H. Shirai and L.B.Felsen, "Modified GTD for Generating Complex Resonances for Flat Strips and Disks", submitted for publication.
- [9] R. Naishadham and L.W. Pearson, "Numerical Evaluation of Complex Resonances of an Elliptic Cylinder", submitted for publication.
- [10] J.R. Ward and R.D. Strum, "The Signal Flow Graph in Linear Systems Analysis", Prestice-Hall, Englewood Cliffs, N.J. 1968.
- [11] P.D. Einziger and L.B. Felsen, "Ray analysis of Two-Dimensional Radomes", IEEE Trans. Antennas Propagat. Vol. AP-31, pp. 870-885, 1983.
- [12] E. Heyman and L.B. Felsen, "Evanescent Waves and Complex Rays for Modal Propagation in Curved Open Waveguides", SIAM J. Appl. Math. Vol. 43, pp. 855-884, 1983.

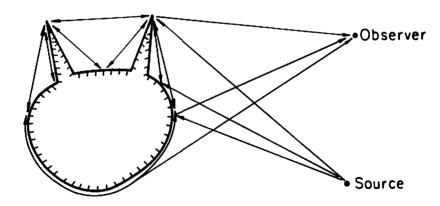
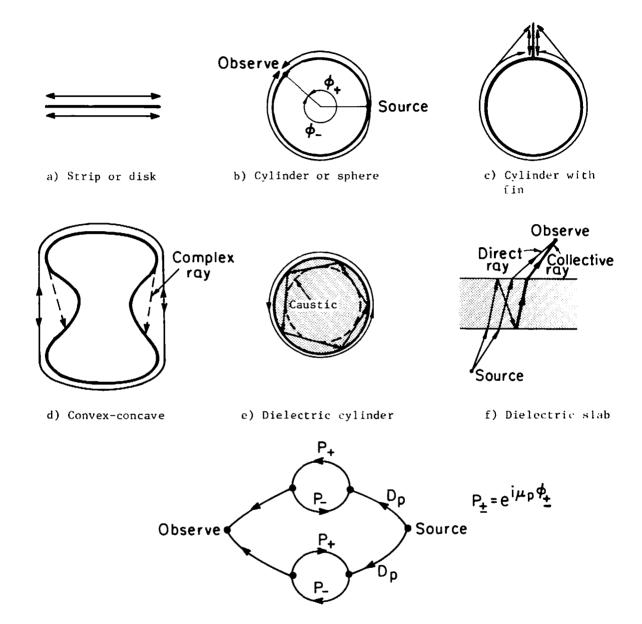


Fig. 1 Scattering centers and interaction mechanisms for a composite scatterer.



g) Flow diagram for (b)

Fig. 2 Various object shapes, interaction paths, and simple flow graph. b), c), d), and e) may involve complex rays [12]. e) consists of high Q (internal) and low Q (external) interactions. In f), all internal reflections after the first are treated collectively. In g)  $\mu_{\rm p}$  and  $D_{\rm p}$  are the angular wavenumber and the diffraction coefficient of the creeping waves, respectively.