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This Week's Citation Classic

Trivelpiece A W & Gould R W. Space charge waves in cylindrical plasma columns. *J. Appl. Phys.* **30:**1784-93, 1959.
[California Institute of Technology, Pasadena, CA]

This paper reports the results of experimental and theoretical studies on the propagation of space charge waves on finite cross section magnetized plasma columns. The existence of backward waves and surface waves (unmagnetized plasmas) are revealed by the experiments. [The *SCI®* indicates that this paper has been cited over 270 times since 1961.]

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"This paper had its origins in a summer of 1956 project to build 1,420 mc low noise traveling wave tubes for use as preamplifiers in the Caltech radio telescope. The tubes that I built had measured noise figures that were much worse than the predicted theoretical minimum of six db. I used the standard low noise tube design formulae, which had been previously demonstrated to result in tubes that could achieve the six db minimum, albeit at higher frequencies. These low noise design formulae are based on the one dimensional Lewellyn-Peterson equations. To explore the possibility that the design formulae needed to be modified for tubes in this lower frequency range, I used the Hahn-Ramo equations for space charge waves on electron beams to analyze how three dimensional effects might influence the propagation of velocity and current noise disturbances on a drifting electron beam.

"In the course of this work, the case of a nondrifting electron beam was explored. The dispersion relation derived for zero drift velocity predicted that slow (phase velocity much less than c) space charge waves could propagate below the plasma frequency on an electron beam (plasma) filling a conducting tube that would otherwise not support any propagating electromagnetic waves in the absence of a plasma. This result was so interesting that Roy Could, my thesis advisor, and I decided to abandon the low noise tube business and build an experiment to investigate the features of these space charge waves on nondrifting plasmas.

"The experiment consisted of a low pressure mercury arc discharge tube about one cm in diameter and 30 cm long. The discharge tube was immersed in an axial magnetic field. The waves were launched by applying the rf fields to the discharge anode and detected by a probe that was moved along the tube to measure their wavelength. The surprise was that this simple apparatus gave remarkably good results. In particular, it verified most of the essential features of space charge waves on magnetized plasma columns, it demonstrated the existence of backward waves, and it resulted in the experimental discovery of surface waves on plasma columns. Although solutions of the complete Maxwell's equations are possible for the cases that were being investigated experimentally, they were difficult to derive and evaluate for the cases of interest. However, since these are slow waves, it is possible to use a quasistatic scalar potential mode to investigate many of their properties. This scalar potential analysis revealed the richness of phenomena associated with these waves and has served as a useful road map for subsequent theoretical and experimental studies.

"I believe that it is this richness of the phenomena associated with waves on finite plasmas that this work demonstrated that has stimulated the large number of subsequent studies of these space charge waves.

"This work was the basis for my PhD thesis, *Slow Wave Propagation in Plasma Waveguides,*[1] and was published as a monograph with the same title.[2] The growth of interest in these waves still continues over 20 years after the work was first reported.[3] For instance, there will be an international conference devoted to surface waves on plasmas, in Sophia, Bulgaria, in October 1981."

1. **Trivelpiece A W.** *Slow wave propagation in plasma waveguides.* PhD thesis. Pasadena, CA: California Institute of Technology, 1958. 145 p.
2 ...., *Slow-wave propagation in plasma waveguides.* San Francisco, CA: San Francisco Press, 1966. 165 p.
3. **Moisan M, Beaudry C & Leprince P.** A small microwave plasma source for long column production without magnetic field. *IEEE Trans. Plasma Sci.* PS-3:55-9, 1975.