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INVESTIGATION OF REACTIVE LOADING

By

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ABSTRACT

This report summarizes the results of a 5-year study of the reactive (or impedance) loading technique. Applications to various geometries are discussed, leading to an appreciation of both the strengths and weaknesses of this technique as a means of cross section modification and control. Small bandwidth is, perhaps, the greatest drawback to any widespread application, and of the many approaches that have been (and are still being) tried to enlarge the bandwidth, network synthesis appears to hold the most promise.

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I
INTRODUCTION

When an electromagnetic wave is incident on a conducting object, a current is induced which, in turn, reradiates to produce a scattered field. At present, one of the major problems in scattering theory is to develop ways to control this scattering through modification of the shape of the object or by changing the current distribution on its surface. It has long been recognized that minor shape changes can be effective in decreasing (or even enhancing) the scattering cross section, especially at high frequencies, and with the development of absorbing coatings during the past decade, the application of these materials has become one of the most important tools for cross section reduction. However, it is desirable to investigate other means of cross section control, particularly those which are effective in the resonance region and which can be used either to decrease or increase the scattering. One such method is surface or impedance (admittance) loading. This has received considerable attention in recent years, and one great advantage of the technique is that in contrast to shaping and the application of microwave absorbers, it does not require alteration of the body's shape or surface characteristics.

In essence, the technique is to introduce an impedance over a restricted portion of the surface using a cavity-backed slot, lumped network or other type of microwave circuit, and as such it is only a special case of the general theory of surface impedance effects. Mathematically at least, it is similar to the application of absorbers, but in practice differs both in the localized nature of the region where the loading is employed and in the greater variety of impedances that can be achieved either to enhance or decrease the scattered field.

The idea of using loading to reduce the reradiated fields dates back to the 1920's (Meissner, 1929) when it was common practice to use lumped inductors and capacitors to detune the broadcast transmitting antenna supporting structures whenever their lengths were near resonance and interfered with the antenna radiation patterns. The first reported application of the loading technique for scattering reduction at microwave frequencies was by Iams (1950), who used a coaxial loading to decrease the scattering from the metallic posts in a parallel plate pillbox structure. King (1956) investigated the change in the current distribution on a thin cylindrical rod when a central load is introduced, and later Hu (1958) and Ås and Schmitt (1958) showed that a high reactive impedance can appreciably affect the scattering behavior of such a rod.

Nevertheless, the potentiality of this technique as a means of cross section reduction in the resonance region was not appreciated until the early 1960's. Following a study at AFCRL, Sletten (1962) reported that for cylinders approximately $\lambda/2$ in length, and $\lambda/4$ and $\lambda/8$ in diameter, significant reductions in their broadside cross sections could be obtained by reactive loading at their centers, and shortly thereafter work was commenced at the Radiation Laboratory aimed at exploring the use of reactive (or impedance) loading as a means of reducing the cross sections of cylinders and related shapes.

II

APPLICATION TO SIMPLE GEOMETRIES

Since the main emphasis in this study was the resonance region for which the loading technique is well suited, and since the resonance characteristics of any body are sensitive functions of its geometry, it appeared necessary to select a specific geometry for the investigation of the technique. The circular cylinder was a natural choice in view of Sletten's work, but because it was desirable to establish an adequate theoretical basis for the study, the body that was actually chosen was a thin circular cylinder of length ℓ, $0 < \ell < 2\lambda$, loaded at its center (Chen and Liepa, 1964).

For a thin cylinder, adequate mathematical tools were already available (King, 1956) for an analysis of the scattering. An approximate solution of the integral equation for the current on the cylinder was obtained as a function of the central load, Z_L, and from this an expression for the far field was derived and computed. It was found that the back scattering cross section at broadside could be reduced to zero by appropriate choice of load, but that a non-zero resistive component R_L was in general necessary for this purpose. It was further shown that for a cylinder of length $\ell < \lambda$ this optimum loading was passive ($R_L \geq 0$), whereas for a cylinder of length $\ell, \lambda < \ell < 2\lambda$, an active ($R_L < 0$) load was generally required. For cylinder lengths near resonance ($\ell \sim \lambda/2$) or shorter, a loading which decreases the back scattering at broadside also decreases the magnitude of the current induced in the cylinder by as much as 70 per cent, and in consequence this same loading reduces the bistatic scattering at all aspects (other than end-on), as well as back scattering for oblique incidence. For a cylinder beyond resonance, however, the loading for a reduced back scattering cross section at broadside is not so effective for bistatic angles or for oblique incidence. The reason for this becomes clear when the dipole currents are examined for the case of oblique incidence. By dividing the current into components which are symmetric or anti-symmetric with respect to the center of the cylinder, it is obvious that a center load affects only the symmetric component and leaves the anti-symmetric one unaltered, suggesting that double loading would be desirable for this application. A theoretical investigation of a thin cylinder with two equal loads symmetrically placed was carried out by Chen (1965) who showed that loading positions could be found at which the impedances necessary to suppress the contributions to the back scattered field provided by both the symmetric and anti-symmetric modes were approximately the same. Using such a (passive) loading, it is to be expected that the back scattering cross section could be significantly reduced at almost all aspects and for cylinders of length up to 1.5λ.

For the case of single loading, confirmation of the theoretical results was provided by measurements carried out using a rod with an input gap located at its center and backed by a symmetrical coaxial cavity of adjustable depth (Chen and Liepa, 1964). The surface and back scattered far fields were measured for various cavity depths at the frequency for which the cylinder was resonant. The agreement with theory was extremely good, and compared with the predicted 40 db maximum reduction of the broadside cross section attainable with a reactive load, the measured maximum reduction was 31 db.

Encouraged by the results of this initial study, we now turned to an investigation of impedance loading applied to a sphere. One of the main reasons for choosing this shape was the desire for a body having non-zero carrying capacity (i.e. volume), both for practical reasons and to explore the efficiency of loading in the presence of the more complex resonance behavior characteristic of such a body. In view of the experimental work of Sletten et al (1964), a thick cylinder might have seemed a more natural choice, but for this shape a rigorous theoretical treatment is impossible. For a sphere, on the other hand, an analysis can be carried out which is tantamount to being exact regardless of the frequency employed, thereby avoiding the uncertainties present in the treatment of even a thin cylinder of length greater than (about) 2λ.

The particular case studied was that of a metallic sphere loaded with a slot in a plane perpendicular to the direction of incidence (Liepa and Senior, 1964, 1966). The slot was assumed to be of small but finite width with a constant electric field across it, and under this assumption the analysis for the external fields was exact. Expression for the scattered far field components, as well as the total surface field components, were derived, and then used to investigate the modifications to the scattering cross section produced by various admittances of slot. The numerical work was limited to the range $0 < ka \leq 10$, where a is the radius of the sphere.

It was found that the loading admittance necessary for any given modification was in general complex, with negative or positive real part, corresponding to an active or passive load respectively. The loading required to reduce the back scattering cross section to zero was examined in some detail. It was shown that for any given slot position, the ranges of ka in which the real part of the loading admittance is negative or positive alternate with one another, with the locations of these active and passive bands being functions of the slot position. For example, with the slot at the shadow boundary $(\theta_o = 90^o)$, there are three active bands in the range $0 < ka \leq 10$, but as the slot is moved towards the front of the sphere, these bands appear to slide in the direction of increasing ka.

At selected frequencies for which the demanded loading is reactive, the theoretical predictions were confirmed by measurements made using a sphere with a circumferential slot backed by a radial cavity whose depth could be varied by the insertion of spacing discs of the appropriate size. Back scatter reductions in excess of 20 db were observed, and measurements of both the surface and back scattered far fields were performed as functions of angle for various values of the load.

Passive loading can also be used to provide an enhancement in the cross section, with the back scatter enhancement being as high as 20 db (or more) for particular values of ka. One interesting feature of this enhancement that was not recognized at the time of the original investigation is that for a sphere of given size in the Rayleigh region the maximum attainable cross section in db m^2 actually <u>increases</u> with decreasing frequency. Consider, for example, the results presented in Fig. 2-1 in which a sphere of radius 0.477 m (ka = 1.0 at 100 MHz) has been loaded for maximum back scatter at each frequency. In contrast to the cross section σ_o of the unloaded sphere, which decreases rapidly for decreasing frequency below 100 MHz, the cross section of the loaded sphere increases apparently without limit. It is believed that such an enhancement is a genuine effect, although in practice there will almost certainly be factors such as ohmic losses which will ultimately limit the increase. If the required loading is supplied by a radial cavity such as Liepa and Senior (1964, 1966) used in their experimental model, it is also to be expected that the bandwidth for the maximum enhancement will be even less than the few per cent available when the sphere was loaded for zero back scattering.

Reverting now to cross section reduction, the complete aspect coverage observed for a loaded thin cylinder of length near $\lambda/2$ is not attainable with a sphere

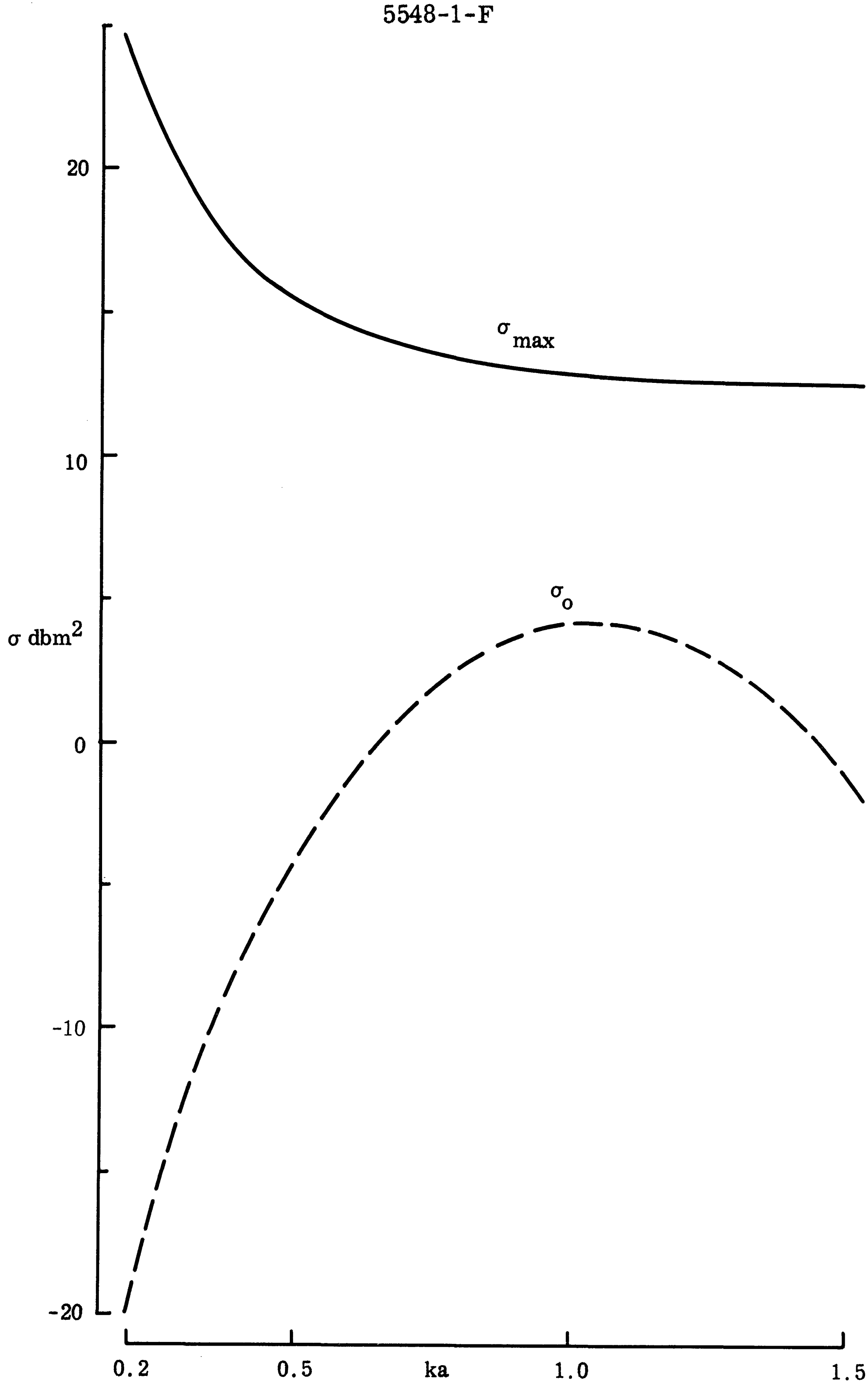

FIG. 2-1: ABSOLUTE BACK SCATTERING CROSS SECTION OF A SPHERE 0.477 m IN RADIUS, UNLOADED (---) AND LOADED FOR MAXIMUM RETURN (—).

loaded in the manner considered by Liepa and Senior (1964, 1966), no matter how small the sphere is. When the sphere is loaded for zero back scattering, the angular beamwidth for 20 db reduction under bistatic operation approaches 64^{o} (total angle) as $ka \longrightarrow 0$; but as ka increases from zero, the beamwidth decreases, and is down to 30^{o} (approx.) at ka = 2.0. From the detailed study of both the surface and far fields of the loaded sphere, it was evident that slot loading in the plane perpendicular to the direction of incidence does not reduce the total scattering cross section to any significant extent, but instead modifies the scattering pattern by redirecting the scattered energy. The reason for this is that the radiated surface field component, which can be identified with the component provided by the voltage across the slot, does not possess the same phase distribution as the corresponding surface field component on the unloaded sphere. In consequence, there is no uniform suppression of the net surface field, and the far field reduction is obtained mainly through phase cancellation. This is in contrast to the case of a thin cylinder of resonant length for which the radiated surface field had essentially the same amplitude and phase distribution as the surface field on the unloaded body, thereby enabling us to reduce the overall surface field and, hence, the scattering at almost all aspects.

The orientation of the sphere loading considered by Liepa and Senior (1964, 1966) is analytically convenient since only the tesseral harmonics of the first order appear in the expressions for the surface and far fields. Practically, however, the choice is not so desirable, and the fact that the voltage appearing across the slot has an asymmetric ($\cos \phi$) distribution means that the loading must be distributed around the slot and cannot be lumped as a single load at the center of the cavity, where it would not be 'seen' by the signal. In order to simplify the practical loading problem, the treatment of Liepa and Senior was now extended to the case of an azimuthally - loaded sphere at arbitrary incidence (Chang and Senior, 1967). The analysis paralleled in large measure that previously given, the only major difference being the occurrence of doubly - infinite sets of modes. Analytical expressions for the surface and far field components were presented, as well as for the loading necessary to produce selected forms of cross section control. Once again emphasis was placed on the reduction of the back scatter cross section, and it will be observed that in general we now have the choice of loading each mode so as to suppress its individual contribution, or of loading one mode (taking into account the effect, if any, of that load on all other modes) so as to suppress the net contribution in the far field. Practically, however, the former type of load would be almost impossible to realize, and since a load placed at the center of a radial cavity affects only the zero order mode, it is most convenient to load in this manner whenever the zero order mode is present, i.e. for all angles of incidence other than normal to the slot.

In both the numerical and experimental work, attention was concentrated on the case of a circumferentially-loaded sphere with the slot in the plane of incidence and normal to the incident electric vector. In the lower resonance region at least, the zero order mode is then the dominant contributor to the far field back scattering of the unloaded sphere, and adequate cross section control can be achieved using a single lumped load at the center of a radial cavity. The real and imaginary parts of the impedance necessary to give zero back scatter were computed as functions of ka, and in Fig. 2-2 the curves are reproduced for the case of a slot of width 0.0399 radians backed by a cavity of inner radius $b = 0.04a$. It will be observed that the load is passive for $0 < ka < 1.685$, and is primarily reactive throughout this range. Much of the later work on network synthesis of loads took,

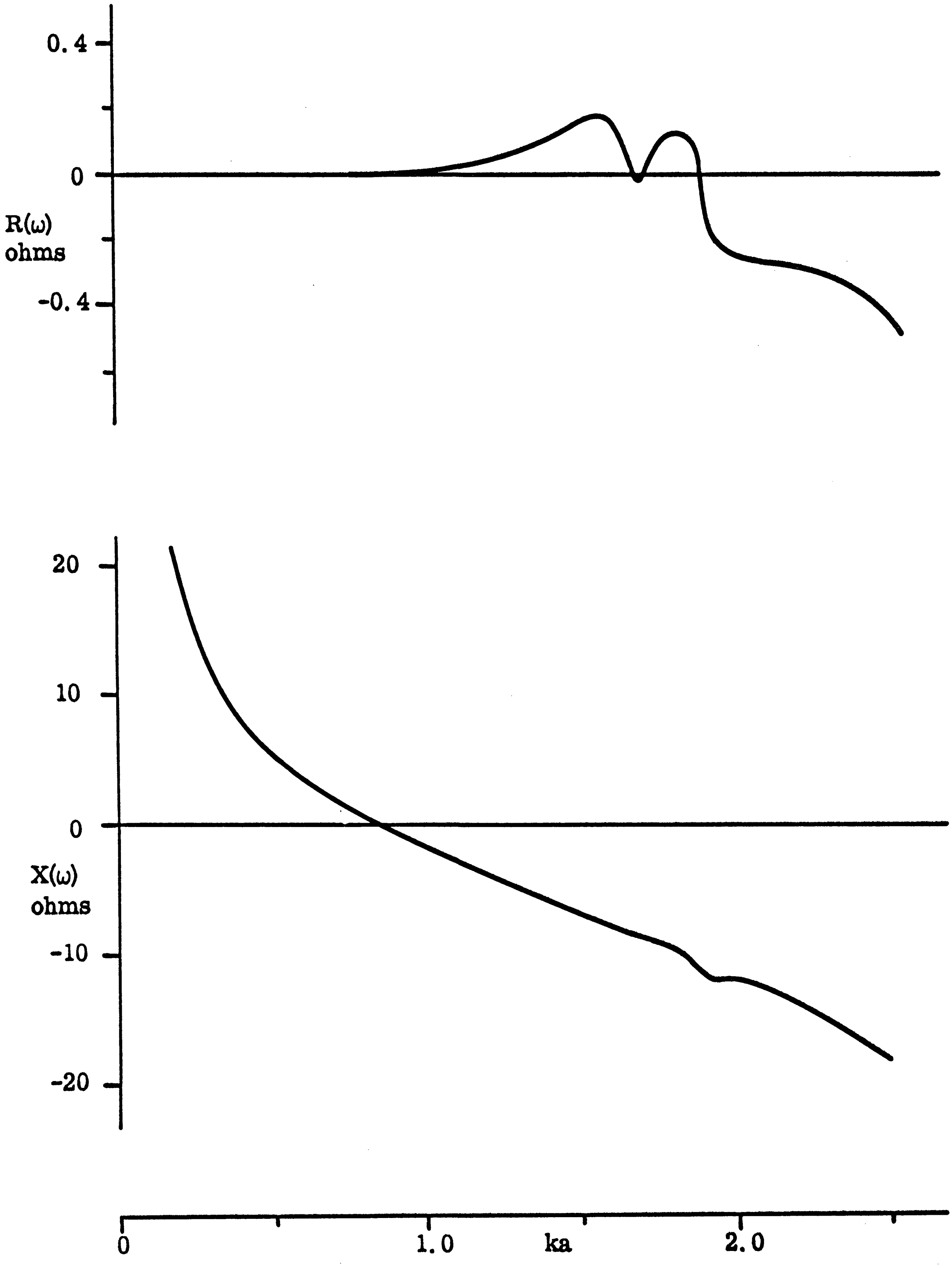

FIG. 2-2: IMPEDANCE Z = R + iX FOR ZERO BACK SCATTERING.

as its starting point, the portion of the curve in Fig. 2-2 out to (about) ka = 1.3 where the required load can be assumed to be reactive. Measurements of the back scattered field as a function of the applied load at two isolated frequencies (Chang and Senior, 1967) confirmed the predictions of the theory, and though the surface field as such was neither computed nor measured, it would appear that the effect of a slot in the plane of incidence and normal to the electric vector is similar to that found for a thin resonant cylinder, namely, that the surface fields are reduced overall, leading to a reduction of the total scattering.

From the investigations of impedance loading applied to these, and other, geometries, certain general conclusions can be drawn which are surprisingly (and distressingly) uniform in spite of the quite contrasting reasonance characteristics of the unloaded bodies. In particular, for any specific cross section modification the bandwidth produced by an elementary loading device is quite narrow (of order a few per cent only), and this represents the single most important drawback as regards practical application of the method at the moment. In essence, it acts as a cancellation method, and the resulting loading necessary to reduce (or enhance) the cross section has exactly the opposite frequency dependence to that obtainable from a simple cavity, or from even an unsophisticated passive lumped network. Unless (or until) techniques can be devised to synthesize and realize the required loading over a significant band of frequencies, the implementation of this method must remain limited to narrow band applications, and the motivation for much of our work during the last two years of the Contract has been the desire to enlarge the bandwidth attainable with the impedance loading method.

III
SEARCH FOR A WIDER BANDWIDTH

The extremely narrow bandwidth (of order a few per cent only), coupled with an aspect sensitivity which, in general, increases with the electrical size of the scatterer, constitute the severest drawbacks to impedance loading as a practical tool for cross section reduction and/or control. In many instances the aspect sensitivity can be reduced at the expense of increased complication by adding further loads, and there are even circumstances under which this sensitivity is not a handicap. But the bandwidth is another matter. It is too narrow even for many so-called narrow band applications, and considerable attention has been given to ways of increasing it. The approaches that have been tried have included the incorporation of designed materials into the loading cavity, the positioning of loads at locations determined by the scattering behavior of the body, the use of multiple loads, and the design of cavities and apertures in what seems the most appropriate manner for the body to which they are to be applied; and though the method which appears to have the most potential at the moment is the active network synthesis approach, it is appropriate to give brief mention to these other investigations as well.

A characteristic feature of almost every load required for some particular form of cross section control is its tendency to look like a negative impedance as a function of frequency. Over a finite frequency band, materials do exist whose permittivity and/or permeability decrease with increasing frequency in a way which seems compatible with the frequency dependence of the desired loading, and it therefore appears feasible that we could reproduce the loading over a significant band of frequencies by filling a cavity of fixed dimension with such a dielectric or magnetic material. This possibility was investigated under joint support from the present Contract and from Contract AF 33 (615) - 5170, and the results are presented in Senior and Knott (1967a, b). The case studied was that of a metallic sphere loaded with a cavity-backed circumferential slot at the shadow boundary, and all the information necessary to select a material adequate to reproduce the loading for zero back scatter over the frequency range corresponding to $0.3 \leq ka \leq 1.5$, where a is sphere radius, was obtained. It should be noted that over this frequency range the impedance is primarily reactive. As regards the real parts of the relative permittivity and permeability, the demanded variation with frequency need not be very great, no more than five fold over the band, but the imaginary parts are quite small. Unfortunately, we are not aware of any existing materials whose constitutive parameters possess a significant (and negative) frequency dependence and yet have low loss (imaginary parts). Nevertheless, the approach may still have some promise when the desired bandwidth is no more than (perhaps) 20 per cent, particularly when the loading position and the center frequency (or ka) can be chosen at will.

In a further attempt to improve the bandwidth for the loading method, we examined the effect of varying the position and number of the loading points. A typical loading curve has marked oscillations as a function of frequency, which oscillations are primarily due to the varying electrical separation between the load (or, more precisely, the phase center of the load regarded as a radiator) and the effective phase center of the scattering from the unloaded body. Over a wide band of frequencies at least, the presence of these oscillations increases the difficulty of reproducing the loading to within the tolerance necessary for accurate cross section control, and it therefore appeared that to suppress these oscillations could be desirable in leading to a larger bandwidth with a conventional loading device.

For any given body illuminated at some aspect, the back scattering can be attributed to contributions coming from a number of individual locations (or phase centers) in the vicinity of the body that are almost invariant over a wide frequency range. In the case of a sphere, for example, there are two such locations: one at the front, associated with the geometrical optics contribution, and the other at the diametrically opposite point identifiable with the creeping wave return, and these are almost invariant for all ka greater than (about) 0.7 (Senior, 1965). The key to the approach is to place a load at each of these centers and to make it responsible for controlling the scattering that appears to originate there, and were we successful in this, it seemed likely that the resulting loads would be much more capable of reproduction.*

To test the conjecture, a body was required for which a rigorous analysis of the scattering problem was possible, and though a sphere was again a natural candidate, an azimuthal slot which had been used in the earlier investigations of Liepa and Senior (1964, 1966) cannot be physically located at either the front or rear-most points. For this reason we considered instead a circular cylinder of infinite length illuminated in a plane normal to the axis. The sources of the scattering are the same as for a sphere, and if the electric vector is transverse, the loading can be accomplished using axial slots. Moreover, these slots can be placed at the front and rear and still have energy coupled into them, whereas with a sphere the limit would have been a point load, which would obviously be ineffective since only a minute amount of energy would be coupled.

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* An additional advantage is that a body loaded in this manner would be less susceptible to detection using short pulses.

The cylinder has two phase centers and therefore requires two slots, but to obviate the more complicated analysis associated with double loading, we considered instead a single slot designed to suppress either the optics or creeping wave contributions. This study was again supported jointly by this Contract and AF 33(615)-1656, and the results are described in Senior et al (1966). For a slot at the shadow boundary loaded to suppress the entire back scattered field, the curve of loading admittance versus frequency (or ka, where a is the radius of the cylinder) was quite similar to that previously found for a sphere with an azimuthal slot placed in the same manner. But when the slot was used to suppress only the physical optics field, the oscillations in the loading curve markedly decreased as the slot was moved towards the front of the cylinder, and for a slot at the very front, the required loading was as shown in Fig. 3-1. This should be compared with the curve in Fig. 3-2 where a slot similarly placed was used to annul the entire field. Alternatively, when the slot was loaded to suppress the creeping wave contribution and placed at the rear-most point of the cylinder, the loading curve was as shown in Fig. 3-3.

Although the curves in Figs. 3-1 and 3-3 are almost completely smooth as functions of ka (and what ripples do exist may be atributable to inaccuracies* in the expressions for the creeping wave and optics contributions when ka is small), it is disappointing to observe that the loads must now be active for all except the very smallest values of ka. In other words, we have smoothed out the curves at the

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* To check on the accuracy of the analytical expressions, the curve in, for example, Fig. 3-3 was first obtained by equating the scattering from the loaded object to the creeping wave return, and then to the exact values for the scattering from a cylinder minus the physical optics scattering. The two loading curves were almost indistinguishable.

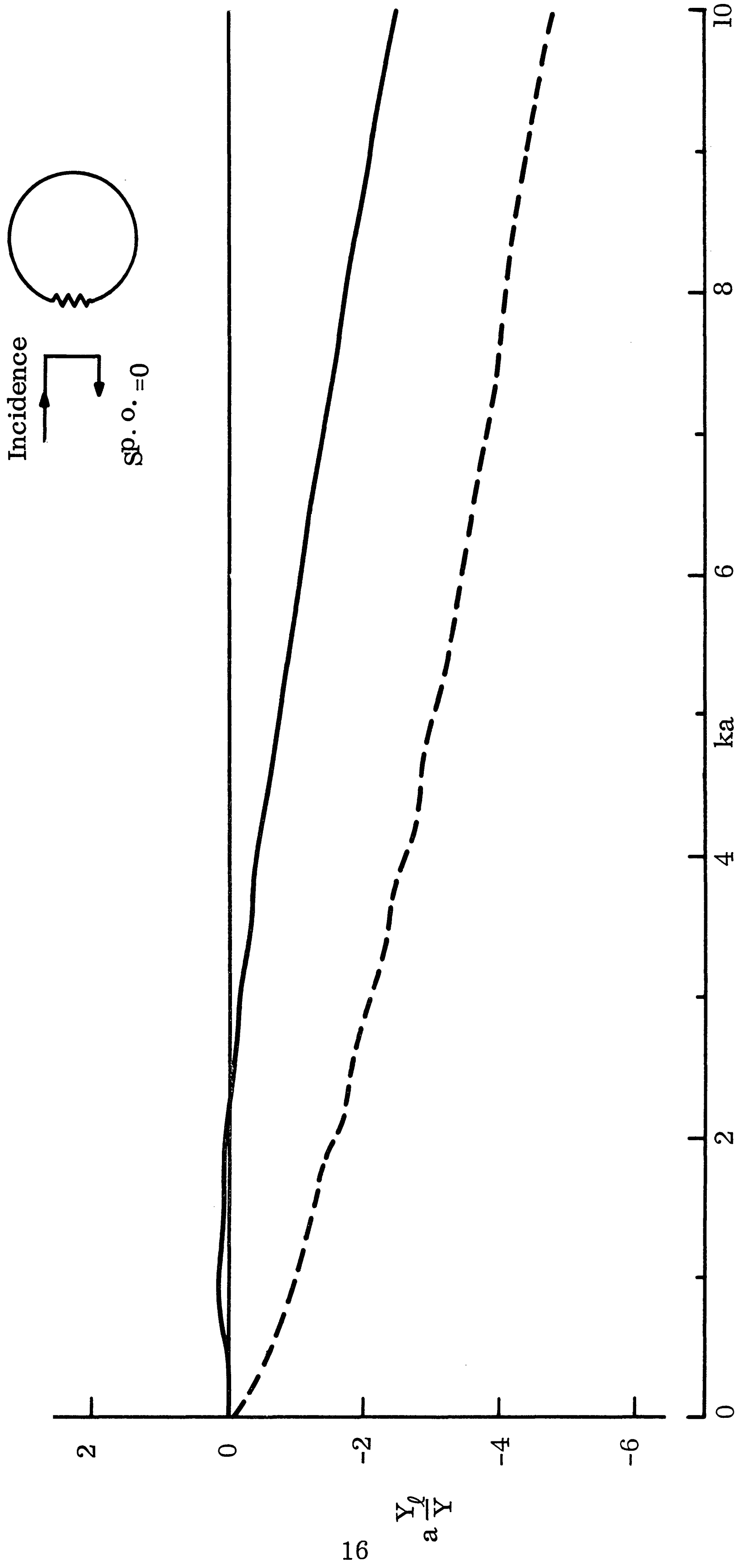

FIG. 3-1: REAL (—) AND IMAGINARY (---) PARTS OF NORMALIZED LOADING ADMITTANCE FOR ZERO PHYSICAL OPTICS CONTRIBUTIONS.

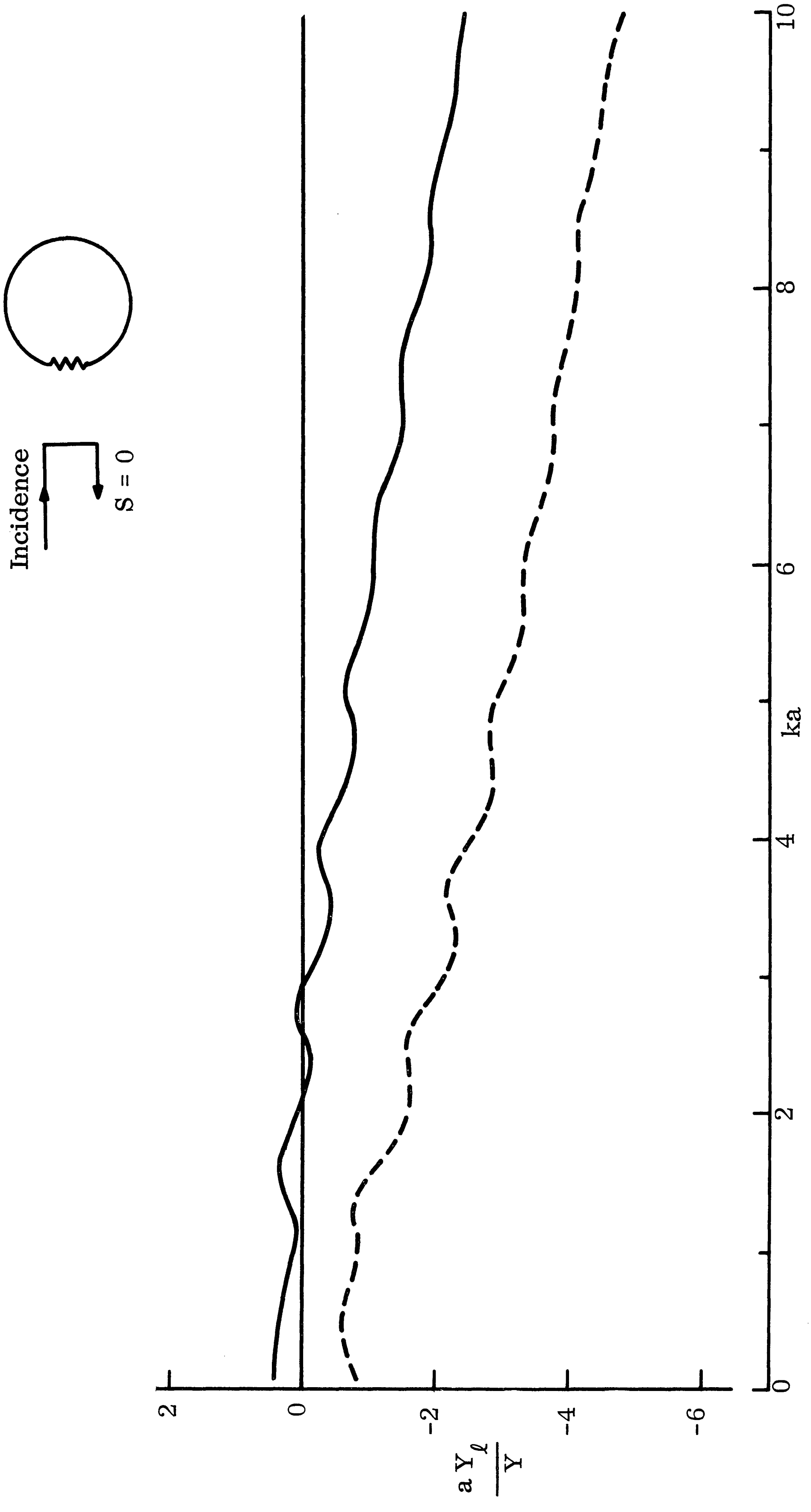

FIG. 3-2: REAL (—) AND IMAGINARY (---) PARTS OF NORMALIZED LOADING ADMITTANCE FOR ZERO BACK SCATTERING.

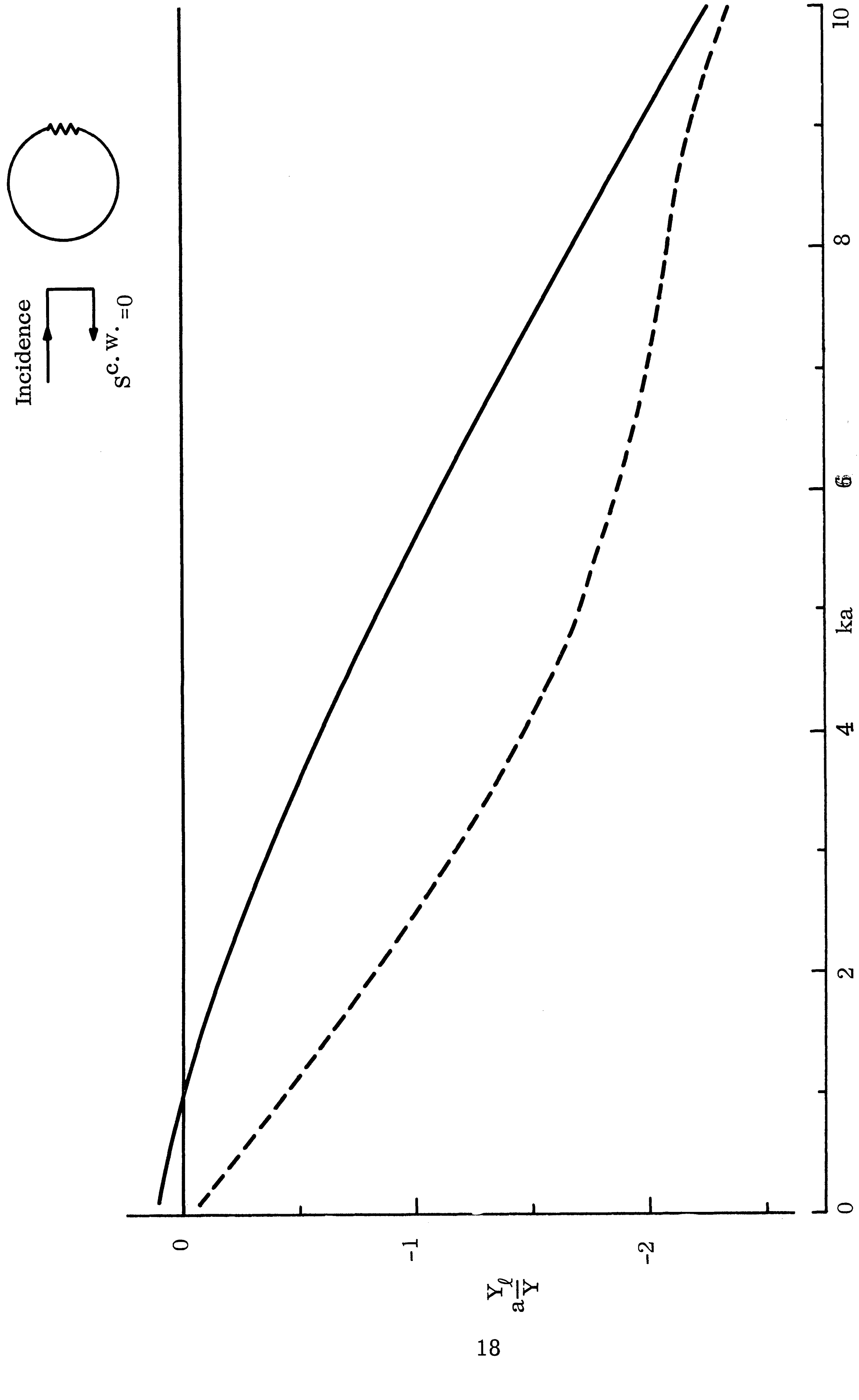

FIG. 3-3: REAL (—) AND IMAGINARY (---) PARTS OF NORMALIZED LOADING ADMITTANCE FOR ZERO CREEPING WAVE CONTRIBUTION.

expense of an almost complete obliteration of the passive loading bands, which suggests that maintenance of a separation between phase centers and loading points is desirable if we are to have any hope of reproducing the desired loading in a manner which is at all elementary. This emphasises once again the cancellation nature of the loading technique. In particular, the fact that the loading required of a rear slot to suppress the creeping wave return is primarily active implies that pure absorption of the creeping waves is not possible by impedance loading. It is to be expected that this would also be true for a sphere or other related shape, with the addition that since the slot must then be of finite length, the loading for creeping wave suppression would probably now be active at all frequencies.

There is one final attack on the bandwidth problem from the field theory point of view that is still under investigation and should be mentioned. This is aimed at exploring the role played by the shape of the cavity and coupling aperture in limiting the bandwidth obtainable from impedance loading. Instead of loading a sphere, for example, with a narrow slot whose associated impedance is adjusted to provide the scattering behavior required, the problem of a spherical shell with circular aperture is being analyzed in the hope that the natural resonances of the cavity can be used to modify the scattering from the shell. The approach is a direct one in which the fields inside and out are matched across the aperture, thereby avoiding the introduction of the concept of impedance. In effect, the aperture and cavity constitute a reactive load, and the initial results, both experimental and theoretical, indicate that either cross section enhancement or reduction is achievable with such a model. A description of the work so far has been given by Chang (1968).

In spite of the effort that has been devoted to these various investigations, it must be admitted none have shown any real promise of providing a marked increase in the bandwidth available from the impedance loading technique. On the other hand, they have served to produce a fuller understanding of the technique, and to pinpoint both its strengths and weaknesses as a tool for cross section control, but it was in anticipation of this somewhat negative conclusion (at least as regards our original search for wider bandwidths) that we decided over a year ago to devote a significant fraction of our future effort to the direct synthesis of the required loads. The desirability of using network synthesis to realize the loading was recognized as early as 1964 at the conclusion of our initial study of the center-loaded dipole (Chen and Liepa, 1964), but it was only with the completion of the sphere investigation of Liepa and Senior (1966) that the true severity of the bandwidth limitation was borne home upon us.

As a direct result of this, a program was initiated whose ultimate goal was the development of practical tools for the network synthesis of a typical load over a bandwidth as large as 50 or 100 per cent centered on a frequency near that corresponding to the first resonant peak in a back scattering curve. The program has embraced both theoretical and experimental work. On the theoretical side, there was first of all the question of the realizability of an impedance whose real and imaginary parts are specified over a finite band of frequencies. This prompted a study of relations between the real and imaginary parts of an impedance, and the extent to which each can be individually prescribed. By using the Hilbert Transform several new and interesting results have been obtained, and these have been reported by McMahon et al (1968).

Given the realizability of the demanded load, a logical approach to the synthesis of an impedance proceeds by approximating it with a rational function of frequency, and once such an approximation has been found, a network can be deduced using any of several fairly standard techniques. Various schemes for carrying out the numerical approximation have been tried, with emphasis on the rate of convergence of the iteration process (McMahon et al, 1968), and, in addition, the accuracy with which an impedance must be reproduced has been examined (McMahon, 1965, 1966). In the case of the loading required to reduce the back scattering cross section of a sphere to zero, it was found that the tolerance is small near resonant frequencies where the scattering from the unloaded body is relatively large, but could be large near anti-resonant frequencies, and it is believed that this conclusion is quite general.

Because of the urgent need for loading devices with bandwidths of at least 20 (or so) per cent, the more long-term theoretical approach to network synthesis has been paralleled with an experimental program in which the approach has been 'cut and try' using circuits whose characteristics would seem appropriate. The loading curves on which attention has been focussed are those shown in Fig. 2-2, with particular reference to the portions out to ka = 1.3 (approx.). It will be recalled that these are for the case of a sphere with a slot in the plane of incidence and normal to the electric vector, and since the load is that which must be placed at the center of the slot to produce zero back scattering, the situation is a convenient one for subsequent experimental verification. In addition, however, the nature of the loading curve is typical.

In the vicinity of the first resonant peak (ka = 1.0), the required impedance is comparable to a pure negative reactance, and for this reason emphasis has been placed on synthesis with active networks. We have had considerable success at realizing a negative reactance using the concept of a negative impedance converter

(NIC) which, at least in principle, is a two-pair active device transforming Z into -Z. Such a device has been known for several years and successfully employed in the design of active filters at frequencies below 100 kHz. But it has not previously been used in the megacycle range, and our efforts have been devoted to overcoming the difficulties associated with the application of active and passive lumped elements in the high frequency regime. Based on the results obtained so far (McMahon et al, 1968), it would appear that the desired loading can be achieved at frequencies up to 50 MHz, and possibly as high as 100 MHz, with the aid of NIC's. In view of the increasing trend to lower frequencies in many practical systems, it is therefore evident that the method of impedance loading using active loading devices will play a vital role in cross section control in the near future.

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APPENDIX:

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13. ABSTRACT

This report summarizes the results of a 5-year study of the reactive (or impedance) loading technique. Applications to various geometries are discussed, leading to an appreciation of both the strengths and weaknesses of this technique as a means of cross section modification and control. Small bandwidth is, perhaps, the greatest drawback to any widespread application, and of the many approaches that have been (and are still being) tried to enlarge the bandwidth, network synthesis appears to hold the most promise.

14. KEY WORDS	LINK A		LINK B		LINK C	
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