The

Radioscientist

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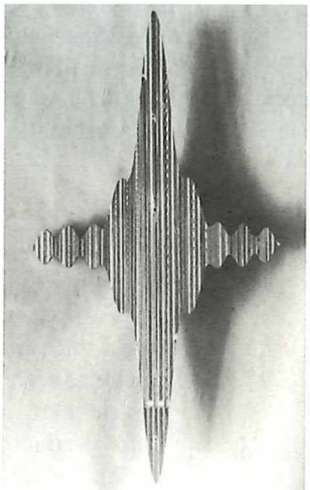

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COVER: See back cover (page 112) for the big picture and p.95, (Section IV) for the small one at the top.

THE EDITOR'S PAGE

A neat solution for the editorship of the new combined URSI magazine is to have the Secretary General be the Editor-in-Chief. For this (December) and the previous issue (September), which were prepared while I was in Germany, the "stories" (as PageMaker calls them) were word processed by the Secretariat since I had no facilities. This worked so well that we will continue this next year, gradually increasing the proportion of the total preparation (layout, etc.) done at URSI HQ so that the final issue of the separate *Radioscientist* (December, 1993) can be completely done in Ghent with my role in this last issue of my term being just the proof reader and layout checker. The new combined magazine will probably retain the name of the *Bulletin*, since that name has a long history (over half a century) and the format of the *Bulletin* was once A4 as *the Radioscientist* is now. **But it will not be the end of *the Radioscientist*—** it will live on as the new, upmarket *Bulletin* with the format, style and all the other features of *the Radioscientist* with maybe the cover photo in colour some day.

If that is a solution, what was the problem? Well, there were several. Firstly, there was no response to my "feelers" for an apprentice Editor-to-be made in the September issue. Secondly, despite the statement on the opposite page (near top right), some readers take some things in *the Radioscientist* as official (see later). Thirdly, the URSI Statutes make the Secretary General responsible for all URSI publications, so if *the Radioscientist* is an URSI publication, it has some "official" taint. You may remember that a separate publishing company was set up in New Zealand, at the instigation of the Board, so that URSI could distance legally (and even more so, geographically) itself from *the Radioscientist* (originally, URSI NEWS). This lead to misunderstandings at Prague about the nature of a "private" company using the URSI logo to launch and sell a magazine. As a result, the publishing company was instead set up in Brussels to publish *the Radioscientist* (see top right of the opposite page) and to dispose of these misunderstandings.

So if the new Secretary General is also the Editor-in-Chief, these problems disappear. But another pops up because, as presently performed, the editorial work is too much for the General Secretary who has his Department to run full time and will have to be Secretary General, like Professor Van Bladel, in his "free" time (in earlier times the Secretary General was a full-time position paid by URSI).

So we need Associate Editors like our Review Editor, James R. Wait, to be fully responsible for some sections. Examples of what is needed are Associate Editors for Features, History, New Developments, Guest Editorials, and Meetings. Such Associate Editors would be responsible for inviting articles and getting contributions in their field, having them refereed and checked for style (text and illustrations) and presented to URSI HQ for word processing and layout. As such, the Associate Editors would be like sole editors of a smaller magazine of a few pages and would get the satisfaction of the task without having the perhaps awesome job of getting the whole magazine together on one's own. It is essential that the Editor-in-Chief has more such edited copy than needed for the issue immediately at hand so that he can select the various articles on size (so that in all just fits into the issue) and on other criteria, and hold over the rest for the next or later issues (I wouldn't want him to have last minute panics as I have had at times). This is how other magazines are handled. **If you would like to become one such Associate Editor, drop me a note (email, fax, letter) saying what field you would take on.**

My point about the Radioscientist appearing "official" is not hypothetical. I wrote under the AGU advertisement in the September issue (page 77) that "national members of URSI are not automatically included" in the discount in subscriptions to RADIO SCIENCE. This is merely because the AGU does not have the names of such national members of URSI to check against when someone claims the discount. There are at least two countries ("Member Committees", I should say) which have a national membership, and some such national members took my words to mean that they were "automatically excluded"! The solution is in the hands of those Member Committees to see that URSI HQ has a list of names it can provide for bodies like AGU which offer discounts to "URSI members".

We—meaning our representatives at URSI Council at Kyoto next August, on the recommendation of the Membership Committee—will have to decide what to call these "URSI members". Here is a point raised in Sydney last August at the URSI Commission symposium, and which the Membership Committee will be considering. If "URSI members" are regarded in the same sense as members of IEEE, then the bodies in various countries which presently pay the affiliation fees to URSI might expect these individual URSI members to take over this financial burden. URSI has already (a decision made at Prague) set up a "network of correspondents", which is essentially the mailing list of those getting the Bulletin and the Radioscientist via KLM. After the end of 1993, and for the following three years, this will include all the participants at Kyoto. So we already have something which works, and maybe should leave it at that. If "correspondents" want a more prestigious title for their CVs, there might be an additional form of membership. One suggestion is to set up a fellowship, perhaps purely honorary, to which appropriate radioscientists might be elected. If you have better ideas, let the Membership Committee know (see names and addresses in the December Bulletin), perhaps through a Letter to the Radioscientist. Even if you haven't, as "correspondents", you might actually send me some correspondence for the Letters page we can't seem to get going. If every "correspondent" wrote one letter (30-50 words, say) every three years, we would have a great Letters page. Maybe we should write that requirement into the Statutes!

SCANNING THE ISSUE

There are two large articles this issue, both on electromagnetics and involving antenna research. Both describe state-of-the-art facilities coming into operation very recently (1992). What I found particularly interesting of these were the EM anechoic rooms, having tried to get one including in the plans for our Department building some 20 years ago. (Alas, I could find no contractor to build one at that time, but we did get a double skin, welded steel screened room with guaranteed attenuation from 16 kHz to microwave). The cover article, *Near field measurements..., is* about the work Christiaan Hygens Laboratory in the Netherlands and follows on from the article about Posthumus in the September issue by the same author, E. Goldbohm. The following one, *Electromagnetics at Arizona State University*, by Constantine Balanis, needs no further introduction.

The final one, *Beyond yesterdays boundaries: A radioscientific trip to the former Soviet Union*, by Ari Sihvola, is very different despite the author coming also from an electromagnetics laboratory. Our Regional Editor from Finland (Ari Sihvola) interprets his region with a broad geographical extent—in early May he visited Western Russia, Belorussia, and Ukraine. After the demise of Soviet Union, the new independent republics need to establish direct connections to international scientific unions. As the formal interaction was formerly administrated through Moscow, the problem which now emerges is the inadequate exchange of information between the West and the New East. This is something our URSI should be active in. As many of us know, the former Soviet Union is by no means a radioscientific has-been, and is still a primary source of ideas and analytical solutions.

Two smaller articles have had to be held over until next issue (March). So all three articles are in the Commission B field—a charge from last year when there were complaints of too much dominance by G and H. There are still some Commissions who have **never** been represented in these pages. Don't complain, you people, contribute instead!

Note from the Editor: The term "URSI Members" used above is a temporary (until the Kyoto G.A.) designation for all radio scientists who receive a *personally addressed copy* via KLM of *the Radioscientist* and the *Bulletin*, whether as a paying subscriber or as an URSI official. The names on this KLM mailing list have been given to AGU to provide an "URSI Membership" list for the purposes of this discounted subscription rate to *RADIO SCIENCE.* National Members of URSI who are on the General Secretariate's list are also included.

Near Field Measurements and the Synthesis of Linear Arrays with Prescribed Radiation Patterns—a Survey of some Early Work at Christiaan Huygens Laboratory

I. Introduction

Many papers have been published on the synthesis of antenna radiation patterns of which [1] by K. Milne and [10] by R.S. Elliott *et al.* will be referred to in this paper. Closely associated with this subject is the measurement of the Near Field [NF] of antenna apertures in general and arrays in particular and the calculation of the Far Field radiation pattern from the NF through the Fast Fourier Transform. The state of the art of the latter has been illuminated in a special issue [2]. It is an object of this paper to retrieve some rather early work in this field in the Netherlands, and Christiaan Huygens Laboratory in particular.

The work to be described started about 1948 at "Nederlands Radar Proefstation" to be continued from 1967 onwards by the affiliated company Christiaan Huygens Laboratory Ltd, both in Noordwijk.

The increasing demand for lower antenna noise stimulated the development of new measurement instruments and a powerful computing tool with sufficient precision and high speed to achieve the set targets. Much effort has been expended on linear arrays, because they allow exact control over the required excitation function, including correction of faulty radiators, and because the aperture is unobstructed.

Besides, considerable time is saved if only the vertical and horizontal apertures have to be measured as is the case if the linear array illuminates a cylindrical reflector or an aperture horn (assuming adequate manufacturing precision of metal surfaces).

In Section II an Analogue Complex Series Analyser machine will be described, which performs Discrete Fourier Transforms and also solves for the complex roots of the Array Polynomical equation

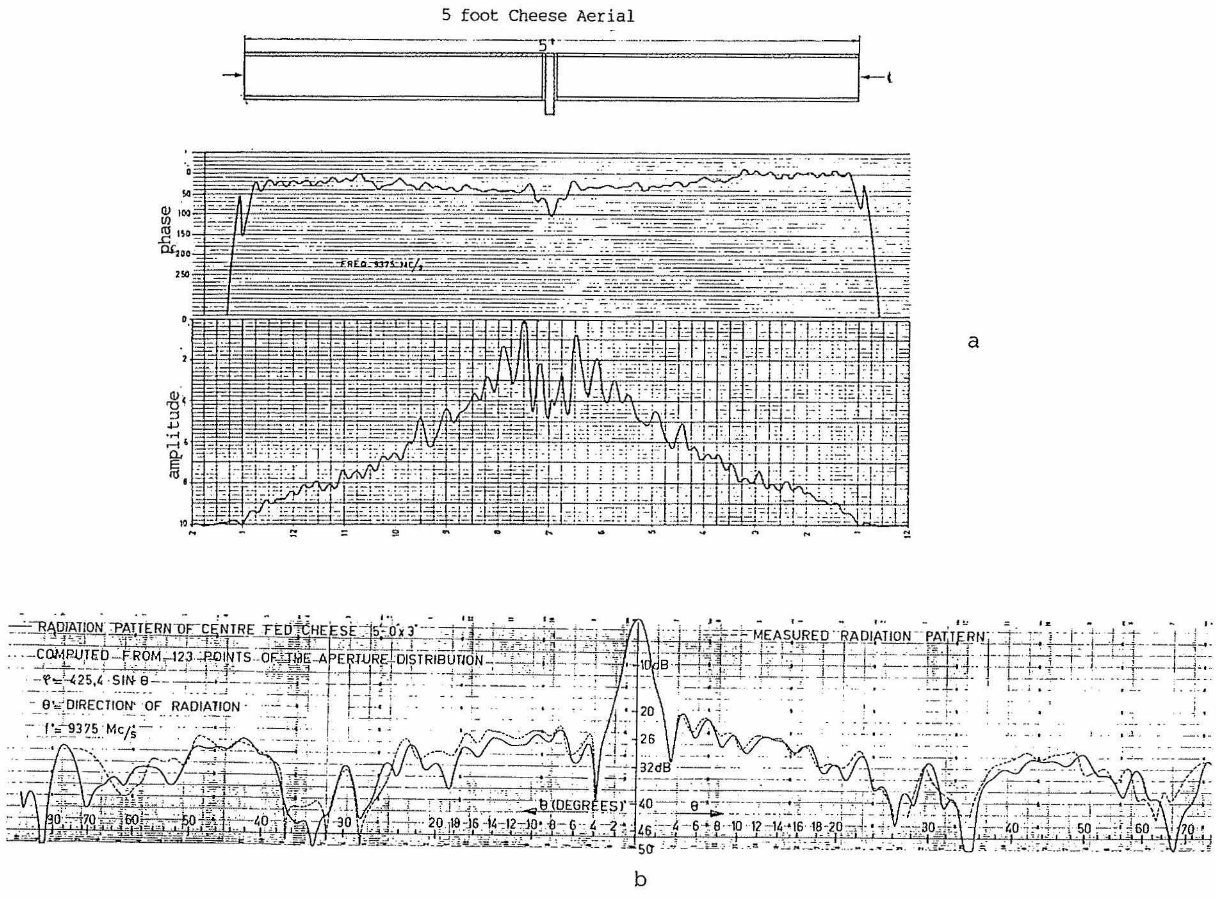


Fig. 1. (a) Phase and amplitude distribution of 5 ft ASRE cheese aerial. (b) Comparison of measured with calculated radiation pattern.

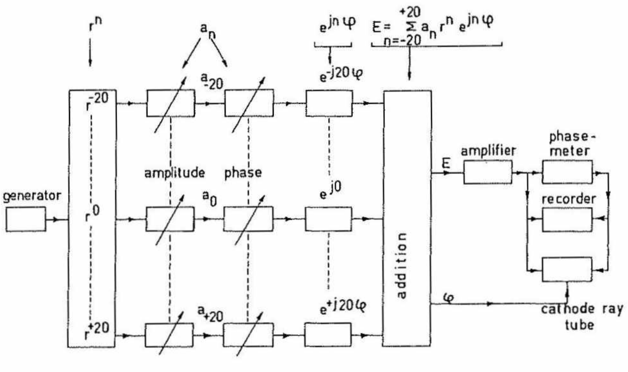


fig. 2 COMPLEX SERIES ANALYSER

$$E = \sum_{-N}^{N} a_n \cdot z^n = 0$$

It facilitates selection of the aperture distribution best suited to the application envisaged, bearing in mind that in the case of shaped patterns, several different current (voltage) excitations will produce shaped beams with the same power pattern [3]. The machine was completed in 1956 (see photograph).

In Section III a planar Near Field scan facility will be described covering the Frequency Bands from 1.5 - 40 GHz and featuring a mechanical accuracy of 0.03 mm (deviation from a perfect straight line). Several solutions of the polynomial equation were calculated and compared to practical realisation results for both Linear and Planar Arrays.

In Section IV, as a check on the foregoing theory, two different aperture distribution solutions producing the same radiation pattern, were selected.

One solution was the symmetrical amplitude distribution of Figure 3, resulting in a real voltage pattern, the other solution of Figure 6 had five complex roots of the polynomial equation replaced by their reciprocal conjugates. The two aperture distributions have been realised experimentally by two scattering targets, viz. two different reflection surfaces suitably contoured for amplitude and profiled for phase. Scattering characteristics are measured and compared to the desired power radiation pattern. The experiment is interesting, because it lends itself to scaling to much higher frequencies, thus reducing the size of the targets and because the plates can be easily and accurately contoured and grooved by a simple machining operation.

In Section V the pros and cons of various NF measurements methods are compared leading to the conclusion that with respect to ease of measurement and correction of the NF distribution the Planar Scan is to be preferred, whilst for overall performance check the Compact Antenna Range is interesting.

The latter however carries an appreciable cost penalty.

The experience obtained induced ESTEC of the European Space Organisation to contract CHL for the design of a large Compact Payload Testing Range. It has a Plane Wave Zone of 7m x 5m x 5m and allows complete evaluation of all electrical operational parameters of satellites with a weight up to 5000 kg. The range, which is shown on the cover of this issue, has just come into operation (1992).

II. The Complex Series Analyser

The complex series analyser solves polynomials of the form:

$$E = \sum_{-N}^{+N} a_n Z^n$$

with $Z = e^{j\phi}$ $\quad \phi = \dfrac{2\pi d}{\lambda} \sin\theta$

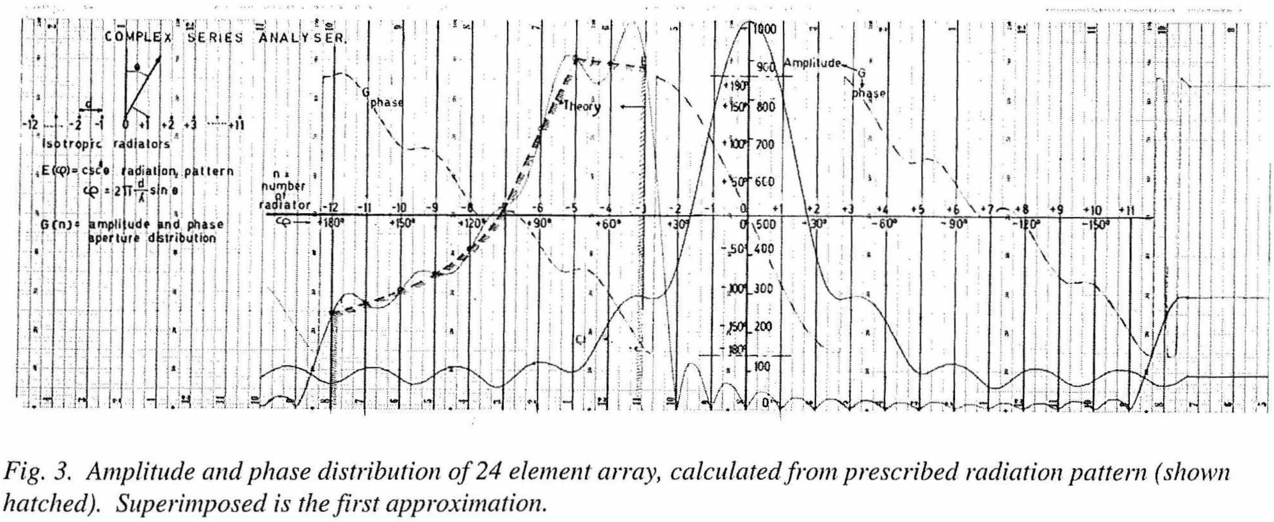


Fig. 3. Amplitude and phase distribution of 24 element array, calculated from prescribed radiation pattern (shown hatched). Superimposed is the first approximation.

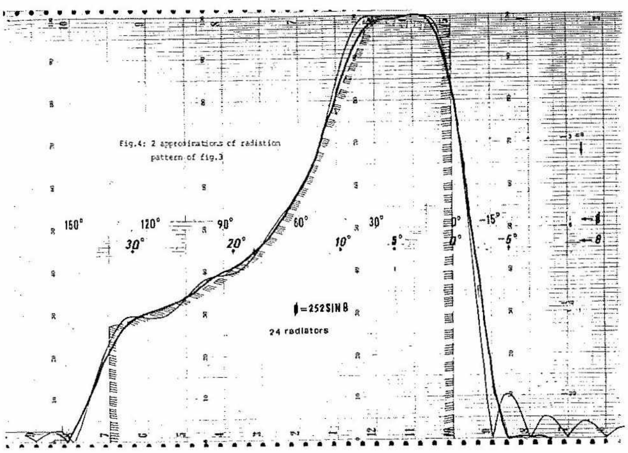


Fig. 4. Two approximations of the radiation pattern of Figure 3.

θ is angle with array normal, a_n may be any complex number: $|a| \cdot e^{jz}$

The machine can therefore simulate the array factor of an array of (2N+1) equispaced radiators.

Thus by a discrete Fourier transform of a given phase and amplitude illumination one obtains a voltage radiation pattern (the array factor)$^{1/2}$ and vice versa! This dedicated analogue computer was particularly convenient for finding the roots of a polynomial, an essential aid to pattern synthesis. To keep its size within bounds, the number of polynomial terms was chosen to be 41. The machine consisted of 41 two-phase resolvers (x-y), the shafts of 40 resolvers being coupled to a gear train with ratios of 1:2:3:...20. The +n resolver being driven clockwise, the -n resolver anti-clockwise from the same gearwheel. The centre resolver remained stationary. The amplitudes of each resolver were set up with a buffered 10 turn helipot, its phase by rotation of the resolver stator (housing). Buffered amplifiers served the addition of x_n and y_n voltages.

The machine was driven with a synchronous motor, which also provides the abcissus input to the display and recorder.

The generator, which provided a 1000 Hz input, also served as a phase reference. A schematic diagram is given in Figure 2.

After amplitudes and phases had been set up, a pattern could be run within 12 sec. The accuracy of the machine depended somewhat on the nature of the problem, but generally 0.3% in amplitude and 0.3° in phase could be regarded as representative. This approximately 3 digit accuracy could be improved to 5-6 digit accuracy by another operation. Also larger arrays could be handled by repeated use and suitable processing (example in Figure 1—see note below—3x 41 elements). In Figure 3 the synthesis of a 24 element array is shown as first approximation. The shaded prescribed pattern has been sampled at 24 equispaced points taking Φ as the angular variable. Its transform, i.e. the aperture distribution, is shown in amplitude and phase in the same Figure with the abcissus representing the element positions. After another transformation a voltage radiation pattern—the first approximation of the prescribed pattern—is produced which shows overshoot at the steep slope and meanders around the prescribed pattern according to the Gibbs' phenomenon. Note that the function goes correctly through the sample points in the shaped region and had nulls in the sidelobe region! And the function is real.

NOTE:

At the request of ASRE in the U.K. a comparison was made of computing time and accuracy of a cheese aerial pattern with known near field (see also [4]). The Admiralty lab used a digital computer and needed 7 hours for the complete determination against 1 hour with our machine.

A second approximation was obtained by a transform of the difference between the ideal pattern and its first approximation to the aperture again. When this correction was applied, another transform yielded a smoothed version of the first pattern with only small ripples and a first sidelobe of -20 dB. If required another 2 way operation can reduce this sidelobe to -40 dB (see Figure 4) and produces a curve which follows the ideal pattern even more closely (within 0.2 dB on the top). The price paid clearly is a less steep front at $\Phi = -15°$, which one should like to be optimum in applications where ground reflections must be reduced (i.e. ATC radar). (Shrinkage of the shaped pattern as observed by Elliott [10] is not obvious). Criteria to define optimum solutions for shaped beams, well known since Dolph for narrow beams, are difficult to specify. The Chebychev scanning function for a 50 element array with -40 dB sidelobes given in Figure 4 of ref [1] neither appears to satisfy such criteria.

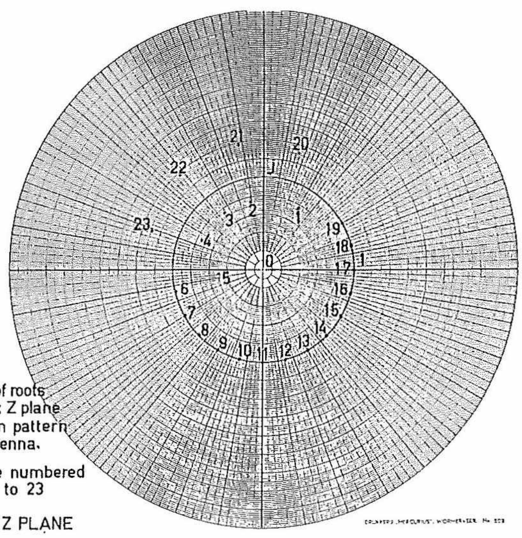


fig 5 position of roots in the complex Z plane of the radiation pattern of a cosec^2 antenna.
the roots are numbered from 1 up to 23
COMPLEX Z PLANE

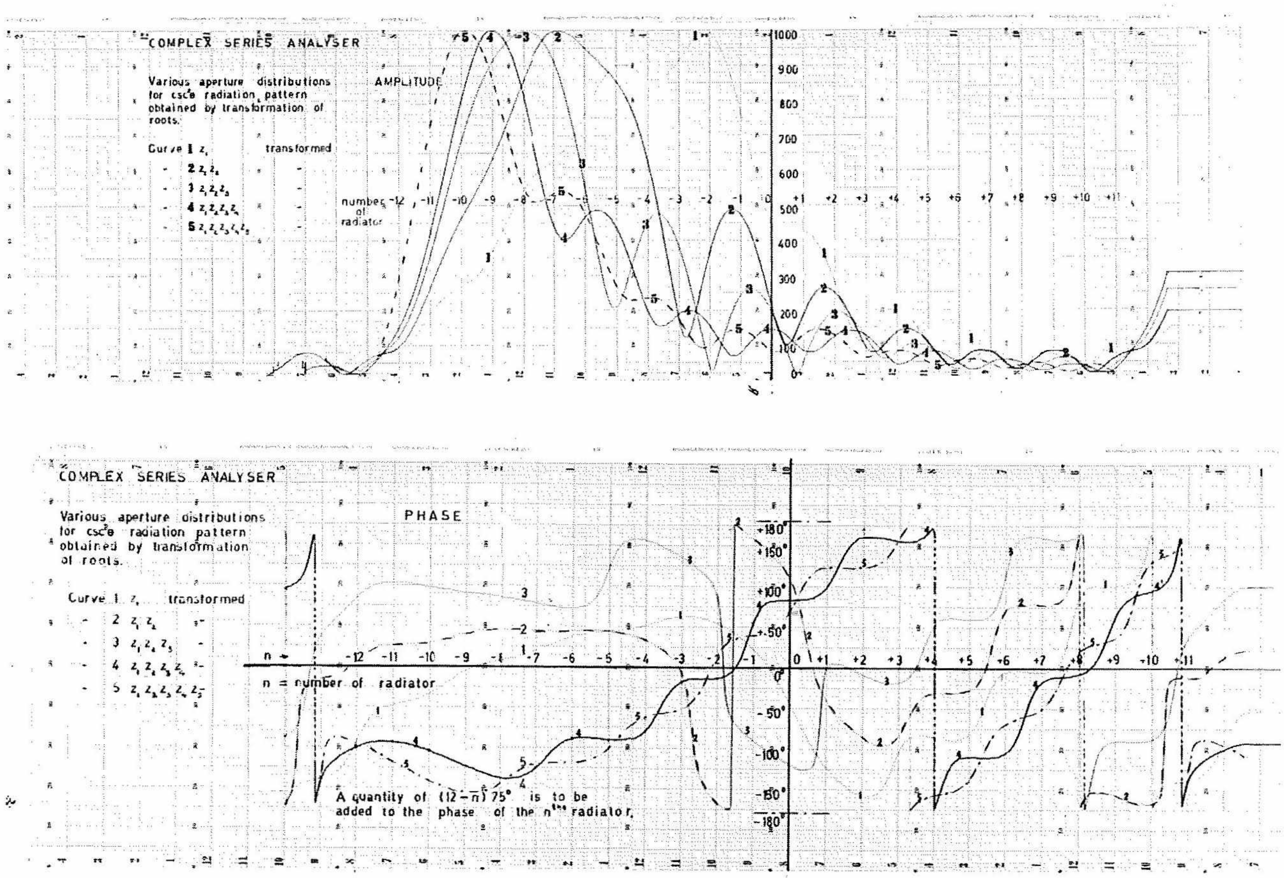


Fig. 6. Five different amplitude-phase distributions of linear array with 24 radiators rendering the same power pattern. Phase correction is required in the lower panel because the pattern squints by ϕ = 75°.

For the slope rises from zero to the ideal front in $\Phi = 12.5°$ or $\theta = 2.84°$ (if $s/\lambda = 0.7$), whereas for the present Figure 4 this amounts to $\Phi = 20°$ or $\theta = 4.55°$ whilst the 24 element array is less than half as long.

Given the dedicated machine above, operations were straightforward. To determine the roots, $Z_k = \rho_k e^{j\phi_k}$ a device called "rootpot" could be switched into circuit. It dealt with the factor $\rho^n \cdot e^{jn\phi}$ in the polynomial $\sum a_n \cdot \rho^n e^{jn\phi}$ for $\rho < 1$.

The rootpot contained another similar gear train with ratios 1:2:3:...40 whose shafts were coupled to 40 helipots, which were electrically connected in tandem and controlled by one knob calibrated from 1-1000. The voltages *rn* were fed to the relevant element n of the machine. The currents i_1, i_2, i_3 etc as shown in Section II-6 of [3] are obtained from successive multiple products of the roots and the polynomial goes to zero when one of the roots is found. By manipulating r and watching for minima developing with the running machine, potential zeros could so be located. Fine adjustment of ρ and ϕ would result in a null and the values of ρ_K and ϕ_K Each root took only a few minutes to determine. Further search would reveal the remaining roots for $\rho < 1$. For $\rho > 1$ an inversion was required.

Once the roots were known, the polynomial could be written, apart from a constant C, as the multiple product: $E = C\prod_{-N}^{N}(Z - Z_n)$. A typical example of the roots of a 24 element array is given in Figure 5. (Note that not all roots are in pairs).

Since Schnelkunoff's paper [5], [6] in 1943, the principle that the power pattern of the polynomial is invariant when one or more roots are replaced by their reciprocal conjugate, became well known, though it had been introduced eight years earlier by Posthumus! Obviously such procedure is trivial when all the roots are situated on the unit circle. But shaped beams, which always have some roots outside or inside the unit circle, sometimes in pairs, will have many different element excitations producing the same power pattern.

The theoretical maximum number of solutions is 2^{2N-1} for 2N elements, but, in practice it turns out (Figure 5) that only

5 roots can be inverted in our example of 24 elements, so that $2^5 = 32$ solutions remain, some of which are mirror images.

As shown in Figure 3, the transform of a real cosec^2 pattern yields a current distribution whose symmetric amplitude sharply peaks in the centre of the array. The accompanying phase function is antisymmetric. For obvious reasons this is undesirable for endfed non-resonant arrays. So for that application we searched for alternative solutions with a peak current at the feed end and the current preferably tapering exponentially towards the load end. Thus approximately equal coupling factors of the slots could be employed, which should alleviate the mutual coupling problem and reduce cross types of slotted waveguides.

In Figure 6a and 6b, the different amplitude and phase distributions are shown, when one up to a total of 5 of the roots shown in Figure 5 are replaced by their reciprocal conjugates. As expected and described by Milne [1], the maximum shift of the peak current is obtained when 5 roots are replaced. This is shown as curve 5 of Figure 6a and Figure 6b.

To test the practicability of the method, a planar array with 12 identical slotted waveguides—each with 103 displaced inclined slots—has been constructed. The linear arrays were fed by a primary waveguide, cruciform slots providing the coupling and phase shifters the phase adjustment. Figure 11 shows the calculated and measured distribution of the feed array.

But with the phenomenal increase in speed and capacity, and an accompanying decrease in price and size of present mini and micro computers, as well as their adaptability to complete automation of the whole measuring and computing sequence, the digital computer was bound to win.

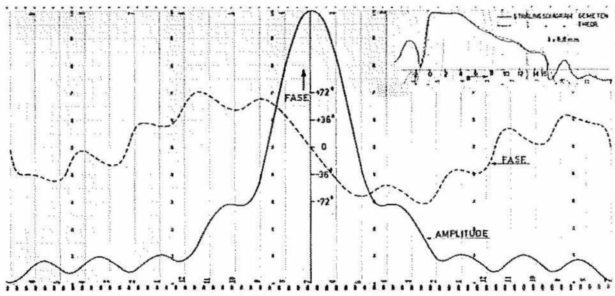


Fig. 7. Phase (FASE) and amplitude distribution of a 24-element linear array. Inset shows the theoretical (dashed) and measured radiation pattern.

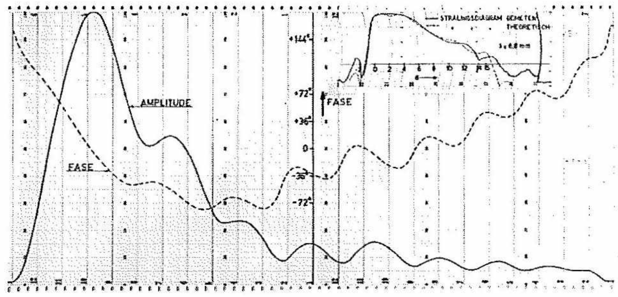


Fig. 8. Equivalent asymmetric phase and amplitude distribution of a 24 element array. Inset shows the theoretical and measured radiation patterns. Vertical scale of the latter is in dB.

The complex series analyser is now part of the historic collection of the Technical University of Delft, Faculty Electrotechniek.

The photograph above left shows the analyser and its console with display and recorder.

III. A Planar Near Field Scanner

A first planar scan facility with a scan area of 4m x 1m and an accuracy of 0.1 mm was built in 1953. The phase and amplitude measurement made use of the serrodyne principle [8]. As probes, dipoles, horns and dielectric filled horns have been used.

Encouraging results so obtained promoted the design and fabrication of a larger and more accurate machine, which resulted in a 11m x 4m facility with inaccuracy of 0.03mm. The probe carriage is guided by straight rails mounted on tempered beam to remove any remaining stress. The probe carriage and the phase and amplitude recorder are driven in synchronism. This facility became operational in 1960. In a later development the output could also be input to a FFT computer so as to obtain radiation patterns. For large planar arrays with several parallel slotted waveguides a time saving device is used, which for most practical purposes yielded satisfactory results. After measurement of each linear array and correction of errors in individual slots the assembly is

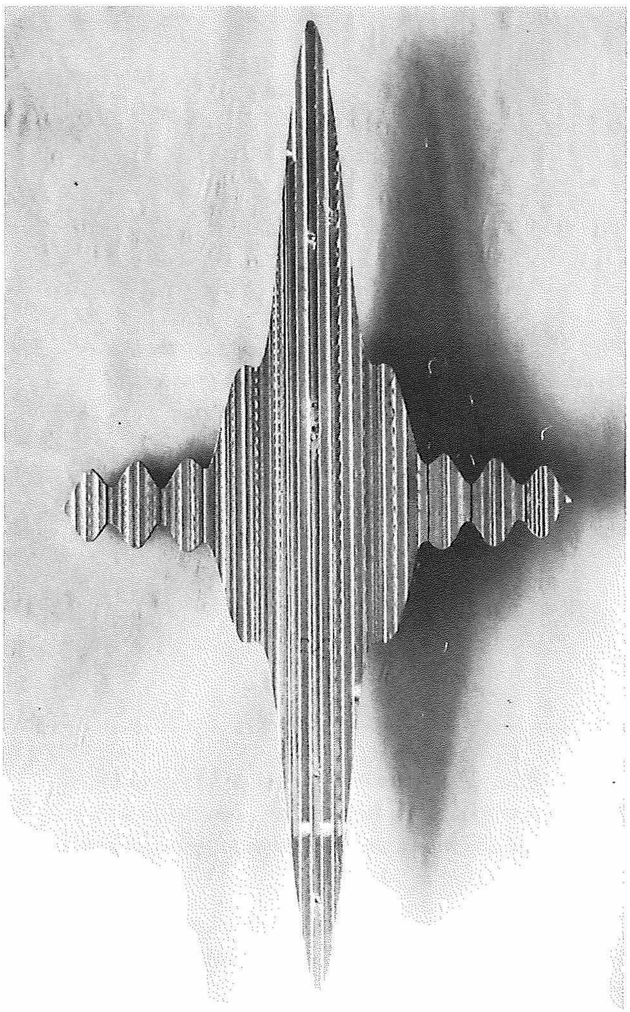


Fig. 9. *Metal reflector to simulate 24-element array.*

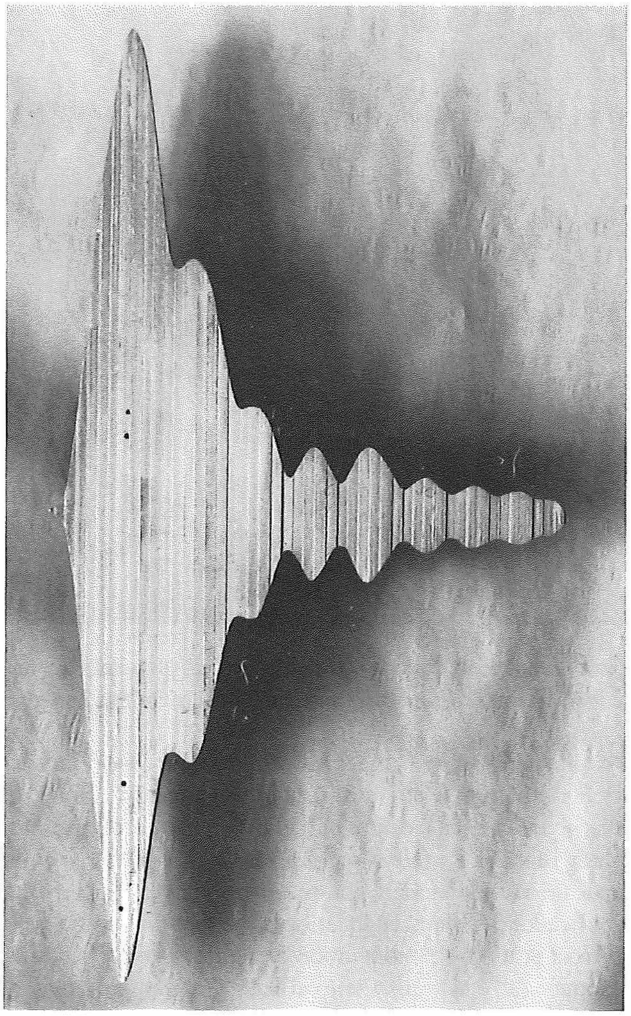


Fig. 10. *Metal reflector to simulate 24-element array.*

measured in the horizontal plane with a long vertical slotted waveguide, taking due care of the polarisation of the array under test. The time so saved becomes impressive, when scans for many beam directions are required. The results so obtained after a Fourier Transform compared favourably with the Far Field measurements of the planar array.

It appears that the property of the Fourier Transform, viz. that a local error in an array is spread over the angular spectrum, is in part taken care of by an averaging effect of the long probes.

A set of equal probes—dipoles or horns—is required, when antennas with dual polarisations are to be measured. At CHL such arrays have been designed and produced. Two slotted waveguides with orthogonal polarisations are combined in a corrugated aperture horn. Due care must be given to equal—phase versus frequency—characteristics of both slotted waveguides. With high speed phase shifters and or switches any polarisation can be had from pulse to pulse of the radar. Polarisation during transmission may be different from that during reception. Using the different polarisation properties of target and clutter—e.g. a ship in sea clutter—better discrimination can be obtained statistically.

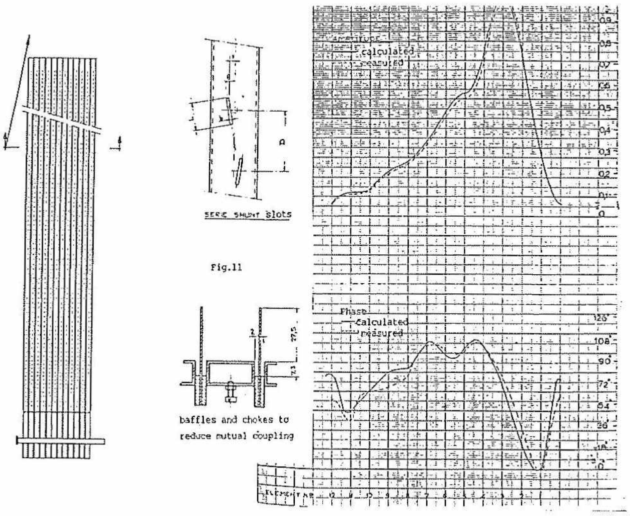
However, if the scattering matrix is measured (5 parameters and 7 measurements) optimal suppression of the clutter with respect to the target can be obtained [12].

SOME APPLICATIONS

Apart from the specific experiments discussed in this paper to test the theory a selection of custom produced arrays is given below.

- A frequency scanned slotted waveguide S-band array, consisting of 73 parallel slotted waveguides, serpentine connected and containing in all 4000 slots. It has been designed and prototype tested in 1963. Dual antennas of this type were installed on two Dutch Guided Missile frigates.

- An X-band phased array, consisting of 16 slotted waveguides, the beam in the vertical plane being steered by phase shifters.



• A similar S-band phased array with dipoles as radiators and fed by a printed frequency independent distribution network. Installed on the new frigates of the Dutch Navy as the HSA Smart System. Vertical beam steered with phase.

• X-band dual polarisation arrays with a fan beam, featuring a horizontal beamwidth of 0.4° and a vertical beamwidth of 18°. Phase shifters included to facilitate polarisation switching. Such and other types of arrays have been installed in various Vessel Traffic Services Systems in Germany, France, Canada, Belgium and the Netherlands.

• Combined back to back arrays at X-band and S-band in Hongkong for VTS.

• Ku-band reflector antennas fed by a linear array with circular polarisation through meander type circular polariser. Installed at airports in the Netherlands. Hungary, Portugal, Saudi Arabia and Singapore. Featuring 0.25° beamwidth.

• X-band arrays with circular polarisation, also for airport movement ASDE equipment.

IV. Profiled Contour Cutting to Mimic Aperture Distributions [9]

As a check on the synthesis of a shaped—beam cosec squared—radiation patterns with 2 arrays with different element excitations, the following experiment has been carried out in 1961. Use has been made of the fact that a plane metal reflector, when its contour is cut symmetrically in the shape of a required illumination function, and is illuminated by a plane uniform wave, will reflect a pattern—as a function of the rotation angle of the reflector—identical to the radiation pattern calculated for that illumination function. Identical, but with the restriction that the rotation angle must be multiplied by 2 (galvanometer effect). Similarly, if the reflector in addition has been profiled in accordance with a required phase function (taking into account the two way propagation), by milling parallel grooves of different depths, it should produce the shaped beam obtained by the synthesis. For the experiment, the reflector is rotated around a vertical axis (coinciding with the axis of symmetry for symmetrical aperture distribution), by a small synchronous motor, which supplies the variable θ. The plane wave is obtained with a small horn transmitting at 34 GHz. The scattered signal is received by another small horn positioned adjacent to the transmitter horn.

As reflecting objects, two 24 element distributions shown in Figure 7 and Figure 8 and discussed in Section II, have been selected for the comparison. For each reflector, 48 grooves (spaced $\lambda/4$) have been milled to obtain a good approximation to a continuous phase function. Photographs of the 2 reflectors are shown in Figure 9 and Figure 10. The radiation patterns recorded are shown as an inset on the top right in Figure 7 and Figure 8 (ordinate in dB). The measured radiation pattern—solid line—and the pattern calculated—dashed line—show quite good agreement in the shaped region. (The calculated pattern variable θ has been divided by 2 to obtain agreement with the measured θ, see above).

The discrepancies in the sidelobe region can be attributed to diffraction effects of the sharp edges of the reflector plates.

V. Conclusion

The synthesis of linear arrays, a classic which can be traced through a period of 55 years, still is a rewarding subject of research.

The dedicated analogue computer, described in this paper, effectively solves the complex calculations involved both in the synthesis and the transform of the measured near field to the far field pattern. Programming, often a tedious job in digital computation, is not required! However by its very dedication the machine lacks the flexibility required for complete automation of the measuring-computing cycle.

As regards the measurement of radiation patterns, there appears to be common opinion, that the accuracy obtained through near field transforms compares favourably with the accuracy obtained directly in far field measurement. This can be explained by the superior control of the environment and measuring conditions provided by an enclosed anechoic room. However, it is open to doubt whether this is generally true. For example, the spherical near field scan, which embraces the complete radiation field, suffers from the huge amount of data collected, when a sizeable antenna is measured. The time consuming measurement and processing is subject to accumulation of errors.

The near field scan selected, whether planar, cylindrical or spherical, should strike a simple balance between required accuracy and completeness against a simple and fast measuring computing procedure. Some such simplifications have been indicated in this paper.

Above considerations should logically lead to the Compact Antenna Range [11], which has similar control over measurement conditions. However apart from the drawback of its appreciable cost, such measurements do not show the source and location of errors in the aperture field. A brief description of a Compact Payload Test Range designed by CHLK for ESA/ESTEC is given in IEE News No. 65, page 20.

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Wanted!

Interesting and striking photographs for *the Radioscientist* front cover. The subject should be identifiable as radio physics or engineering within the URSI range of Commissions A to K. Until we can afford colour, prints should be glossy black and white suitable for digital scanning (size within reason is no longer important). The "portrait" format used so far on our cover is preferred but a striking photograph or graphic (e.g., analogue data) which needs "landscape" mode (short and wide) is also welcome.

Please send submissions together with a descriptive caption to :

The Editor
The Radioscientist
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Dunedin
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Electromagnetics at Arizona State University

Arizona State University

The main campus of Arizona State University is located in Tempe, a city with a population of 120,000. Tempe is adjacent to Phoenix, the capital of Arizona. This fast-growing metropolis, known as "the Valley of the Sun", includes a number of cities and communities and has a population of almost two million. Centrally located in the state, the Valley is known for its sunny, warm winters and hot, dry summers. Yet, Tempe is within a three-hour drive of the Mogollon rim country and mountain areas.

College of Engineering and Applied Sciences

The College of Engineering and Applied Sciences is vigorously pursuing distinction in academic research as evidenced by its Engineering Excellence Program. In cooperation with state government, local industries, and federal agencies, the Engineering Excellence Program was initiated in 1978 to address engineering needs related to rapid industrial growth and innovative product development in the state of Arizona. The format of its phased and dynamic master plan continues to accommodate the interest of the three-way partnership. As of 1990, more than $130 million has been invested in achieving this goal. A five-story, 120,000 square foot Engineering Research Centre was completed in 1984. The new six-story, 185,000 square foot Barry Goldwater Centre for Science and Engineering Building is scheduled for occupancy in 1992. Included in this push for excellence are state-of-the-art engineering facilities rarely found on a university campus.

Department of Electrical Engineering

The Department of Electrical Engineering forms the leading edge of the engineering excellence program. With over 900 undergraduate students and 400 graduate students, the faculty is dedicated to excellence in teaching as well as excellence in research. Courses are offered in essentially all areas of electrical engineering. The faculty of the Department of Electrical Engineering is dynamic. While more than one-third are relatively new at ASU, 11 are Fellows of the IEEE and 3 are NSF Presidential Young Investigators.

The Department of Electrical Engineering offers graduate programs leading to MS in Engineering, MS with a major in EE, and the PhD with a major in EE. Teaching and research assistantships are available on a competitive basis. Areas of emphasis are strength include : *Electromagnetics, Power/ Instrumentation, Solid State Electronics, and Systems.*

Telecommunications Research Centre

The Telecommunications Research Centre (TRC) at Arizona State University was established in 1985, during the second phase of the Engineering Excellence Program. The TRC is one of seven research centres in the College of Engineering and Applied Sciences, and the mission of the TRC is to focus, plan and promote the research activities of the faculty with interest in Telecommunications. Multidisciplinary programs are encouraged and promoted. Dr. Constantine A. Balanis has been serving as Director since August 1988. Ultra-modern laboratories and computational facilities are associated with the centre. The targeted areas of excellence are : *Antennas, propagation and scattering; Microwave circuits, devices and measurements; Optical Communications; Signal Processing; and Communication systems.*

Antennas, Propagation and Scattering

Faculty, research analysts and graduate students working in these areas address a wide range of theoretical and experimental research issues, including the development of rigorous analytical models, computer codes and precise measurement techniques. In addition, state-of-the-art experimental facilities such as the Electromagnetic Anechoic Chamber (EMAC) are used by these researchers to measure antenna patterns and the radar cross section (RCS) of various scatterers.

Theoretical solutions to complex electromagnetic problems are obtained by selecting the most appropriate technique for the problem under consideration. These techniques include high frequency asymptotic methods such as geometrical optics (GO), geometrical theory of diffraction (GTD), physical optics (PO), physical theory of diffraction (PTD), and other techniques such as the moment method (MM), the finite-difference time-domain (FD-TD) approach, and the Lorentz Mie scattering. One aim of this research is to facilitate the design of advanced antennas and scatterers, incorporating complex structures such as satellites, aeroplanes, missiles, helicopters, ground-based vehicles and ships, which may be comprised of both metallic and nonmetallic materials.

Topics of research include :

- Slotted waveguide antennas
- Microstrip antennas
- Phased array antennas
- Conformal antenna arrays
- Broadband antennas

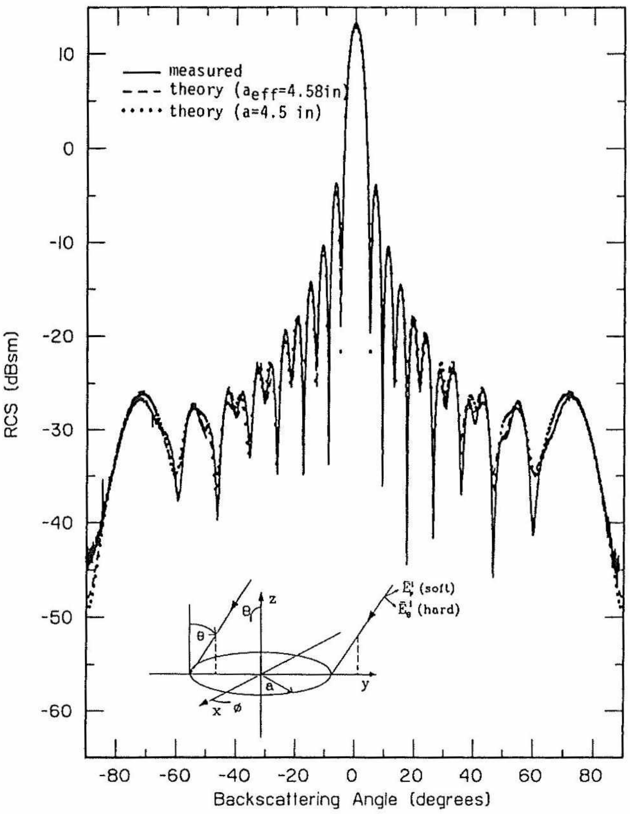


Fig. 1. Hard polarisation measured and predicted monostatic RCS patterns for a circular disk (a = 4.5 inch, f = 9.228 GHz).

•Radar Cross Section (RCS) of scatterers

•Optical characterisation of surface micro features

•Inverse Synthetic Aperture Radar (ISAR)

•Materials for antenna and RCS pattern control

•Antenna and RCS measurements

To illustrate the point, representative examples of some of the problems that were investigated by ASU are included here. The references that are indicated reflect the work of authors associated with ASU. However, there have been many other investigators who have addressed similar problems using the same methods and published extensively in the open literature. I have taken this approach to keep the references to a small number.

The GO plus GTD, and PO plus PTD have been used extensively to predict the characteristics of antennas on truncated structures, such as ground planes and cylinders [1]-[11], and the radar cross section of basic structures which are used as basic building blocks of more complex targets. RCS examples include strips, plates, discs, corner reflectors, and others [12]-[18]. Figure 1 exhibits the predicted and measured monostatic RCS of a circular disc. The comparison between the two is excellent. In addition, impedance boundary conditions have been used to analyse electromagnetic problems for which the material properties or surface characteristics are important [19]-[20]. This approximate boundary condition is often appropriate for lossy or layered materials or for statistically rough surfaces, and it provides means whereby reflection, diffraction, and surface wave phenomena on physical structures can be studied. The exact solution for diffraction from and impedance wedge was presented by Maliuzhinets. An asymptotic evaluation of the exact solution isolates the incident, singly reflected, multiply reflected, diffracted, surface wave, and associated surface wave transition fields. The multiple reflected fields from the exact solution arise as ratios of auxiliary Maliuzhinets functions. However, by using properties of the Maliuzhinets functions, this representation can be reduced to products of reflection coefficients which are much more efficient for calculation [20].

The Moment Method has been used at ASU by many faculty and graduate students to address a number of antenna and RCS problems [21]-[33]. Examples include long and short slots on waveguides, microstrip patch antennas, and horn antennas. Straight and meandering leaky-wave long waveguide slot antennas have been analysed by enforcing boundary conditions of the magnetic field in the vicinity of the aperture, which leads to a set of integral equations. The integral equations are then solved by Moment Method [24]. Straight long slots have high inner sidelobes in the far field amplitude patterns, which reduce their utility as high-performance antennas. To reduce these sidelobes, a long slot may be meandered from the waveguide centre line to the sidewall and back to the centre line in such a way to produce the desired radiation pattern. Figure 2 displays the predicted pattern of a long curved slot with a sine power distribution (SPD) meander pattern which is used to control the characteristics of the radiation pattern.

A new method of designing arrays of side wall slots has been analysed. The method involves the utilisation of an untilted side wall slot, which is normally not excited, but which is induced to radiate through the internal placements of a pair of strips around the slot. Coupled integral equations are derived and solved using the Moment Method to obtain the slot aperture electric-field, the surface currents on the strips, and the internal forward and backward scattering parameters. Numerical results have been compared with experimental data to validate the method and to determine the range of useful dimensions for the composite element [25]-[27]. Figure 3 shows the geometry, and the predicted and measured reflection coefficient of a nontilted narrow wall waveguide slot with a pair of tilted strips inside the waveguide to allow for radiation by the nontilted slot. The authors of this paper, Drs. Shahrokh Hashemi-Yeganeh and Robert S. Elliott, were awarded by the IEEE Antennas and Propagation Society the *1991 R.W.P. King Award.*

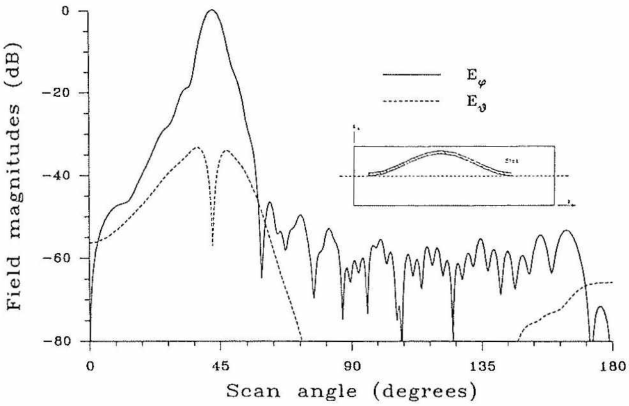
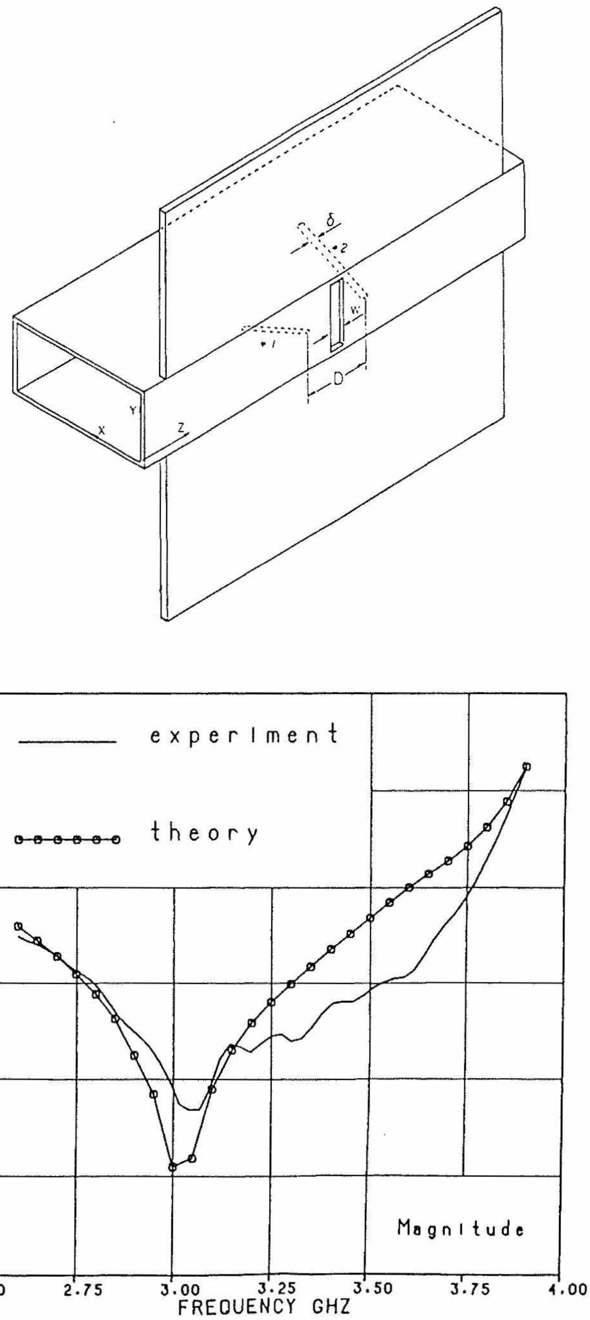


Fig. 2. Far field radiation patterns for a slot antenna with sine power distribution (PSD) meander pattern (length = 20 λ, width = 0.08 λ.

The input impedance and RCS of probe-fed rectangular and circular microstrip patch elements have been investigated using a full-wave spectral domain Green's function/Galerkin approach, which fully accounts for the effect of connecting a vertical probe feed to the patch. Comparisons of the measured and calculated RCS patterns and input impedance data demonstrate the efficacy of the theory [28]. Figure 4 exhibits the calculated and measured monostatic RCS of a circular microstrip patch, as a function of frequency from about 6 to 18 GHz, at an incidence angle of 63 degrees from the normal. These methods can also be used to analyse infinite and finite arrays of these elements [29]-[31].

Corrugations on the inner surfaces of horn antennas have been used to provide symmetrical E- and H-plane patterns and to reduce cross polarisation. Due to high costs and heavy weight of the corrugations, a simple and effective alternative to accomplish the same goals is to cover the inner surfaces of the horn with lossy material [32]-[33]. The penalty in doing this is a sacrifice in gain. However, by properly selecting the properties of the material, the loss in gain can be small ; less than 1 dB. Experimental studies have demonstrated the effectiveness of using lossy material to shape the amplitude patterns of the horn. Figure 5 displays the measured amplitude radiation patterns of a standard gain horn with strips of lossy materials placed on the interior E-plane walls of the horn. Three different width strips were used; 2 cm, 5 cm and 10 cm. As the width of the strips increases, the sidelobes are reduced with a simultaneous reduction in the gain. A full-wave analysis is being developed to predict the performance of such horns.

The Finite-difference time-domain (FD-TD) method solves Maxwell's time-dependent curl equations directly in the time domain by converting them into finite-difference equations which are then solved in a time-marching sequence by alternately calculating the electric and magnetic fields in an interlaced spatial grid. The FD-TD has been applied extensively to scattering and penetration problems. Recently it has been used to model wire and aperture antenna radiation



Waveguide geometry and reflection coefficient for a pair of tilted strips plus a slot.

[34]-[36]. A critical step in each of the antenna configurations is the modelling of the feed. For each geometry, alternate suggestions to model the feed were made [36].

Graduate courses that are regularly offered include antenna analysis, design and measurements; advanced electromagnetic theory; high-frequency and low-frequency methods; modal solutions; spatial-, time-, and spectral-domain techniques; and microwave analysis, design and measurements. Research projects leading to M.S. and PhD. degrees are sponsored by government and industry.

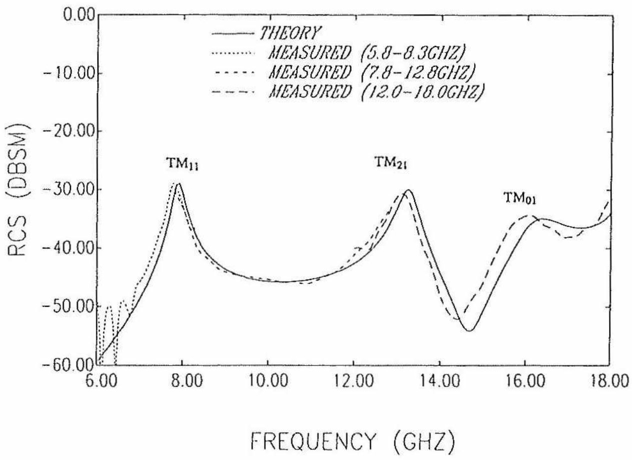


Fig. 4. Measured and calculated monostatic RCS of a circular patch without a probe feed (radius of patch = 0.71 cm, height of substrate = 0.07874 cm, dielectric constant of substrate = 2.20, loss tangent of substrate = 0.0009, incidence angle = 63° from normal.

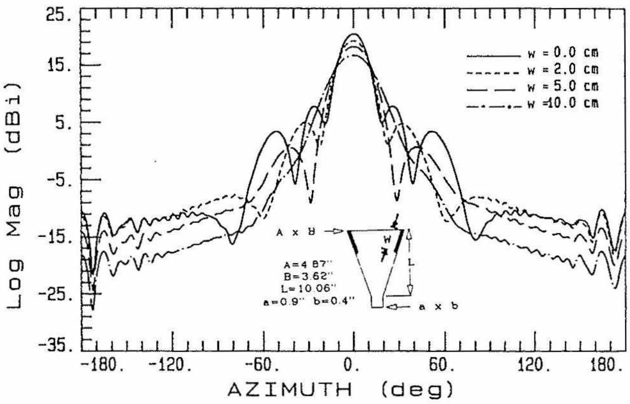


Fig. 5. E-plane radiation pattern of pyramidal horn with E-plane walls partially covered with absorbing material of width w.

Microwave Circuits, Devices and Measurements

Research programs in microwaves and millimetre-waves include analysis, design, fabrication and testing of monolithic and hybrid integrated circuits (MMIC's, HMIC's). The objectives of these programs are to develop rigorous analyses of the behaviour and characteristics of multilayer multiconductor planar transmission lines, such as microstrip couplers and filters, anisotropic reciprocal and nonreciprocal circuits and devices, including phase shifters, isolators and circulators. Effects of microstrip transitions and discontinuities, and leakage and coupling in multimode structures are being investigated. Frequency and time domain analyses are used to model, design and optimise ultra-fast electronic devices and circuits. Optical measurement techniques for these devices are being developed utilising subpicosecond laser pulses. Interaction between laser pulses and semiconductor microwave devices is under investigation. Research also in progress involves microwave applications of superconductivity. A state-of-the-art microwave laboratory to support research is equipped with automatic network analyser, spectrum analyser and cascade microwave probe station, each with testing capability of up to at least 20 GHz.

Topics of research include :

•Full-wave analysis of planar transmission lines on anisotropic substrates

•Signal distortion in microstrip lines

•Spectral domain analysis of microstrip discontinuities

•Time-domain analysis and measurements utilising subpicosecond laser pulses

•Drift velocity measurements in microwave devices

•Analysis, design, and fabrication of active and passive microwave circuits

•Microwave applications of superconductivity

Microstrip lines are widely used in Microwave Integrated Circuits (MICs) and in high-speed high-density digital integrated circuits. Traditionally microstrip lines are dispersive; therefore wideband signals, such as pulses, are distorted [37]-[42]. In microstrips with multiple centre conductors,

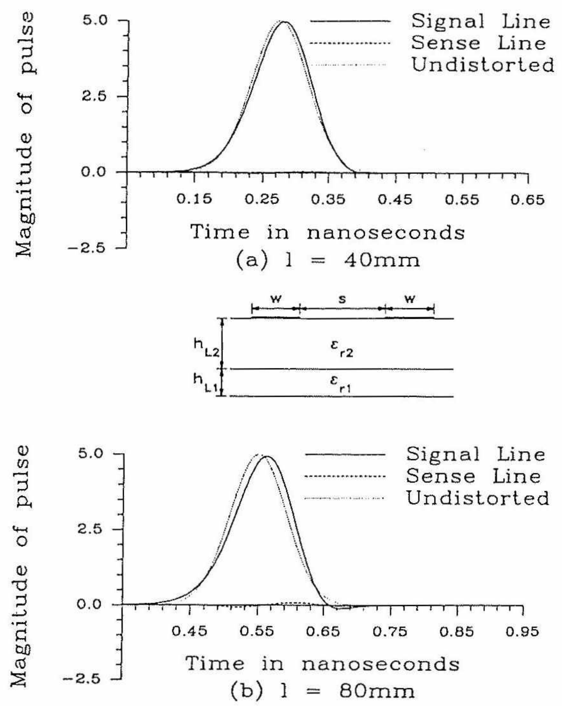


Fig. 6. Gaussian pulse distortion on a coupled microstrip for l = 120 and 160 mm (pulse half maximum, half width = 50 ps)

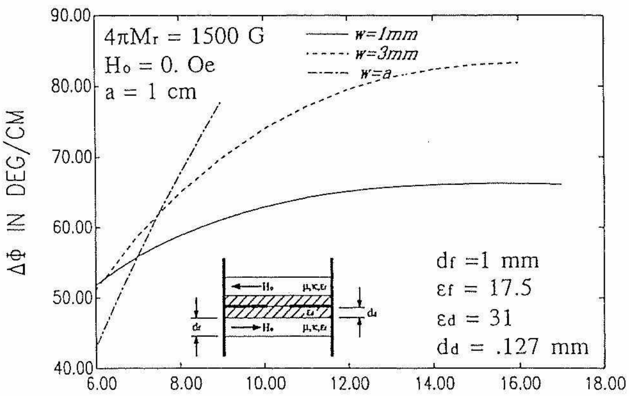


Fig. 7. Differential phase versus frequency of a slot line between two oppositely magnetised ferrite layers.

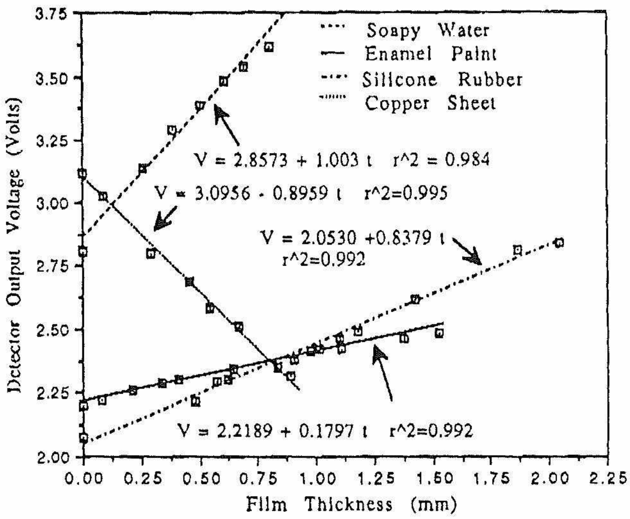


Fig. 9. Results of output voltage of instrument -v- film thickness for various materials.

additional distortion to the signal is contributed by coupling, which can be significant. Coupling distortion (crosstalk) can be minimised, in fact even eliminated at a single frequency, by utilising at least two substrates with carefully selected heights and electrical properties [40]-[42]. Using this method, the spacing of interconnecting transmission lines of digital and microwave circuits can be kept small while at the same time the signal crosstalk is reduced. Figure 6 shows typical responses of Gaussian pulses as they travel in single- and two-conductor, two-substrate compensated for minimum distortion microstrip lines; distances of travel of 40 and 80 mm are used for the data of Figure 6. A United States patent entitled "Multilayer-multiconductor microstrips for digital integrated circuits" dated September 3, 1991 has been awarded to the inventors of this method, C. A. Balanis and J. P. K. Gilb.

A new type of phase shifter, utilising oppositely magnetised ferrite layers, has been developed for broadband high nonreciprocity applications [43]-[44]. The structure has been investigated using a full-wave solution and design aspects of the new structure (including bandwidth, characteristic impedance, and nonreciprocity) has been addressed. Figure 7 shows the differential phase versus frequency of a slot line between two oppositely magnetised ferrite substrates. Also high-speed transmission media in the form of multilayer metal-backed coplanar waveguides have been studied, and a novel concept [45] has been introduced to overcome overmoding effects which limits the operation of this type of printed line. The new transmission line has less losses at discontinuities than the microstrip line as well as better immunity to external electromagnetic interference.

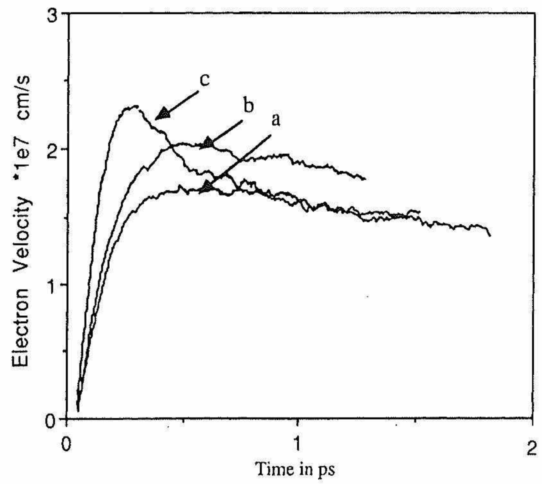


Fig. 8. Average electron velocity evolutions in a GaAs sample after illuminating it with a laser pulse when (a) the sample is enclosed in a metal box, (b) absorbing boundary conditions are used, (c) an electro-optic crystal is added.

Electron transport phenomena in ultrafast semiconductor devices is another area of research interest. In such devices strong electromagnetic fields coexist with the moving charges. The problem at hand could be highly nonlinear from both the electromagnetic and the semiconductor points of view. The approach developed is based on using an Ensemble Monte Carlo technique to analyse the carrier transport inside the semiconductor sample for transients on the subpicosecond scale [46]-[47]. This technique is supplemented with a self-consistent three-dimensional full-wave electromagnetic solution derived from Maxwell's equations. The two techniques are coupled together to give the comprehensive solution for ultra short transients in semiconductor devices. An example of typical results of interest is shown in Figure 8. The calculated average velocities of optically generated electrons in a GaAs sample are shown as a function of time. The only difference between the three curves is the applied boundary conditions; all other parameters are the same. Curve (a) depicts the average velocity when the sample is enclosed in a metallic box. Replacing the metallic box with absorbing boundary conditions increases the average velocity as depicted in curve (b). When electro-optic crystal of $LiTaO_3$ is added on top of the sample, the average velocity evolution becomes as shown in curve (c). This figure clearly demonstrates the importance of properly accounting for the dynamic electromagnetic forces in ultra fast semiconductor device operations.

A microwave technique has been invented which makes real-time, non-contacting measurement of the thickness of both liquid and solid films in the thickness range 0.1 to 1 mm [48]-[49]. This has now been developed into a low-cost instrument that, while internally microwave-based (2.3 - 2.6 GHz), requires only a low voltage dc supply for its operation. Results of output voltage of the instrument versus film thickness for various materials are shown in Figure 9. A field of current interest deals with the application to microwave systems of the phenomenon of kinetic inductance in thin-film superconductors. As demonstrated by Pond et al. [50], kinetic inductance can reduce the velocity of a propagating wave to 0.01c, where c is the speed of light. Irving Kaufman is the co-author of U.S. Patent 5,075,655, awarded 12/24/91, which relates to this field.

A wide variety of microwave engineering, electromagnetic theory and antenna courses are offered to support research in microwave engineering. Topics covered in these courses include polarisation, magnetisation, anisotropy, ferrite devices, acoustic surface waves, passive microwave circuits, filter design, and active devices such as FETs, Gunn, Impatt and varactor diodes, and their circuit applications.

Optical Communications

Several aspects of fibre optic communications are being examined. Three major thrusts can be identified: fibre systems, integrated optic structures, and discrete optic components. The fibre systems work examines properties of coherent optic systems, including their ability to carry a large number of channels and their susceptibility to nonlinearities. Integrated optic structures for light modulation, generation, and detection are being designed, built, and tested. Discrete devices (such as fibre couplers, laser diodes, and photodetectors) are also investigated.

Facilities include a fibre communications laboratory (where fibre loss, fibre bandwidth, laser bandwidth and spectral width, and other optic measurements can be made), an MBE machine (for construction of integrated optic devices), a large microelectronics clean room, and laboratories for evaluating materials, devices, and systems.

Topics of Research

Fibre-Optic Couplers

•Nonlinear Phenomena in Single-Mode Fibres

•Multichannel Local Area Networks Using Fibres

•Computer Aided Design of Fibre Systems

•Faraday rotation in fibres

•Polarisation theory in fibres

•Graded-index lens theory

•Coherent Optical Detection

•Optical Frequency-Division Multiplexing

•Integrated Optics

•Laser Diodes

•Holography

•Photonics Education

Multichannel LANs can be constructed utilising fibre transmission. The advantages are increased throughput, while not increasing the speed of the electronics. Operating characteristics are analysed by developing the theoretical relationship between message delay and system throughput [51]-[52].

Stimulated scattering and stimulated Raman scattering limit the power that can be transmitted in a fibre-optic-frequency-division multiplexed system. Generally, the launch-power-limiting phenomenon is dependent on the number of channels being multiplexed [53].

Design of fibre systems can be cumbersome, involving numerous calculations and many iterations before achieving a suitable result. A sophisticated computer-aided design program was developed for automatically producing designs to input specifications [54]. The system includes a data base of typical components for automatic selection.

Photonics education is becoming more and more important for the training of electrical engineers. Workshops and studies have produced several recommendations for enhancing the photonics content of the conventional electrical engineering curriculum [55]-[56].

Several courses in electrical engineering directly support the optic communications research program. These include the following: lasers, coherent optics, fibre optics, quantum mechanics, semiconductor optoelectronics, and solar cells. Numerous other courses, such as those in communications, electromagnetics, and solid state electronics, indirectly support the optics program and insure that graduate students obtain a broad electrical engineering education.

A series of short courses on fibre optics is offered to a national audience. The series includes *"Fusion, Splicing, and Installation Workshop", "Fibre Optic Communications," and "Erbium-Doped Fibre Amplifiers.."*

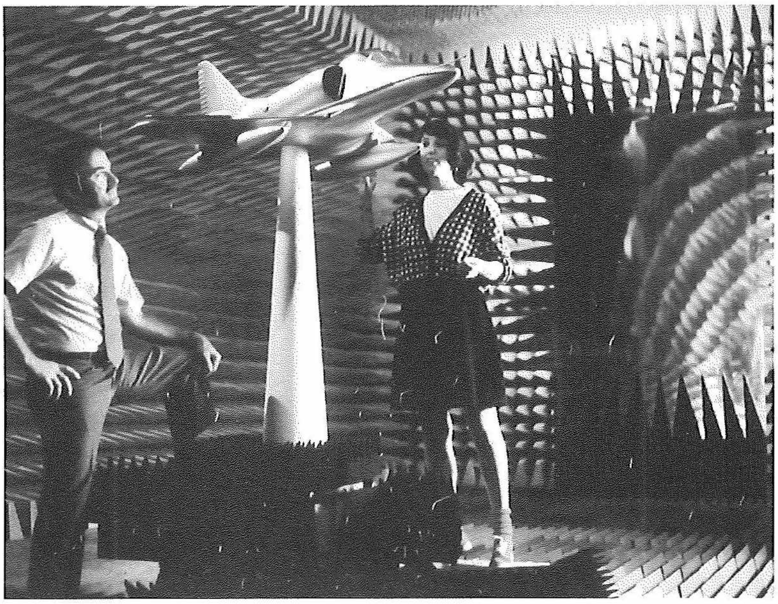


Fig. 10. Radar positioning inside ASU's EMAC facility.

BUILDING FOR EXCELLENCE

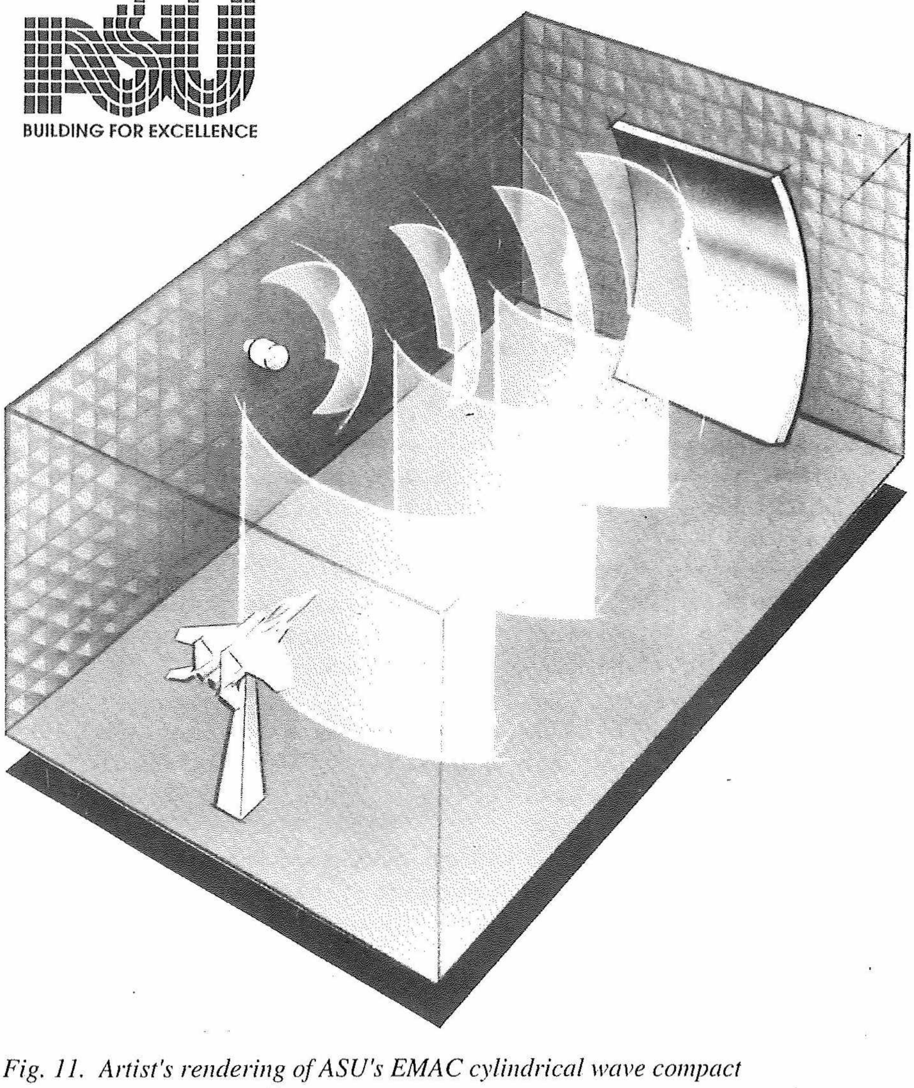


Fig. 11. Artist's rendering of ASU's EMAC cylindrical wave compact range (by Michael Hagelberg).

Electromagnetic Anechoic Chamber (EMAC)

The Electromagnetic Anechoic Chamber (EMAC) is a 2,200 square foot facility that is designed to perform precision antenna pattern and radar cross section (RCS) measurements in the microwave region. It is used to primarily support the research of faculty and graduate students in conjunction with research projects. Figure 10 shows the interior of the EMAC facility with Constantine A. Balanis and Leslie A. Polka examining the positioning of a scale model radar target. A unique March Microwave Systems B.V. compact range, positioned inside the 51 ft. (15.5m) by 26 ft. (8m) by 18 ft. (5.5m) anechoic chamber, converts the spherical waves from the system's feed horn into high quality cylindrical wavefronts in the test region. This is illustrated graphically in an artist's rendering in Figure 11. Cylindrical wave measurements are acquired utilising an HP8510B Network Analyser, and are then transformed to plane wave results via transformations and computer software. Target orientation is handled by an Orbit AL-4303-1 azimuth-over-elevation positioner, driven by a Scientific Atlanta 4139 positioner controller. ASU has the distinction of being the first to implement this cylindrical wave range configuration. ASU's EMAC is a facility that is virtually unequalled in a university setting.

Measurement capabilities of the EMAC include :

•2.5m test region

•Antenna patterns

•RCS patterns

•ISAR imaging

•Time-domain gating

•S-parameters

•Material properties

•0.01 - 20.0 GHz

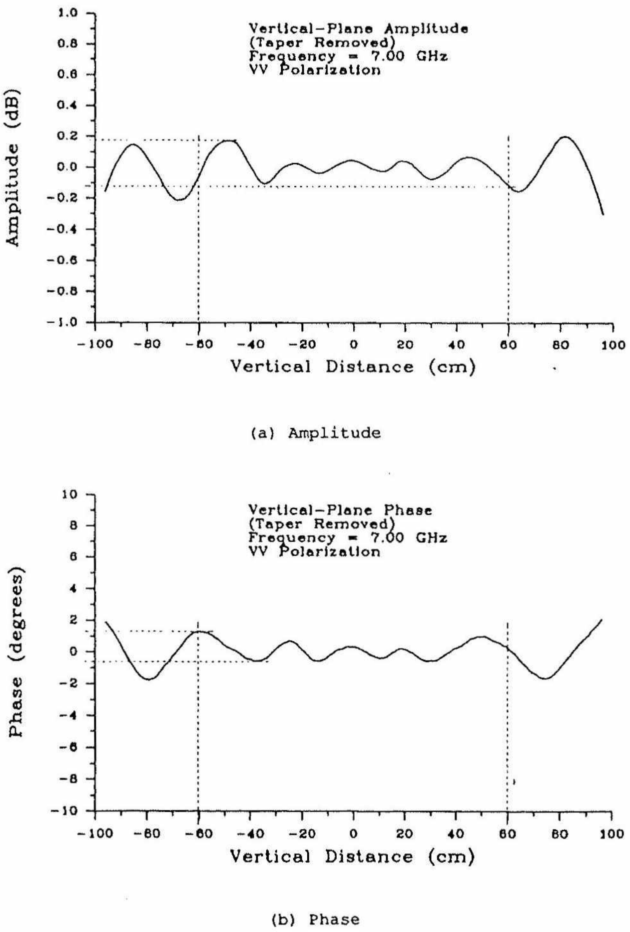


Fig. 12. Amplitude and phase of the vertical-plane quiet zone fields relative to a planar phase front.

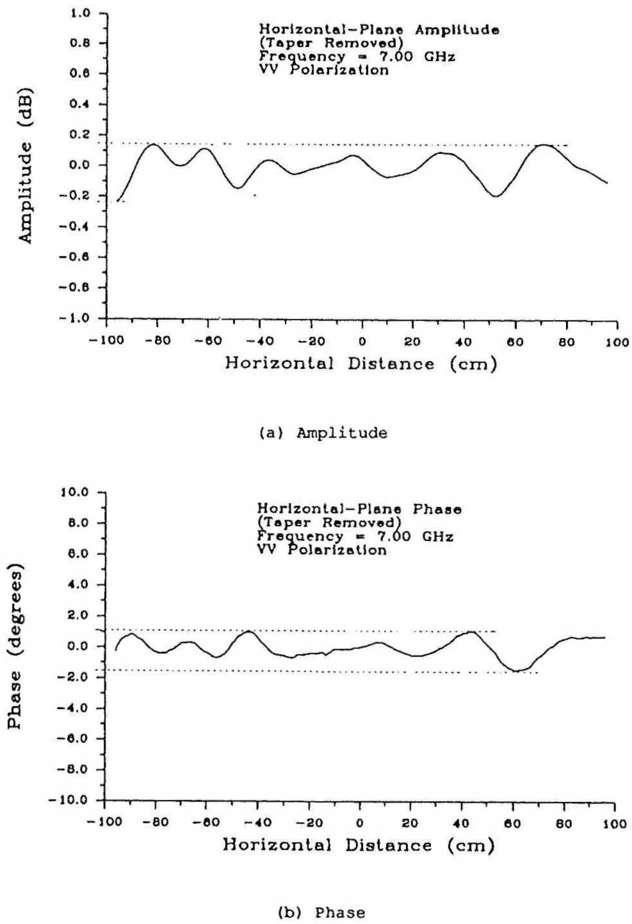


Fig. 13. Amplitude and phase of the horizontal-plane quiet zone fields relative to a cylindrical phase front.

The interior walls of the EMAC are covered with wedge and pyramidal shaped microwave absorbers. The "quite" zone is a function of frequency, but typically ranges from 2-2.5 meters in the azimuthal plane and about 2 meters in the elevation plane. The vertical plane amplitude and phase variations in the quite zone, with the linear taper removed, are displayed in Figure 12(a, b). Similar responses are shown in Figure 13(a, b) for the horizontal plane. Scale models (typically 1/7 to 1/10) of airframes have been tested in the EMAC for antenna and RCS measurements.

EM Faculty

There are a number of faculty at ASU with an interest in Electromagnetics. The emphasis on active research in electromagnetics was initiated in the early 1980s with the creation of the Engineering Excellence Program. A number of new faculty with interest in Electromagnetics joined the Department of Electrical Engineering in the 1980s, and now enjoy a good complement of faculty and courses. Presently there are the following faculty:

Constantine A. Balanis, Regents' Professor and Director of the Telecommunications Research Centre (PhD., 1969, Ohio State University) Antennas, Propagation, Scattering, Numerical Electromagnetics, Transient Analysis in MIC Transmission Lines.

James T. Aberle, Assistant Professor (PhD., 1989, University of Massachusetts) Radiation and Scattering from Conformal Antennas, Planar Microwave Circuits, Numerical Electromagnetics.

Samir M. El-Ghazaly, Assistant Professor (PhD., 1988, University of Texas at Austin) Microwave Semiconductor Devices, Microwave Transmission Lines, Wave-Device Interaction, Numerical Techniques.

El-Badawy El-Sharawy, Assistant Professor (PhD, 1989, University of Massuchusetts) Microwave Circuits, Ferrite Devices.

Robert O. Grondin, Associate Professor (PhD., 1982, University of Michigan) High Speed Phenomena in Semiconductors.

Shakrokh Hashemi-Yeganeh, Assistant Professor (PhD, 1988, UCLA) Numerical Electromagnetics, Slot Array Antennas.

Irving Kaufman, Professor (PhD, 1957, University of Illinois at Urbana) Microwaves, Solid State Electronics, Nondestructive Testing.

Joseph C. Palais, Professor (PhD., 1964, University of Michigan) Fibre Optics, Holography, Electro optics.

Thomas E. Tice, Professor Emeritus (PhD., 1951, Ohio State University) Radar Systems, Antennas, Radar Scattering, Electromagnetics.

Books

Three widely adopted and used text books in electromagnetics have been authored by faculty from the Department of Electrical Engineering and Telecommunications Research Centre. The first, *Antenna Theory: Analysis and Design* (Wiley, 1982), is authored by Constantine A. Balanis and has been widely used as a reference and textbook at the senior and graduate levels. The second, *Advanced Engineering Electromagnetics* (Wiley, 1989), is also authored by Constantine A. Balanis and it is used as a reference and textbook primarily at the graduate level. The third, *Fibre-Optic Communications*, third edition, (Prentice-Hall, 1992) is authored by Joseph C. Palais, and it is primarily used as a textbook at both the senior and graduate levels.

Continuing Education

Faculty from the Department of Electrical Engineering and the Telecommunications Research Centre at ASU, in cooperation with the Centre for Professional Development, offer three Electromagnetics related national short courses. These include: "*Antenna Analysis, Design and Measurements*" with Constantine A. Balanis and Thomas E. Tice as instructors; "*High Resolution Radar*" with Thomas E. Tice and Donald Wehner as instructors; and "*Fibre Optic Communications*" with Joseph C. Palais as the main instructor. Attendees of these courses are from industry, government and academia.

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A radioscientific trip to the former Soviet Union

St. Petersburg, Petrograd, or Leningrad?

Looking from the West, and at least travelling from Finland, the most natural port of entry to Russia is St. Petersburg, the former Leningrad. From Helsinki, St. Petersburg is only one hour's flight away. This city is a great industrial and cultural centre in Russia, despite the fact that it cannot boast of traditions gilded by centuries of age, like so many other European cities. St. Petersburg was founded on the mouth of the river Neva in the early 18th century by the western-oriented Tsar Peter the Great. It may be due to this fact that St. Petersburg does not seem to be part of the Byzantine East; rather, with its architecture characterised by the large number of buildings of classicism, St. Petersburg looks very European.

It was here that my exploration of the Western part of the former Soviet Union started. In addition to paying a radioscientific visit to St. Petersburg, I was heading South. Belorussia and Ukraine are significant republics in the new Commonwealth of Independent Nations. Thanks to the scientific contacts between our Electromagnetics Laboratory at the Helsinki University of Technology and the Radiophysics Department of the St. Petersburg State Technical University, I was fortunate to be joined on the road by Associate Professor Sergei A. Tretyakov. It was indeed essential to have a translator—in remote places and railway stations of the Steppes, communication was inconceivable without knowledge of Russian.

Our main destination was the city of Gomel in the southern part of Belorussia (or "Byelarus", as many White-Russians would like to translate the name of their republic, thereby following the transliteration rules from the Belorussian language rather than from Russian). The Russian country is indeed vast—a train from St. Petersburg to Gomel takes around 17 hours. After equipping ourselves with bread and cheese, we entered the sleeping cabin.

Post-Soviet radio science—who survives?

The major issue in the minds and conversations of the people in the former Soviet Union is the state of the country's economy. On the micro economic level of everyday life, take, for example, travelling. Travelling is not expensive—the train ticket from St. Petersburg to Gomel was 87 roubles, which amounts to less than one US dollar. The official exchange rate during the first week of May 1992 was 100 roubles for 1 US dollar. But how about income? In terms of hard currency, the salaries in Russia and other republics are Lilliputian—a university teacher can earn one thousand roubles per month. The salaries have been increased during the year but the customer prices have escalated more steeply—from the state-supported levels of the end of 1991, the price of some goods has increased even hundredfold. For example, sugar cost between 60 and 100 roubles per kilogram. Also, contrary to pre-market-economy Russia, fancy goods are there on shelves of shops, but for example, a kilogram of bananas can cost 200 roubles.

The country's incredible inflation rate makes ephemeral the kinds of statements above the exchange rates—in July a dollar bought already 130 roubles, up from 100 in May. Still, I cannot resist mentioning an example of ex-Soviet-Western interaction I am myself affiliated with. In August 1992, the 22nd European Microwave Conference will be held at the Helsinki University of Technology. We have accepted several Russian and Ukrainian papers for representation in this meeting. For the scientists responsible for these contributions, whom we would really like to have come into our country, the British organising company running the conference promised to relax the 250-pound-Sterling registration fee to "only" 70 pounds, which is the normal student fee. Well, even this sum amounts to about ten months' salary for a senior scientist at a university in Russia (moreover, these people dreaming to participate have to find their own support because their institutes cannot afford paying the expenses of their researchers going abroad). Imagine paying a $30,000 student fee from your own pocket to get into a conference!

In addition to trying to open scientific and professional communication avenues with the research people in this part of the former Soviet Union, my plan for the trip was also to advertise URSI. The International Council of Scientific Unions (ICSU) has decided that all the FSU republics can be automatically admitted as members of the scientific unions adhered to by the old Soviet Union. The problem is to find people to organise this transfer—in former times, all formalities had to go through Moscow*, now direct relations are needed.

The future of the research people in the fields of URSI looks bleak—radio science, the very nature of which is military oriented, suffers especially hard from the defence budget cuts. Already in the Gorbachev era, scientists were affected adversely. While trying to keep the weapons and armaments intact, the government reduced military budget with immediate cuts in research and development. Nowadays the situation is even worse. Radiophysics scientists in the universities are struggling to survive by taking increased teaching loads, as project money in the form of grants from the Ministry of Defence or the military industries is scarce. The non-academic radio scientists are in an even worse plight.. For discussion about the state of post-Soviet science

* See, for example, the list of the officers published in the December Bulletins—nearly everybody of the Soviet Union National membeer Committee is from Moscow.

The Institute of Physics of the Belorussian Academy of Sciences in Minsk hosts also the publishing house of the all-union applied optics journals. Note the differences in spelling and even in words of the closely related Russian and Belorussian languages.

in general, see the enlightening articles by Roald Sagdeev and Avgenii Feinberg in the May 1992 issue of *Physics Today*.

Gomel State University—radioactive or radioscientifically active?

Gomel, the second largest city in Belorussia, is located on the river Sozh, a tributary of Dnieper. It is in the southern part of Belorussia, close to the Ukrainian border. This fact was unfortunate six years ago, when an accident occurred in one of the reactors of the Chernobyl nuclear power plant. This plant is located in Ukraine, just on the border to Belorussia, and due to the prevailing southerly winds, Belorussia received most of the radioactive clouds from the Chernobyl plant.

I was told about those incidents that as the polluted clouds were spreading and moving towards Russia and Moscow, Soviet Air Force planes were ordered to drop these down. This can be achieved through seeding condensation nuclei in the clouds and thereby producing rainfall.

Due to the radioactive precipitation, some rural areas not far from Gomel have been considered by the government too polluted to live. People have been ordered to move from their villages, and also to leave nearly all their belongings behind. It seems strange that this action was not taken until 1991, *five years* after the accident. The reason lies probably in the bureaucracy of the ex-Soviet control society and the secrecy that shadowed all elements strategically essential to its operation, like nuclear power.

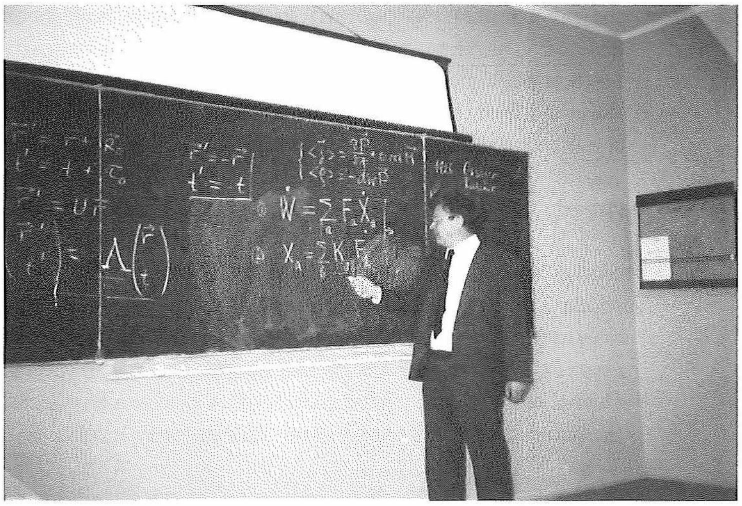
However, life in Gomel seemed to be unaffected by the shadow of the past. Children played, people worked. The only difference to other communities that could be sensed in everyday conversation with the people was the ability of Gomelians to relate what the units of a Curie or a Becquerel meant and their awareness about radioactivity levels.

Gomel is one of the three centres of physics research in Belorussia, the other two being Minsk and Mogilev (Magilov). The Physics Department of the Gomel State University had strong emphasis on the electromagnetic and optical properties of materials—they study anisotropic, gyrotopic, and optically active media and wave guiding structures. URSI-related scientists hold eminent positions in the university administration—Associate Professor Igor V. Semchenko, Dean of the Physics Faculty, and Professor Anatoly N. Serdyukov, Deputy Rector on Science, are both electromagnetically and optically very active. These were the two scientists at the university with whom I established most fruitful professional contacts.

Belorussian Academy of Sciences and a case study about ethics in science

After visiting Ukraine for one day and seeing Kiev with its fascinating old churches, monasteries, and the now-anachronistic megalomanic monuments for the "eternal union of the Ukrainian and Russian nations", we took the fourth

Gomel StateUniversity was still celebrating the 500th anniversary of the translation of the Bible into the Belorussian language. The national hero, F. Skaryna, receives late fame.



Anatoly Serdyukov has not forgotten science under the pressure of his duties as the Vice Rector of the Gomel State University. The lecture photographed here started as a comment on my presentation and lasted for two hours. The problem was on the basic physical restrictions on the electromagnetic material parameters of general media.

successive night train and travelled to Minsk. This city is the capital of Belorussia. Judging from the age of the buildings in the city, Minsk has suffered more destruction during the war compared to Kiev. However, now the issue was science. And in that respect Minsk has much to offer. There, one can find two places of interest from the "Ursian" point of view—the Physics Departments of both the Belorussian State University and the Belorussian Academy of Sciences.

We had the great privilege of meeting with Academician Fyodor Fyodorov, the 81-year old grand old man of Belorussian and ex-Soviet physics. The first Candidate of Sciences and Doctor of Science of Belorussia, Fyodorov studied in the 1930's in Leningrad with the great Vladimir A. Fock. Fyodorov's many books and enormous number of scientific articles cover wide areas of physics, but in the URSI community, his research on the electromagnetics and optics of anisotropic and gyrotropic materials is most interesting. Fyodorov gave us an audience in his private home in one of the large blocks of flats in the centre of Minsk, close to the buildings of the Academy of Sciences.

Along his extensive radiophysics career, Academician Fyodorov has also been advancing the dyadic, or coordinate-free way in electromagnetic analysis. And it is with this sub-field of his work that Fyodorov—or Fedorov**, with which name he is probably mostly known in the West—has attracted attention in the URSI community. Through the letter published in *Radio Science*,[2] Fyodorov has expressed his feelings about being a victim of plagiarism. Although coming out of print only last year, this letter exposes to radioscientists an issue that has been alive for several years[3]. The controversy discussed therein culminates in the objectively observable fact of a surprisingly high correlation between the text, figures and equations in two books—Fyodorov's *Optics of anisotropic media*[4] and the monograph *Theory of Electromagnetic waves. A coordinate-free approach* by Professor Hollis C. Chen[5]. From the argumentation in [1] - [3] and the related correspondence one can sense how hot this kind of issue can be. Furthermore, the case is still open.

I think URSI could serve a valuable purpose in warming the global scientific environment and thereby reducing the risk of the type of conflicts arisen here. This can be done by increasing our interaction with radioscientists in the former Soviet Union. Let us hope that the new republics will soon be active members in URSI.

Missionary work for IEEE, too

The return back to St. Petersburg brought me to the renovated Grand Hotel Europe, which with its golden faucets and omnipresent well-dressed musicians entertaining guests with concert-level classical music performances—the least expensive room was US$205—gave some comfort after four nights in trains. But there was still work to do—a visit to the St. Petersburg State Technical University and negotiations about how IEEE could start its expansion in this great city. The Institute of Electrical and Electronics Engineers works through its Regions and Sections, but the crucial point in

Academician Fyodor Fyodorov at his home in Minsk

** The most curious Fyodorov-transliteration, "Fiodarau", can be found in a couple of short polemical articles published in *Nature*[1].

The village of Besed close to Gomel is empty and closed due to high radioactivity levels from the Chernobyl catastrophe. However, the pollution distribution is very inhomogeneous and only certain spots are considered unsafe to live from the public health point of view. The most heavily polluted areas are guarded by the military.

fostering its growth is the fact that unlike URSI, IEEE has individual membership. And because of the absolute incapacity of Russians to pay even the modest membership fees in hard currency, some exceptions to the tight IEEE rules have to be conceived. Now the idea is to start a so-called "Section-in-Development" in St. Petersburg. With this undertaking, Region 8 of IEEE (covering Europe and Africa) will be temporally assisting with its own funds the hard start over there. Let us wish them all success.

The last night on my journey was crowned with a spectacular visit to the theatre. In the schedule there was Alexandr Borodin's opera Prince Igor. This pleasure elevated my thoughts towards issues that transcend radio science. In Russia, everything is experiencing transients, and among other changes, a heavy toll hits the names of venerable places—there is no Leningrad anymore, not to mention no Stalingrad. The wonderful Kirov Theatre will be re-christened with its Tsar-time name Mariinsky Theatre.

One wonders whether all this is absolutely necessary. After all, was Kirov really that bad a man?

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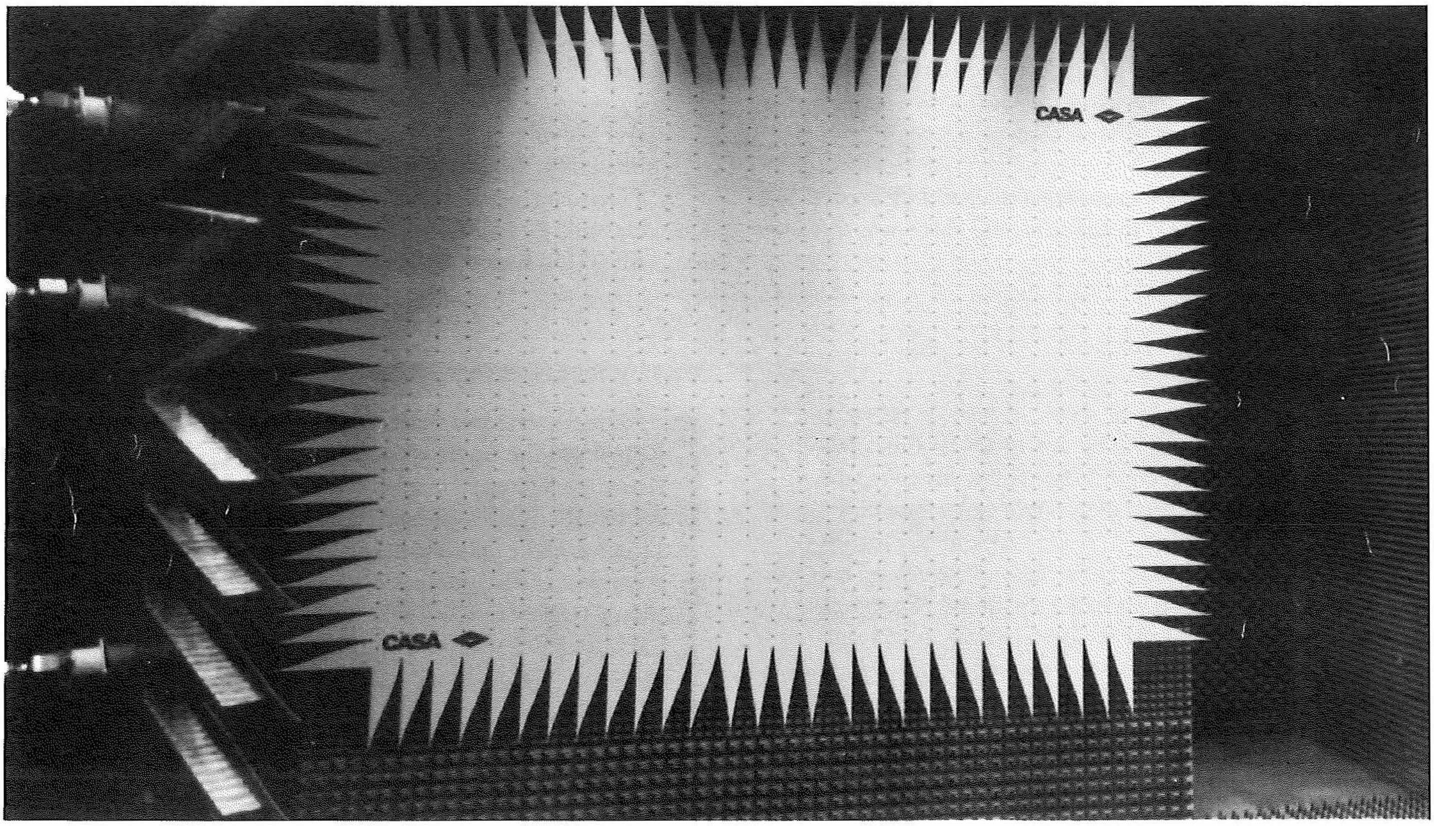

ESA's Compact Payload Test Range situated at ESTEC Noordwijk-Netherlands. This shows one of the two reflectors and the polarisation-v-elevation-v-azimuth positioner and the plane wave scanner mounted on the polarisation table. (See Near field measurements and the synthesis of linear arrays with prescribed radiation patterns... *p.89 this issue).*