necessary to ensure that temporary peak loading conditions are identified. Obviously, these requirements are both time-consuming and expensive.

Due to the magnitude of even the task of *measuring* area-wide compliance, the obligation of *ensuring* area-wide compliance should not be imposed absent compelling justification. The burden on smaller carriers, for example, may effectively preclude needed expansion of service and the speed at which new services are rolled out to the public. Indeed, even for larger carriers, the area-wide compliance obligations create the perverse incentive to avoid multi-transmitter areas, reversing the Commission's prior policies of encouraging the consolidation of facilities to limit environmental impacts.

PCIA also does not believe a one percent threshold is necessary to achieve the Commission's goals. The likelihood that a transmitter contributing only one percent of the MPE limit for that transmitter type will be "responsible" for rendering the area non-compliant is negligible, especially where, as in this case, many of the transmitters under scrutiny were previously categorically excluded from *any* evaluation. In effect, by eliminating the bulk of the categorical exclusions, the Commission is now requiring assessments from a wide range of carriers that, under the old regime, were determined to be "highly unlikely" to exceed the applicable MPE limits. Given the broader applicability of the compliance regulations, the Commission should revisit the one percent exemption.

PCIA further urges the Commission to also clarify its policies with regard to liability for non-compliant multi-transmitter sites. Given that a carrier may have no control over the property of the site, the carrier may not be notified, much less consulted, at the time a subsequent transmitter is added or an existing transmitter modified. If the result of adding a

new transmitter or modifying a transmitter results in the area exceeding the applicable MPE limits, the original licensees bear, under the Commission's rules, a "continuing" obligation to remain in compliance. This would imply that the pre-existing carriers remain exposed to potential forfeitures, or are otherwise in noncompliance, if the new entity adding a transmitter makes some error, whether intentional or unintentional, that results in the facilities becoming noncompliant. The Commission should therefore state that carriers have no obligations with respect to facilities added or modified after they have conducted their own routine assessments of the area, unless the carrier is notified of the change.

VI. THE COMMISSION SHOULD MODIFY THE DEFINITION OF "COVERED SMR" CONSISTENT WITH OTHER PROCEEDINGS

The *Order* adopts certain presumptions regarding the use of mobile and portable devices for certain CMRS offerings, including those provided by "covered SMRs."[18] PCIA notes, however, that it has petitioned for reconsideration of the definition of "covered SMR," which it believes is over inclusive, in several proceedings where this term has been used before.[19] For reasons described in those petitions for reconsideration, PCIA believes that certain small SMRs should not be subject to the same requirements imposed on other commercial mobile radio service providers. For consistency, PCIA urges the FCC to ensure

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[18] *Order*, ¶65 & n.78.

[19] *See* Petition for Reconsideration of PCIA, CC Docket No. 94-54 (filed Aug. 23, 1996); Petition for Reconsideration of PCIA, CC Docket No. 94-102 (filed Sept. 3, 1996) at 15-17.

that any modification of the "covered SMR" designation be applied in the present context as well.

VII. CONCLUSION

Carriers are sincerely attempting to understand and comply with the regulatory scheme delineated in the *Order*. Unfortunately, absent clarifications that have not yet been released, carriers have not been able to fully comprehend and assess the extent of the obligations imposed by the *Order*. PCIA therefore urges the Commission to clarify the *Order* and to defer the transition date to a more reasonable one year after the release of OST Bulletin No. 65. PCIA also urges the FCC to standardized procedures for area-wide EME assessments and to limit imposing that extraordinary compliance burden except in limited cases.

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Dated: September 6, 1996

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of

Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation	)))	ET Docket No. 93-62

COMMENTS ON PETITIONS FOR RECONSIDERATION

AT&T Wireless Services, Inc. ("AT&T"), by its attorneys, submits these comments in response to certain Petitions for Reconsideration filed contemporaneously with its own Petition for Reconsideration of the Commission's Report and Order in the above-captioned proceeding.[1]

I. The Commission Should Reject Calls for More Onerous Regulation of Transmitter Sites

In the Order, the Commission eliminated its categorical exclusion for cellular and paging facilities, thereby significantly expanding the number of wireless facilities subject to routine evaluation. The Commission's decision to take such action was not based on scientific evidence that eliminating the categorical exclusion was necessary, but, as the Commission concedes, on "an abundance of caution"[2] and "generally worst-case assumptions."[3] Several parties nevertheless ask the Commission to tighten its regulations

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[1] Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation, ET Docket No. 93-62, Report and Order, FCC 96-326 (rel. Aug. 1, 1996) ("Order").

[2] Id. at ¶ 92.

[3] Id. at ¶ 91.

still further. For example, the Cellular Phone Taskforce ("Taskforce") requests that the Commission modify Section 1.1307 to require routine environmental evaluation of all transmitters, facilities, and operations that are less than 2,000 feet from any residence.[4] Another commenter wants the Commission to require applicants to demonstrate that each area within 1000 meters of a facility will not be out of compliance because of exposure from that facility and any other RF source within 1000 meters.[5] Given that the Commission has conducted its own studies, as well as taken into account the studies and reports provided by other parties in this proceeding, the Commission should reject the calls for more burdensome regulation and, instead, should reinstate its well-founded categorical exclusion for cellular and paging facilities.

As AT&T indicated in its petition, all cellular and paging licensees had previously been categorically excluded from routinely demonstrating compliance because these sites are extremely unlikely to exceed the maximum permissible exposure ("MPE") limits.[6] This exclusion also released these licensees from responsibility for evaluating and maintaining compliance at multiple transmitter locations. The Commission's Order, however, eliminated this categorical exemption for cellular and paging licensees, and instead requires these entities to utilize Table 1 in Section 1.1307(b)(1) ("Table 1") of the Commission's rules to determine whether specific new or modified facilities remain excluded based on certain

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[4] Petition for Reconsideration of the Cellular Phone Taskforce at 7 (Sept. 3, 1996).

[5] Petition for Reconsideration of the Ad-hoc Association of Parties Concerned About the Federal Communications Commission's Radiofrequency Health and Safety Rules at 6 (Sept. 6, 1996).

[6] Petition for Reconsideration of AT&T Wireless Services, Inc. at 2-3 (Sept. 6, 1996) ("AT&T Petition").

power and height criteria.[7] Carriers that are not excluded under Table 1 are obligated to perform a "routine" evaluation to determine if the facility produces power densities exceeding the MPE limits.

As AirTouch Communications ("AirTouch") correctly notes in its petition, the Commission's decision to eliminate the categorical exemption for cellular and paging licensees disregards the evidence in the record demonstrating that existing facilities in these services are unlikely to exceed the new MPE limits for RF emissions in the first place.[8] Indeed, the Commission admits that "there is no evidence that typical installations in these services cause ground-level exposures in excess of [its] limits."[9]

Because there is little chance that a stand-alone cellular or paging facility will exceed the MPE limits or contribute significantly to overall radio frequency ("RF") emissions at multiple-transmitter locations, both the Taskforce's proposal to require all licensees to conduct routine transmitter inspections on every facility and the Order's elimination of the categorical exemption will do very little to further the Commission's goal of protecting the public from excessive RF emissions. As the Commission itself stated in the Order, requiring routine evaluation of facilities that offer little or no potential for exposure in excess of the

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[7] Cellular and paging facilities operating at power levels above 1000 watts ERP and PCS facilities operating above 2000 watts ERP that are located on "relatively short towers or rooftops where access may not be restricted" are subject to "routine evaluations." Order at ¶ 86. In its petition, AT&T asked the Commission to clarify that the certification requirement may be satisfied by including a statement of compliance in an application and, if no application is required, through retention of the statement in the operator's files. AT&T Petition at n.2.

[8] Petition for Partial Reconsideration of AirTouch Communications at 3 (Sept. 6, 1996) ("AirTouch Petition").

[9] Order at ¶¶ 92-93.

specified guidelines "would place an unnecessary burden on licensees."[10] AT&T agrees with the petitions of AirTouch and Paging Network ("PageNet") that this requirement contradicts the Commission's stated goal of reducing unnecessary regulatory burdens.[11] The Commission accordingly should grant the requests of these petitioners to reinstate the categorical exemption for paging and cellular licensees.

Finally, while AT&T does not oppose the request of the American Mobile Telecommunications Association (AMTA) to narrow the definition of "covered SMR systems" for purposes of categorical exclusion,[12] it believes that the Commission should treat similar services alike. To the extent the Commission agrees that AMTA's facilities should be excluded, it should also exempt from the RF emissions compliance obligations the facilities used by AT&T for data-only services.

II. Power Density and Field Strength Limits At Multi-Transmitter Sites Should Be Increased From One Percent to Ten Percent

If the Commission declines to reconsider elimination of the categorical exclusion for cellular and paging facilities, it should reevaluate the power density and field strength limits that trigger responsibility for bringing multiple-transmitter sites into compliance. Under the Commission's new rules, when the MPE guidelines are exceeded in an accessible area as a

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[10] Id. at ¶ 86. AT&T has more than 4,500 existing transmitter sites which will have to be physically evaluated by trained engineers if categorical exclusion is not reinstated. On-location measurements or a site visit will be required at all collocated multiple-transmitter sites. It is AT&T's experience that only three or four cell sites can be evaluated by an engineer in a work day.

[11] AirTouch Petition at 4; Petition for Reconsideration and Clarification of Paging Network at 3 (Sept. 6, 1996) ("PageNet Petition").

[12] See generally Petition for Reconsideration of the American Mobile Telecommunications Association, Inc. (Sept. 6, 1996).

result of emissions from multiple collocated facilities, any licensee whose transmitters produce field strengths or power density in excess of one percent must ensure the entire area around its facility is in compliance with the applicable limits.[13] As AT&T demonstrated in its petition, this one percent threshold for MPE guideline compliance is too low.[14] The Commission, thus, should grant the requests of numerous petitioners to increase the one-percent trigger for site-wide compliance to ten percent. Similarly, the Commission should establish a reasonable distance from the antenna's center of radiation at which the threshold be should be measured. AT&T fully supports the requests of Ameritech Mobile Communications, Inc. ("Ameritech") and the Personal Communications Industry Association ("PCIA") to designate a measurement point ten meters from the center of radiation of the antenna.[15]

Adopting these proposed modifications will alleviate somewhat the myriad logistical difficulties for licensees at multiple-facility sites. As PCIA correctly notes, determining the licensee of nearby facilities will be difficult, and determining their power and frequency will

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[13] The Commission at least partially justified its new policies on site-wide compliance by reference to a study of two multiple-transmitter roof tops conducted by Doty-Moore Tower Services. Order at ¶ 85, n.112. The Commission wholly ignores the fact that site surveys conducted by Hatfield & Dawson on behalf of AT&T (then McCaw Cellular Communications, Inc.) found that the Doty-Moore conclusions were entirely wrong. Both sites were found to comply with allowable MPE limits. See Reply Comments of McCaw Cellular Communications, Inc. at 8, 11-12 (filed April 25, 1994). Thus, the Commission's reliance on the incorrect Doty-Moore study for purposes of establishing its new regulations is misplaced.

[14] AT&T Petition at 6-8.

[15] Petition for Reconsideration and Clarification of Ameritech Mobile Communications, Inc. at 7 (Sept. 6, 1996) ("Ameritech Petition"); Petition for Reconsideration and Clarification of the Personal Communications Industry Association at 15 (Sept. 6, 1996) ("PCIA Petition").

be nearly impossible.[16] In all likelihood, licensees may only be able to ascertain compliance through field measurements, an expensive and potentially lengthy process. Monitoring of at least 24 hours will be necessary to identify temporary peak loading conditions.[17] As PCIA and AT&T explained, raising the threshold to ten percent and establishing a reasonable measurement radius will help ensure that the Commission's rules regarding multiple-transmitter responsibility do not create the perverse incentive for licensees to avoid co-location with other facilities.

The Commission should also grant the request of AT&T and other petitioners for clarification of the compliance obligations of previously authorized stations. While the Commission states that all licensees are expected to comply with the Order, it implies that existing stations may continue to operate their facilities in compliance with the RF limits applicable "at the time of licensing and authorization."[18] Similarly, as AirTouch states in its petition, the Order could be read to subject existing licensees to enforcement measures if a new licensee adds a facility at an existing site, or if an existing licensee adds or modifies a facility at a site where one or more licensees already operate, and that new or modified facility causes the site to exceed acceptable MPE limits.[19] AT&T agrees with AirTouch

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[16] PCIA Petition at 15.

[17] Because of these logistical difficulties, AT&T renews its request that the Commission define "site" as a limited radius around an antenna or group of antennas. AT&T Petition at 6. Absent the establishment of reasonable site boundaries, ensuring site-wide compliance will be extremely burdensome, if not impossible.

[18] Order at ¶ 119. This implication is supported by the Commission's statement "that the new RF guidelines will apply to station applications filed after January 1, 1997." Id. at ¶ 112.

[19] AirTouch Petition at 7.

and U S WEST that, at the very least, any incumbent already complying with the standards should be able to expect the burden of site-wide compliance to fall upon newcomers or modifying incumbents who precipitate the excessive emissions.[20]

III. The January 1, 1997 Compliance Date Should Be Extended

If the Commission decides not to reinstate the cellular and paging categorical exclusion or increase the field strength and power density threshold at multiple-transmitter locations, it is essential that licensees be given more time to comply with new regime. AT&T supports the numerous petitioners who request that the Commission extend the compliance deadline, which is now set at January 1, 1997, to one year after the release of the updated OST Bulletin No. 65.[21] As AT&T and other petitioners made clear, there are numerous justifications for such an extension of the compliance deadline. The new rules impose significant responsibilities on licensees, especially those -- like AT&T -- who operate thousands of transmitters across the country. It is unrealistic to expect that licensees can ensure compliance with a new and complicated regulatory regime within such a short time frame.[22] The Commission recognizes that "applicants may need to undertake significant analysis and study in order to comply with the new guidelines."[23] After determining what

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[20] Id.; U S WEST Petition at 7.

[21] See Ameritech Petition at 5; PageNet Petition at 4-5; PCIA Petition at 5, 10; Petition for Reconsideration/Clarification of U S WEST at 5 (Sept. 6, 1996) ("U S WEST Petition"). BellSouth also requests an extension of the transition period to six months after the release of the revised Bulletin. Petition for Reconsideration and Clarification of BellSouth at 5-6 (Sept. 6, 1996) ("BellSouth Petition"). AT&T believes the year long period is necessary to complete the process adequately.

[22] See PageNet Petition at 4-5.

[23] Id.

the obligations are and how to meet them, licensees must then evaluate every transmitter facility to ascertain exemption or compliance. Because this is impossible within the given time period, failure to extend the transition period will require the filing of waiver requests by essentially every carrier. This clearly is not a result intended or desired by the Commission.[24]

AT&T further agrees with PCIA's proposal that, if the Commission declines to reinstate the categorical exemption for cellular and paging facilities, it should, at a minimum, institute a presumption that individual requests for waivers of the new compliance requirements are deemed granted unless affirmatively denied by the Commission.[25] Any waiver process, however, is unnecessary and wasteful, overburdening the Commission and carriers without achieving any positive outcome.[26] Because so many licensees will be unable to comply with the rules, it would make more sense to allow carriers adequate time for transition to the new rules.

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[24] See PageNet Petition at 4-5; PCIA Petition at 10.

[25] See PCIA Petition at 14. AT&T also shares the concern of Ameritech that waivers will offer little help to overwhelmed licensees unless the absence of OST Bulletin No. 65 or lack of time to comply equals the "good cause showing" that will justify a waiver. Ameritech Petition at 6.

[26] See U S WEST Petition at 9.

CONCLUSION

For the foregoing reasons, the Commission should reconsider certain aspects of the RF Radiation Order, as detailed above.

Respectfully submitted,

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October 8, 1996

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I, Tanya Butler, hereby certify that on this 8th day of October 1996, I caused copies of the foregoing "Petition for Reconsideration" to be sent by first-class mail, postage pre-paid or by messenger(*) to the following:

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FI/58687 1

Exhibit 0

3 key papers that will help assure that exposure is properly caculated for workers servicing wireless transmittors.

#1 - on eyeglasses, emphasizes how exposure can be more than 10 fold if metal frame eyeglasses are worn.

#2 - Shows that due to reflections, especially corner reflections, that exposure can increase 16 fold or more

#3 - Shows that when men work in pairs, or a group of 3 close together that the exposure level is higher, since as a group the men act as an antenna.

E 7-#1

Effect of metal-framed spectacles on microwave radiation hazards to the eyes of humans

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Abstract—*A novel measurement technique using a monopole antenna probe has been applied to a full-size, image-plane type model of a human to determine the microwave fields near the eyes and to evaluate the effect of scattering structures, such as metal-framed spectacles, on those fields. The measurement technique relies on a 'subtraction' technique to determine the changes in fields when a scattering structure is introduced, and allows a large number of measurements to be performed in a relatively short space of time and with a high degree of accuracy. Investigations conducted in an anechoic chamber yield angles of incidence, test frequencies and wave polarisation values that give details of shielding, enhancement and depolarisation effects due to this particular scattering structure that appeared not to have been previously studied. It has been found that the introduction of a pair of metal-framed spectacles can, in certain cases, cause an increase in field levels by up to approximately 20 dB, a significant perturbation of the incident microwave field which should be accounted for in the setting of safety standards relating to acceptable levels of incident power.*

Keywords—*Cataract formation, Measurement technique, Metal-framed spectacles, Microwave radiation hazards*

Med. & Biol. Eng. & Comput., 1989, 27, 191–197

1 Introduction

THE EFFECTS of microwave radiation on a biological system are well documented (OSEPCHUK, 1983). The eyes are particularly susceptible to damage arising from heat through exposure to microwave radiation of sufficient intensity because there is very little blood circulation through the eyes, and therefore they possess a very poor cooling mechanism. The damage caused by microwave exposure of sufficient intensity is the formation of cataracts, small opaque areas formed in the crystalline lens of the eye. Apart from death through acute overexposure, cataract formation appears to be the only irreversible thermally induced effect of microwave exposure (CLEARY, 1980). The incident power levels that are needed for cataract formation have been found to be approximately 150 mW cm^{-2}, for a duration of at least 1 h and a frequency of at least 500 MHz. The general population is rarely, if ever, exposed to such a power level (JAMES, JR, 1983). However, those persons who are occupationally exposed may at times be subjected to these levels of power, particularly in the presence of metal-framed spectacles, in effect a small scattering or antenna structure situated very close to the eyes, which may cause an increase in field intensity levels above those that might normally result.

Standards pertaining to the allowable power levels in the case of the general population and those who are occupationally exposed do exist (*American National Standards Institute*, 1982; *Standards Association of Australia*, 1985), specifying power levels approximately one order of magnitude lower than those necessary for cataract formation, but those standards pay little or no attention to the problem that may exist when a metallic object, such as a pair of metal-framed spectacles or jewellery, is placed on or near the body. Metal-framed spectacles can be expected to alter the incident fields in the course of scattering that occurs from their frame, and this effect must be taken into account. The Australian Standard (*Standards Association of Australia*, 1985), for example, includes only the following two clauses:

(*a*) '*Protective clothing and equipment.* Where protective clothing or equipment, which has been proven to be effective in reducing the amount of electromagnetic energy reaching the body, is used, the exposure limits may be relaxed in certain situations. However, caution must be exercised in using protective clothing or equipment which may have the effect of protecting part of the body while concentrating the field elsewhere, resulting in other hazards for the wearer.'

(*b*) '*Surgical implants.* When a metallic surgical implant concentrates with the electromagnetic wave to which it is exposed, it is possible for the electric and magnetic fields adjacent to the implant to be concentrated. These situations should be referred to a competent authority for evaluation.'

Although neither of these clauses makes direct mention of

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the effect that metal-framed spectacles may have on radiation near the eyes, they are both relevant. For example, metal-framed safety spectacles are issued as a safety measure, not for the purpose of protecting the wearer against electromagnetic hazards, but against the more 'usual' workshop hazards. However, caution must be exercised in using equipment which, while providing protection from one type of hazard, results in other unwanted hazards. The second clause illustrates the Standards Association's concern over the effect that an implanted metal object may have on the incident fields. However, this concern should also be extended to the case of a metal object placed close to the human body, particularly when placed close to a part of the body that is particularly susceptible to damage from electromagnetic energy, as is the case with a pair of metal-framed spectacles.

2 Possible effects of metal-framed spectacles

Typical dimensions of a pair of spectacles are shown in Fig. 1, although the detailed shape will vary from one set of spectacles to another and will be dictated by such factors as wearer comfort and fashion. The induced EMF

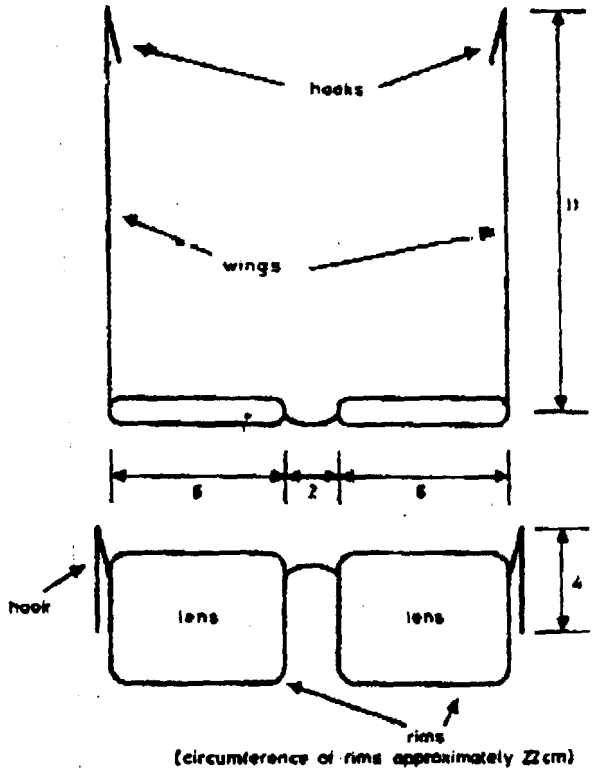


Fig. 1 *Typical dimensions (to nearest cm) of a pair of metal-framed spectacles (not to scale)*

theory (JORDAN, 1950) predicts that excitation of a linear wire section will occur due to that component of the incident electric field which is parallel to the wire axis. In fact, maximum excitation will occur when the incident electric field is polarised parallel to the wire axis, giving a direction of [illegible] to the wire axis. Resonance will occur when the wire length is equal to an integral number of half-wavelengths. Loop antennas are much more difficult to analyse than linear wire antennas, but one simple resonance is that occurring when the circumference of the loop is one wavelength long so that a wave travelling around the loop returns to its starting point in phase and travelling in the same direction.

Considering the various parts of the spectacles—the wings, hooks and rims as shown in Fig. 1—as being isolated from each other, we can predict frequencies at which the lowest-order resonances can be expected to occur. The wings and hooks can be regarded as linear wire sections, while each rim can be regarded as an approximation to a 'simple' square loop antenna. The resonance of the complete spectacle structure can be predicted by considering the total 'wrap-around' length, approximately 34 cm. The results of these simple approximations are shown in Table 1. The inevitable presence of the head will modify the

Table 1 Lowest-order resonant frequencies for each various segment of the spectacles

Segment	Resonant frequency
Wing	1·4 GHz
Hook	3·75 GHz
Rim	1·4 GHz
Complete structure	900 MHz

expected responses in a fairly complex manner, but this will not be considered in any detail here. Similarly, the effect of the spectacle lens will not be considered.

We can deduce from Table 1 that the frequency range of interest is that above approximately 1 GHz.

3 Measurement assembly

To determine the change in fields around the eyes of a human when a pair of metal framed spectacles is worn, it is preferable to determine the reception pattern of a rather complex antenna system, where the effect under study is the change in fields that is caused by a change in the passive scattering parts of the assembly near to the item that is directly connected to the antenna terminals. This can be achieved, for a range of orientations of the spectacles with respect to the direction of incidence and polarisation of the incident field, by measuring the transfer coefficient S_{21}, from the port of a standard, fixed antenna to the port of the antenna under test for sufficient orientations of the latter to allow the pattern to be resolved. Measurement of the reception pattern of the field probe by itself allows one to determine the necessary reference data. Introduction of a human, or equivalently a model of a human, near to the field probe allows the change in field intensity at the probe site to be determined, assuming that all other experimental variables are unchanged. Introducing the spectacles on to the human then allows the change in field intensity between the other two cases to be determined, i.e. comparison of this third set of results with the probe by itself gives information on the change in field intensity caused by a human wearing spectacles relative to the free-space condition. Comparison of this third set of results with the results obtained when the human is introduced into the system provides information on the change effected by the presence of spectacles relative to a human not wearing spectacles. It is this comparison which is of particular importance in this investigation.

A simplified block diagram of the measurement assembly used to measure the reception patterns of the antenna system is shown [illegible] automatic network analyser system is used to measure the transfer coefficient S_{21} on command from an HP 9845B system control computer. The antenna assembly mounted on the circular earth plane is sequentially rotated to a specified set of values of θ by a rotation control unit (RCU) that receives commands from an Intel 8085 microprocessor. That microprocessor in turn receives its commands from the system control computer regarding the value of θ required.

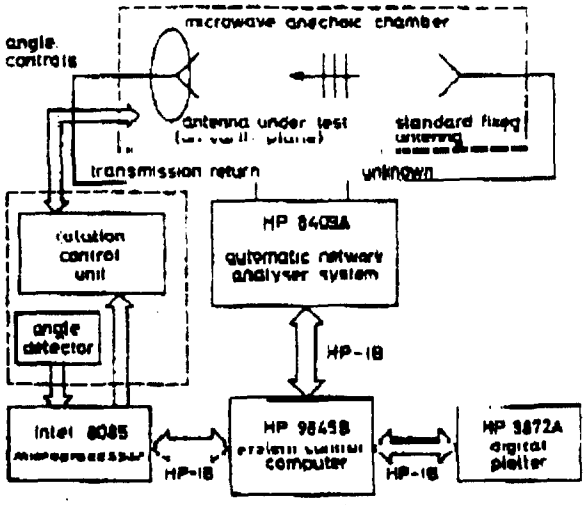


Fig. 2 *Simplified block diagram of the automated antenna radiation pattern measurement system based on a computer-controlled microwave network analyser, the HP 8409A*

The main advantage of using an image, or earth, plane for studying the effect of metal-framed spectacles on microwave radiation near the eyes of humans can be explained as follows. A model of a human subject has a plane of bilateral symmetry that divides the head into halves though the centre of the forehead, nose and chin. Introduction of a highly conducting image plane into that plane of symmetry provides a shielded half-space that, among other things, allows a probe to be placed through a small hole into the region near the surface of the eye. The transmission line that transmits the probe signal to the measuring assembly can be entirely shielded from incident and scattered waves by the image plane, in which case it will not affect the quantity to be measured.

The use of an image plane for experimentally testing antennas that have a plane of symmetry over which the tangential electric field is zero is well known and established as a standard test procedure (*The Institute of Electrical & Electronic Engineers*, 1979). In the case of certain simple structures, such as centre-fed resonant thin-wire antennas, it is well known that tests on one half of the structure with an earth plane in the plane of bilateral symmetry will yield results that are directly and simply related to those for the complete structure.

Ideally an infinitely large, flat, highly conducting sheet is required for a perfect image to be created. In practice a finite size sheet of some chosen shape must be used and, whereas specific circumstances will tend to dictate the size of sheet that may be used, the shape may be more open to choice. A circular shaped image plan 1·8 m in diameter was chosen because the effects of its size on the reception characteristics of certain types of antennas can be accurately modelled and also modified by treatment of the edge with microwave-absorbent material (GRIFFIN, 1982).

3.1 *Field probe*

A thin straight wire of length l projecting at right angles from the image plane through a channel at the top of the nose will respond to the electric field near the inner corner of the eye that is polarised normal to the image plane. The wire can be the inner conductor of a coaxial transmission line and can be regarded as a monopole antenna with an electrical length of (l/λ) wavelengths, where λ is the wavelength of the incident electromagnetic wave. Its response to the magnetic field is negligible compared with that to the electric field.

However, because the probe starts at the image plane and extends some distance out to the position of the eye, it will therefore give some weighted average of the fields that exist in the region near the probe. This weighted average can be determined using the induced EMF theory (JOHNSON, 1950), but the details will not be given here.

The total length of the monopole protruding from the earth plane is chosen so as to allow that monopole to extend out from the earth plane with its end situated directly in front of, and in the centre of, the eye. The ratio of monopole length l to monopole diameter D is approximately 30.

3.2 *Experimental variables*

The experimental variables used for this study are as follows. Assuming plane uniform TEM waves incident on the subject, the direction of incidence (θ and ϕ values in spherical co-ordinate terms), the polarisation of the incident waves (u_θ and u_ϕ components of electric field E) and its frequency are the variables associated with the source, as shown in Fig. 3. Knowledge of the source power is not necessary because if all experimental variables are kept constant between the three sets of measurements, then a direct comparison of the three sets of results will yield the information required.

Measurements have been restricted to one of two orthogonal polarisations of the incident TEM wave, two orthogonal polar planes through the complete three-dimensional response pattern. It is possible to identify four distinct measurement modes corresponding to the choice between either horizontal, H, polarisation or vertical, V, polarisation, and the choice between a response pattern in

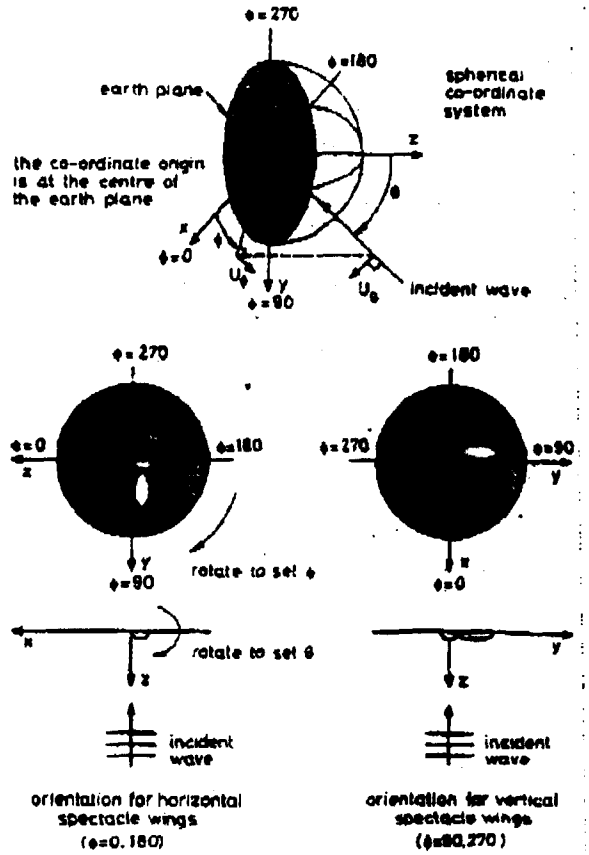


Fig. 3 *Spherical co-ordinate system used to describe the incident transverse electromagnetic waves and the orientation of the model for any set of experimental measurements*

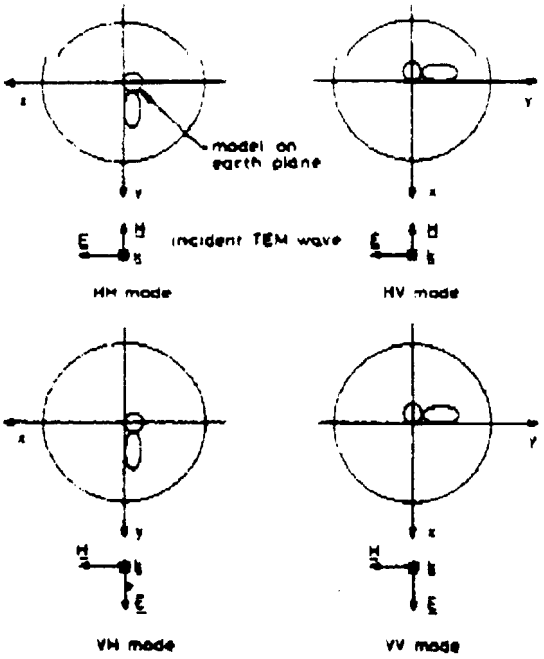


Fig. 4 *Measurements with each of two polarisations (horizontal, H, or vertical, V) in each of two polar planes (using horizontal, H, or vertical, V) give the four measurement modes HH, HV, VH and VV as illustrated above*

a polar plane parallel to the wing structure of the spectacles, referred to as H, or normal to the wing structure, referred to as V. Fig. 4 illustrates the orientations of the polarisation of the incident TEM wave and the phantom relative to the floor of the anechoic chamber. The monopole extends along the z-axis from the origin of the coordinate system, and it remains parallel to the floor of the chamber, the horizontal, H, as does the propagation vector $\underline{k}$ of the incident TEM wave.

4 Results

The results for each measurement mode are presented in one of the following manners. Response patterns at one particular excitation frequency and for each of the three systems—the monopole by itself (referred to as monopole), the phantom in place on the earth plane (referred to as and phantom), and the spectacles subsequently mounted on the phantom (referred to as and spectacles)—are plotted on the same set of axes. The response of the system is plotted against the orientation of the earth plane, where the negative values of azimuth angle θ are those that correspond to values of ϕ equal to either 0° (horizontal wing) or 270° (vertical wing), while positive values correspond to values of 180° (horizontal wing) and 90° (vertical wing). The maximum level of response for the monopole mounted by itself on the earth plane is assigned an arbitrary zero level, and all other response patterns are plotted relative to this. It should be clear that the difference in response between the case when the phantom is placed on the earth plane and that when the spectacles are mounted on the phantom will give the effect that the metal-framed spectacles introduce. Therefore, a second set of results will also be presented when the difference in response at particular frequencies between these two systems is plotted against the direction of incidence. Therefore, a positive response implies that the spectacles cause an increase in the field surrounding the eye, while a negative response implies a decrease.

4.1 *HH measurement mode*

The response of the field-measuring monopole at of 6000 MHz

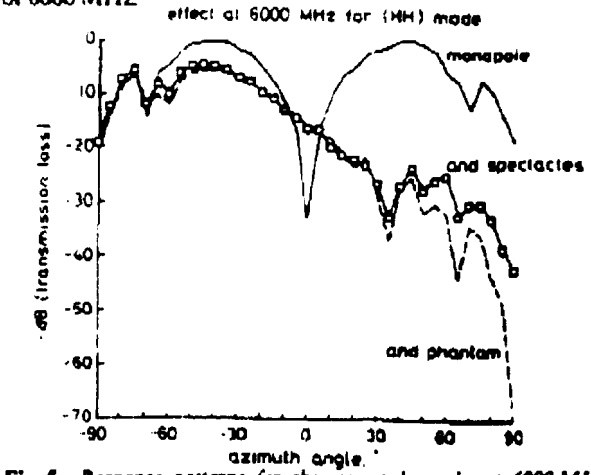


Fig. 5 *Response patterns for the monopole probe at 6000 MH for the HH mode showing the monopole by itself, then with the phantom in place, and finally with metal-framed spectacles on the phantom*

Examination of the response of the monopole antenna mounted by itself on the earth plane revealed the expected cos θ form of response at frequencies close to the resonant frequency of approximately 2 GHz (not shown here), while at higher frequencies minor lobes begin to develop as expected (as shown in Fig. 5) (Stutzman and Thiele, 1981). Minor departures which occur in addition to the expected response are mainly due to edge effects occurring due to the finite size of the earth plane. However, these minor departures from theory are of no real concern here, where the monopole antenna response is used essentially as a reference by which to determine the effect of introducing the phantom and the spectacles.

When the phantom is introduced on to the earth plane, then for negative values of θ the phantom is placed behind the monopole antenna, when looking from the transmitter, and so should have little effect on the overall shape of the response pattern, but for positive values of θ the phantom is directly in the path between the transmitter and the monopole antenna, and so would be expected to introduce a significant amount of attenuation to the signals received by the monopole.

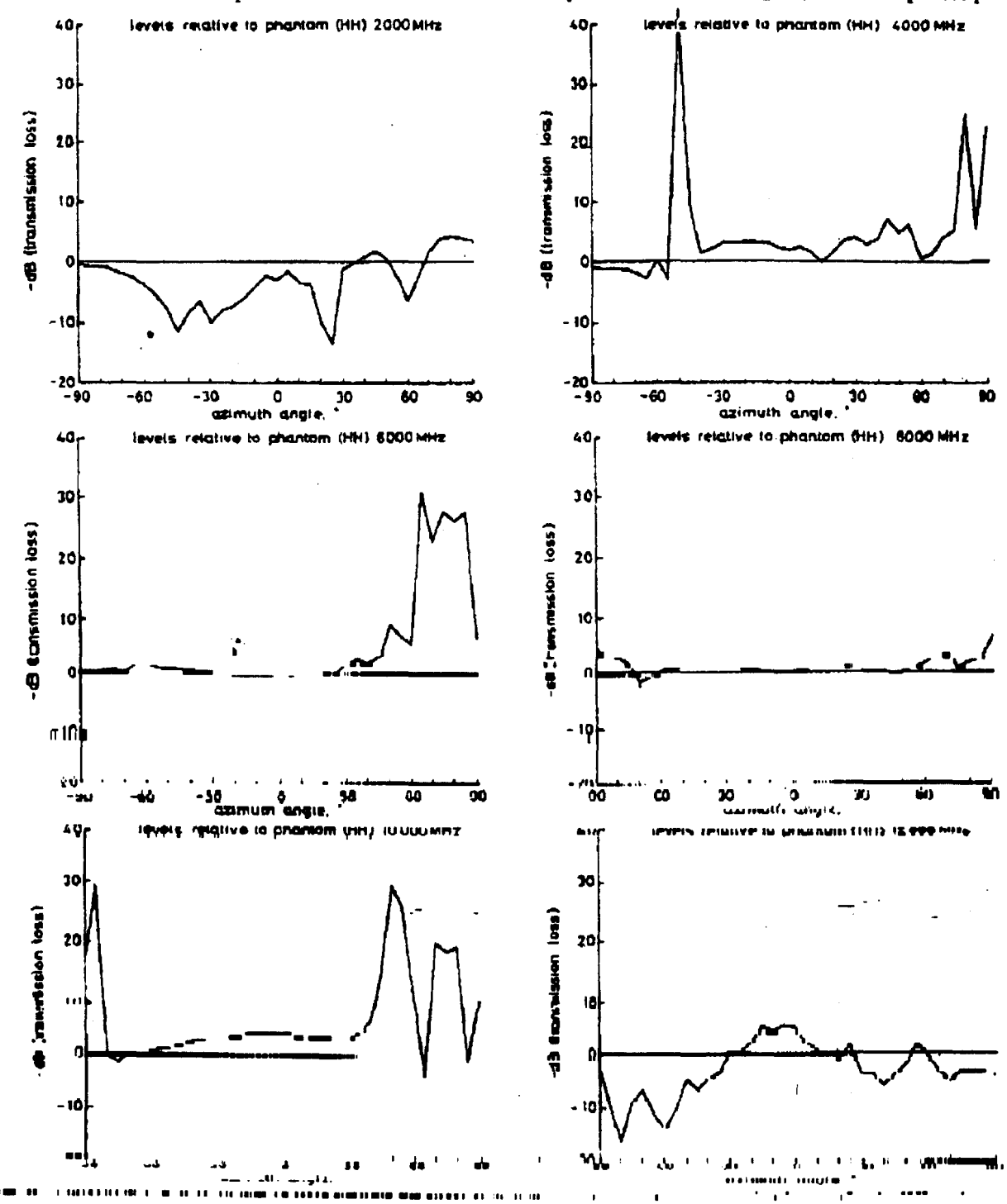
The finer details of the pattern shown in Fig. 5 are typical of the results obtained for the frequency range considered and are due to a number of effects. The phantom is composed of a thin shell filter with a material suitable for simulating the microwave properties of the human body and therefore acts as a lossy cavity resonator which will resonate at different frequencies depending on its orientation relative to the incident fields. We might therefore expect to find dramatic dips in response at frequencies which cause the phantom to resonate and that the position of these dips would shift as the frequency varies. A standing wave pattern will also be formed around the phantom and any dips in response could be due to the monopole being placed in the position of a null in the standing-wave pattern. Diffraction effects may also account for some of the details in response pattern, as could depolarisation, coupling and scattering effects.

However, it is the third set of results, those obtained when the spectacles are introduced onto the phantom, that are of greatest interest and require a more thorough examination. It is these results which determine the effect

that metal-framed spectacles have on incident fields. Assuming that source power is kept constant and that all other factors concerned with the study are unchanged between all three sets of results, then a simple comparison of this set of results with the previous one should yield the information we require.

A detailed discussion of the results obtained for this third case will not be presented here, but instead the *difference* between the radiation patterns obtained for the phantom with and without spectacles has been determined and is presented in Fig. 6. The difference between the two results is plotted against orientation for frequencies of 2000 MHz to 12 000 MHz in 2000 MHz steps. Fig. 6 illustrates the fact that there is a consistent increase of up to 5 dB over the frequency range 4000 to 10 000 MHz for angles of incidence in the range $-80° \leqslant \theta \leqslant 60°$.

This result is consistent with what we expect, as the incident TEM wave has a component of electric field parallel to the wing of the spectacles for all orientations except those close to $\theta = \pm 90°$, and a component parallel



to the rim of the spectacles for all orientations except those close to $\theta = 0°$. However, the monopole probe is at right angles to the wing structure and also to the equivalent of the loop antenna, the magnetic linear wire antenna. Therefore only a very small amount of re-radiated electric field will be parallel to the monopole probe. But the presence of the phantom and the fact that the monopole probe is in the near-field of the spectacles will increase the parallel component of re-radiated electric field somewhat.

4.2 *HV measurement mode*

The response of the monopole probe is given in Fig. 7. Results for the monopole mounted by itself on the earth plane for this mode are identical to those obtained for the mode discussed in the previous section, and illustrate the precision and repeatability of measurements.

The phantom forms an obstruction between the monopole and the transmitter for all values of θ, except those close to zero, and so would be expected to introduce significant attenuation to the levels reaching the monopole. This is confirmed by the results where we find that the overall shape of the response pattern when the phantom is introduced is similar to that for the monopole by itself, but with a corresponding decrease in levels. This is particularly true for frequencies above approximately 6000 MHz.

When the spectacles are introduced onto the earth plane, it is found that the basic shape of the results remains fairly constant for frequencies above approximately 6000 MHz, but accompanied by a shift in level. The basic shape of the radiation pattern obtained is fairly symmetrical around $\theta = 0°$, and this is consistent with the fact that the orientation of the incident electric field with respect to the spectacles is more or less symmetrical about $\theta = 0°$, i.e. the electric field is in the plane of the rims for all orientations but normal to the wing. Any departure from this symmetry is due to the presence of the phantom.

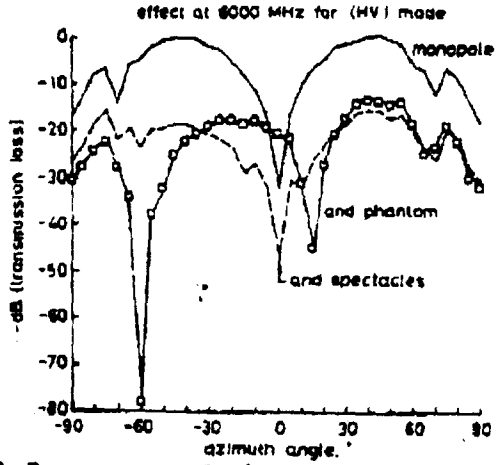


Fig. 7 *Response patterns for the monopole probe at 6000 MHz for the HV mode*

The difference between results obtained for the phantom with and without spectacles are plotted as a function of orientation for frequencies of 2000 to 12000 MHz in 2000 MHz steps and presented in Fig. 8. This shows that there is an increase in radiation levels relative to the phantom of up to 20 dB for frequencies below 6000 MHz, and for most values of θ.

The electric field of the incident TEM wave has a component parallel to the rim of the spectacles for all orientations, and this may cause a significant amount of re-radiation to occur, with a component of electric field parallel to the monopole probe. Excitation of the wing structure may also occur due to scattering and depolarisation occurring from the phantom.

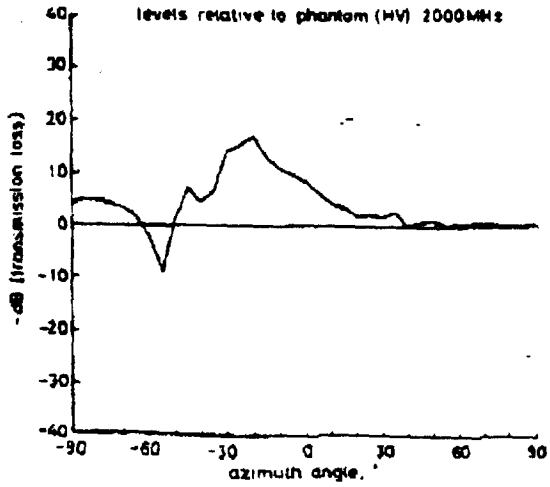
4.3 *VH and VV measurement modes*

Polarisation of the incident electric field is normal to the monopole and so one would expect zero response for all orientations. The absolute level of radiation experienced by the monopole for vertical polarisation of the electric field compared with horizontal polarisation is reduced by as much as 30 dB, which puts all measurements very close to the limits of the dynamic range of the network analyser. When an item is introduced onto the earth plane along with the monopole one would expect there to be an increase in the level of radiation at the monopole due to scattering and subsequent depolarisation occurring from the new item, and this is confirmed by the results.

A detailed discussion of results is not possible here. Suffice it to say that there is a consistent increase of up to 40 dB in radiation levels at the monopole site for the VH mode, but a consistent decrease for the VV mode.

5 Conclusion

A measurement technique has been proposed that allows a large number of accurate measurements to be performed in a relatively short space of time. It has been shown that the introduction of a pair of metal-framed spectacles causes an increase in the signal received by the



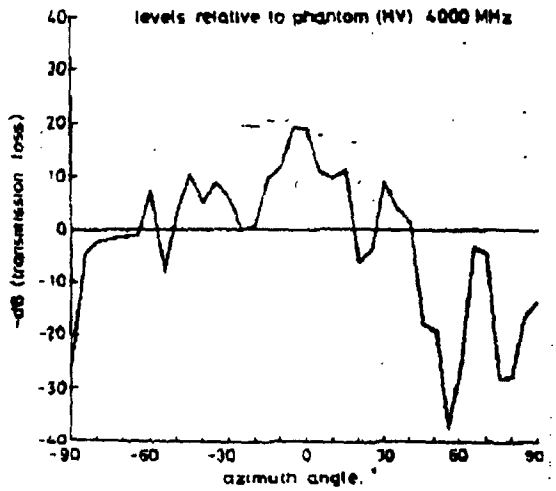


Fig. 8 *(caption opposite)*

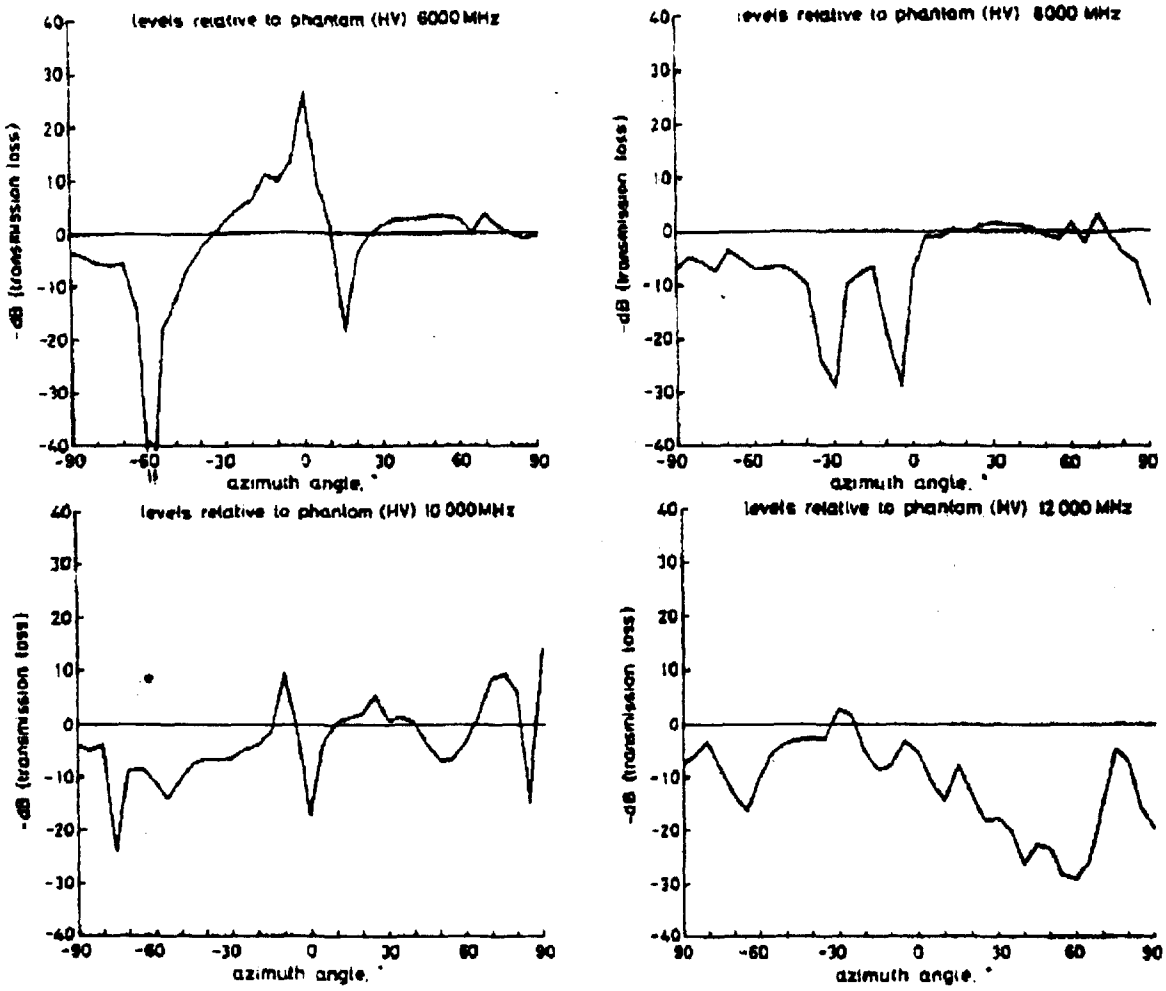


Fig. 8 *Patterns at 2, 4, 6, 8, 10 and 12 GHz showing the effect of adding metal-framed spectacles to the phantom for the HV mode*

monopole probe by up to 5 dB for the HH mode and by up to 20 dB for the HV mode. Measurements obtained for the case of vertical polarisation exhibit similar results.

We can therefore conclude that the introduction of a pair of metal-framed spectacles, or for that matter any metallic object, does significantly alter the incident microwave field, and that this effect must be accounted for in the setting of safety standards relating to acceptable levels of incident power.

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Nicholas Davies graduated with a BE (Hons.) from the Electrical & Electronic Engineering Department at the University of Adelaide and is currently a Ph.D. candidate in that same Department, while holding the position of Cadet Research Scientist with the Defence Research Centre, Salisbury. His research interests include the areas of microwave biohazards, microwave scattering and its subsequent measurement, antenna and probe design, and computer simulation of antenna and scattering structures.

Donald W. Griffin is a graduate of the University of Adelaide with the degrees BE, BA and Ph.D. His experience after graduation included positions with the Australian Defence Scientific Service, the Royal Radar Establishment in the UK and Cornell and Syracuse Universities in the USA. Dr Griffin has been a member of the academic staff at the University of Adelaide for the past 22 years and is now Reader and Chairman of the Department of Electrical & Electronic Engineering. His teaching and research interests lie mainly in the microwave and antenna engineering fields.

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Numerical calculation of electromagnetic energy deposition in models of man with grounding and reflector effects

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Image theory has been used to obtain moment-method solutions of the deposition of electromagnetic energy in standard man as a function of grounding and reflector effects. The calculated values are in good agreement with experimental data. For the $\mathbf{E}\parallel\mathbf{L}$ orientation, the resonant frequency of standard man shifts from 77 MHz in free space to 47 MHz when standing on a ground plane. The dependence of reflector effects on spacing and frequency are in agreement with the gain enhancement calculated for dipoles by antenna theory.

1. INTRODUCTION

Experimental observations of grounding and reflector effects have been reported previously, but numerical methods have not been available to confirm the observations [*Gandhi et al.*, 1977b]. We have used image theory to reduce the problem of man either grounded or in front of reflectors to that of a multibody target in free space. Moment-method solutions of the electric-field integral equation have a pulse-function basis and delta functions for testing. A 180-cell model of the 50th-percentile standard man was used in the calculations [*Hagmann et al.*, 1977].

2. APPLICATION OF IMAGE THEORY WITH COMPRESSION

If all reflectors and ground planes are assumed to be perfect conductors and infinite in extent, then they may be removed if suitable images of the scattering body are included. Since polarization currents in the images contribute to the scattering, it is necessary to treat all parts of the scattering body and the images as discrete cells. If pulse functions are used as a basis, it is necessary that each subvolume be small enough that the electric field that it contains may be assumed constant.

A moment-method solution with pulse functions will relate the column matrix E, which contains the unknown electric-field values in each cell, to the column matrix E^i, which contains values of the incident electric field in each cell, through a square matrix A by the equation

$$AE = E^i \tag{1}$$

Equation 1 may be solved directly, but a reduction of matrix size will allow the solution to be found with greater economy; or alternately, more cells may be used for greater accuracy. A reduction in matrix size is possible by the use of "compression," which is described next.

The geometry involved when images are used causes the fields to have symmetry. Let m be the number of unique values of E that are repeated n times with possible sign changes. We may order the cells so that the indices from 1 to m correspond to the unique E values, and for any integer $1 \le \ell \le m$, then E_{ℓ}, $E_{\ell+m}$, ..., $E_{\ell+(n-1)m}$ correspond to values related to E_ℓ by symmetry.

The relationship of all $m \times n$ of the E values to the m-unique E values may be expressed in matrix form:

$$\begin{bmatrix} E_1 \\ E_2 \\ \cdots \\ E_{mn} \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ \cdots \\ I_n \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ \cdots \\ E_m \end{bmatrix} \tag{2}$$

where I_1, I_2, ..., I_n are m by m matrices with ± 1 on the diagonal and zero elsewhere, and I_1 is the m by m identity matrix.

Compression may be obtained by noting that only the first m simultaneous equations need to be used in equation (1); substituting (2) in (1) will give a series of m simultaneous equations in the m-unknown unique values of E.

$$A \begin{bmatrix} I_1 \\ I_2 \\ \cdots \\ I_n \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ \cdots \\ E_m \end{bmatrix} = \begin{bmatrix} E_1^i \\ E_2^i \\ \cdots \\ E_m^i \end{bmatrix} \tag{3}$$

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$$A' \begin{bmatrix} E_1 \\ E_2 \\ \cdots \\ E_n \end{bmatrix} = \begin{bmatrix} E_1' \\ E_2' \\ \cdots \\ E_n' \end{bmatrix} \tag{4}$$

where A' is an m by m matrix formally defined by A' = first m rows of:

$$A \begin{bmatrix} I_1 \\ I_2 \\ \cdots \\ I_n \end{bmatrix} \tag{5}$$

In implementing compression, the computation of matrix A' is made by making n modified passes through the loops that would normally be used to accumulate the scattering matrix.

We have used compression with image theory to treat a body with one plane of symmetry above a ground plane, as is shown in Figure 1. The field relationships used for a body with one plane of symmetry in front of a flat reflector are shown in Figure 2. It is also possible to use compression with image theory to treat a body in a corner reflector, if the corner reflector has a dihedral angle equal to $180°/N$ where N is an integer. Field relationships used for a body with one plane of symmetry in front of a 90° corner reflector are shown in Figure 3.

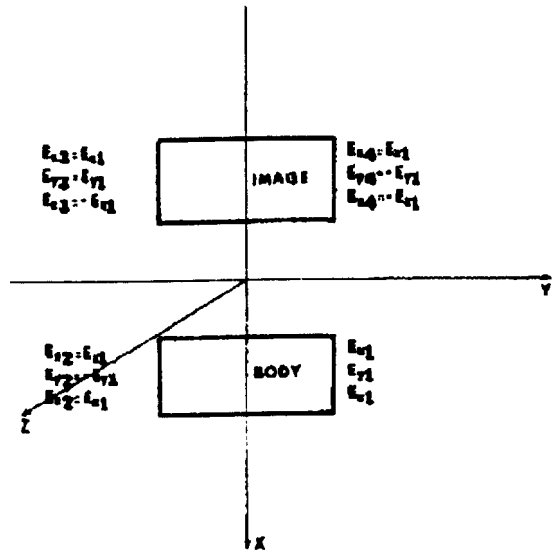

Fig. 2. Field relationships for a body with one plane of symmetry in front of a flat reflector; $E \parallel \hat{z}$, $k \parallel \hat{x}$.

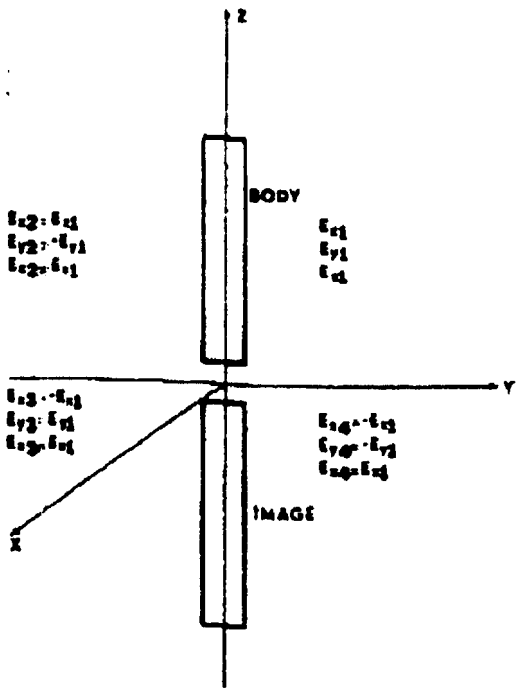

Fig. 1. Field relationships for a body with one plane of symmetry above a ground plane; $E \parallel \hat{z}$, $k \parallel \hat{x}$, x-y plane is the ground plane.

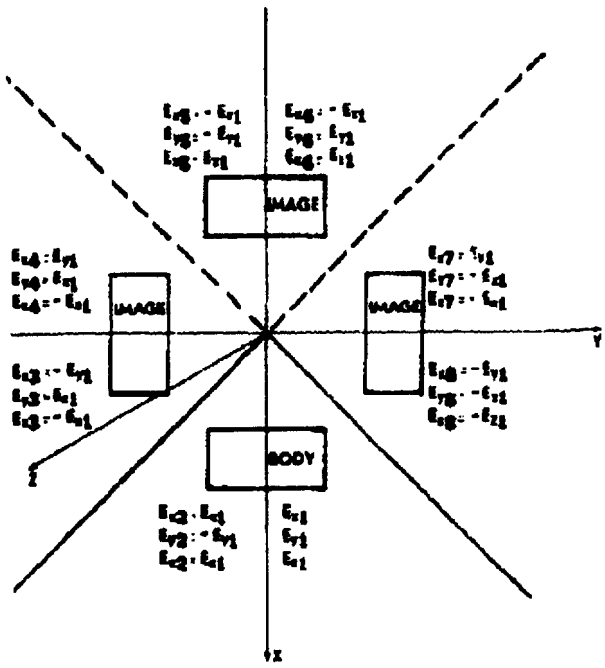

Fig. 3 Field relationships for a body with one plane of symmetry in front of a 90° corner reflector; $E \parallel \hat{z}$, $k \parallel \hat{x}$.

There are two types of symmetry relationships used for **E** values in the three figures: (1) Two points located symmetrically in respect to a plane of symmetry of the body that contains both **k** and **E'** will necessarily have **E** values that are mirror images so that the two halves are indistinguishable under reflection. (2) Two points located symmetrically in respect to a plane of symmetry of the body that contains **k** and is perpendicular to **E'** will necessarily have **E** values that are negated mirror images, so that if the values are exchanged, they will correspond to the solution for oppositely directed **E'**. This relationship is also found for two points located symmetrically in respect to a ground plane or to a flat reflector as required for symmetrical motion of a charge and its image.

An alternative to the use of image theory with compression is to use special Green's functions in place of the free-space Green's function. Special Green's functions are available that could be used to account for scattering objects located near targets having various shapes and even finite conductivities [*Tai*, 1971; *Baños*, 1966]. We have not yet pursued the use of such Green's functions.

The results of calculations for grounding and reflector effects are described in the next sections.

3. GROUND EFFECTS

All calculations of grounding effects have assumed that a man is standing on or above a perfectly conducting ground plane that is infinite in extent. The incident field is vertically polarized with **k** directed from the ventral to the dorsal aspect of the man. Internal fields in the model are the same as those in one-half of a double-man, which consists of the model and its image in free space. A 180-cell model of the 50th-percentile standard man has been used for the calculations [*Hagmann et al.*, 1977].

The calculated resonant frequency of man standing on a ground plane is 47 MHz as compared to 77 MHz for man in free space. The specific absorption rate (SAR) of man on the ground plane at the reduced resonant frequency is 32.5 percent greater than the SAR for man in free space at the free-space resonant frequency. At lower frequencies, the SAR of man standing on a ground plane may be increased considerably from that of the same model in free space. This increase results from these frequencies being closer to resonance for the grounded man. For example, at 10 MHz the SAR of man standing on a ground plane is 0.0163 W kg^{-1} per mW cm^{-2}, which is about seven times that found for the same model in free space.

Figures 4 and 5 illustrate, respectively, the distribution of absorbed energy in man at 10 MHz in free space and in contact with the ground plane. The enhancement of local energy deposition due to the grounding effect is approximately a factor of 60 in the area of the heel.

Figure 6 shows the part-body and whole-body SAR for the model of man with different spacings from the ground plane at 10 MHz. Figure 6 is consistent with the experimental observation on models that a small separation that breaks electrical contact with the ground plane is sufficient to eliminate much of the grounding effect [*Gandhi et al.*, 1975]. Several calculations made for the grounded resonant frequency of 47 MHz show a fall-off in magnitude of grounding effects with increasing distance from the ground plane, which is similar to the results at 10 MHz (Figure 6). A model composed of 292 cells was made by dividing each of the six lowest cells in each leg of the 180-cell model into eight identical cubical cells. Six solutions made for the 292-cell model and duplicated with the 180-cell model suggest that the fall-off of the grounding effect with increasing distance from the ground plane may be slightly slower than is found with the 180-cell model.

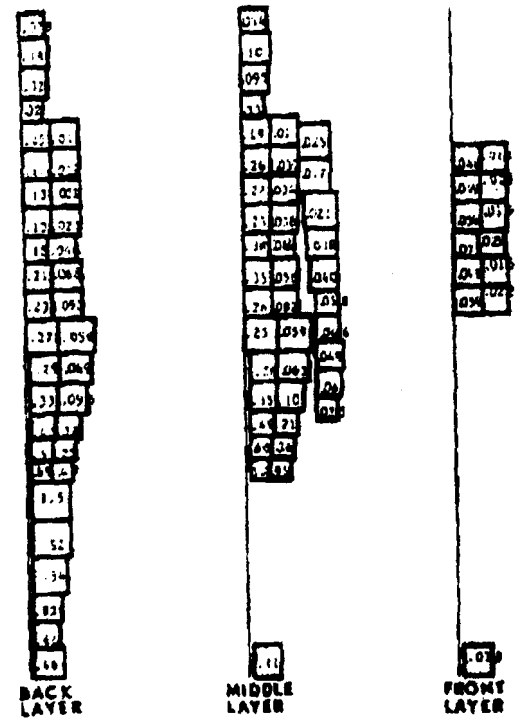

Fig. 4. Local SAR values (W kg^{-1} per mW cm^{-2}) × 100 for inhomogeneous model of man in free space at 10 MHz.

Figure 7 shows part- and whole-body SARs for the model of man standing on a ground plane at various frequencies. The part-body resonances shown in Figure 7 have also been observed in calculations for the same model of man in free space [*Gandhi et al.*, 1977a]. The enhancement in absorption of energy due to the presence of a ground plane is greatest in the leg and least in the head. Figure 8 shows whole-body SARs for the model of man both in free space and when standing on a ground plane at various frequencies. Grounding effects are most prominent at low frequen-