Potential Effects of Broadband Wireline Telecommunications on the HF Spectrum

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ABSTRACT

Power line telecommunications and various forms of digital subscriber line transmissions are recent and rapidly evolving technologies using the existing electricity power or telephone lines for data transmission at rates higher than 1 Mb/s. As these lines were not designed for transmission of high data rates, they produce noise-like interferences in the HF range. The intensity depends on the electrical characteristics of the lines (balance, match, screening) as well as on the density and area coverage of these new systems. Exact calculations are impossible at this time because of missing models for the new wirebound communication systems with respect to emission of radio noise in the HF band. Early measurements and estimations showed that radio noise from PLT and xDSL has the potential to cause problems for military HF radio communications and communication intelligence. A Research Task Group under NATO was assigned to study the issue and determine possible solutions. Briefly, the findings of the RTG do indicate that PLT emissions have the potential to cause appreciable degradation in the exploitation of the HF spectrum by military users.

INTRODUCTION

This article summarizes the results of the work carried out by IST-050/RTG-022, the Research Task Group (RTG) on HF Interference, Procedures and Tools under NATO's Research & Technology Organization (RTO). The RTG was active in 2004–2006, and addressed the concerns raised by the potential for unintentional radio interference that may be caused by the operation of broadband wireline telecommunications systems. Power line telecommunications (PLT, PLC) and various forms of digital subscriber line (xDSL) transmissions use the existing mains electricity or telephone wiring, including in-premises cables, for telecommunications with data rates higher than 1 Mb/s. As these lines were not designed for such broadband transmissions, they will cause unintentional radio frequency (RF) emissions that may adversely affect the established radio noise floor directly, or by cumulative propagation from many such sources. The existing high frequency (HF) background noise is likely to be increased via ground wave and/or sky wave propagation.

The implication for NATO is that an increase of the existing HF noise floor by the use of PLT and/or xDSL may cause problems for military radio users as well as for HF communication intelligence (COMINT) in all NATO countries. The signal-to-noise ratio may thus be reduced for tactical and strategic HF radio as well as for fixed sensitive COMINT sites.

This article was first published in April 2008 in the proceedings of the RTO Research Symposium IST-083 on Military Communications. The article is a summary of the RTO Report written by the RTG [1]. For further details on any of the aspects addressed in this article, the reader is advised to consult [1].

APPROACH

Exact calculations of HF radio noise emissions from the broadband wireline telecommunications networks were not feasible due to missing models for these transmission systems. Therefore, methods have been investigated to find procedures, models, and tools applicable to the assessment of interference from PLT and xDSL on the HF radio signal environment.

The RTG addressed itself to the HF radio emission effects of broadband wireline transmissions. It investigated and found means that allow calculation of cumulative field strengths of HF noise radiated by PLT or xDSL. This will enable NATO nations to determine the threat to mili-

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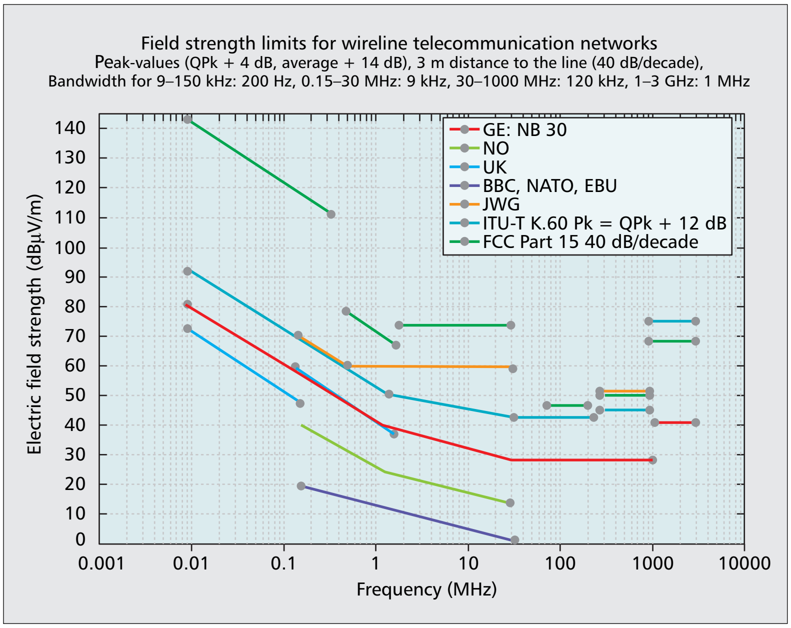

■ **Figure 1.** *Field strength limits proposed for broadband wireline telecommunication networks. All limits extrapolated to 3 m measurement distance.*

tary HF radio communications and COMINT systems from PLT and xDSL, and to take appropriate steps. Also, the RTG chose to concentrate its work on the PLT issue rather than xDSL because PLT systems will have the more significant impact regarding HF interference (power lines have less symmetry and will have impedance discontinuities), they will be deployed in large numbers, and the current versions of xDSL have no documented HF interference-causing problems, while the very-high-rate DSL (VDSL) variants covering the entire HF range were still in the definition phase during the three-year mandate of the RTG.

PLT systems come in two distinct types: in-house PLT, where the signals are transmitted using house power wires, and access PLT, where the signals are transmitted outdoors on medium- or low-voltage (overhead or underground) power distribution lines. The RTG developed comprehensive measurement principles and procedures for both access and in-house PLTs. Furthermore, these are specified for both investigative and regulatory measurement categories.

A great number of in-house PLT systems (e.g., HomePlug [2, 3]) are expected to be deployed. Such products are readily available on the market and can be installed by anyone, with no verification of the quality of the installation. For these reasons, in-house PLT rather than access PLT has been the main concern for parts of the study.

Wireline Emission Limits

Currently, there are several existing/proposed electric field strength emission limits for wireline communications, specified at a distance of 3 or 10 m (North America), and specified in different values. In the HF band these limits (all converted to a distance of 3 m to the line and in peak values) range between 0 to 74 dBµV/m, depending on the country or organization. Figure 1 shows the existing/proposed limits at the time of study. It is also known that other nations such as South Africa, Japan, South Korea, China, India, and Australia were in the experimental phase of performing PLT field trials. Proposals by these nations for field strength or common mode current limits were not available during the RTG's study period.

The international regulatory framework has not reached a consensus on emission limits. The broadband wireline telecommunication technology is promoted globally in order for everyone to have the means of exchanging large amounts of data for Internet applications. A cost-effective and practical way is to use the existing wireline infrastructure (i.e., power and/or telephone lines). Power lines are widespread, but have the worst technical characteristics for emitting broadband noise-like signals when transmitting high data rate signals (several megabits per second). While there is not much experience regarding radio interference from PLT data communications technology, in the meantime commercial interests are promoting its widespread implementation. It would take some time for radio interference experience to be gathered and the subsequent regulatory framework to be developed, preferably harmonized internationally. In the meantime, the regulatory authorities recommend that measures be taken to minimize such interference to other users.

Electromagnetic Ambient Noise Environment

In all radio communications the limiting factor is the ability to receive weak signals against background noise. However, because of the characteristics of the HF band, this background noise is not the noise generated in the receiver (as it is on VHF and higher frequencies), but the ambient noise in the external environment. In effect this noise enters the receiver via the antenna along with the wanted signals, so the radio environment influences the receiving process.

The ambient noise environment consists of two parts, the irreducible residual natural (atmospheric and cosmic) noise and incidental man-made noise from local sources. The combination of these two determines the minimum usable signal level.

The ambient noise floor has been measured by several organizations including the International Telecommunication Union — Radiocommunication Standardization Sector (ITU-R), the British BBC, Defence Evaluation & Research Agency (DERA, now DSTL), Radio Society of Great Britain (RSGB), and the German Telefunken Systemtechnik (TST). The noise survey requires the selection of a radio frequency that is not occupied by an existing radio signal. It is almost impossible to find spot frequencies where there is a 9 kHz band without any signals. Because of this congestion, sweeping the HF band using an electromagnetic compatibility (EMC) measuring receiver with a 9 kHz bandwidth does not measure the background noise level. Additionally, measurements made with a typical loop EMC measuring antenna will be limited by the noise of the receiver system, not the environmental noise.

To carry out a swept measurement of the true ambient noise floor at HF, a much narrower bandwidth than 9 kHz — on the order of 100–200 Hz — should be used, and the noise produced by the measuring system itself has to be lower than the ambient noise to be measured. The results of the noise measurement are then converted to a 9 kHz bandwidth for comparison with field strength limits which rely on that bandwidth in the HF range.

Usually, it is impractical to measure the ambient noise floor in industrial or business locations where the man-made noise will exceed the natural noise floor. The best locations for measuring the ambient noise floor without being influenced by man-made noise will be in rural or quiet rural areas. In interpreting published plots of the ambient noise floor, it is important to take into account the conditions of measurement, particularly the bandwidth and the detector used (peak, quasi-peak, or average), and the type of antenna.

In the course of the studies, the RTG determined that ITU-R Recommendation P.372-8 noise curves (based on measurements carried out in the 1970s) are still valid in Europe. Recent measurements carried out in Germany and Great Britain indicated that there is no marked difference between these measurements, specifically no increase of the ambient noise in quiet rural zones within the last 30 years, as shown in Fig. 2.

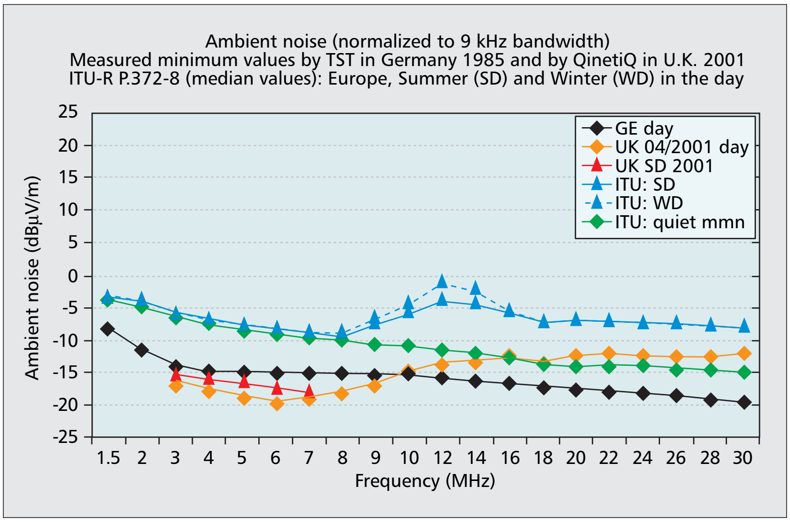

Figure 2. *Minimum ambient natural noise measured in Germany, 1985, and the United Kingdom, 2001; and ITU-R Recommendations for median natural and man-made noise in Europe. (mmn: median man-made noise in quiet rural areas).*

Protection Requirements

As the sensitivity of HF receiving systems in general is determined by the ambient noise, the protection requirements are derived from the ambient noise levels specified in ITU-R P.372-8, as well as from the minimum noise measured in Europe.

PLT and xDSL will cause unintentional RF emissions that may increase the established radio noise floor directly nearby or, by cumulative propagation, far away from many such sources. This type of emission is quite different from that produced by electronic devices and equipment: it is broadband noise, most of the time at a high level and extending over the HF band.

The incidental noise generated even by devices and equipment compliant with relevant EMC standards can greatly exceed the existing noise floor. As a result, reception of low-level HF signals is possible only because of the statistical nature of this incidental noise. Many devices radiate near the limit of their standard on only a few discrete frequencies or on a narrow band of frequencies. In addition most incidental noise is relatively short-lived. HF communication services are opportunistic; that is, frequencies and time are chosen to optimize the probability of a satisfactory signal-to-noise ratio. If incidental noise prevents communication at any particular time, the transmission is repeated at a later time when the interference has ceased. Adaptive radio systems can automatically select the best propagating frequencies in relation to the best propagation conditions and the maximum data throughput, but only if the noise floor is low enough (i.e., below the decision threshold of the systems built into the operating protocol). However, system performance will be reduced when the broadband noise floor is steadily increased by PLT and/or xDSL.

Protection of HF radio communications and intelligence systems from interference by broadband wireline telecommunications may be realized by limiting their emissions (see above). From the perspective of NATO, it is desirable that these limits be harmonized for the following reasons:

- Emissions from wireline communications travel long distances and past international boundaries; therefore, differences in emission limits introduce additional difficulties to interference assessment and mitigation functions.
- Different national emission levels, and thus different levels of PLT-induced noise, increase the ambient noise levels, which have the potential to affect interoperability among NATO nations.

Therefore, it is necessary to define worldwide harmonized standards covering EMC aspects of wireline telecommunication networks including their in-house PLT networking extensions. These standards should ensure that broadband wireline telecommunications will not degrade HF radio reception directly in the immediate vicinity of the wirelines, as well as far away from widely deployed urban telecommunication networks by cumulative interference.

Regarding possible increase of the existing HF noise floor by widespread use of PLT and/or xDSL, the minimum noise levels measured in Europe (Fig. 2) should be the criteria when setting PLT emission limits for the protection of sensitive HF receivers. This is supported by U.K. conclusions from measurements where it was determined that an increase above 3 dB over the existing noise floor will reduce the availability on HF circuits and is likely to cause severe prob-

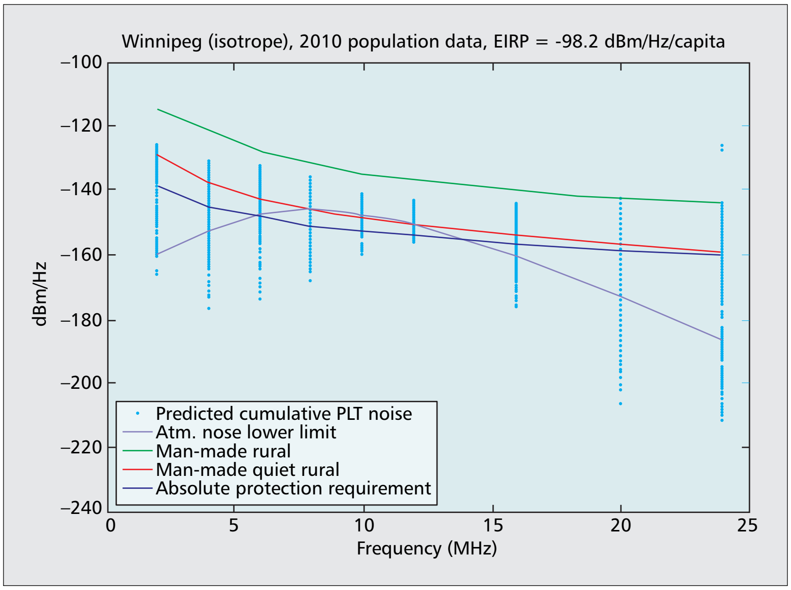

Figure 3. *Example predicted cumulative PLT noise parameters with receiver in Winnipeg, compared to established background noise levels. The magenta curve, absolute protection requirement, corresponds to –15 dBμV/m in Fig. 2.*

lems. Based on these measurement results, the cumulative interference field strengths far away from telecommunication networks should not be higher than –15 dBμV/m (9 kHz bandwidth) across the entire HF range if no measurable increase in minimum noise levels is to be tolerated. The RTG referred to this criterion as the *absolute protection requirement*. It should be noted that this value is in the range of 10 to 1 dB below the ITU-R quiet rural noise curve, which represents median values, across the HF band.

Propagation Path Loss Models

There are two major radio wave propagation mechanisms in the HF frequency range: *sky waves*, in which the radio waves are refracted in the ionosphere, and *ground waves*, propagating along the ground.

Sky Waves

Sky waves propagate by refraction in the E and F regions of the ionosphere. They may suffer absorption when passing through the D region (below the E region). The ionospheric conditions vary with time of day, time of year, and solar and geomagnetic activity. Different *prediction models* exist, in the form of software, to predict the propagation path loss at different frequencies as well as the maximum usable frequency (MUF) and lowest usable frequency (LUF) for propagation. The input parameters to such prediction programs are typically time of day, month, transmitter and receiver coordinates, frequency, sunspot number, and possibly a geomagnetic index (used in programs that use special models for high latitudes). Sunspot numbers and geomagnetic indices can be found on the Internet.

Due to the variations and uncertainty in ionospheric conditions, prediction programs can only give statistical information, such as "a signal-to-noise ratio exceeding xx dB will be received with a probability of yy percent."

Ground Waves

Ground waves propagate near the ground in the form of space and surface waves. The space wave consists of a direct wave and a reflected wave, normally canceling each other in the HF range: due to low grazing angles, the reflection coefficient is close to –1, and the difference in path length between the direct and reflected wave is short compared to the wavelength. Therefore, the surface wave is dominant. It can be described as a current induced in the transition between air and ground.

Surface waves are most dominant in the lower part of the HF frequency range (and below) and for vertically polarized transmitter/receivers close to the ground (compared to the wavelength). When the frequency is increased (or antennas elevated), the space wave gains importance.

The electrical characteristics of the ground (conductivity, permittivity and permeability) are important in predicting the received field strength, and tables and figures connecting ground types to conductivity/permittivity exist in the literature. Permeability is normally assumed to be that of free space.

The attenuation from terrain obstacles decreases with decreasing frequency. Models as well as measurements indicate that the terrain profile may be considerably less important than ground constants at the lower HF frequencies.

Time variability of the ground wave path loss is much less than that of the sky wave. Main causes of variation are changes in ground moisture content from heavy rainfall or snow/ground frost at land, and waves and tidal variations at sea.

Recommended Prediction Models

For sky wave propagation, the recommended model is *ICEPAC* [4], as this is the most advanced model and has been used effectively for frequency planning by the administrations of several of the countries involved in the RTG.

For ground wave propagation, the recommended model is *GRWAVE* [5] since it has been thoroughly verified and does not require any detailed terrain information. The limiting factor in predictions will often be the available data, meaning that a more sophisticated model cannot necessarily give significantly more accurate predictions, even though such a model may be more accurate in isolated cases. However, one should be aware of the limitations of *GRWAVE*, and use caution when utilizing it outside its validity range. In certain cases, such as mixed sea/land paths, where there is a need for more than one ground conductivity/permittivity, the RTG recommends using *Millington's* method [6].

Modeling of Wire-Line Transmission Systems

In this section, four key concepts necessary for the modeling of wireline transmission systems are presented.

WIRELINE SYSTEM ANTENNA GAIN

The antenna gain of a wireline transmission system is defined as the ratio between equivalent isotropically radiated power (EIRP) and injected power. For PLT systems, several measurement results are reported in the literature. After a review of these reports, the RTG recommends using the following antenna gains:

- –30 dBi for in-house systems
- –15 dBi for overhead access systems
- –50 dBi for underground access systems

It should be recognized that there are uncertainties in these numbers on the order of ±5 to ±10 dB due to statistical spread. Furthermore, in the case of overhead access system power lines, at resonant frequencies the antenna gain may be higher by 10–13 dB.

RADIATION PATTERN OVER A LARGE AREA

In the assessment of cumulative effects of PLT emissions at far distances, when summing up a large number of different sources (in-house or access) with different wiring geometries over a wide area, it is reasonable to approximate the effective radiation pattern of the area as isotropic (in elevation as well as in azimuth).

OVERHEAD ACCESS PLT MODELING

In modeling the emissions from an overhead access PLT line, the PLT wires can be modeled as a successive set of dipoles, assuming that the standing waves present are the dominant emission source and the current has a sinusoidal distribution along the wire.

As the PLT medium is basically a wire, the dipole is the nearest model to a wire. To implement such an approach, the dipole model formulation needs to be addressed first. Both half-wavelength and one-wavelength dipoles are suitable; however, the half-wavelength has the wider half-power beamwidth (78° vs. 48°); therefore, it is preferable (the wider the beamwidth, the smoother the pattern overlap). Given the PLT geometry, the cylindrical coordinate system is more practical than the spherical coordinate system generally used in electromagnetics. In the vicinity of an access PLT line and up to 200 m, the use of the expression for the exact solution of a half-wavelength dipole is recommended, which is valid at any distance in both near-field and far-field. Beyond 200 m, the expression for far-field approximation may be used.

DISTANCE CONVERSION FACTOR

The distance conversion factor refers to the rate of decrease of the field strength as a function of slant distance from the emission source (in-house or overhead access PLT).

In-house PLT systems contain both vertical and horizontal power lines. To model these lines, numerical electromagnetic computational models have to be used. In view of the great variety of in-house wiring geometries, a universal model is not possible. Therefore, measurement results obtained by various groups are more suitable for use. The results have frequency and distance dependence, and range from 10–40 dB per decade.

In the vicinity of the overhead access PLT and up to 200 m, the proper determination of the distance conversion factor requires that the reflected field from the ground also be taken into consideration. Therefore, the best method for such an assessment is the two-ray method, using the exact solution expressions referred to above.

For overhead access PLT, the RTG developed a matrix (decrease per frequency and slant distance) using the recommended modeling technique above, as shown in Table 1.

Zone (m)	2 MHz	3 MHz	5 MHz	10–30 MHz
r_dir ≤ 20	16	18	23	29–31
20 < r_dir ≤ 30	22	26	31	35
30 < r_dir ≤ 200	32	35	37	38
r_dir > 200	20	20	20	20

Table 1. *Distance conversion factors (dB/decade) — λ/2 dipole model.*

CUMULATIVE PLT TOOL

The parameter of interest when considering cumulative effects in the far-field is the EIRP per unit bandwidth caused by each signal source, in units of dBm per Hertz, at different frequencies. Therefore, in the computation of cumulative effects of PLT emissions, the RTG recommends that these be computed using a source defined in terms of EIRP rather than electric field strength.

The RTG has developed a cumulative PLT tool, which was used to perform cumulative PLT noise calculations at hypothetical sensitive receiver locations. It builds on ICEPAC, and computes the PLT noise at a sensitive receiver site and compares it to ITU-R noise curves and RTG's absolute protection requirement. Some of the input parameters are average EIRP per PLT installation, market penetration rate (PLT modems per capita), average modem duty cycle, the location of the sensitive receiver, the extent of the geographical area over which PLTs are situated, population data (current and future) [7], receiver antenna pattern (default is isotropic), and so on.

For each receiver location and frequency, the percentage of parameter combinations was computed where the estimated cumulative PLT noise level is:

- Above the quiet rural level
- Above quiet rural + 6 dB
- Above the rural noise level

The results indicated the following:

- There is a high probability that PLT would cause increased noise levels at sensitive receiver sites given the projected market penetration.
- The percentages are highly influenced by assumptions on transmitter EIRP, PLT market penetration, and duty cycle.

The percentage of parameter combinations was also computed where the estimated PLT noise level is above the absolute protection

While it is highly desirable that the regulatory limits on PLT emissions be harmonized throughout the NATO countries and the world, the RTG recognizes that NATO, by itself, has no regulatory authority over the emission limits.

requirement. Again, the probability of the cumulative effect of PLT exceeding the absolute protection requirement is predicted to be relatively large for all frequencies and receiver locations investigated. Figure 3 shows an example result for Winnipeg, Canada.

We have used the assumptions listed below. The parameter values used are "best knowledge" estimates, elaborated on in [1]. Note that a change in any of these parameters will shift all estimated cumulative PLT noise levels up or down by the corresponding number of dBs:

- Isotropic antenna patterns (referred to as isotrope in Fig. 3)
- 2010 population data
- Modem duty cycle of 0.3
- Market penetration rate of 0.05 PLT modems/capita
- Market factor of –18.2 dB (product of last two items)
- PLT modem EIRP of –80 dBm/Hz/PLT modem (e.g., –50 dBm/Hz output power as in Homeplug, and –30 dBi antenna gain from house wiring)
- Net PLT modem EIRP of –98.2 dBm/Hz/capita

Conclusions and Recommendations

The cumulative PLT tool indicated that there is a high probability that PLT would cause increased noise levels at sensitive receiver sites given the existing and projected market penetration. These increased noise levels would have adverse effects on military communications and COMINT systems, and also outside the military community on any HF spectrum users that typically operate in low-noise regions.

Currently, there are no commonly accepted regulatory emission limits for PLT. While it is highly desirable that the regulatory limits on PLT emissions be harmonized throughout the NATO countries and the world, the RTG recognizes that NATO, by itself, has no regulatory authority over the emission limits. Therefore, it is recommended that NATO nations seek the implementation of this goal by working together with the national and international regulatory authorities.

Finally, as stated above, VDSL variants were still in the definition phase during the term of the RTG, but this is no longer the case. It is recommended that the IST Panel form an Exploratory Team or an RTG to assess whether the VDSL systems would cause potential interference in the HF spectrum.

Note that this article is a synopsis of the Report [1]. The authors' expectation is that the interested reader will consult the Report for in-depth information. A comprehensive reference list can also be found there.

Acknowledgments

The RTG members would like to express their thanks and appreciation for the support received from the following organizations: NATO RTA Office, Paris, France; Defence Research and Development Canada, Ottawa; Communications Research Centre, Ottawa, Canada; Forschungsgesellschaft für Angewandte Naturwissenschaften, Wachtberg, Germany; Norwegian Defence Research Establishment, Kjeller, Norway; and Industry Canada, Ottawa, Canada.

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