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0.4 TO 10 GHz AIRBORNE ELECTROMAGNETIC ENVIRONMENT SURVEY OF U.S.A. URBAN AREAS

RALPH E. TAYLOR
JAMES S. HILL

MAY 1976

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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0.4-TO 10-GHZ AIRBORNE ELECTROMAGNETIC-ENVIRONMENT SURVEY OF UNITED STATES URBAN AREAS

Ralph E. Taylor
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771 USA

James S. Hill
RCA Service Company
Springfield, Virginia 22151 USA

Summary

An Airborne Electromagnetic-Environment Survey (AEES) of some U.S. metropolitan areas measured terrestrial emissions within the broad-frequency spectrum from 0.4 to 10 GHz. A Cessna 402 commercial aircraft was fitted with both nadir-viewing and horizon-viewing antennas and instrumentation, including a spectrum analyzer, a 35-mm continuous-film camera, and a magnetic-tape recorder. Most of the flights were made at a nominal altitude of 10,000 feet, and Washington, D.C., Baltimore, Philadelphia, New York, and Chicago were surveyed.

The 450- to 470-MHz land-mobile UHF band is especially crowded, and the 400- to 406-MHz space bands are less active. This paper discusses test measurements obtained up to 10 GHz. Sample spectrum-analyzer photographs were selected from a total of 3750 frames representing 38 hours of data.

Introduction

An airborne-measurement survey was made over U.S. urban areas, continuously covering the frequency range from 0.4 to 10 GHz to obtain electromagnetic-environment data in the space bands of interest to the National Aeronautics and Space Administration (NASA).

Although previous aircraft flights over both urban and suburban areas have been reported in the literature, their measurements cover only portions of the frequency spectrum of interest to NASA.

The airborne measurements were made during a 13-day period from April 24 to May 6, 1975, with an instrumented commercial Cessna 402 aircraft over Washington, D.C.; Baltimore, Maryland; Philadelphia, Pennsylvania; New York, New York; and Chicago, Illinois. The Palestine, Texas, area was also measured in the 450- to 470-MHz bands to determine the magnitude of interference from UHF-band fixed/land-mobile emissions to NASA’s experimental high-altitude meteorological balloons launched in the Palestine area. In addition, the 450- to 470-MHz band was measured between New York and Chicago; between Chicago and Waco, Texas; and between Longview, Texas, and Washington, D.C.

Figure 1. Cessna 402 Aircraft for NASA AEES Flight Tests

The spectrum analyzer consisted of a Hewlett-Packard HP-8555A RF section, an HP-141T (long persistence) display unit, an HP-8552A IF section, and an HP-8445B preselector (Fig. 2).

Figure 2. AEES Antenna and Instrumentation Measurement System
To record the data, a Benrus 3625, 35-mm scope camera with a 100-foot magazine took photographs of the display unit in the spectrum analyzer with Eastman Tri-X panchromatic film. A special camera timer controlled the shutter opening (exposure time) and the intervals between exposures. The shutter opening was variable from 0.1 to 150 seconds, and could be triggered either manually or automatically. The selected scan time was 20 seconds per frame with a 30-second interval between frames.

An HP-3960B magnetic-tape unit (Fig. 2) recorded the horizontal and vertical outputs of the spectrum analyzer in a backup mode. A Realist PRO-5 UHF (pocket) scanner monitored uplink voice transmissions from 468.8 to 468.875 MHz.

Several passenger seats were removed to accommodate the electronics and equipment rack. The 300-pound rack was bolted directly to the floor-support cross members (Fig. 3). A Topaz 500 GC WD static inverter provided the prime 120-volt, 60-Hz power from the aircraft’s 28-vdc supply. All antennas were mounted on the underside of the fuselage (Fig. 4). The horizon antennas were tilted so that the upper edge of the half-power beamwidth (HPBW) point on the radiation pattern was along the horizon for maximum geographical coverage.

A cavity-backed, constant-beamwidth, circularly polarized, spiral antenna (AEL Model ASN-115A) with an HPBW of 70 degrees covered the 0.4- to 2.0-GHz range. A constant-beamwidth, broadband, linearly polarized horn antenna (AEL Model H-1498) covered the 2.0- to 10-GHz range. For increased sensitivity, an HP-8447 low-noise preamplifier (LNA) with a measured noise figure of 0.5 dB and 22-dB gain covered the 0.4- to 1.4-GHz portion of the range. To prevent signal overload, a tunable low-loss band-reject filter (0.5-dB insertion loss and 45-dB notch depth with 3-dB bandwidth c. 5 MHz) was tuned to reject local high-power UHF-TV broadcast signals. For 1.0- to 2.0-GHz operations, the LNA and band-reject filter could be bypassed with a coaxial cable (Fig. 2).

In terms of effective isotropic radiated power (EIRP) at the Earth’s surface relative to the peak-gain point on the radiation pattern, the threshold sensitivity of the nadir system varies from 0.007 to 0.098 watts (7 to 98 milliwatts) over 0.4 to 1.4 GHz (Table 1). The nadir system is less sensitive from 2.0 to 10 GHz, where the threshold EIRP varies from 11 to 110 watts, respectively. The horizon-viewing system is even less sensitive over the 2.0- to 10-GHz range, but sensitivity is sufficient for detecting high-power continuous-wave transmitters or radar.

Table 1
AEES Receiving System Sensitivity at an Altitude of 10,000 Feet

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Overall System Noise Figure (dB)</th>
<th>Threshold EIRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nadir-Viewing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Antenna (Watts)</td>
</tr>
<tr>
<td>0.4</td>
<td>8.5</td>
<td>0.007</td>
</tr>
<tr>
<td>0.6</td>
<td>11.4</td>
<td>0.009</td>
</tr>
<tr>
<td>1.4</td>
<td>16.3</td>
<td>0.006</td>
</tr>
<tr>
<td>2.0</td>
<td>36.3</td>
<td>15</td>
</tr>
<tr>
<td>4.0</td>
<td>36.3</td>
<td>15</td>
</tr>
<tr>
<td>10.0</td>
<td>36.3</td>
<td>150</td>
</tr>
</tbody>
</table>

*Corresponds to 0.5-dB deflection on spectrum analyzer for 0-dB attenuation setting.*

Figure 3. Aircraft AEES Electronic System

Figure 4. Aircraft Antenna Installation
(Horizon Looking Antennas)
The flight survey began in the Washington/Baltimore area and continued to Philadelphia, New York, and Chicago. A cross-country flight was made from Chicago to Palestine, Texas (Fig. 5), with a return path to Washington. The flight paths over these cities were planned on aeronautical charts as straight-line courses approximately 50 statute miles long. Flight paths were selected to transverse the central (urban) city, as well as industrial, residential, and rural areas. The altitude was a nominal 13,000 feet, except for Chicago and Palestine, where additional tests were conducted from an altitude of 2500 to 15,000 feet.

The measured values of the calibration signals were within 1 to 2 dB of the theoretical value at 10,000 feet.

Figure 5. USA Cross-Country Aircraft Flight Path

The flight path over each city has been projected on a Landsat photograph for that area, relating geographical area with test measurements (Figs. 6 through 9). These figures also show nadir footprints of the 70°- and 50°-HPBW-antenna radiation patterns. At 10,000 feet, the 70°-HPBW ground footprint of the nadir antenna is approximately 2.7 miles in diameter. The horizon 70°-HPBW antenna footprint increases to about 13 miles in diameter at 5 degrees below the horizon. Because the aircraft's ground speed averaged 200 miles per hour and a 35-mm photographic frame was taken every 30 seconds, the antenna footprints overlapped significantly between adjacent frames.

To fully scan the frequency spectrum from 0.1 to 10 GHz, six separate runs along the nominal 50-mile flight path across each city were necessary. Each set of six runs provided an average of 100 minutes (1-2/3 hours) of data. In general, a major frequency band was covered during each run.

Flights across each city were made in three time blocks (local time): morning (0730 to 0930 hours), afternoon (1130 to 1700 hours), and night (2230 to 0200 hours). The morning and afternoon runs covered periods of major activity, and the nighttime runs represent periods of less activity.

The instrumentation system was operationally calibrated during a flyover test of ground-based radiations of known power output at the amateur-band frequencies of 430, 1290, and 2130 MHz for altitudes of 2500, 5000, and 10,000 feet.
These photographs were selected from 5750 frames representing 38 hours of test data. The following comments apply generally for data obtained in the foregoing frequency bands:

1. 0.4- to 1.4-GHz frequency range using nadir antenna (Figs. 10 and 11):
   a. 410 to 800 MHz:
      (1) Solid band of emissions is attributable to UHF-TV channels 14 to 69, land-mobile systems, etc.
      (2) Frequency spectrum is remarkably similar along the 50-mile flight path and from city to city.
      (3) Peak EIRP values range from 10 to 200 watts over the 410- to 800-MHz range.
      (4) Because the radio horizon distance is about 141 miles for a 10,000-foot altitude, there is indication that high-power UHF-TV transmissions (e.g., several megawatts EIRP) are present from a distant city that appears in the antenna.
      (5) The 420- to 450-MHz amateur band is relatively quiet and free of emissions.
   b. 450 to 470 MHz (Figs. 11, 12, and 13): The fixed/land-mobile UHF band is densely populated, especially during the morning and afternoon. Emissions present in the 460- to 470-MHz band shared by meteorological satellites can interfere with space operations during daylight hours.
   c. 400 to 420 MHz (Figs. 13 and 14): Philadelphia, New York, and Chicago data indicate that the 400- to 403-MHz space bands are relatively free of terrestrial emissions that might interfere with space missions.
   d. 1090 MHz (Figs. 10 and 11): Multiple aircraft air-traffic control radar beacon transponder emissions (called "fruit," 16-18 are evidenced at 1090 MHz. Transponder emissions from the test aircraft are sometimes present.

2. 1.525 to 1.575 GHz (Fig. 15): The 1.525- to 1.535-GHz maritime/aeronautical mobile-satellite bands are relatively free of emissions from the Chicago area.

3. 1.625 to 1.675 GHz (Fig. 15): The 1.635- to 1.660-GHz maritime/aeronautical satellite bands contain emissions equal to 2 watts EIRP in the Chicago area.

4. 2.2 to 2.3 GHz (Figs. 14 and 15): The Earth-to-space satellite data relay bands contain single emitters with EIRP's of about 5 watts in the New York and Chicago areas. The expanded portion of this range is 2.24 to 2.26 GHz. Fig. 14 shows a single 800-watt emitter in Chicago.

5. 2.07 to 6.15 GHz (Fig. 15): In the Chicago area, this band contains single, 65-watt emission at 2.1 GHz and single, 50-watt emission at 6.11 GHz.

6. 4 to 10 GHz: This frequency range is typically occupied by multikilowatt EIRP emissions, including commercial aircraft radar.

Figure 8. Aircraft Flight Profile, New York City, NY

Figure 9. Aircraft Flight Profile Chicago, Ill.
(a) Washington-Baltimore, Afternoon
April 24, 1975
Time: 150610 (Start Run)

(b) Washington-Baltimore, Afternoon
April 24, 1975
Time: 151343 (Run Midpoint)

(c) Washington-Baltimore, Afternoon
April 24, 1975
Time: 152007 (End of Run)

(d) Philadelphia, Afternoon,
April 26, 1975
Time: 145617

(e) Philadelphia, Afternoon,
April 28, 1975
Time: 145724 (4-Mile Point)

(f) Philadelphia, Afternoon,
April 28, 1975
Time: 15051.1 (30-Mile Point)

(g) Chicago Afternoon,
May 1, 1975
Time: 143020 (Start Run)

(h) Chicago, Afternoon,
May 1, 1975
Time: 143650 (Run Midpoint)

(i) Chicago Afternoon,
May 1, 1975
Time: 144250 (42-Mile Point)

(j) New York City, Afternoon,
April 29, 1975
Time: 145000 (Start Run)

(k) New York City, Afternoon,
April 29, 1975
Time: 145435 (17-Mile Point)

(l) New York City, Afternoon,
April 29, 1975
Time: 145935 (33-Mile Point)

Figure 16. Washington-Baltimore, Philadelphia, Chicago, and New York City (Afternoon) -0.4 to 1.4 GHz
Scale: * Same as (a)  
** Same as (d)  
Altitude: 10,000 Feet  
Aircraft Heading: North  
Analyzer Bandwidth: 36kHz  
Antenna: NADIR
Figure 11. Chicago (Morning-Nighttime) −0.4 to 1.4 GHz and 450 to 470 MHz
Scale: *Same as (a)  
Altitude: 10,500 ft  
Analyzer Bandwidth:  
Aircraft Heading: North  
Antenna: NADIR
Time: 081741 (Start Run)  
Time: 081842 (4 Mile Point)  
Time: 082009 (10 Mile Point)  
Time: 223035 (Start Run)  
Time: 223746 (Run Midpoint)  
Time: 224427 (End of Run)  
Time: 150111 (Start Run)  
Time: 150234 (6 Mile Point)  
Time: 150406 (10 Mile Point)  
Time: 230120 (Start Run)  
Time: 230251 (5 Mile Point)  
Time: 230422 (10 Mile Point)
Figure 12. Washington-Baltimore, Philadelphia, New York City, and Chicago (Mornings-450 to 470 MHz)

Scale: *Same as (a) 
Altitude: 
Analyzer Bandwidth: 
Aircraft Heading: North 
Antenna: NADIR
Figure 13. Chicago (Morning and Afternoon) 450 to 470 MHz; New York City (Morning and Nighttime) 400 to 420 MHz

Scale: **Same as (a)**

**Altitude:** Figs 1a to 13f - 10,000 Feet

**Analyzer Bandwidth:** 10 kHz
Figure 13. Philadelphia and Chicago (Afternoon) -40 to 420 MHz; Washington-Baltimore (Afternoon) -2.24 to 2.26 GHz; Chicago (Night) -2.2 to 2.3 GHz. Analyzer Bandwidth: 10 kHz. Antenna: NADIR.
New York City, Morning
April 30, 1975. Heading: South
Time: 081341 (8-Mile Point)

Chicago, Afternoon
May 1, 1975. Heading: South
Time: 152019 (7-Mile Point)

Chicago, Morning
May 1, 1975. Heading: North
Time: 082316 (20-Mile Point)

Chicago, Afternoon
May 1, 1975. Heading: South
Time: 155150 (25-Mile Point)

Chicago, Night
May 2, 1975. Heading: South
Time: 225927

Chicago, Night
May 2, 1975. Heading: South
Time: 085262 (31-Mile Point)

Chicago, Afternoon
May 1, 1975. Heading: North
Time: 144521

Figure 15. New York City (Morning) - 2.2 to 2.3 GHz, Chicago 1.525 to 1.575 GHz

Scale: *Same as (a)
**Same as (d)

Analyzer bandwidth:
Figs. 15a to 15c - 30 kHz
Figs. 15d to 15e - 9,500 feet
Figs. 15f - 10,500 feet
Figs. 15g - 9,500 feet
Figs. 15h to 15i - 100 kHz

Antenna: NADIR
Table 2  
Signal Distribution in the Fixed/Land Mobile UHF-Band, System 450-470 MHz

<table>
<thead>
<tr>
<th>Location</th>
<th>Time Block</th>
<th>Altitude K ft</th>
<th>% Signals Above Indicated Level at Input to Spectrum Analyzer</th>
<th>No. Frames Observed</th>
<th>Signals per Frame**</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>%40</td>
<td>%50</td>
<td>%60</td>
</tr>
<tr>
<td>Palestine, Texas</td>
<td>A</td>
<td>7.0</td>
<td>0</td>
<td>0</td>
<td>7.6</td>
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<tr>
<td></td>
<td>A</td>
<td>5.0</td>
<td>0</td>
<td>0</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>10.0</td>
<td>0</td>
<td>0</td>
<td>4.3</td>
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<td>0</td>
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<td>0.4</td>
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<td>24.2</td>
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<td>C</td>
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<td>60.5</td>
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<td>Chicago, A</td>
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<td>0.1</td>
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<td>15.0</td>
<td>0.1</td>
<td>4.6</td>
<td>31.2</td>
</tr>
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</table>

*A-morning, B-afternoon, C-night  
**20-second scan time per frame; 30-seconds time internal between frames.

The greatest activity occurred during the afternoon, with less activity at nighttime. At Palestine, morning and afternoon activity was similar to nighttime activity in the major cities.

Analysis of the percentage of signals above the -60dBm input power level to the spectrum analyzer indicates that (Table 2):

1. Chicago activity is greater than Palestine activity at all altitudes during the morning and afternoon periods;
2. Palestine activity is greater at 5000 or less feet in the morning and afternoon, and morning activity is greater than afternoon activity; and
3. Chicago activity increases with altitude, and there is generally more activity in the afternoon than in the morning.

Data obtained between cities with the horizon antenna shows little activity in the 450- to 470-MHz UHF band for the fixed/land-mobile system, and signals in rural areas are relatively few. As the test aircraft approached metropolitan areas, activity increased in relation to population density.

Conclusions

In general, RF activity is greater below 1.5 GHz, a region containing allocated UHF-TV transmissions, fixed/land-mobile and air-traffic control radar beacon systems, etc. The region from 1.5 to 10 GHz contains fewer, but more high-powered emitters. However, a more extensive flight survey should reveal an even greater number of emitters in this frequency range.

The 450- to 470-MHz fixed/land-mobile UHF band is especially active. Meteorological satellite missions operating within the overlapping 450- to 470-MHz band can experience RF interference from terrestrial emissions, particularly during daylight hours when the populace is active.

Acknowledgments

The authors thank the Department of Transportation, Federal Aviation Administration, Air Traffic Control Automation Division (ATT-500), for advice and support in obtaining air-route clearance for heavily congested zones; the Federal Airways Corporation for aircraft operation; and Page Airways, Inc., for mounting the antennas and instrumentation on the test aircraft.
References


