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

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MAY 1976

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND
0.4 TO 10 GHz AIRBORNE
ELECTROMAGNETIC ENVIRONMENT
SURVEY OF U.S.A. URBAN AREAS*

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May 1976

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0.4- to 10-GHz AIRBORNE ELECTROMAGNETIC-
ENVIRONMENT SURVEY OF UNITED STATES URBAN AREAS

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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 5750 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 band 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.

Aircraft Instrumentation

A Cessna 402 aircraft (Fig. 1) was selected for the test because both antennas and instrumentation could be mounted readily without major modifications to the aircraft and because low-cost operation was a primary consideration. A combination of nadir- and horizon-viewing antennas were mounted on the bottom of the fuselage for maximum geographical coverage; a standard equipment rack mounted inside the passenger cabin housed the instrumentation electronics.

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 tuner 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 GCWD static inverter provided the prime 120-volt, 60-hertz power from the aircraft’s 28-volt-dc 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.

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.

| Frequency (GHz) | Overall System Sensitivity (W) | Threshold EIRP
|----------------|-------------------------------|-----------------
| 0.4            | 0.5                           | 0.007         | 0.041|
| 0.8            | 1.4                           | 0.009         | 0.028|
| 1.4            | 18.3                          | 0.005         | 0.019|
| 2.0            | 36.3                          | 15            | 45   |
| 4.0            | 54.3                          | 14            | 109  |
| 8.0            | 63.3                          | 150           | 646  |

*Corresponds to 70-dB deflection on spectrum analyzer for 0-dB attenuation setting.*
Aircraft Flight Profile and Schedule

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 0.4 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 0000 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 130, 1250, and 2450 MHz for altitudes of 2500, 5000, and 10,000 feet.

Aircraft Survey Data Measurements

Aircraft survey electromagnetic-environment measurements presented here cover the following ranges: 400-420, 450-470 MHz and 0.4-1.1, 1.25-1.575, 1.625-1.75, 2.2-2.3, 2.24-2.26, 2.07-2.15, and 6.1-6.2 GHz. Figures 10 through 15 are sample photographs for these frequency ranges referenced to the Earth’s surface.
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 80-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 1.558-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 1.636- 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 band contains 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.

Signal Distribution Analysis of Fixed/Land-Mobile UHF-Band System

Table 2 lists 450- to 470-MHz observations obtained 2500 to 15,000 feet over Chicago and Palestine, Texas, by spiral aircraft flights with the nadir antenna. Observations obtained 10,000 feet over New York and Philadelphia with the nadir antenna have been included for comparison. Except for Palestine, the cities surveyed had similar activity during the morning, afternoon, and nighttime periods at an altitude of 10,000 feet. This was evidenced by the number of signals per frame observed.
Figure 10. 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: 30kHz
Antenna: NADIR

(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 26, 1975
Time: 150507 (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: 143000 (Start Run)

(k) New York City, Afternoon,
April 29, 1975
Time: 144418 (17-Mile Point)

(l) New York City, Afternoon,
April 29, 1975
Time: 145955 (33-Mile Point)
Figure 11. Chicago (Morning-Nighttime) -0.4 to 1.4 GHz and 450 to 470 MHz
Scale: 'Same as (a)  
**Same as (g)  
Altitude: 10,500 ft  
Aircraft Heading: North  
Analyzer Bandwidth:  
Fig. 11a to 11f -30kHz  
Fig. 11g to 11i -10kHz
Antenna: NADIR
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

Figures 12a-12f -10,000 Feet Figures 12a-12f -10kHz Antenna: NAIR

Figures 12g-12l -10,000 Feet Figures 12g-12l -30kHz
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. 13a to 13f - 13f - Horizon

Analyzer Bandwidth: 10 kHz
Figure 13. Philadelphia and Chicago (Afternoon) -400 to 420 MHz; Washington-Baltimore (Afternoon) -2.24 to 2.26 GHz; Chicago (Night) -2.2 to 2.3 GHz. Analyzer Bandwidth: Figs. 14a to 14f = 10 kHz; Figs. 14g to 14i = 30 kHz. Aircraft Heading: South Antenna: NADIR.
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)
Antenna: NADIR

(a) New York City, Morning
April 30, 1975. Heading: South
Time: 081341 (8-Mile Point)

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

(c) Chicago, Morning
May 1, 1975. Heading: North
Time: 032316 (20-Mile Point)

(d) Chicago, Afternoon
May 1, 1975. Heading: South
Time: 155150 (26-Mile Point)

(e) Chicago, Night**
May 2, 1975. Heading: South
Time: 025927

(f) Chicago, Morning
May 1, 1975. Heading: North
Time: 082625 (31-Mile Point)

(g) Chicago, Night
May 2, 1975. Heading: South
Time: 230154 (26-Mile Point)

(h) Chicago, Afternoon
May 1, 1975. Heading: North
Time: 152533 (10-Mile Point)

(i) 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 6.15 GHz
Scale: *Same as (a)
**Same as (d)
Antenna: NADIR

Analyzer bandwidth: Figs. 15a to 15g - 30 kHz
Figs. 15h to 15i - 100 kHz
## 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. Signals per Frame</th>
<th>Signals Observed</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>-40 -50 -60 -70 -80</td>
<td>Total</td>
<td>Observed</td>
</tr>
<tr>
<td>Palestine, Texas</td>
<td>A</td>
<td>7.0</td>
<td>0 0 7.6 35.0 100</td>
<td>340</td>
<td>17</td>
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<tr>
<td></td>
<td>A</td>
<td>5.0</td>
<td>0 0 5.5 31.2 100</td>
<td>631</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>15.0</td>
<td>0 0 4.1 32.4 100</td>
<td>788</td>
<td>25</td>
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<td></td>
<td>B</td>
<td>2.5</td>
<td>0 0 2.8 15.0 100</td>
<td>140</td>
<td>9</td>
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<tr>
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<td>B</td>
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<td>0 0 2.4 32.6 100</td>
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<tr>
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<td>B</td>
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<td>0 0 1.9 25.7 100</td>
<td>691</td>
<td>24</td>
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<td>15.0</td>
<td>0 0 1.9 25.3 100</td>
<td>691</td>
<td>22</td>
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<tr>
<td>New York, A</td>
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<td>2.8</td>
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<td>2.7</td>
<td>27.3 65.7 100</td>
<td>1445</td>
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<td>4.2</td>
<td>22.1 55.9 100</td>
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<td>0.5</td>
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<td>0.1</td>
<td>4.7 23.1 60.9 100</td>
<td>2857</td>
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<tr>
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<td>0.9</td>
<td>7.9 32.5 60.5 100</td>
<td>483</td>
<td>14</td>
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<td>Chicago, A</td>
<td>3.0</td>
<td>0.1</td>
<td>3.5 21.7 51.4 100</td>
<td>755</td>
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<td>Illinois, A</td>
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<td>8.6 37.4 62.3 100</td>
<td>872</td>
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<tr>
<td></td>
<td>10.0</td>
<td>0.4</td>
<td>5.9 29.5 54.5 100</td>
<td>825</td>
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<td>15.0</td>
<td>0.6</td>
<td>6.5 38.0 72.5 100</td>
<td>1232</td>
<td>30</td>
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<tr>
<td>Chicago, B</td>
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<td>0.4</td>
<td>3.5 24.2 59.3 100</td>
<td>942</td>
<td>20</td>
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<td>0.4</td>
<td>7.5 39.9 70.6 100</td>
<td>1052</td>
<td>17</td>
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<td>10.0</td>
<td>0.3</td>
<td>3.9 47.4 70.1 100</td>
<td>692</td>
<td>11</td>
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<td></td>
<td>15.0</td>
<td>0.1</td>
<td>4.6 31.2 71.3 100</td>
<td>1235</td>
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</table>

* A-morning, B-afternoon, C-night

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 IF 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


