Table 1. Television and radio broadcast facilities on the north tower of the World Trade Center. Heights above the roof are approximate.

Call sign	Channel	ERP (kW)	Height above roof to center of radiation (ft)
WNBC	4	17.4/3.47	335
WNYW	5	17.4/3.47	335
WPIX	11	58.9/11.7	309
WWOR	9	47.9/4.79	282
WNET	13	43.7/4.8	282
WABC	7	64.6/6.46	256
WNYC	31	2820/282	206
WCBS	2	21.4/4.3	200
WNJU	47	4570/457	153
WNBC-aux	4-	17.4/3.47	92
WNYW-aux	5	17.4/1.74	86
WKCR-FM	89.9	0.63	42
WPAT-FM	93.1	5.4	42
WNYC-FM	93.9	5.4	42
WQCD-FM aux	101.9	3.3	42
WABC-aux	7	64.6/6.46	49
WPIX-aux	11	58.9/11.9	38
WNET-aux	13	47.9/4.8	32
WWOR-aux	9	47.9/4.79	18

Table 2. Calibration data for the Narda Model 8742 broadband, isotropic electric field probes available for measurements at the World Trade Center. After initial evaluations, probe serial number 1004 was not used during for the main set of measurements.

Probe Calibration Data Supplied by Narda						
Probe SN	1004	2011	2016	2018	2019	2020
Freq(MHz)	Mar-97	Demo	Dec-96	May-97	Dec-96	Dec-96
	1004	2011	2016	2018	2019	2020
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Max	1.57	1.47	1.41	1.51	1.40	1.38
Min	0.64	0.68	0.71	0.66	0.71	0.73
Max(dB)	1.958997	1.673173	1.492191	1.789769	1.46128	1.398791
Min(dB)	-1.9382	-1.67491	-1.48742	-1.80456	-1.48742	-1.36677

Table 3. Summary of correction factors for probes actually used during RF measurements at the WTC within the applicable frequency range. Calibration date is shown above the serial number.

	Demo	Dec-96	May-97	Dec-96	Dec-96
Freq. (MHz)	SN 2011	SN 2016	SN 2018	SN 2019	SN 2020
27.12	1.23	1.26	1.43	1.22	1.17
100.00	0.94	0.90	1.06	0.90	0.87
300.00	1.29	1.25	1.24	1.19	1.20
500.00	0.94	0.90	0.83	0.89	0.87
750.00	0.74	0.71	0.67	0.74	0.73
915.00	0.84	0.81	0.73	0.78	0.74
Max(dB)	1.11	1.00	1.55	0.86	0.79
Min(dB)	-1.31	-1.49	-1.74	-1.31	-1.37
Overall average low reading (%)				**-21.58**	
Overall average high reading (%)				39.47	
Overall average low reading (dB)				-1.06	
Overall average high reading (dB)				1.44	

Table 4. Observed variation in measured percentages of spatially averaged MPE over all orientations and three repetitions for all ten evaluation points on WTC roof for each measurement team. A total of 120 measurements were obtained at the ten points by each team.

Team	Mean deviation (%)	Positive deviation (dB)	Negative deviation (dB)
A	13.85	0.56	-0.65
B	14.08	0.57	-0.66
C	9.93	0.41	-0.45
D	14.42	0.59	-0.68
E	10.75	0.44	-0.49
Average	12.61	0.51	0.59

Table 5. Measured values of fields in high resolution area of WTC roof (% MPE)

28.2	29.5	30.6	31.6	[illegible]	31.9	[illegible]	33.1	39.0	38.5	42.0
25.4	27.2	27.8	28.3	30.7	29.8	30.8	33.1	36.5	41.8	42.7
28.4	30.1	32.8	31.8	34.2	32.6	[illegible]	35.4	36.7	39.6	44.6
28.5	30.5	31.2	31.8	35.6	35.3	37.4	35.3	38.0	39.8	41.0
28.4	29.9	31.9	33.1	35.9	35.0	33.5	35.9	35.9	41.1	41.5
28.7	30.8	31.9	33.3	32.2	32.7	32.8	36.7	38.8	42.2	47.2

Table 6. Interpolated values of fields in high resolution area of WTC roof based on measured values in colored cells only (% MPE)

28.2	28.9	29.7	30.4	31.1	31.9	[illegible]	35.0	38.0	40.0	42.0
28.3	[illegible]	29.8	30.5	31.3	32.0	34.2	36.3	38.5	40.7	42.8
28.3	29.1	29.9	30.6	31.4	32.1	34.5	36.8	39.1	41.4	43.7
28.5	29.2	30.0	30.8	[illegible]	32.4	34.9	37.5	40.0	42.6	45.1
28.6	29.3	30.1	30.9	31.7	32.5	35.3	[illegible]	40.7	43.5	46.2
28.7	29.5	30.3	31.1	[illegible]	32.7	[illegible]	[illegible]	41.4	44.3	47.2

Table 7. Percentage difference between Interpolated values and measured values (%). Colored cells represent cells in which actual measurement data were used to interpolate other values

	-1.76	[illegible]	-3.88	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7.41	[illegible]	7.29	[illegible]		[illegible]	-2.83	[illegible]
[illegible]	-3.72	[illegible]	-3.8	[illegible]	-1.46	[illegible]	[illegible]	[illegible]	[illegible]	-2.30
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	

Table 8. Summary of RF measurements and analysis on roof of WTC north tower. Each condition is referenced to a specific colorized roof map that illustrates the distribution of RF fields on the WTC roof.

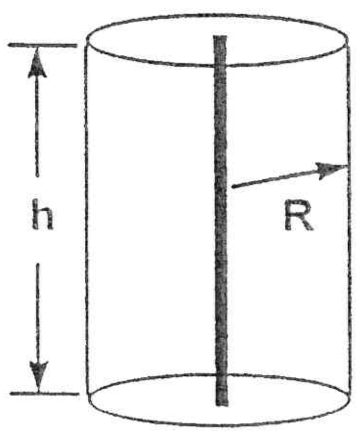
		Percent of roof area with spatially averaged RF fields (%)		
Conditions of RF measurements and/or analysis	Max MPE (%)	[redacted]	21-50	[redacted]
Normal broadcast + 72 MHz pagers (Fig. 6)	70.2	[redacted]	35.94	[redacted]
Normal broadcast + all wireless (Fig. 7)	314.1	[redacted]	60.48	[redacted]
Normal broadcast w/o 72 MHz pagers or any other wireless (Fig. 8)	56.6	[redacted]	14.47	[redacted]
Normal broadcast with 72 MHz pagers ≥ 6 feet above roof surface (no other wireless) (Fig. 9)	57 2	[redacted]	19.55	[redacted]
Normal broadcast with all wireless antennas ≥ 6 feet above roof surface (Fig. 10)	67.2	[redacted]	32.32	[redacted]
Tower maintenance mode + 72 MHz pagers (Fig. 11)	147.0	[redacted]	43.11	[redacted]
Tower maintenance mode + all wireless antennas (Fig. 12)	352.0	[redacted]	20.93	[redacted]
Tower maintenance mode w/o 72 MHz pagers or any other wireless (Fig. 13)	138.3	[redacted]	48.18	[redacted]
Tower maintenance mode with all wireless antennas ≥ 6 feet above roof surface (Fig. 14)	144.3	[redacted]	46.47	[redacted]
Emergency broadcast backup + 72 MHz pagers (Fig. 15)	156.3	[redacted]	31.89	[redacted]
Emergency broadcast backup + all wireless (Fig. 16)	373 0	[redacted]	14.37	[redacted]
Emergency broadcast backup w/o 72 MHz pagers or any other wireless (Fig. 17)	135 2	[redacted]	40.56	[redacted]
Emergency broadcast backup with all wireless antennas ≥ 6 feet above roof surface (Fig. 18)	149.3	[redacted]	33.46	[redacted]
Wireless antennas w/o 72 MHz pagers and no broadcast (Fig 19)	273 9	[redacted]	32.94	[redacted]
Spatial peak from only wireless antennas > 800 MHz (Fig 20)	276 0	[redacted]	0 79	[redacted]

Appendix A

A Brief Description of the RF Field Calculation Models Used In RoofView

The underlying calculation engine within RoofView for near-field analysis is based on a cylindrical model for vertical collinear antennas. In concept, when sufficiently close to an antenna, the beam of the antenna has not formed and, hence, the far-field gain of the antenna cannot be exhibited. This means that a vertical collinear antenna having a gain of 10 dBd (decibels relative to a halfwave dipole antenna) cannot exhibit 10 dBd of gain very close to it. Thus, calculations of RF field power densities close to such antennas, using a far-field model, will generally greatly over predict the field magnitude. When in close proximity to such antennas, alternative calculation models should be used to more accurately evaluate the RF fields.

RoofView uses a near-field method of computing the field based on assuming that the total input power delivered to the antenna, at its input terminal, is distributed over an imaginary cylindrical surface surrounding the antenna (see Figure A-1). The height of the cylinder is equal to the aperture height of the antenna while the radius is simply the distance from the antenna at which the field power density is to be computed. Within the aperture of the antenna, this approximation is quite accurate but as the antenna is elevated



$$S = \frac{P}{2\pi Rh}$$

Figure A-1. Distribution of power over surface of an imaginary cylinder.

above the region of interest, the model output must be corrected for mounting height. For example, when compared to a method of moments technique in which the RF field is calculated at a high spatial resolution parallel to a vertical collinear type of antenna, the spatial average value of the field, within the aperture dimension, is closely approximated by the value obtained from the cylindrical model. In one evaluation (Tell, 1996), the differences in spatial average values of the field were found to range from about 0.1 dB to about 1 dB between the two computational approaches, depending on the distance from the antenna.

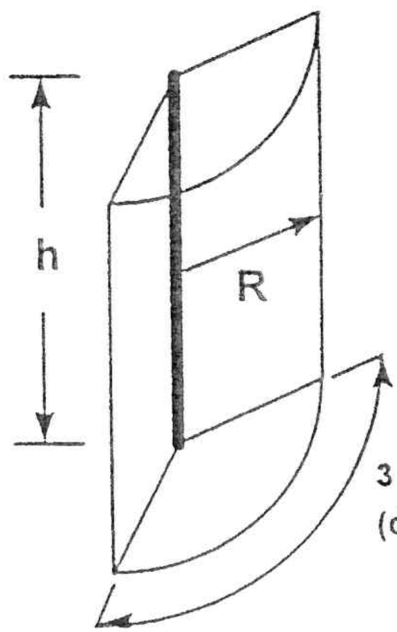
RoofView performs the correction for antenna mounting height automatically in its calculations, allowing the user to conveniently explore the effects of antenna mounting heights relative to controlling excessive RF field levels on roof-top antenna sites. RoofView allows for antenna mounting heights between 0 and 10 feet relative to the roof surface. If a mounting height less than 0 feet is input, RoofView uses 0 as the mounting height. If a value greater than 10 feet is input, RoofView uses the correction applicable to a mounting height of 10 feet.

The primary application of RoofView is in the near-field vicinity of roof mounted antennas. The cylindrical model, while highly accurate in the near-field region, becomes less accurate with increasing distance from the antenna and, eventually, will over estimate the magnitude of the RF fields at long distances from the antenna. There exists a cross-over point at which the near-field model and the far-field model will produce the same value of power density. Beyond this point, typically in the range of 1-5 times the aperture height of the antenna, the far-field model will yield more accurate values of power density. A general rule is that the appropriate model to use yields the lower power density at a given calculation distance. For example, closer to the antenna under study, the near-field model yields lower values of power density and provides more accurate predictions. Farther from the antenna, the far-field model yields lower values of power density and is the right model to use. Care must be used, however, in trying to compare the outputs of various models since the cylindrical model automatically produces values of the spatially averaged power density, the field parameter needed for direct comparison with most of the applicable standards for human exposure. Far-field models generally do not automatically perform this operation and, hence, it is possible that one might erroneously compare a spatially averaged power density to a spatial peak power density. If this occurs, the observed cross-over point for the two models will generally be farther from the antenna than the actual dividing line between near- and far-field models; remember that the spatial peak power density from the far-field model will occur farther from an antenna than the point at which an equivalent, spatially averaged power density will occur. RoofView provides for a user selectable distance, referenced to the aperture height, at which the calculation engine begins to allow the computed field density to decrease according to the inverse square law. For distances up to this limit, the near-field model is applied; at further distances, the near-field computed power density at the limiting distance is then adjusted downward in accord with the inverse square law.

One important observation from near-field analysis of RF fields is that, for a fixed antenna input power, very close to an antenna, the RF fields will be greater for smaller antennas. This fundamental concept is contrary to the way many communications engineers think about antennas. Traditionally, it is well understood that larger antennas offer greater gain than smaller antennas, and, therefore, will result in stronger signals assuming the same input powers. This concept is true in the far field of an antenna but is not true in the near field. This is because the gain specified for antennas by manufacturers is always associated with the far field. So, a short paging antenna, though it may have significantly lower gain than a much taller model, will exhibit much higher power densities near it than the higher gain, taller model with the same input power. You can explore this phenomenon easily with RoofView by adjusting the aperture height of antennas and watching the change in the colorized roof map. Smaller antennas result in greater near-field power densities than larger antennas. This can become particularly important when considering very short aperture antennas such as those contained in three-way and four-way antennas that contain multiple radiating, short apertures.

The cylindrical model for computing RF fields in the near-field region of vertical collinear antennas is discussed in some depth in various technical reports including Tell (1995, 1996).

The cylindrical model may be modified to account for azimuthal directivity by increasing the power density calculated for the simple full cylinder model by a factor equal to the number of times that the 3 dB beam width will divide into 360 degrees. This approach provides a conservative estimate of the RF field in the direction of maximum radiation since the actual azimuthal dispersion of power extends beyond the 3 dB beam width limits. Hence, when the 3 dB beam width is used, RF fields will generally be over estimated since all of the radiated power is assumed to be spread over a partial cylindrical surface that is smaller than that over which it is actually dispersed (see Figure A-2).



$$S = \frac{360\ P}{\theta_{BW}\ 2\pi R h}$$

Figure A-2. Modified cylindrical model for sector-type antennas assumes that all power is radiated through the reduced portion of a partial cylindrical surface.

The Super Tellamatic MPE Power Density Calculator contained within RoofView provides for three different models for computing RF fields. Cylindrical spatial average, cylindrical spatial peak and far-field spatial peak models may be applied. The cylindrical spatial peak model produces RF fields that are 3.0 times greater than the spatial average model; this is based on evaluation of the ratio of spatial peak and average fields near vertical collinear antennas (see Tell, 1996). Actual ratios of the spatial peak and average fields can range between two and four times but in many practical applications, a figure of three times represents a good average value. The spatial peak model may find applications in instances where one is interested in estimating the maximum field values that could be found during an RF field survey of an antenna site. Alternatively, evaluating RF exposure situations relative to the use of protective clothing where peak power density values have been specified by the manufacturer could be another practical application. For example, in some working conditions, it may be acceptable for workers to not wear head protection for RF fields. The issue of partial body exposure to RF fields may be importantly related the spatial peak value of RF fields rather than that value as averaged over the whole body.

The far-field spatial peak model makes use of the antenna gain and includes a ground power reflection factor of 2.56 as specified in FCC documents for including in routine RF field evaluations.

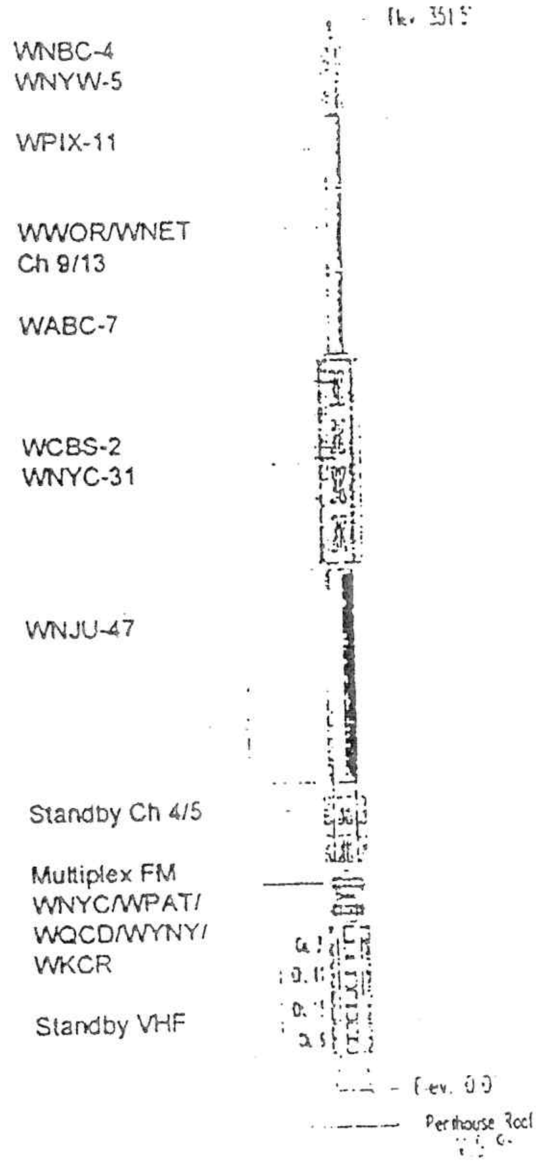


Figure 1. Drawing of antenna mast on the north tower of the World Trade Center.

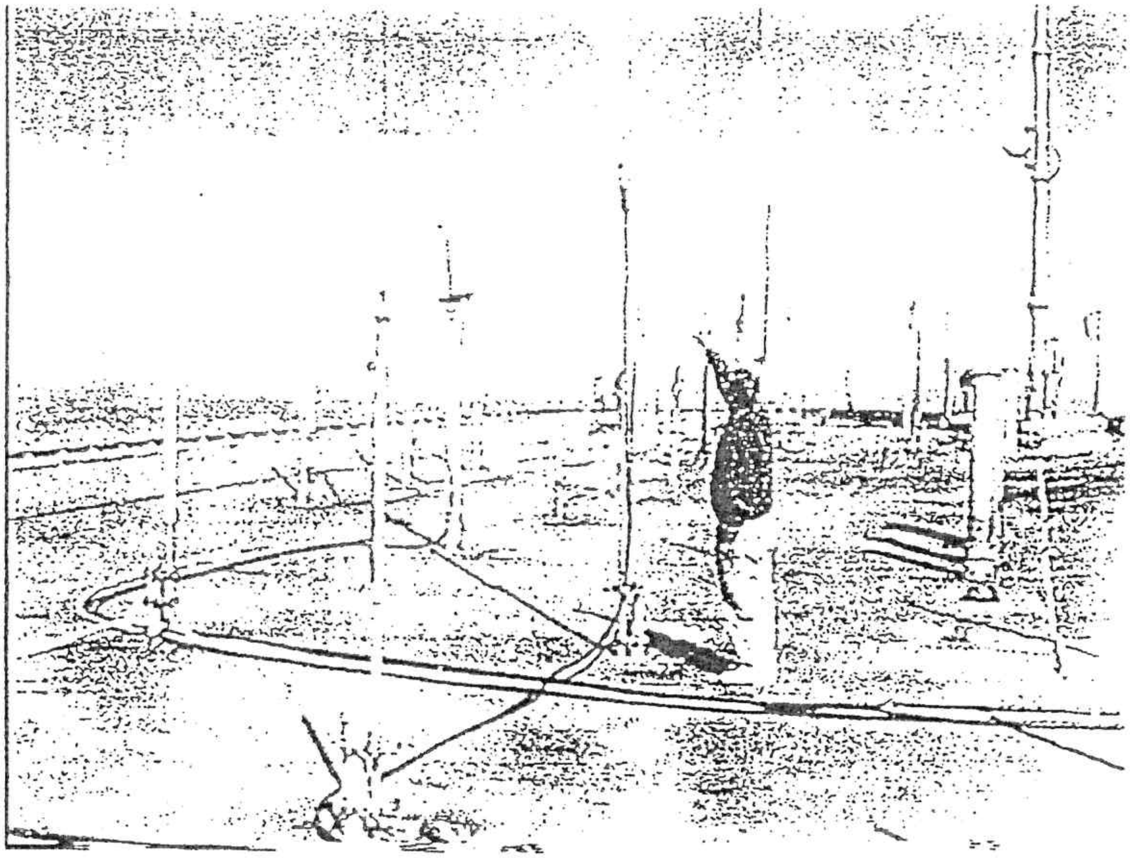


Figure 2. View of some of the many wireless communications antennas mounted on the roof of the WTC. Most antennas are mounted on 10 foot centers but in many cases, due to obstructions, alternate spacings are used. Many of the antennas are mounted close to the roof and some are elevated considerably above the roof surface.

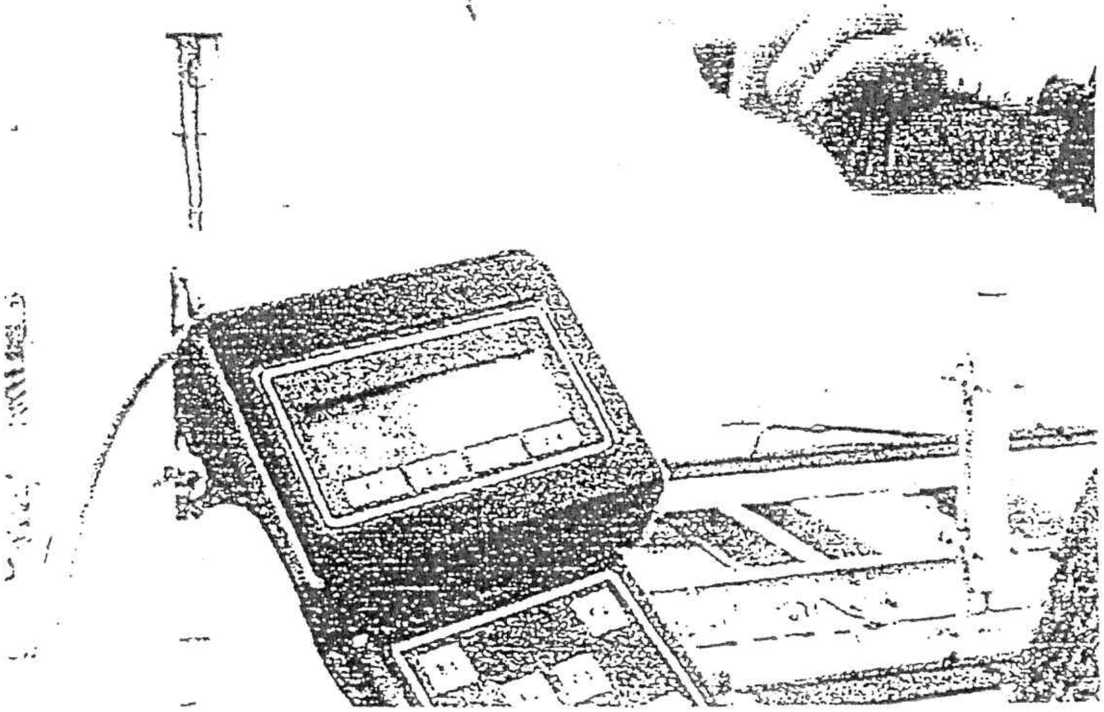


Figure 3. Photograph of the Narda Model 8718 digital RF survey meter and the Model 8742 broadband, isotropic, frequency shaped electric field probe used during the field measurements. A total of five measurement [illegible], each using one of these meter-probe combinations, were used to acquire the large amount of measurement data during the study.

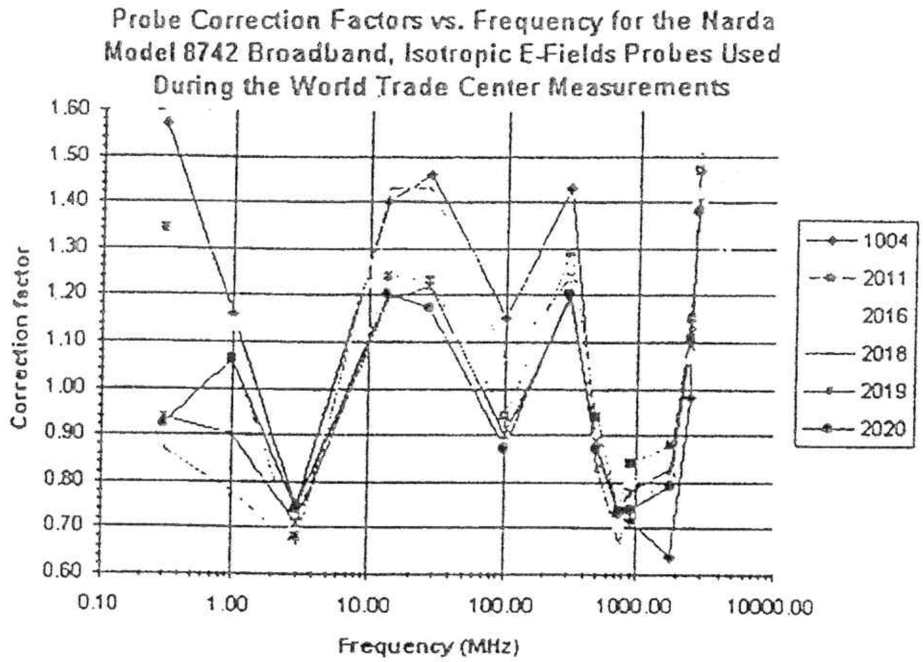


Figure 4. Graph showing the distribution of correction factors for the Narda Model 8742 broadband, isotropic frequency shaped electric field probes used during the WTC RF measurement project The probe with serial number 1004 was not used during the actual survey process due to its generally greater correction factor at most frequencies. All probe correction factors are seen to comply with the manufacturer's specification of a maximum deviation of ±2 dB from the frequency variation of the standard for human exposure adopted by the FCC in the frequency range of 0 3 MHz to 2,000 MHz..

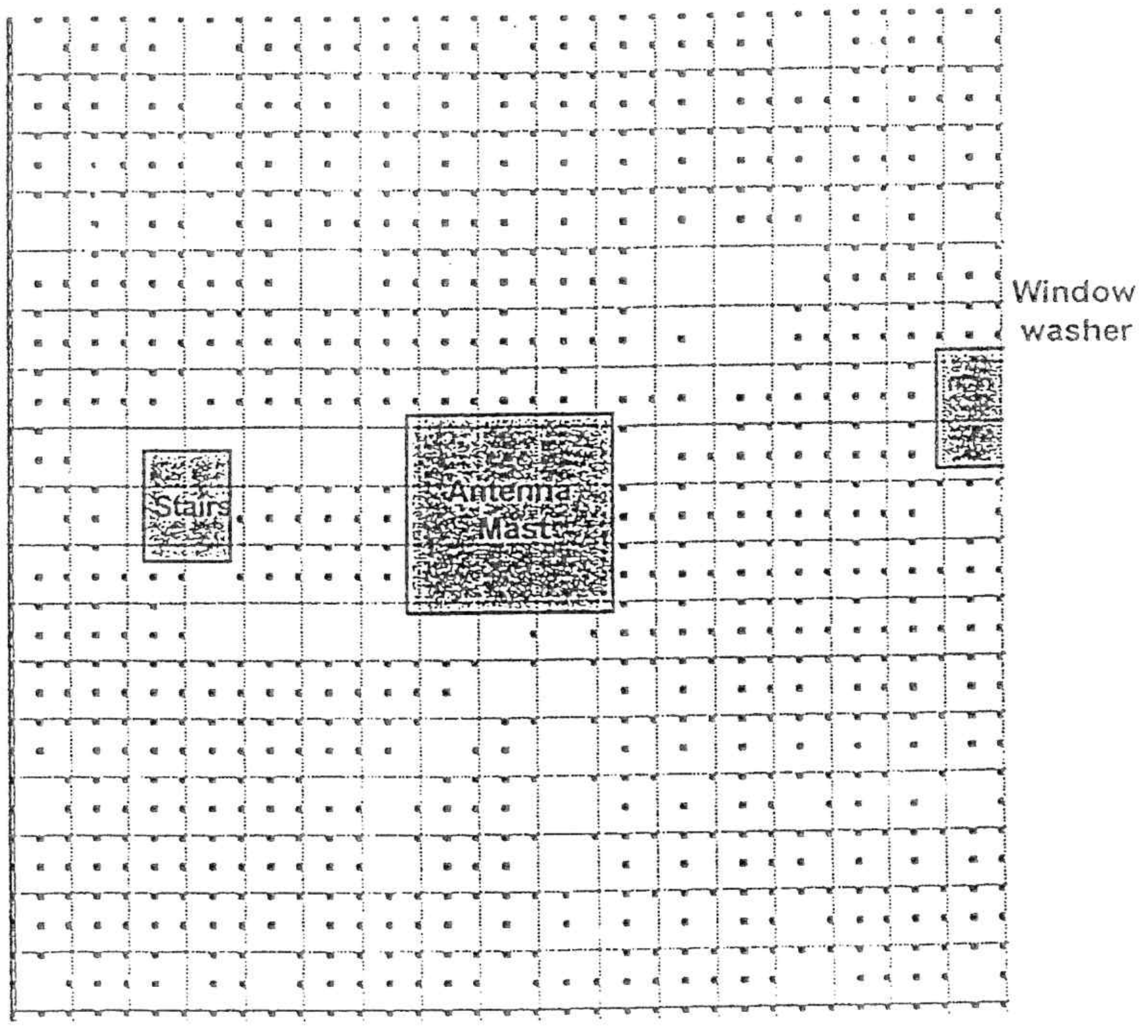


Figure 5. WTC roof map showing the location and distribution of all included 889 measurement points. The overall measurement area was 170 feet by 170 feet with measurement points spaced generally five feet apart except when a point fell within 2.5 feet of an existing roof-mounted antenna or other metallic structure such as cable trays and roof-mounted lights that might perturb the local fields

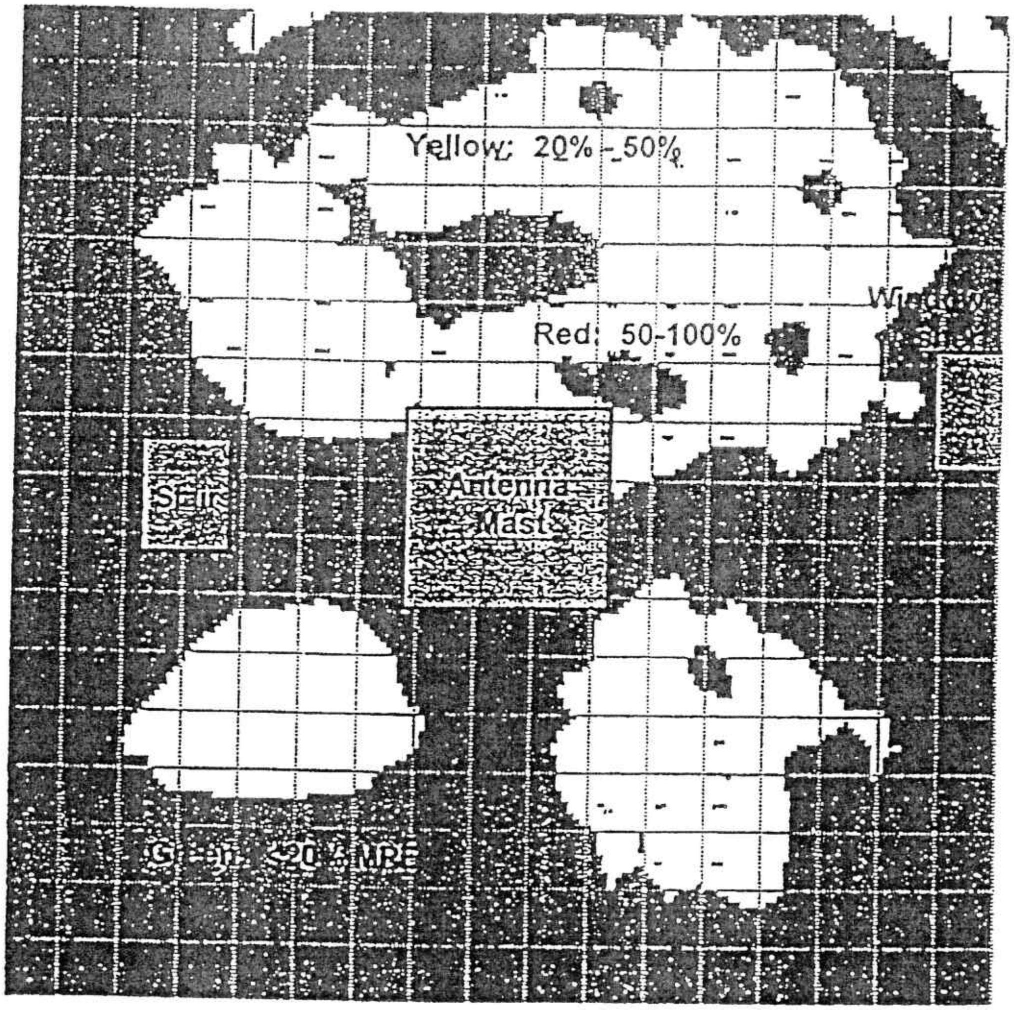


Figure 6. Roof map showing measured ambient RF fields on roof of north tower of World Trade Center during normal broadcast operations with contributions from 72 MHz paging links included Maximum field is 70 2% MPE

Statistical summary of RF Fields on WTC roof (see Figure 6)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	17070	62.75
21-50	9778	35.94
51-100	350	1 31
>100	0	0 00

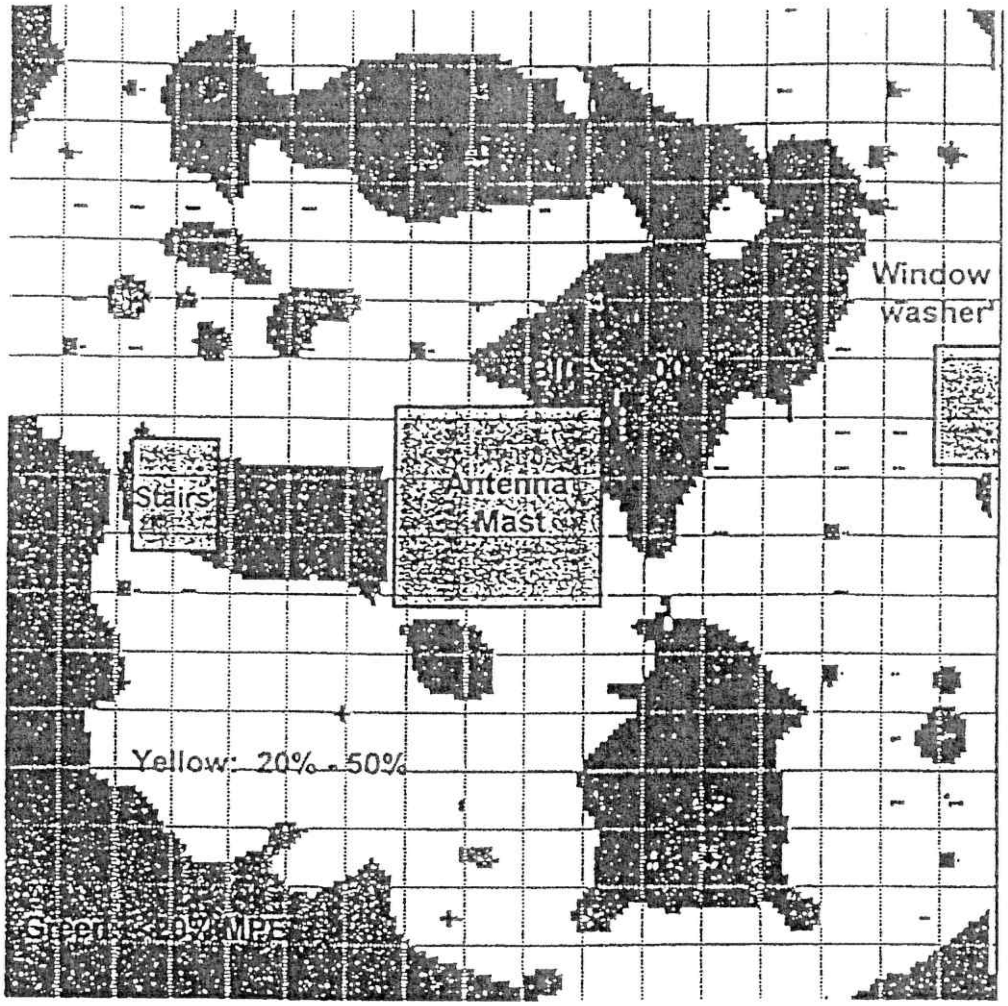


Figure 7. Roof map showing combined RF fields from measured ambient fields of normal broadcasting operations with calculated contribution of all wireless telecommunications antennas. Maximum field is 314 1% MPE

Statistical summary of RF Fields on WTC roof (see Figure 7)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	4502	16.55
21-50	16454	60.48
51-100	5963	21 92
>100	286	1 05

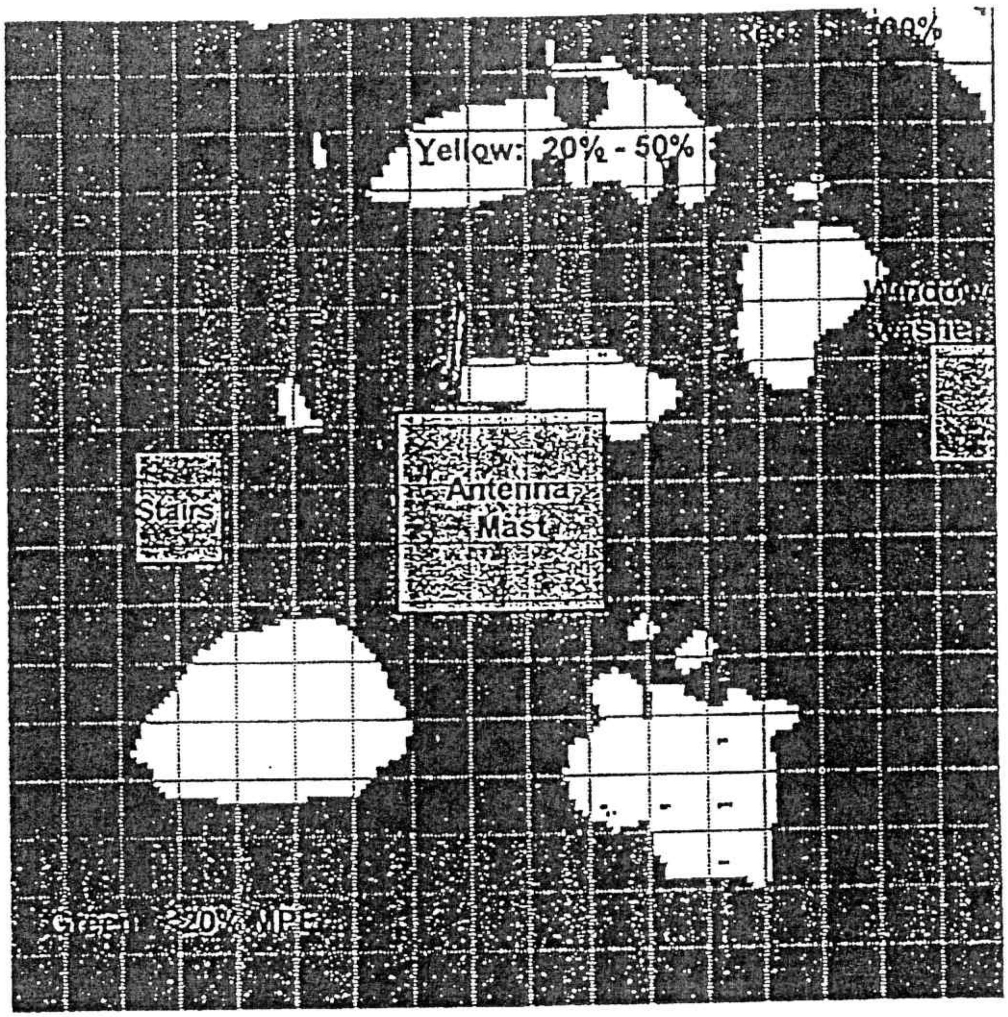


Figure 8. Roof map of normal broadcast ambient RF fields with contribution of 72 MHz paging links removed via analysis with RoofView Maximum field is 56.6% MPE.

Statistical summary of RF Fields on WTC roof (see Figure 8)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	23262	85.51
21-50	3937	14.47
51-100	6	0.02
>100	0	0.00

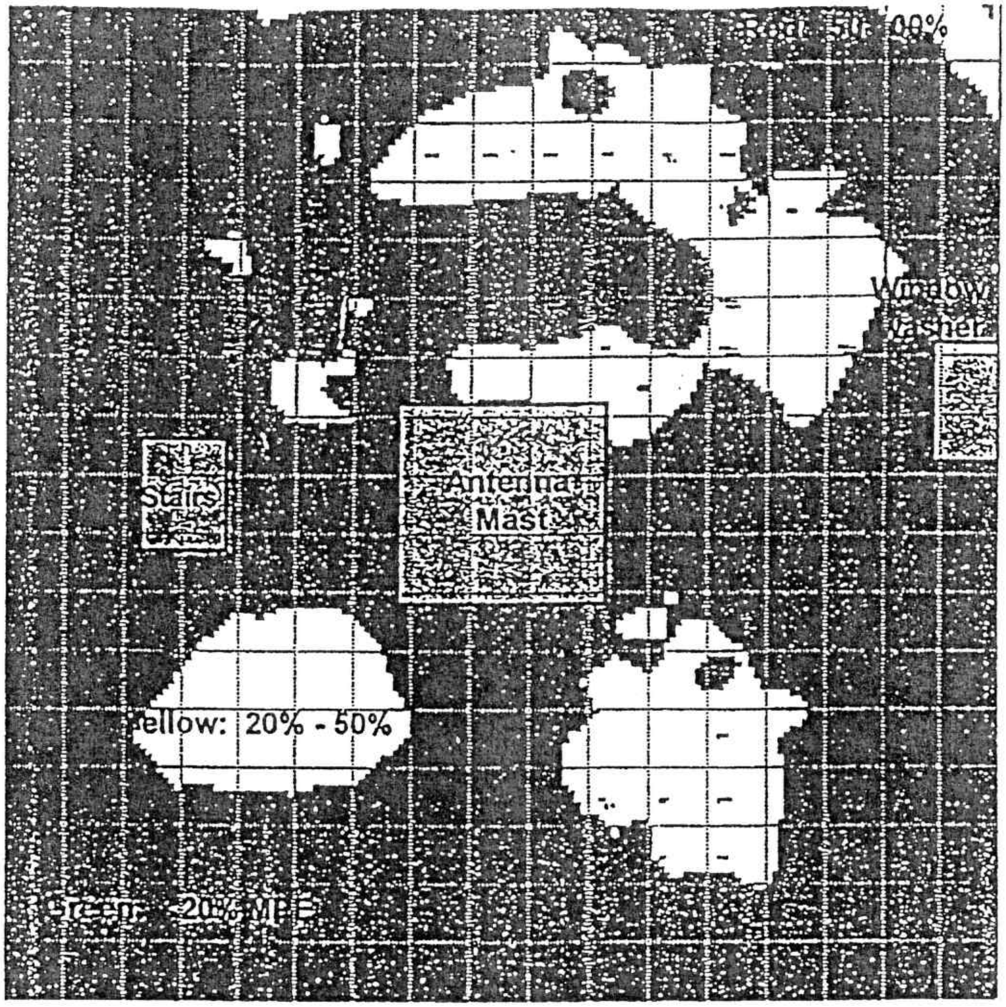


Figure 9. Roof map of RF fields during normal broadcast operations with calculated effect of raising 72 MHz paging links to 6 feet above roof No other wireless antennas active Maximum field is 57 2% MPE

Statistical summary of RF Fields on WTC roof (see Figure 9)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	21878	80 42
21-50	5318	19 55
51-100	9	0 03
>100	0	0 00

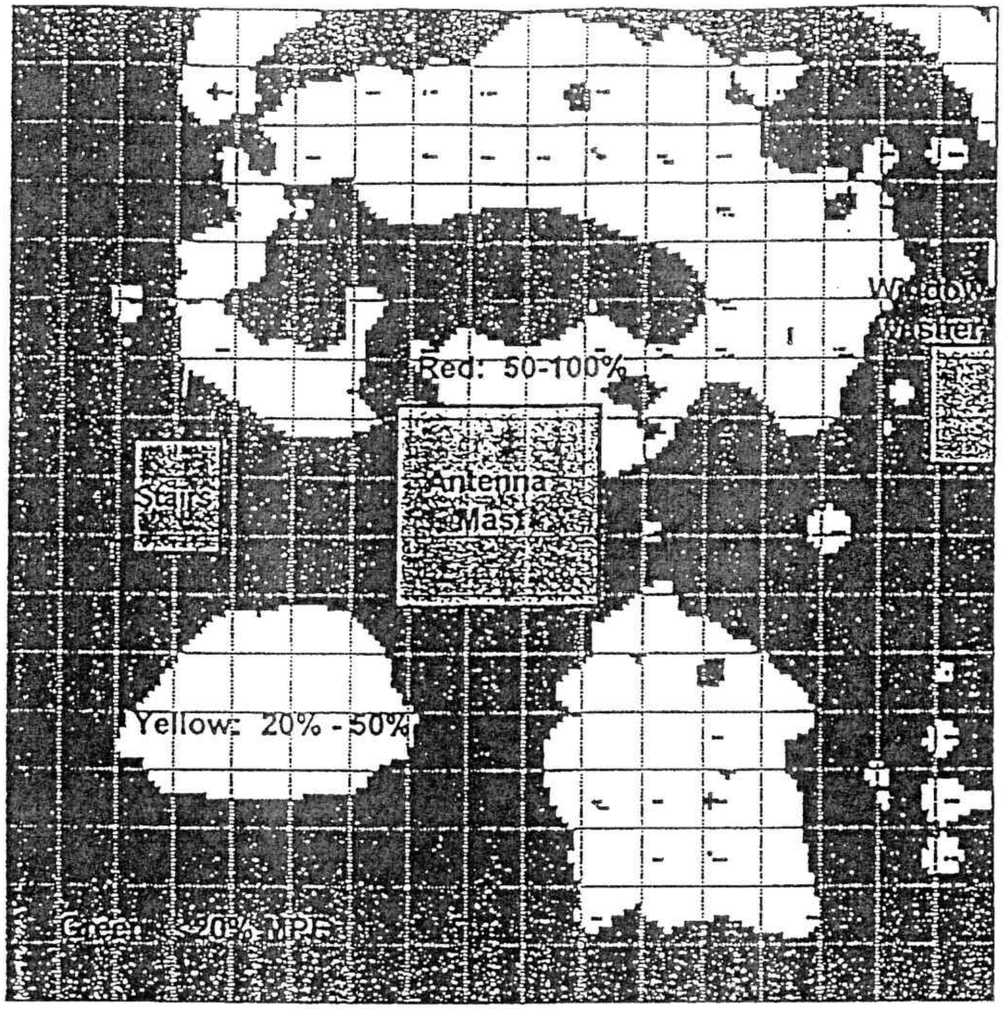


Figure 10. Roof map of RF fields during normal broadcasting operations with calculated effect of raising all wireless antennas to 6 feet above roof level. Maximum field is 67.2% MPE

Statistical summary of RF Fields on WTC roof (see Figure 10)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	18325	67.36
21-50	8794	32.32
51-100	86	0.32
>100	0	0.00

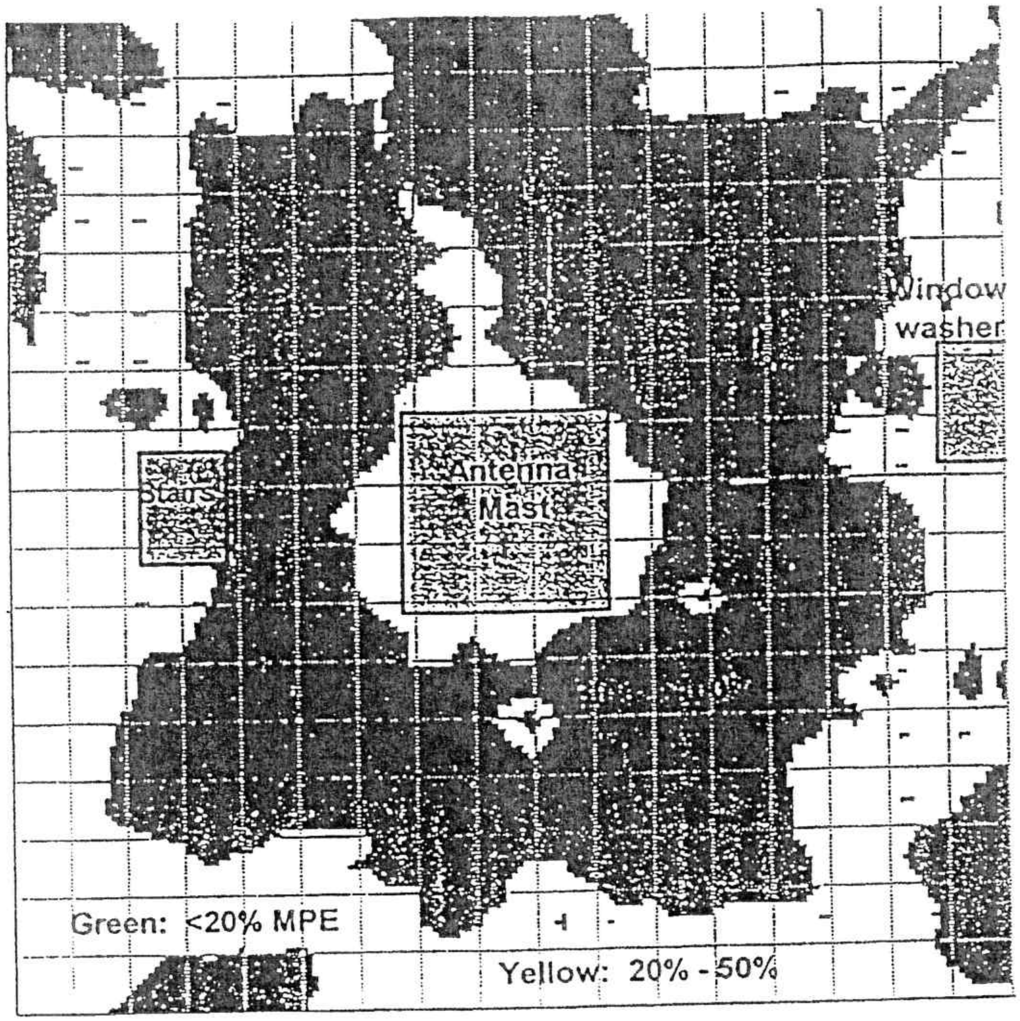


Figure 11. Roof map showing measured ambient RF fields on roof of north tower of World Trade Center during tower maintenance mode of broadcast operations with contributions from 72 MHz paging links included Maximum field is 147.0% MPE.

Statistical summary of RF Fields on WTC roof (see Figure 11)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	1043	3.83
21-50	11728	43.11
51-100	13298	48.88
>100	1136	4 18

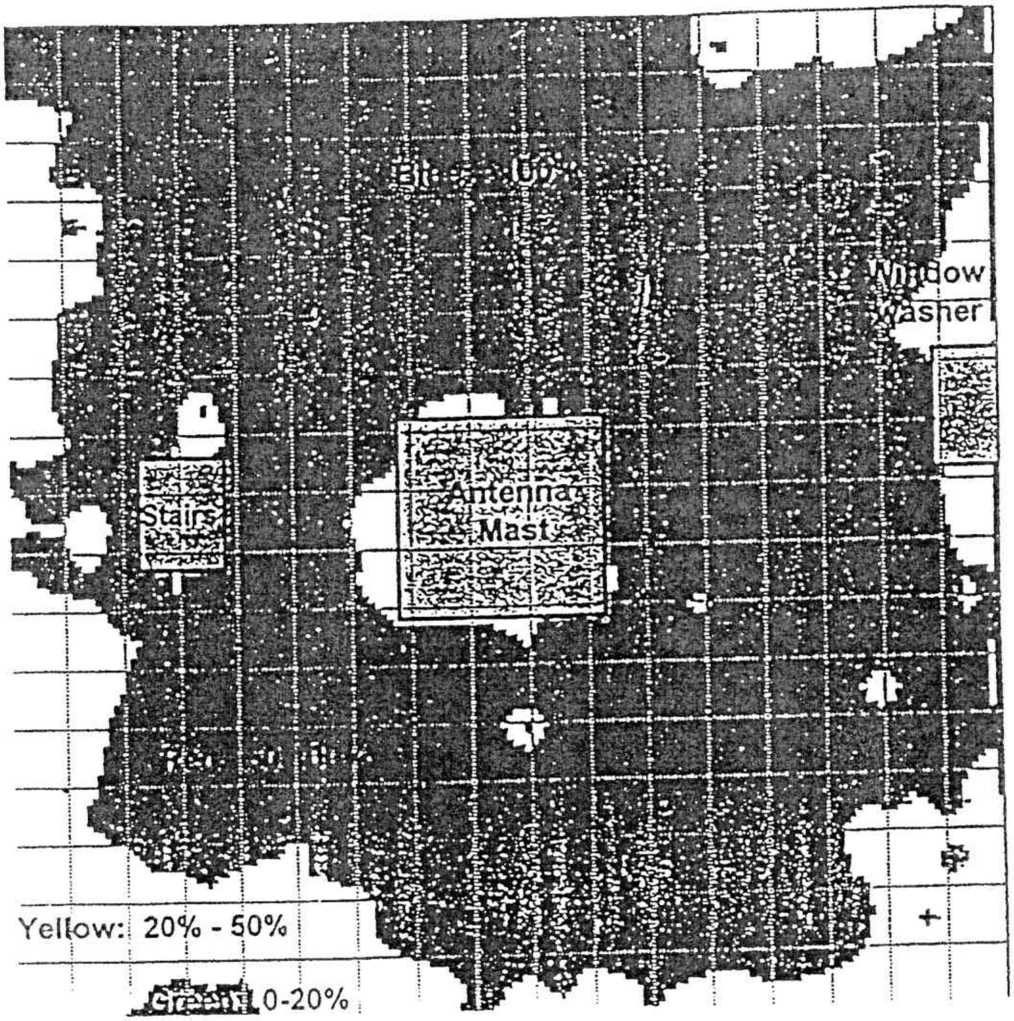


Figure 12. Roof map showing measured ambient RF fields on roof of north tower of World Trade Center during tower maintenance mode of broadcast operations with calculated contributions from all wireless telecommunications antennas included Maximum field is 352% MPE

Statistical summary of RF Fields on WTC roof (see Figure 12)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	130	0.48
21-50	5695	20.93
51-100	16891	62.09
>100	4489	16.50

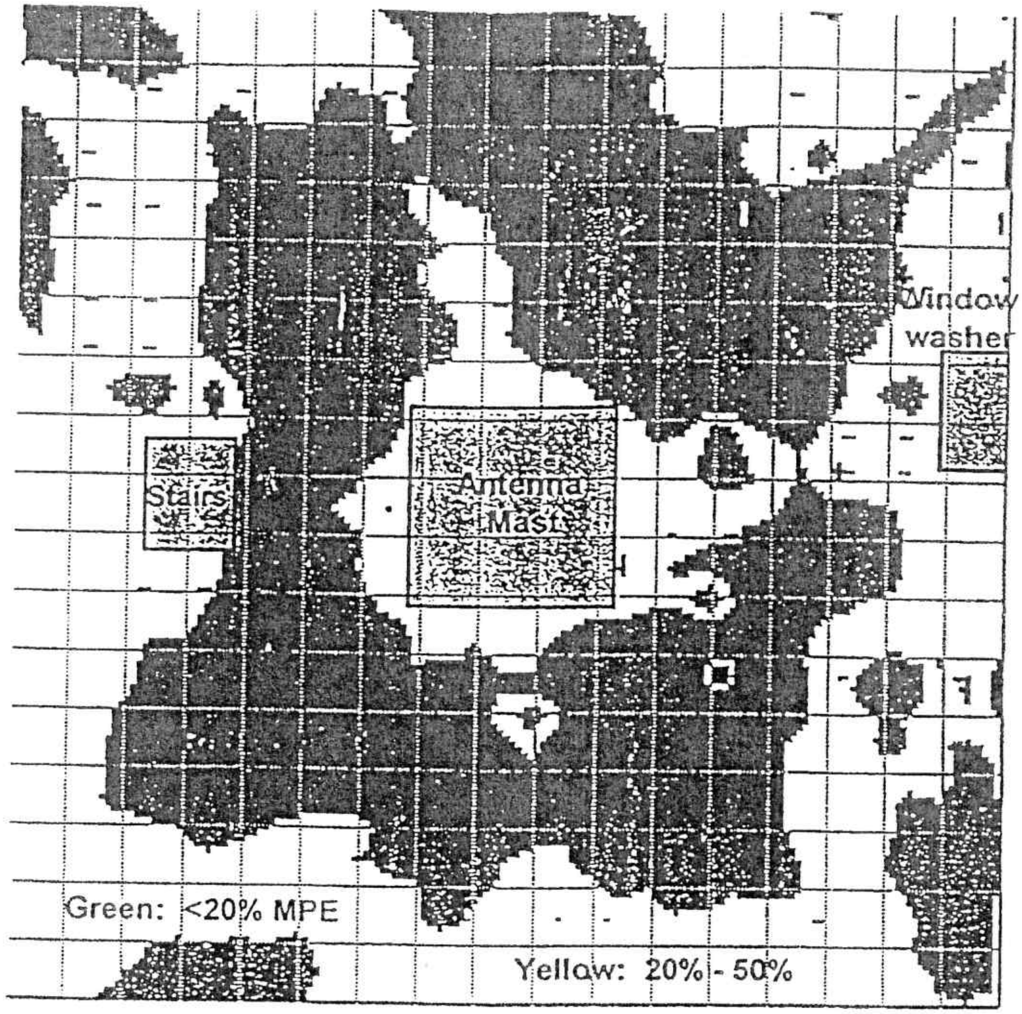


Figure 13. Roof map of RF fields during tower maintenance mode with contribution of 72 MHz paging links removed with RoofView Maximum field is 138.3% MPE.

Statistical summary of RF Fields on WTC roof (see Figure 13)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	1546	5.68
21-50	13108	48.18
51-100	12035	44.24
>100	516	1.90

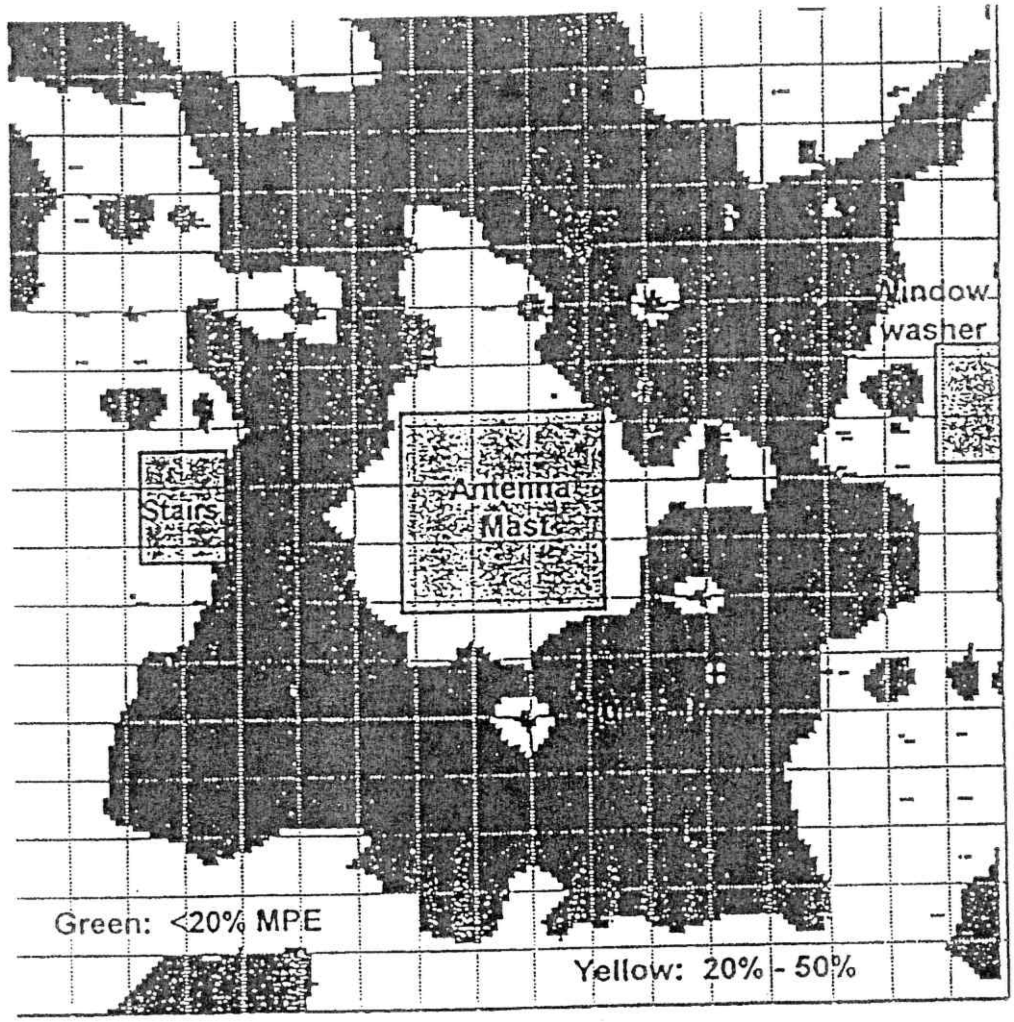


Figure 14. Roof map showing RF fields during broadcast tower maintenance mode with calculated effect of all wireless antennas raised to at least 6 feet above roof
Maximum field is 144.3% MPE

Statistical summary of RF Fields on WTC roof (see Figure 14)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	992	3.65
21-50	12641	46.47
51-100	12879	47.34
>100	693	2.55

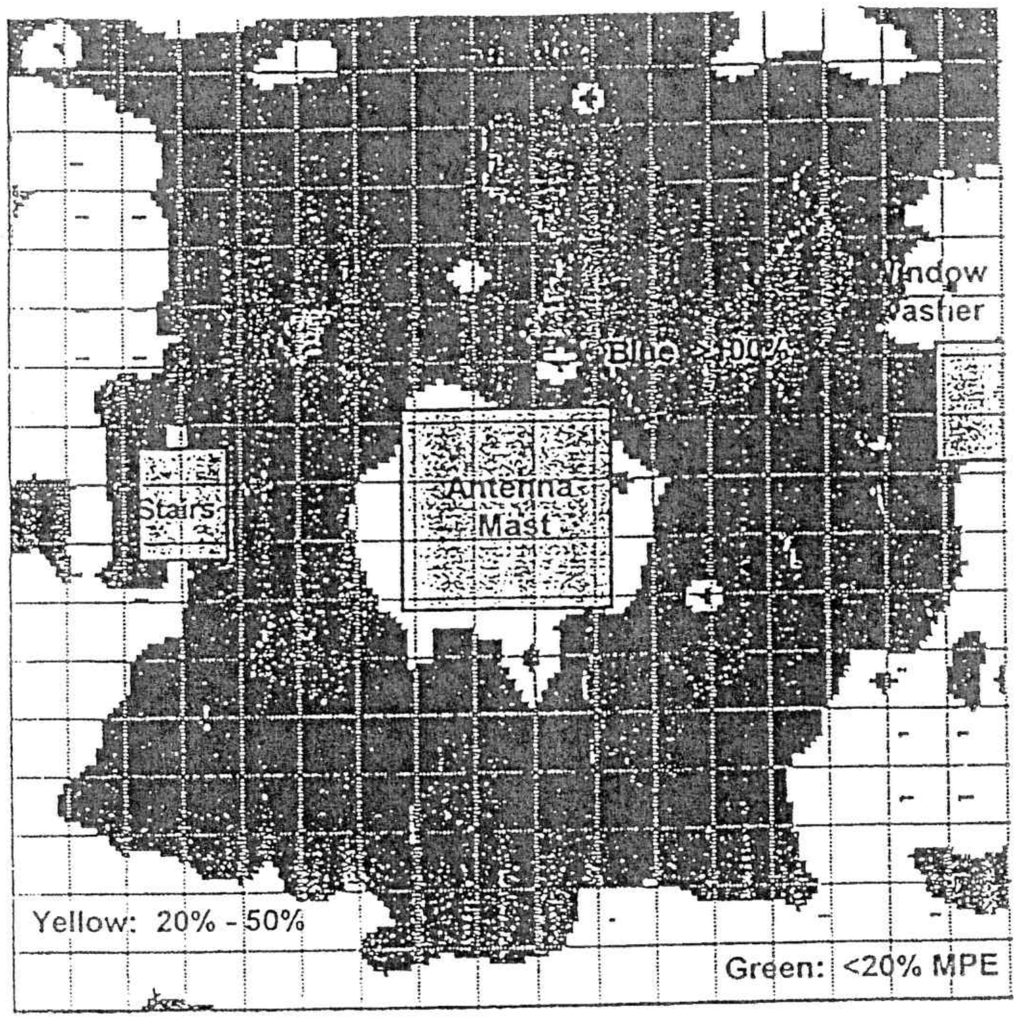


Figure 15. Roof map showing measured ambient RF fields on roof of north tower of World Trade Center during emergency backup broadcast operations with contributions from 72 MHz paging links included. Maximum field is 156 3% MPE

Statistical summary of RF Fields on WTC roof (see Figure 15)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	253	0 93
21-50	8677	31.89
51-100	15694	57 69
>100	2581	9 49

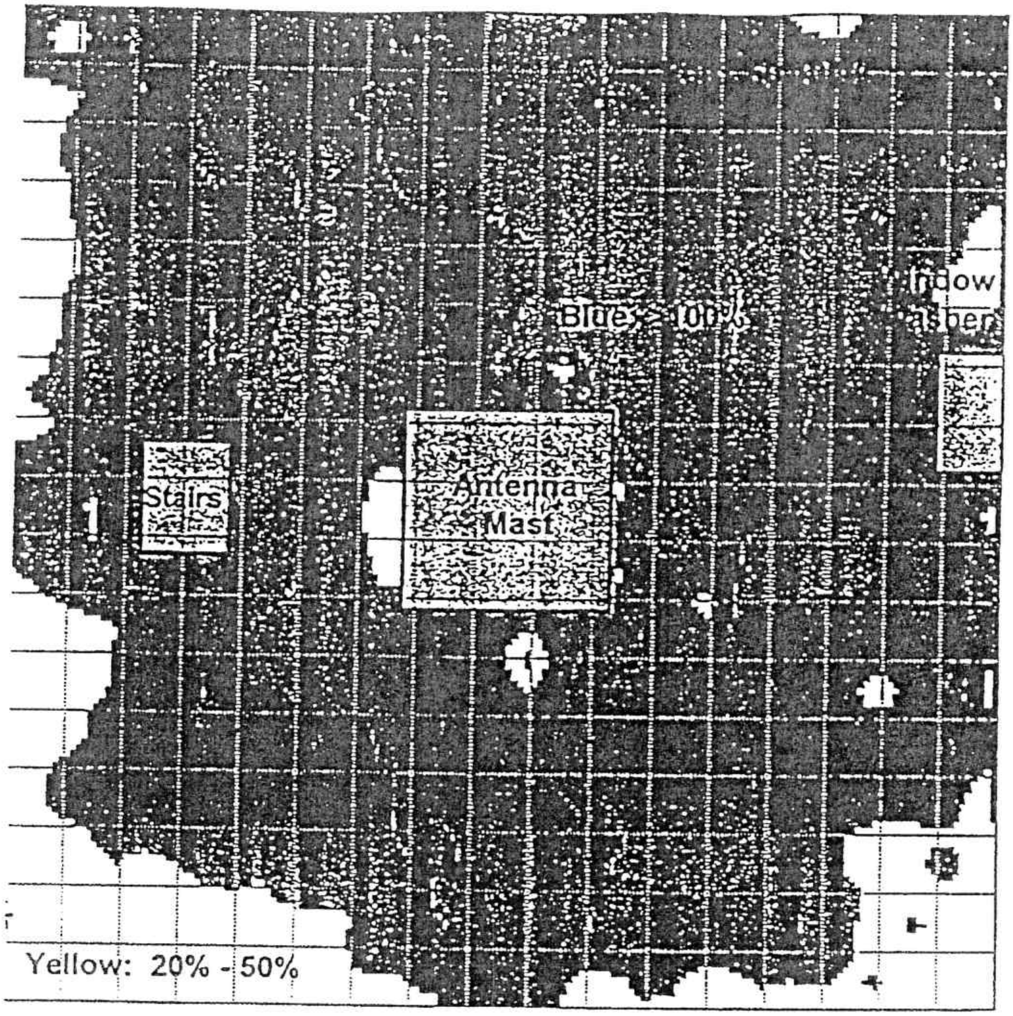


Figure 16. Roof map showing measured ambient RF fields on roof of north tower of World Trade Center during emergency backup broadcast operations with calculated maximum contributions from all wireless telecommunications antennas Maximum field is 373 0% MPE

Statistical summary of RF Fields on WTC roof (see Figure 16)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	3	0 01
21-50	3910	14 37
51-100	16016	58 87
>100	7276	26 75

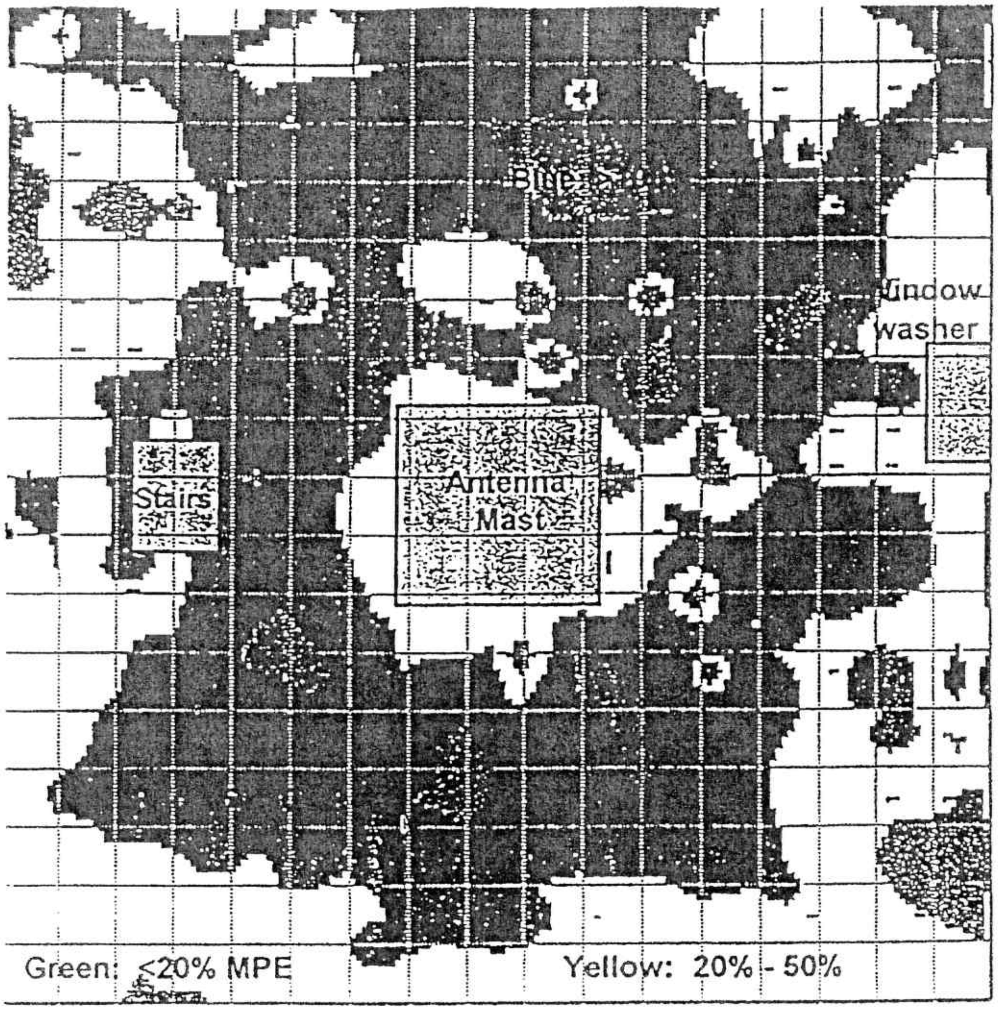


Figure 17. Roof map of emergency backup broadcast ambient RF fields with contribution of 72 MHz paging links removed via analysis with RoofView. Maximum field is 135.2% MPE

Statistical summary of RF Fields on WTC roof (see Figure 17)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	1135	4.17
21-50	11034	40.56
51-100	14148	52.01
>100	888	3.26

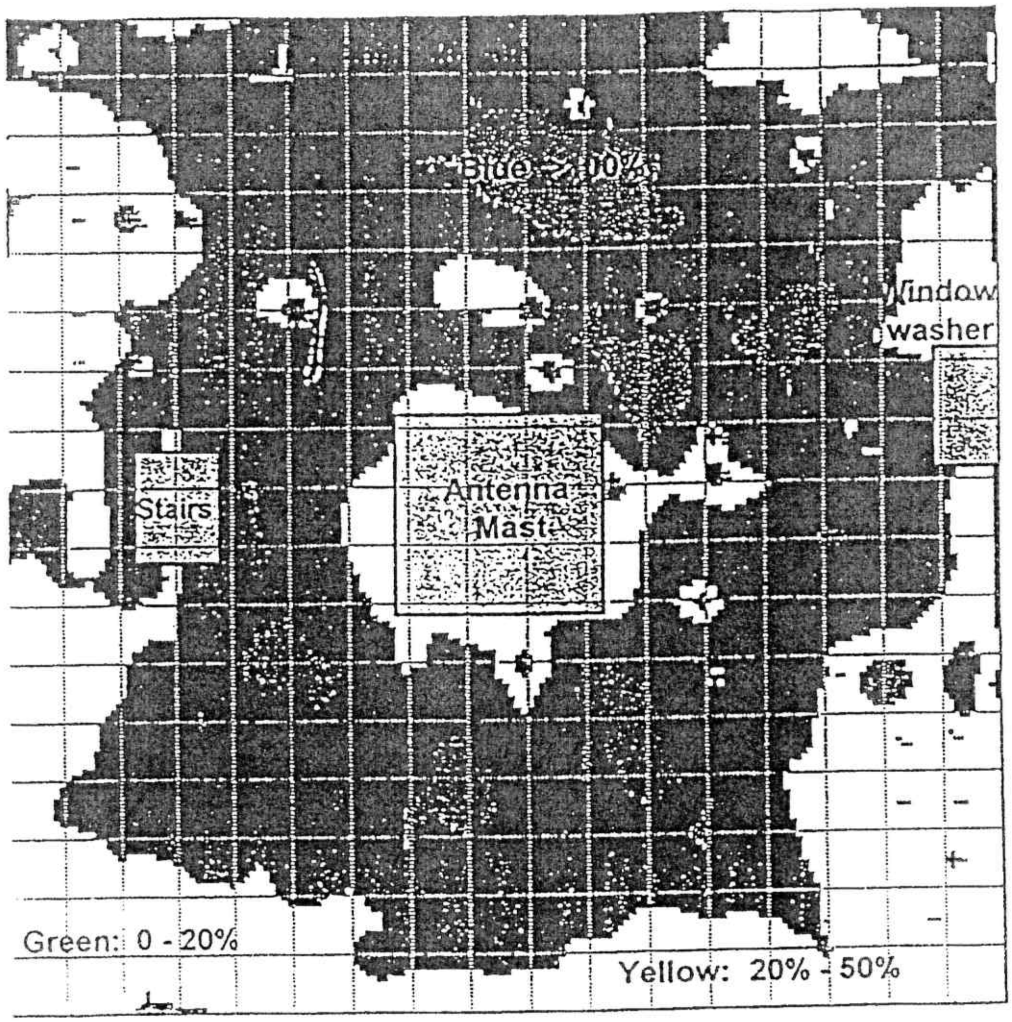


Figure 18. Roof map of RF fields during emergency broadcast backup operations with calculated effect of all wireless antennas raised at least 6 feet above roof level Maximum field is 149 3% MPE

Statistical summary of RF Fields on WTC roof (see Figure 18)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	249	0 92
21-50	9104	33.46
51-100	16151	59 37
>100	1701	6 25

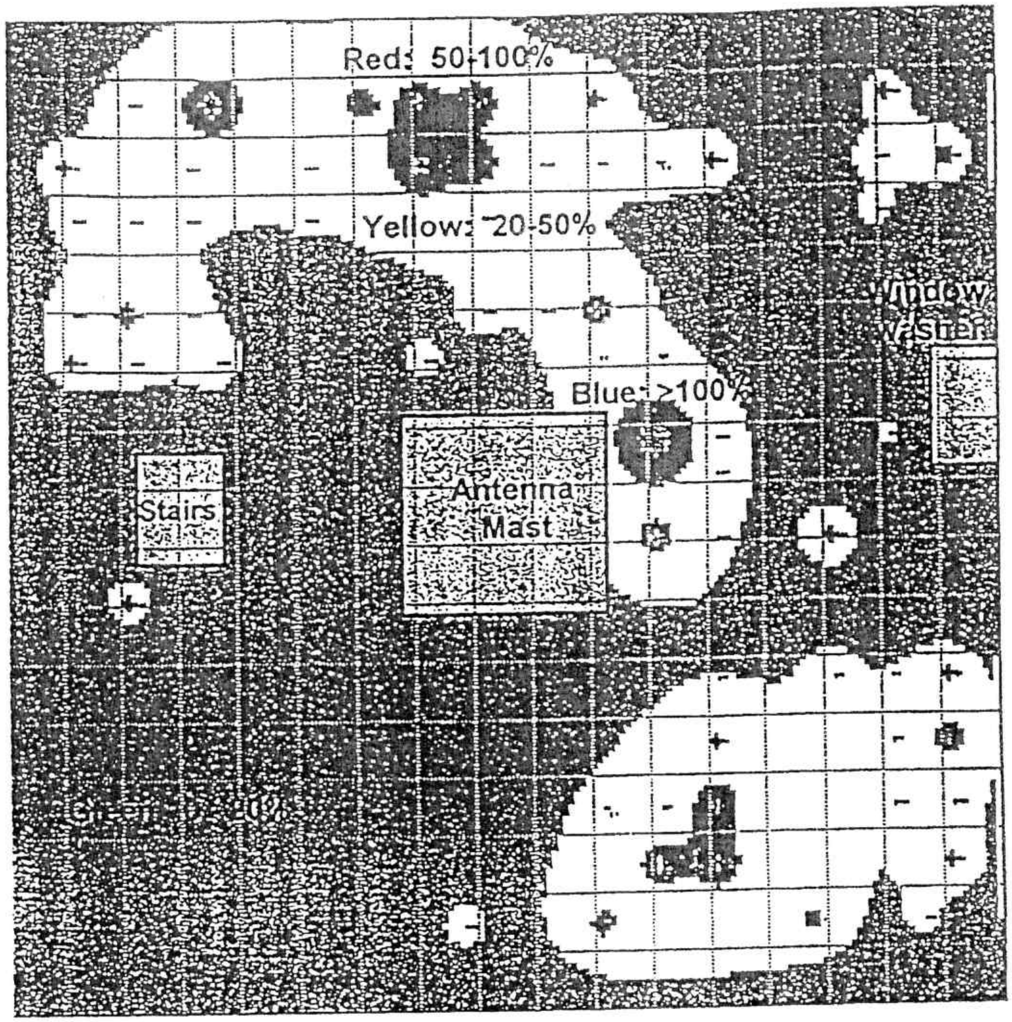


Figure 19. RoofView computed roof map for all wireless telecommunications antennas assumed operating but without contribution of RF fields from any of 72 MHz paging links or any contribution from broadcasting facilities. Maximum field is 273.9% MPE

Statistical summary of RF Fields on WTC roof (see Figure 19)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-20	17324	63.68
21-50	8960	32.94
51-100	833	3.06
>100	88	0.32

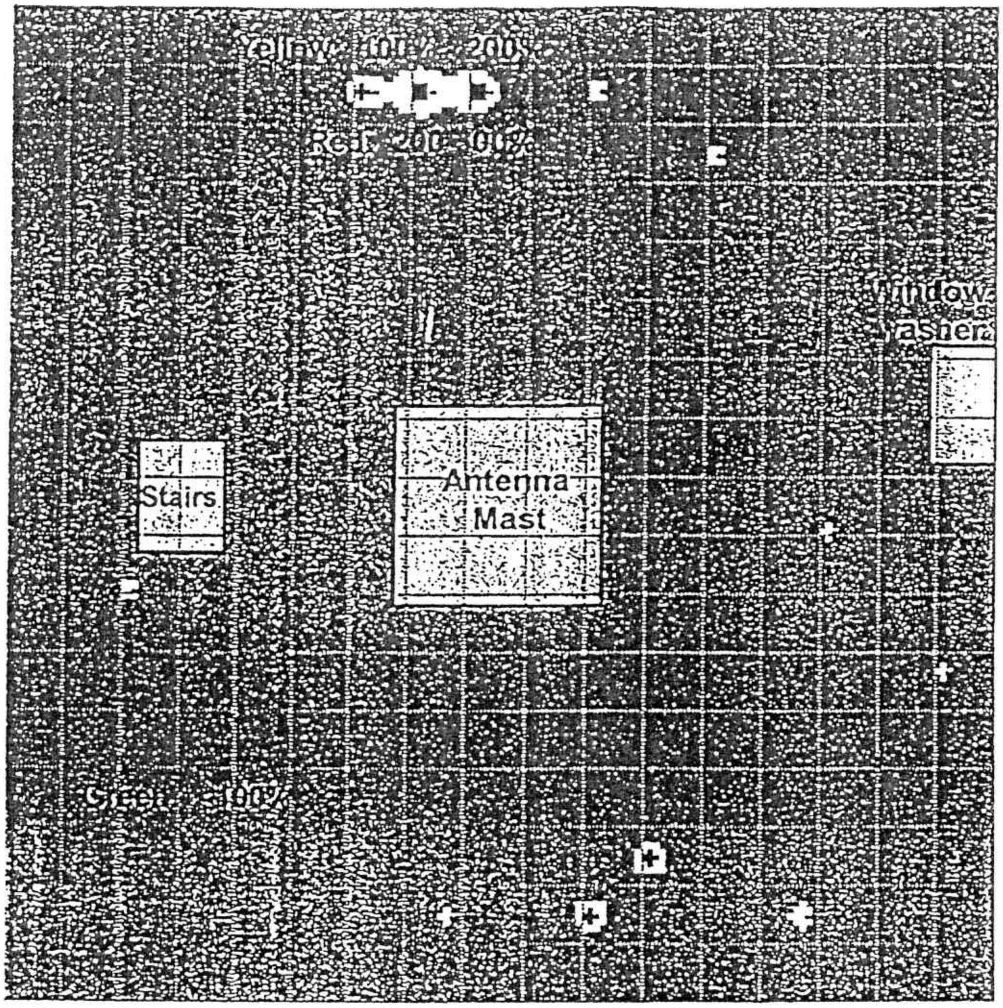


Figure 20. Roof map of calculated spatial peak RF fields from all wireless antennas only operating above 800 MHz Maximum peak field is 276% MPE

Statistical summary of RF Fields on WTC roof (see Figure 20)		
Percent occupational MPE range (%)	Roof area in this range (ft^2)	Percent of roof area in this range (%)
0-100	26956	99 08
101-200	216	0 79
201-300	33	0 12
>300	0	0 00