

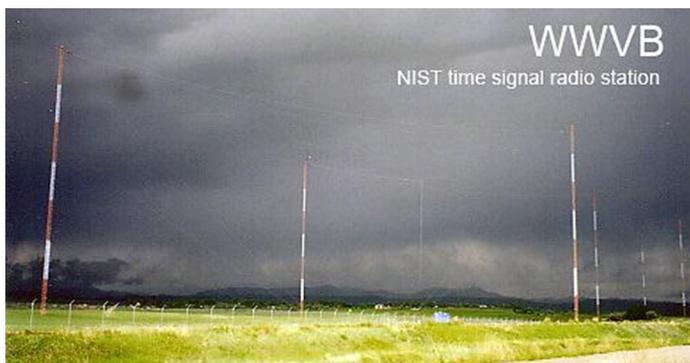
**Carnegie Hall**  
 881 Seventh Ave.  
 New York, NY 10019

## INTRODUCTION

360°RF has performed onsite spectral analysis and 60 kHz RF signal field strength measurements at specified locations within Carnegie Hall. Multiple locations within five rooms were tested for the signal strength of the National Institute of Standards and Technology (NIST) radio signal broadcast at 60 kilohertz for purposes of time-synchronization of clocks, watches and other types of time-keeping equipment.

The five rooms measured were:

- Citi Café, on the Parquet Level;
- Rohatyn Room on the First Tier Level;
- Jacob’s Room;
- Box Office Lobby, outside the ticket windows; and
- The Parterre Bar in Zankel Hall.



<b>Station</b>	WWVB
<b>Frequency</b>	60 kHz
<b>Transmitting power</b>	50 kW
<b>Location</b>	Fort Collins, CO
<b>Geographical coordinates</b>	40° 40' N, 105° 03' W
<b>Modulation</b>	69%

## Equipment and Measurement Procedure

For these measurements at 60 kHz, 360°RF utilized a special test fixture containing a Balanced Active Dipole, with an up-converter to 50 MHz with which the up-converted received 60 kHz signal could be measured and analyzed. The spectral analysis tool is a Hewlett-Packard 8569A spectrum analyzer. A secondary tool used for audio analysis is a Kenwood TS-680S radio.<sup>1</sup> In addition, an Aaronia HF-6085 V5 spectrum analyzer is used as a backup analyzer. This equipment affords clear reception of radio station WWVB, transmitting from Ft. Collins, Colorado in eastern Connecticut as well as a weaker but discernable signal in Yonkers, New York (approximately 15 miles north of Carnegie Hall itself).

The antenna is normally oriented horizontally but can be erected vertically where necessary to localize or alleviate local noise issues. In Carnegie Hall, the high-impedance dipole antenna was situated horizontally due to the relatively low ceiling height and close proximity of room ceilings to the antenna elements.

<sup>1</sup> Radio was used for audible confirmation of the WWVB broadcast within the detected 60 kHz signals, and for identification of analyzer detected noise.

## Desired Signal

Radio station WWVB, operated by the U.S. government as part of NIST, broadcasts a specially-modulated signal at 60 kHz for the purpose of providing synchronization signals for time-keeping pieces, as well as a frequency standard. The time information is presented by amplitude-modulation (called Amplitude-Shift-Keying) of the transmitted carrier using a time code called IRIG "H". The timing of this code, as well as the carrier frequency of the transmitter itself, is derived from a set of highly-accurate atomic clocks at the transmitter facility in Colorado. The carrier level is shifted by 17 dB, or from 100% down to about 2% to start each second. Thus, audible reception of WWVB would present a once-per-second "ticking" noise. When demodulated with a receiver using a beat frequency oscillator, the ASK-modulated signal greatly resembles Morse code.

The fact that the time code signal is derived from atomic clocks gives rise to the name "Atomic clock" applied to most radio-synched clocks, now widely available around the world. WWVB is not the only radio station transmitting time-keeping signals; within the Very Low Frequency (VLF) range, there are also MSF in the UK (also transmitting on 60 kHz but with a different form of modulation), DSF77 in Germany (77.5 kHz), and JJY in Japan (40 and 60 kHz). There are also a series of stations broadcasting other types of time and frequency-standard signals within the shortwave High Frequency (HF) bands at 2.5, 5.0, 10.0, 15.0, 20.0, 25.0 (all MHz), and other frequencies, including several in Canada such as CHU on 3.330, 7.850 and 14.670 MHz. Some of these HF stations broadcast time-code modulated signals as well as audio time and atmospheric propagation announcements.

The WWVB signal is fairly strong throughout most of the western and central United States, Canada and Mexico, but does present some challenges for many locations along the east coast, US. As well, many of today's electronic appliances including the ubiquitous "wall warts" used to recharge the batteries of cell phones and other equipment, TVs, cash registers, Uninterruptable Power Supplies (UPS) for computers, light dimmers, and even electronic fluorescent lamp ballasts generate signals that can override that of WWVB.

## Signal Propagation

Shortwave and higher frequency signals tend to bounce off a layer of electrons in the upper atmosphere (85 to 600 km altitude) called the ionosphere. VLF signals though, such as the 60 kHz signal from WWVB, tend to propagate along the ground in what is called a ground wave. This reduces distortion as well as attenuation of VLF signals since they don't bounce so readily from the ionosphere. Long wave signals tend to propagate further during darkness, which is why most Atomic clocks using such VLF signals for synchronization are programmed to attempt time synchronization typically at midnight or 3 AM local time. Along the U.S. east coast, the signal from WWVB can be fairly strong but local interference signals such as those from computerized equipment mentioned earlier, as well as electrical noise from power lines, motors, etc. can overpower the WWVB signals.

Atomic clocks use a very small antenna relative to the 60 kHz wavelength, and it is sometimes possible to mount the clock in a different position within a room such that there is less noise pickup; for example, turning the clock 90° might provide a better Signal-to-Noise Ratio (SNR) of the WWVB signal compared to the noise source. In addition, the small antenna can also be greatly affected by proximity to metal in the vicinity of the clock. Simply moving the clock several feet one direction or another can thus also improve the SNR sufficiently that synchronization is accomplished.

Once started by inserting the batteries, most Atomic clocks will attempt synchronization within several minutes. It can take many minutes for a clock to accomplish synchronization, however.

If synchronization is not accomplished, the clock might try again in an hour, and might continue to try synchronization several times before stopping. The user manual should describe how the clock performs synchronization. To reduce battery drain, most atomic clocks are programmed to stop synchronization attempts after a certain number of failures, in which case they should be set manually.

If the time signal has a poor SNR, it is possible for the clock to perform a partial synchronization and display the wrong time; for example, some such clocks will display the time exactly one hour slow or fast.

## Measurement Results

The following describes the results of our measurements within each room. In each case, the most desirable location for a clock was investigated first, and then possible secondary locations were measured. In several rooms, measurements were performed in undesirable locations to attempt to pinpoint the source or locations of interfering signals or noise, such as near the Parterre Bar in Zankel Hall.

Measurement locations and results are annotated on floor plan drawings included at the end of this report. Results are generally shown in an RF signal level called dBm, or decibels above one milliwatt. Note that the results are expressed with a minus sign before the number, meaning, for example, -60 dBm. The more positive this number, the stronger or higher the noise level or signal strength; for example, -55 dBm would be a signal that is 5 dB stronger than -60 dBm. An increase of 3 dB is a doubling of signal strength.

The ideal clock locations are where the noise level is most negative, and where there is a discernible 60 kHz signal. For example, near the wall between windows in a small room off the Rohatyn Room of the First Tier, a location was found that seemed fairly quiet at -110 dBm; this location did not seem to suffer from measureable noise, although it is uncertain that the WWVB signal, which would arrive from the west (in the direction of Colorado) would penetrate the building or windows sufficiently strong as to be decodable since this wall is on the northern side of the building.

### Parquet Level, Citi Café

It was desired to place a clock on the wall over the main bar in the center of the room. When high noise levels were found in this location, measurements were then performed at the satellite bars at each end of the room, as well as between the double doors opposite the main bar.

360°RF measured a very high noise level near and over the main bar, at least some of which was found to be produced by a Uninterruptible Power Supply (UPS) used with the two cash register terminals (Carnegie Hall staff turned off the UPS and much of the randomly-sweeping noise went away). The UPS produced a strong, raspy signal that swept across the 60 kHz frequency spectrum which would likely be many times stronger than the signal from WWVB.

The wall above each of the two mini-bars also demonstrated substantial noise levels (both somewhat higher than the main bar), but in their case the noise is thought to be generated by what appeared to be fluorescent lamps embedded in the decorative trimming above the bar counters. Neither appeared to be promising locations for an “Atomic clock.” The center wall between the double doors did not appear to be a reasonable location for such a clock due to wall trimming and decorations, but was measured and found to be nearly as noisy as either mini-bar.

The ceiling of this room appears to have at least some Compact Fluorescent Lamps (CFLs) which may contain electronic circuitry operating at or near the same frequency as WWVB at 60 kHz. This kind of circuitry normally produces broadband noise which can prevent reception of weak signals over a wide range of frequencies from VLF through the upper shortwave bands.

The following images show several of the measurement locations.



Above Left: Measurement location 1 at center of main bar. The UPS is almost directly below the antenna, sitting under the bar counter. Right: Location 3 in front of one minibar.

Below: Location 2 in front of other minibar at other end of room.



**Tier Level 1, Rohatyn Room**  
Measurements were first taken inside a small room with windows overlooking the street, then in two other locations within the Rohatyn room itself.

The center of the wall in between windows in the small room appeared to be fairly quiet, with no discernable power line noise or computer noise. The noise level appeared to be about -110 dBm and in fact, the WWVB signal appeared to be very faintly audible. This wall location, however, is on the

north side of the building and the WWVB signal has to either penetrate the building or come through the windows; thus, it is not clear that the signal will be strong enough to synchronize an Atomic clock. Inside the Rohatyn room itself, two additional locations were tested; both were found to be extremely noisy at about -60 and -55 dBm. This noise appears to be either from power line disturbances (which are generally caused by arcing high voltage insulators or across other high voltage leakage paths), or possibly dimmers used for the overhead lighting.



Left: Center of north wall in small room off the Rohatyn Room; the measurement dipole antenna can barely be seen in the center top portion of the image. This location was found to be among the quietest measured throughout the entire Carnegie Hall.

Below: Rohatyn Room, north wall just outside the small room above. This location was found to be extremely noisy with strong electrical noise, possibly produced by the CFL lights in the ceiling above. In addition, these lights are thought to be dimmable; such light dimmers often are strong generators of this type of electrical noise. The portable air conditioners in this room should not be a problem.

Additional measurements were taken near the location of the camera for the image at right (Location 2) but again, the electrical noise level was found to be very strong.



Note that any location where the noise was lower than about  $-60$  dBm, 360°RF attempted to audibly confirm presence of the WWVB broadcast. However, only in the Rohatyn Room was the broadcast thought to have been detected.

## Jacob's Room

Jacob's Room has large open windows facing the street, but the room is also on the north side of the building. The most desirable clock location within this room appeared to be on an east wall, shown below. However, this wall also has inset decorative metal trim which could detune or otherwise affect an Atomic clock's internal antenna. If such a clock were to be placed on this wall, it should ideally be located at least several inches from the metal trim, such as far up the wall seen in the following photo. This location was very quiet at about -110 dBm.

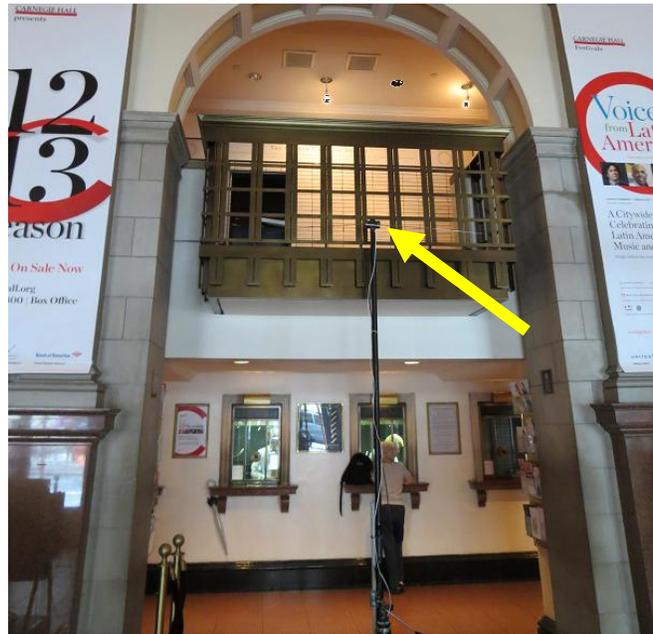
A second desirable location might be above the TV set seen above the minibar below. However, in addition to the close proximity of the TV set itself, which could conceivably internally generate interfering noise that prevents the clock from synchronizing properly, the noise level was measured at -60 dBm, likely far too high for reception of WWVB. No other locations within Jacob's room appeared to be suitable for a clock.



## Box Office Lobby

Two locations within the Box Office Lobby were measured; both were found to have fairly quiet noise levels, but this lobby is on the north side of the building at ground level and so might not produce a sufficiently-strong signal level. The Box Office Lobby measurement locations, which were next to one another, are shown below.

Location 2 simulates the Atomic clock being mounted on the latticework of the center balcony, while location 1 is close to the support column. Location 2 showed a noise level of only  $-98$  dBm while location 1 measured  $-95$  dBm. A potential issue might occur if the latticework seen on the balcony face is actually metal, as this would certainly detune the antenna as well as block radio signals.



## Parterre Bar, Zankel Hall

The measurement engineer was told that Zankel Hall is actually underground; however, this might not make much difference since WWVB signals mainly propagate via ground wave. Measurements were undertaken at five locations near the Parterre Bar, of which four are shown below.

The view shown at left, faces the bar proper. The measurement antenna was located behind the counter just below the ceiling of the archway. This location proved to be the noisiest measured within all of Carnegie Hall at about  $-20$  dBm, with continuously sweeping signals across the entire VLF band.

Location 2 is in front of the bar at the wall (near the camera location for the previous image), and measured  $-65$  dBm. The extremely strong signals at location 1 may have been generated by, again, light dimmers for the overhead ceiling lighting since the noise seemed to be strongest next to the alcove seen above for liquor stock where the light dimmers may be located.



This first image was taken with the camera to the right of Parterre Bar, measuring the signal level next to the immediate-leftmost column. This is location 3 and the signal level was about  $-95$  dBm, fairly quiet. However, this is the east face of the column and so the WWVB signal would have to penetrate both underground somewhat, as well as go through the column.

This center image shows measurement location 4, which is the small alcove to the right of the column seen above, behind the measurement instruments.

This location had a noise level of just  $-110$  dBm, but suffers the same potential disadvantages as location 3 above.



The image to the left shows location 5, which is where the first image of the bar was taken. This location showed a noise level of only  $-90$  dBm, but appears to be a fairly poor location for a clock, since the clock would have very limited visibility.

## Conclusion

360°RF has performed a number of measurements within various rooms at Carnegie Hall with the aim to find potential locations where an Atomic clock might be able to synchronize to time signals. However, most of those locations were found to be afflicted with high electrical noise levels, with only a few potentially being quiet enough as to permit reception of the generally weak WWVB signals in the area.

Much of the electrical noise appears to be from either high voltage arcing or, more likely, from solid state light dimmers, of which there are many within Carnegie Hall. There is no effective way to filter out this noise since it is generated directly on the same frequency as the desired radio signals transmitted by NIST radio time standard station WWVB on 60 kHz. These quieter locations were noted in the preceding description and are shown on the following floor plans as well, and should present the best possibility of usable reception and synchronization to WWVB.

The following pages present floor plans of each of the five rooms, showing approximate locations of the measurement antenna as well as measured noise or signal level. The plans should be considered approximate since different furniture or features may be installed within each room at any give time. No floor plan was available for the Box Office Lobby so what is shown herein is drawn from the best recollection of 360°'s measurement engineer.

