MEASUREMENT OF VHF SIGNAL STRENGTH FOR TERRESTRIAL BROADCAST SERVICE IN MINNA, NORTH CENTRAL NIGERIA

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Abstract

Preliminary calculations including the expected signal strength at the receiver is required for the design of a radio communication system in order to predict the behaviour of the radio signal. Signal strength measurement was made from a broadcasting station transmitting at a frequency of 91.2 MHz along a 7.15 Km path. Results from the experiment reveal that received signal strength (RSS) values were higher during the wet season as compared to lower values recorded during the dry season for the link. Also, the RSS was higher during the morning and evening/night hours while lower values were recorded during the afternoon time. Signal attenuation caused by atmospheric and environmental losses was calculated and for the dry season, average clear-air attenuation fluctuated between -1 dB to 0.6 dB while wet season values fluctuated between -1.5 dB and 0.9 dB. Also, the RSS was modeled using ITU-R P.526-12 to predict path losses due to diffraction over the earth's curvature and result obtained show that this model underestimated the RSS for the radio link while 4 (0.22%) corresponded to cases of enhanced field strength out of the measured 1777 field strength data.

Keywords: Signal strength, Attenuation, Diffraction

Introduction

Radio broadcasting is the transmission of electromagnetic waves of audible program material through radio-frequency for direct reception by the general public. The electromagnetic wave is made to propagate from a transmitting antenna to a receiving antenna by modifying the amplitude, frequency, or relative phase of the wave in response to some message signal usually in the form of voice or music (Anderson, 2014).

A radio broadcasting service is usually planned in the very high frequency (VHF) band so that a satisfactory service would be provided within a defined coverage zone. Such intended coverage zone might be a town and its immediate surroundings. A service that is termed 'satisfactory' may be defined by specifying the received field strength to be equal to or greater than a certain value at a given percentage of locations within the intended coverage area, for a specified percentage of time (Aboaba, 2015).

The daily changes of water vapour in the troposphere and the ionization by the sun in the ionosphere affect radio propagation. Practical applications from the understanding of the effects of these varying conditions on radio propagation abound, from choosing frequencies for international shortwave broadcasters, designing efficient mobile telephone systems, radio navigation to radar systems operation. Radio propagation is also affected by a number of other factors determined by its path from one point to the other (Hall & Barclay, 1991). The path can be a direct line-of-sight path or over-the-horizon path aided by refraction in the atmosphere. For most communication links, the presence of the earth, the atmosphere, the ionosphere, atmospheric hydrometeors such as raindrops, snow and hail modifies the signal propagation. The natural environment has an influence on the propagation of radio waves and this influence is highly dependent on the frequency used, the directivity of the antennas involved and the proximity of the antennas to the ground. The physical nature of the intervening path may also have a significant effect on the propagation of radio waves since propagation over land is different from propagation over water, which is also different from propagation over heavy vegetation or over urbanised areas where tall buildings produce different scattering and diffraction effects (Collin, 1985). Since radio waves are a form of electromagnetic radiation, like light waves, when they travel, they interact with objects and the media in which they travel. As a result, they are affected by the phenomena of reflection, refraction, diffraction, absorption, polarisation and scattering (Paris & Hurd, 1969).

In order to achieve a reliable and efficient communication between a transmitter and a receiver, knowledge of the spatial and temporal variability of field strength is required. Where the user expects a very high quality signal, especially in broadcast applications, this assumes greater significance. Also the performance of any communication circuit depends on the models employed to calculate the coverage area and interference problems (Prasad *et al.*, 2006). In the VHF and UHF (ultra high frequency) bands, field strength prediction takes account of the effects of the refractive nature of the atmosphere and of the terrain in the vicinity of the transmitter and receiver. Allowance is also made for location variability for prediction of land area coverage, with account taken of local clutter surrounding the receiver (Grosskopf, 2007). Moreover, the diurnal and seasonal variations between actual values of field strength and the predicted values may be caused by variations in atmospheric conditions. Such variations can result in marked increases (or decreases) in field strength over a period of several hours or even several days, and more permanent variations can arise when the radio refractivity gradient of the atmosphere varies markedly from the normal values to which the propagation curve relates (Australian Broadcasting Handbook, 2004).

Relevant Theory

The power flux per unit area P_a (W/m^2) at a distance r (m) from a loss free isotropic antenna radiating a power P_T (W) is given by (Freeman, 1997):

$$P_a - {}^{P_T}/_{4\pi r^2} \qquad (1)$$

where 4πr^2 is the surface area of a sphere at a distance *d* (m) from the source.

The power at the receiver is given by:

$$P_R = P_T \left(\frac{\lambda}{4\pi r^2}\right)^2 \qquad (2)$$

where λ is the wavelength

The free space loss, L_{FSL} between transmitter and receiver antennas is defined by:

$$L_{FSL}(dB) = 10Log\left(\frac{P_T}{P_R}\right) \qquad (3)$$

where dB means decibel.

Combining equations (2) and (3), the free space loss is given as:

$$L_{FSL}(dB) = 20Log\left(\frac{4\pi r}{\lambda}\right) \qquad (4)$$

Equation (4) is restated more conveniently as

$$L_{FSL}(dB) = 32.45 + 20Log(r_{km}) + 20Log(F_{MHz}) \qquad (5)$$

Or as (ITU-R, 2009):

$$L_{FSL}(dB) = 139.3 - E + 20Log(F_{MHz}) \qquad (6)$$

And the free space field strength for 1 kW e.r.p.(effective radiative power), E_{FS} is given by:

$$E_{FS}(dB\mu V/m) = 106.9 - 20Log(r_{km}) \tag{7}$$

For a non free-space environment, the field strength can be related to the basic free space loss by (Barringer and Springer, 1999):

$$L_{FSL}(dB) = 137 + 20Log(F_{MHz}) + P_{T} + G_{T} - E(dB\mu V/m) \tag{8}$$

Also, field strength can be expressed as a function of received voltage, $E(dB\mu V)$, received antenna gain, $G_r(dBi)$ and frequency $F_{MHz}$when applied to an antenna whose impedance is 50 ohms. This is given as:

$$E(dB\mu V/m) = E(dB\mu V) - G_r(dBi) + 20Log(F_{MHz}) - 29.8 \tag{9}$$

For received voltage calculation, this equation becomes:

$$E(dB\mu V) = E(dB\mu V/m) + G_r(dBi) - 20Log(F_{MHz}) + 29.8 \tag{10}$$

where G_r is the isotropic gain of the receiving antenna

The diffraction path loss is taken as the sum of the free space loss that exists in the absence of obstacles and the diffraction loss introduced by the obstacles (Roda, 1988). The diffraction field strength, E, relative to the free-space field strength, E_0, is given by (ITU-R, 2012):

$$20\ log\frac{E}{E_0} = F(X) + G(Y_1) + G(Y_2)\ \ dB \tag{11}$$

where X is the normalised length of the path between the antennas at normalised heights Y_1 and Y_2.

$$X = 2.188\beta f^{1/3} a_e^{-2/3} d \tag{12a}$$

$$Y = 9.575\ X\ 10^{-3} \beta f^{2/3} a_e^{-1/3} h \tag{12b}$$

where: *d* = path length (km)

a_e = equivalent Earth's radius (km)

h = antenna height (m)

f = frequency (MHz)

β is a parameter allowing for the type of ground and for polarisation. It is related to K, the surface admittance by the following semi-empirical formula:

$$\beta = \frac{1+1.6\ K^2 + 0.67\ K^4}{1+4.5\ K^2 + 1.53\ K^4} \tag{13}$$

The distance term is given by:

$$F(X) = 11 + 10\ log(X) - 17.6\ X \quad \text{for } X \geq 1.6 \tag{14a}$$

$$F(X) - -20\ log(X) - 5.6488X^{1.425} \quad \text{for } X < 1.6 \tag{14b}$$

The height gain term G(Y) is given by the following formula:

$$G(Y) \equiv 17.6\ (B - 1.1)^{1/2} - 5log(B - 1.1) - 8 \quad \text{for } B > 2 \tag{15a}$$

$$G(Y) \equiv 20log(B + 0.1B^3) - 5log\ (B - 1.1) \quad \text{for } B \leq 2 \tag{15b}$$

where:

$$B = \beta Y \tag{15c}$$

Methodology

The transmitter, which is a broadcast station, is the Niger State owned FM station transmitting at 91.2 MHz. It is called Crystal FM and it is located at Maitumbi, Minna. Its line of sight distance from the receiver is 7.15 Km. The receiver is located at the mini campus of the Federal University of Technology, Bosso, Minna. The climatic condition in Minna is a tropical one with two main seasons, the dry or harmattan season which occurs from November to March and the wet or rainy season which commences from April and ends in October every year (Abiola *et al*., 2013). The measurement was done from January to March and from May to July, that is, three months of dry season and three months of wet season.

The instrument used for the signal strength measurement is the Geberit Digital Signal Level Meter, GE-5499 covering the signal range of 30-120 dBμV and antenna (Figure 1). Figure 2 shows the map of the transmitting and receiving stations while table 1 gives details of the parameters of the experiment.

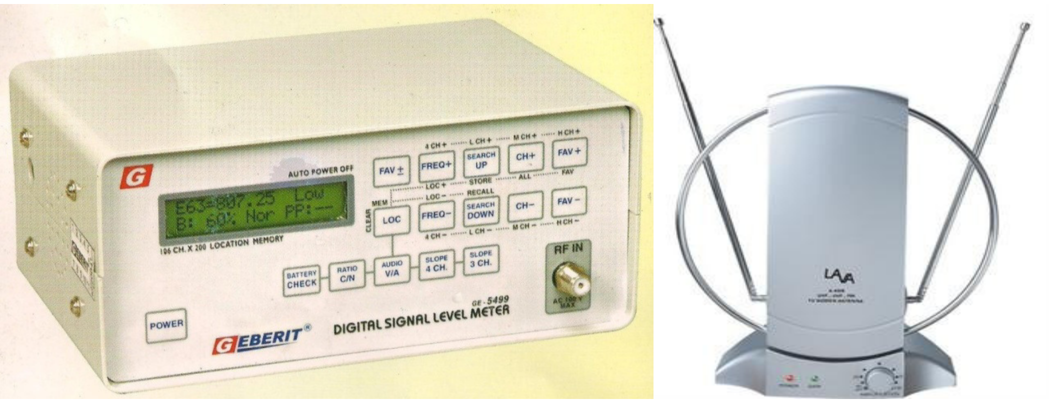

Figure 1: Geberit field strength meter and antenna

Figure 2: The transmitting station (Crystal FM) and the measurement site (Physics Lab 1)

Table 1: Measurement parameters

Frequency (MHz)	91.2
Tx height (m)	450
Rx height (m)	3.2
Distance (km)	7.15
Tx Power (kW)	15

Results and Discussion

Seasonal Variation of Signal Strength

Measurements were made for six months but only four months are shown here because of space constraints. Figures 3a-b show the mean daily variation of Signal Strength for the VHF link for a typical dry season month and a typical wet season month. Using the month of January for a typical dry month, mean signal strength measured for the link varied from 56 dBμV to 81 dBμV.

Measurement made for the wet season months reveal that higher signal strength values were recorded for the link. For the month of May, a typical wet month, mean signal strength measured for the link ranged between 58 dBμV and 89 dBμV.

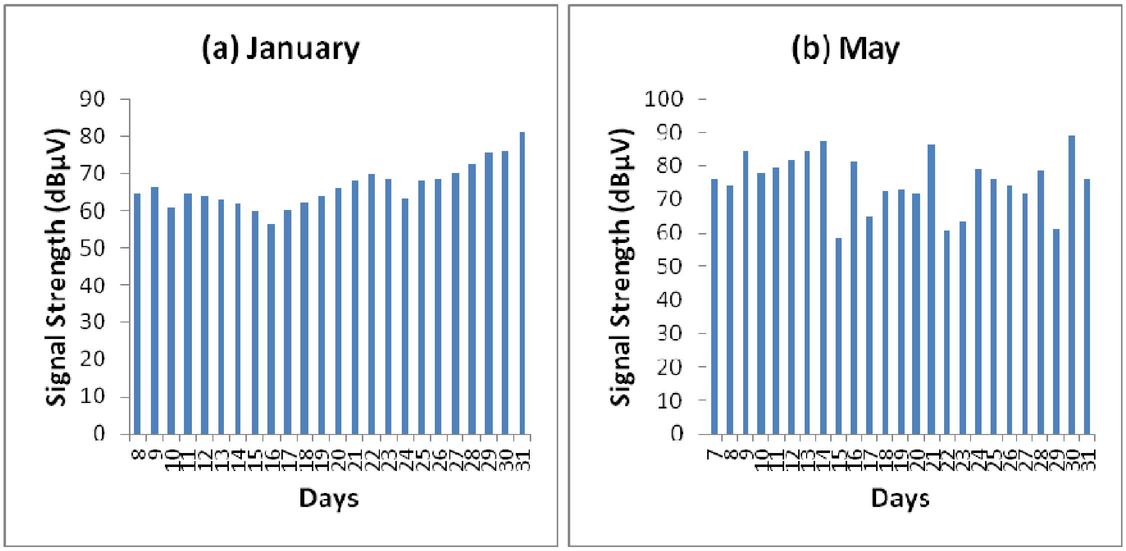

Figure 3a&b: Mean daily VHF Signal Strength Variation for a typical dry month (January) and a typical wet month (May)

Mean Diurnal Variation of Signal Strength

Figures 4a-b show the mean values of diurnal variation of the received signal strength during broadcast hours. The measurement was taken from 9 am when broadcast begins to 10 pm when the radio station ends broadcast daily. From the results, it is observed that hourly signal strength shows a noticeable diurnal trend. The received signal strength (RSS) was generally higher during the morning and evening/night hours while lower values were recorded during the afternoon time. Using the month of January as an example, a peak value of RSS of 68 dBμV was recorded around 9.00 am local time but thereafter the RSS decreases towards afternoon until a minimum value of 65 dBμV was reached by 3.00 pm. The RSS value then began an upward rise with a value of 67 dBμV from 4.00 pm until another peak value of 71 dBμV was reached by 9.00 pm. This trend of morning/night peak and midday minimum was observed in the other months and links, with very few cases of minor deviation.

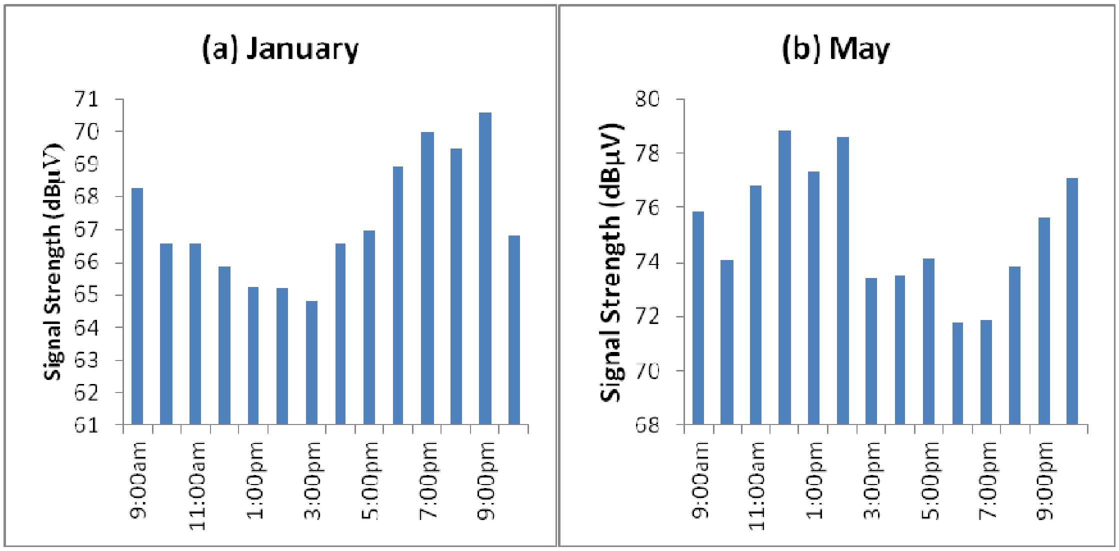

Figure 4a&b: Mean Diurnal Variation of Signal Strength for a typical dry month (January) and a typical wet month (May)

Cumulative Frequency Distribution of Signal Strength

The cumulative frequency distribution of the received signal strength (RSS) for the link for the entire database is presented in Figure 5. This curve shows the fraction of the total number of times for which the received signal exceeded a specified power. For this link, 1,777 signal strength values were recorded. The RSS value having the highest number of occurrence is 85 dBµV. This occurred 322 times which is equivalent to 18.12%; while the RSS value that occurred least is 40 dBµV. This was observed only once which is equivalent to 0.06% of the time. Figure 5 also shows that for 99.89% of the time, the RSS will exceed 35 dBµV.

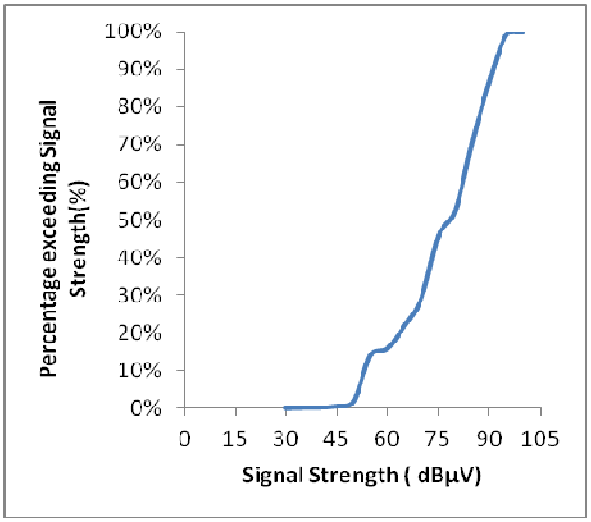

Figure 5: Cumulative Frequency Distribution for Crystal FM Minna

Attenuation of Received Signals

During transmission, there is a certain power expected at the receiver end of the terrestrial link. For instance the RSS expected at the receiver end is 69.3 dB when a transmitting power of 8.5 kW is used. However, the actual RSS fall below this level indicating that there is signal attenuation as a result of atmospheric or environmental losses. The attenuation of the signal level was calculated and the effect is observed in all the measured values of signal strength. Some of the results are shown in Figures 6a and 6b. Taking the month of February which is a typical dry month for an example, it is seen that the average clear-air attenuation fluctuates between -1 dB to 0.6 dB.

For a typical wet month (July), the average attenuation fluctuates between -1.5 dB and 0.9 dB. One of the factors that contributed to this clear-air attenuation is the k-factor (effective-earth radius factor) fading. Diffraction or k-type fading in line-of-sight links result due to the variation of the effective earth radius factor which also arises because of the time-varying nature of the primary tropospheric parameters of temperature, pressure and relative humidity.

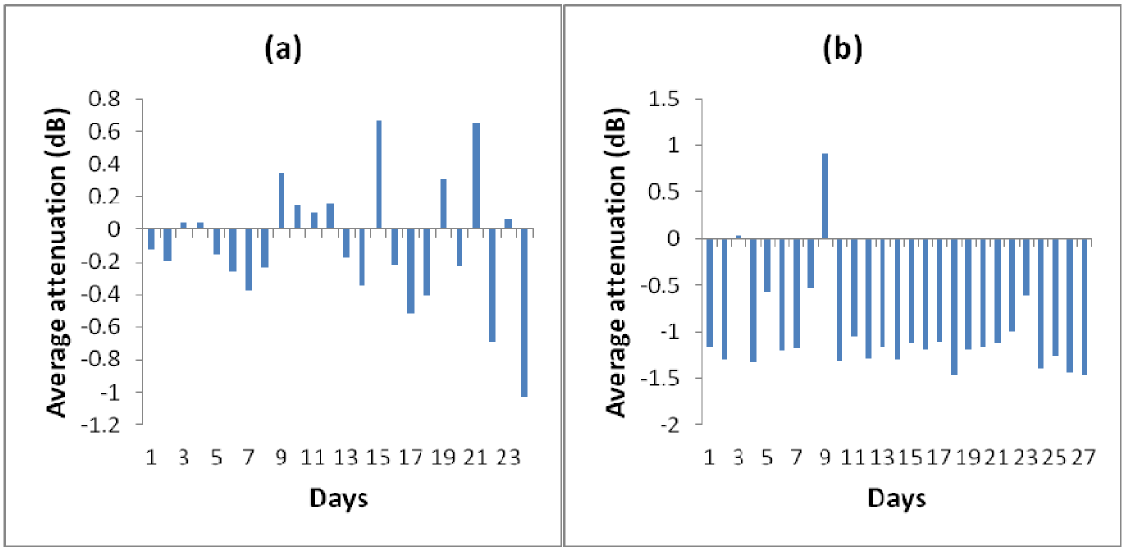

Figure 6a&b: Clear air attenuation for a typical dry month (a) and a typical wet month (b)

Modelling of Field Strength using ITU-R model

The received signal strength was converted to field strength. Subsequently the diffraction values were modelled using the procedure in Recommendation ITU-R P.526-12. The step-by-step calculation of this procedure is given from equation 11-15c. This recommendation uses antenna height and range to predict path losses due to diffraction over the earth's curvature. Free space field strength for the link was also calculated using equation 5, and assuming that free space loss along the path is classified as enhanced signals. Figure 7 gives comparisons between the predicted field strength, the free space field strength and the measured field strength. From the Figure, it is observed that ITU-R model underestimated the received field strength for the radio link. This observation indicates that some refractive effects are prevalent all the time. Since the majority of the data lie between the free space and diffraction threshold values, this indicates that refractive effects (atmospheric effects) are able to increase the received field strength well beyond the diffraction level and this enhancement in field strength provided by the atmosphere is sufficient to reach the free space threshold as seen in few cases in the figure. Of the measured 1777 data, 4 (0.22%) corresponded to cases of enhanced field strength. One of the factors or type of refractive conditions responsible for this type of enhanced field strength is ducting. This anomalous effect allows radio signals to reach distant receivers that would not propagate beyond the radio horizon under normal atmospheric conditions.

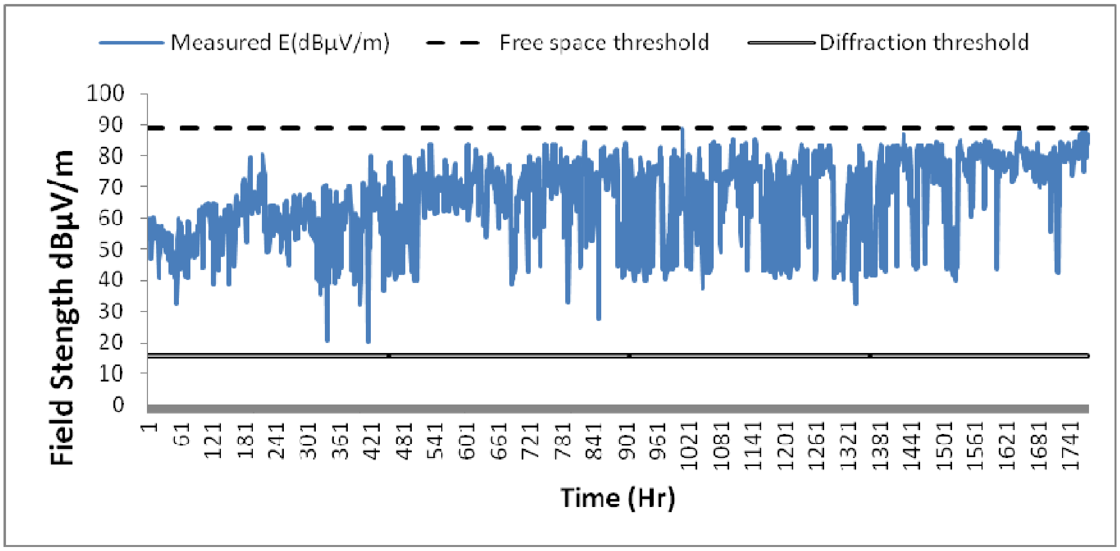

Figure 7: Comparison of measured Field Strength with ITU-R Models of Free-Space and diffraction values for Crystal FM Link

Conclusion

Signal Strength measurements have been carried out for one of the terrestrial broadcast services in Minna. Measurements carried out reveal the effects of weather on the received signal strength (RSS) as low values were recorded during the daytime and during the dry season while peak values were recorded at night times and during the wet season. The received signal strength was converted to field strength and the field strength was modelled using the procedure in Recommendation ITU-R P.526-12. From the result, it was observed that ITU-R model underestimated the received field strength for the radio link. The experimental results obtained are required for engineers planning to design an efficient radio communication system in this region of the world since preliminary calculations including the expected signal strength at the receiver are very necessary for such designs.

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