# QUANTIFICATION OF SPECTRUM UTILIZATION

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**Abstract.** Given basic technical details such as transmitter power, location, antenna type, height and gain, the coverage area of the transmitter is estimated. For a bandwidth, B, and transmission period, T, of a radio communication transmitter, an equation is derived to substantially reduce the effect of assumptions and approximations of the expression, BAT, (which generally defines spectrum utilization, U) on the quantification of spectrum utilization, U. The derived expression is applied to VHF television transmitters in Nigeria.

## 1. INTRODUCTION

In the 20th century, many attempts were made with different approaches to define and produce formulas for estimating frequency spectrum utilization. Among such contributors are [1,2,3]. After all the attempts, no exact applicable or stringent scientific or technical criteria formula emerged and frequency spectrum utilization [4]. Later, alternative attempts were made to apply informal, approximate and heuristic methods of estimating spectrum utilization [5,6]. It is, however, generally but not universally agreed that the components of spectrum-space used should be radio frequency bandwidth, B, physical space (such as area, A) and time, T, such that the product of B, A and T determines the utilization, U, of spectrum-space [1, 7]. Hence,

$$U = BAT \qquad (1)$$

A radio transmitter is said to "utilize" a frequency spectrum when and if it denies other services the free use of the spectrum. Radio frequency spectrum utilization is a significant concept in the process of spectrum planning and management. The increase in demand by various radio communication services and the evolution of dynamic technologies has necessitated the expression of spectrum utilization in some quantitative form. In line with the studies, the present study employs the generally agreed components B, A and T, to derive an expression that does not assume a perfect free-space nor a smooth earth's surface as eqn (1) does.

*Nig. J. Pure Appl. Phys. (2003) Vol.2 pp1-5. Printed in Nigeria, ISSN 1596-0862. E-mail: njpap@futa.edu.ng For rights of reproduction and web access, contact African Journals Online, UK, www.inaps.ajol*

The derived expression therefore substantially reduces the effects of assumptions and approximations of eqn (1), on the accuracy of the quantification of spectrum utilization. An accurate quantification would enhance meaningful assignment of radio frequencies to demanding services, with the least fear of interference.

## 2. COVERAGE AREA, A

For a transmitter with transmitted power $P_t$, suitable antenna height and gain, the coverage area at whose boundary, the median field strength, E, is 1mV/m, an acceptable level of field strength for a reliable and good-quality reception, may be estimated for this area using the expression

$$E = \frac{(30P_t)^{1/2}}{r} \qquad (2)$$

where E is in volts/meter, $P_t$ is in watts and r is in metres.

## 3. SERVICES THAT UTILIZE RADIO FREQUENCY SPETRUM

Services that utilize radio frequency spectrum fall into three major sectors, namely; broadcasting, telecommunication and the non-telecommunication sectors. Services in the broadcasting sector include; Amplitude-modulated (AM) radio services using the medium frequency band; Frequency-modulated (FM) radio services using the VHF Band II for voice and data. Television services (terrestrial), using VHF Bands I & III and UHF Bands IV and V. In the telecommunication sector, we have; Fixed services that include telephony, telegraphy, fax and some other value-added services; Mobile services (Land, Aeronautical and Marine) utilizing both VHF and UHF Bands. Banking, Air-ticket booking and consultancy are among the services in the non – telecommunication sector.

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Each nation has its frequency allocation, which it can assign to individual radio services. At the local level, these spectrum-consuming services are for education, information and entertainment that enhance cultural and socio-economic development. At the national level, the services are for management and administration of industries and natural resources, defence, radio communications, meteorology, space research and other organs of national development. Globally, the spectrum plays a major role in the international exchange of information. An appropriate quantification of spectrum utilization will enhance an efficient and equitable frequency assignment free from harmful interference for reliable services.

## 4. QUANTIFICATION OF SPECTRUM UTILIZATION

Radio frequency spectrum utilization implies its occupation by a radio transmission of bandwidth, B, covering a geometric space or area, A, over a period, T. The product of B, A and T {as in eqn (1)}, determines the utilization of spectrum-space [8]. The "generally, but not universally " agreed expression is contained in eqn (1) and it assumes amongst others, a perfect free space, a flat and smooth earth's surface, total consumption of dedicated spectrum-space within the secondary area-coverage model of a transmission. Based on eqn (1), an expression is derived, which obviates its assumptions and significantly reduces their effects on the quantification of spectrum utilization.

## 5. DERIVATION OF EXPRESSIONS FOR QUANTIFICATION OF SPECTRUM UTILIZATION

### 5.1 *Spectrum space-utilization factor, $\Phi$*

If and when, for some geo-physical reasons, a transmitter does not fully "utilize" the spectrum-space dedicated to it, a factor that relates what spectrum-space is "utilized" to the dedicated/available spectrum-space, is denoted, in this work, by $\Phi$ and termed spectrum space-utilization factor. Let A be the Spectrum space dedicated to, and available for consumption by a transmitter; and $A_c$ be the Spectrum space utilized by the transmitter, where $A_c < A$, then

$$\frac{A_c}{A} = \Phi \quad (3a)$$

$$\therefore \quad A_c = \Phi A \ (\text{for } 0 < \Phi < 1) \quad (3b)$$

Substituting $A_c$ for A in eqn (1) for spectrum utilization by specific transmitter yields;

$$U_s = B\Phi AT \quad (0 < \Phi < 1) \quad (4)$$

where $U_s$ is the spectrum utilization by a specific transmitter.

### 5.2 *Spectrum utilization – time factor, $\rho$*

For an assigned dedicated radio frequency, its spectrum is available for consumption twenty-four (24) hours a day and is denoted by T. When the daily average transmission period, say, $T_v$, which is also the spectrum utilization-time of the transmitter, is less than the twenty-four hours, the average daily utilization-time, $T_v$, is related to the daily twenty-four hours over which the dedicated spectrum is available for utilization, by a factor, denoted by $\rho$ in this work. This is then termed the spectrum utilization-time factor, hence,

$$\frac{T_v}{T} = \rho \quad (5a)$$

and $$T_v = \rho T \ (0 < \rho < 1) \quad (5b)$$

Substituting $T_v$ for T in eqn 4, when the transmitter transmits for a few hours daily, we have;

$$U_s = B\Phi A\rho T \ (0 < \rho < 1) \quad (6)$$

### 5.3 *Spectrum utilization factor, $\Gamma$*

For a given spectrum utilizer, there is, by Radio Regulation, a given frequency bandwidth, B. Therefore, variability of spectrum utilization, U, is largely due to the other two components, namely, physical space, A , and time, T , whose magnitudes depend on the spectrum space-utilization factor, $\Phi$, and the spectrum utilization-time factor, $\rho$, respectively. Therefore, for a given transmitter with a bandwidth, B, spectrum utilization is largely determined by the product of the two factors, i.e. $\rho\Phi$, which product is denoted in this work by, $\Gamma$, and termed spectrum utilization factor. Hence,

$$\Gamma = \rho\Phi \quad (7)$$

and eqn (6) may be written for the specific transmitter as;

$$U_s = \Gamma_s B_s A_s T_s \ (0 < \Gamma < 1) \quad (8)$$

Let H denote degradation due to meteorological and other environmental factors. Therefore, factor H varies with time, location and meteorological factors such as temperature, pressure, height, and water vapour among others. The introduction of the factor of degradation, H, to eqn (8) produces the expression;

$$U_s = H_s\Gamma_s B_s A_s T_s \ (0 < H < 1) \quad (9)$$

Where there is an aggregate of many transmitters in a frequency band region, these could be treated as the summation of the application of eqn (9) to individual (specific) transmitters. Eqn (9) can then be expressed generally as;

$$U_n = \sum_{i=1}^{n} H_i \Gamma_i B_i A_i T_i \ (1 \leq n \leq p) \qquad (10)$$

where n is the number of individual transmitters being considered in a locality, p is the optimum number of transmitters that may be installed in a locality without causing harmful interference, H is the factor of degradation due to meteorological and environmental conditions, Γ is the spectrum utilization factor, B is the bandwidth of transmission by individual transmitters, T is the twenty-four hours of the day and A is the available spectrum dedicated to a transmitter. Eqn (10) is the derived basic general equation for quantification of Radio frequency spectrum utilization.

## 6 RESULTS

Eqn (10) has been used to quantify radio frequency spectrum utilization in each state of Nigeria. The results obtained are as shown in Table 1. Eqn (10) is also applicable to both specific and an aggregate of many transmitters in a frequency band region. Thus if factors Γ and/or H should fall below 1, there will be an under-utilization of the available dedicated frequency spectrum and spectrum utilization efficiency will also fall below the optimum. Eqn. (10) substantially reduces errors due to both approximations of area, A and time, T, and their collective effects on the quantification of frequency spectrum utilization. This expression is applied to television transmitters in Nigeria, prior to the importation and location of the one hundred and one (101) VHF television transmitters by the Nigerian Television Authority, (NTA). The results are shown graphically state-by-state in Fig. 1.

Spectrum utilization by every transmitter in each state is down by over 60% to start with. This is because of the general trend of starting the daily broadcast at either 4.p.m. or 5.p.m. and terminating each day's broadcast any time between 11.p.m. and 1.a.m. These shifts give an average daily spectrum utilization-time, $T_v$, of about eight (8) hours. Thus it gives a utilization-time factor of 8/24 or 1/3. This and the "below-optimum" spectrum space-utilization account for the low spectrum utilization figures in many states. However, where there are more transmitters than one, the spectrum utilization figure for the state is improved. For example, in Lagos state, we have VHF channels 10 and 5 at Victoria Island, channel 7 at Tejuoso and channel 8 at Ikeja. Even though, spectrum spaces utilized, $A_{c1}$, $A_{c2}$, $A_{c3}$, $A_{c4}$, and spectrum utilization-times, $T_{v1}$, $T_{v2}$, $T_{v3}$ and $T_{v4}$ may all defer, the summation of individual spectrum utilization pushes the overall spectrum utilization in Lagos state to a level relatively higher than what would have obtained if one transmitter only were covering its area.

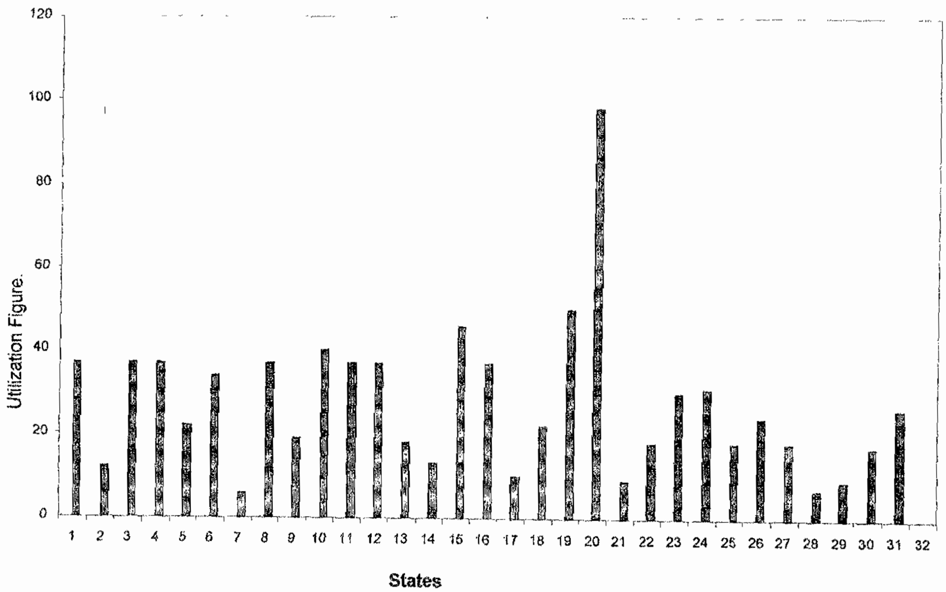


**Fig. 1. Quantification of Spectrum Utilization by Terrestrial VHF Television in Nigeria.**

Table 1: Quantification of Frequency Spectrum Utilization by Terrestrial VHF Television in Nigeria.

| S/No | State | Spectrum-space available ($Km^2$) | $U_n$ ($km^2$) | Utilization Figure |
|---|---|---|---|---|
| 1 | Abia | 12321 | 4536 | 37 |
| 2 | Adamawa | 36963 | 4536 | 12 |
| 3 | Anambra | 12321 | 4536 | 37 |
| 4 | Akwa-Ibom | 12321 | 4536 | 37 |
| 5 | Bauchi | 61605 | 13608 | 22 |
| 6 | Benue | 24642 | 8384 | 34 |
| 7 | Borno | 73926 | 4536 | 6 |
| 8 | Cross-River | 24642 | 9072 | 37 |
| 9 | Delta | 24642 | 4536 | 19 |
| 10 | Edo | 24642 | 9820 | 40 |
| 11 | Enugu | 12321 | 4536 | 37 |
| 12 | Imo | 12321 | 4536 | 37 |
| 13 | Jigawa | 24642 | 4536 | 18 |
| 14 | Kano | 24642 | 3217 | 13 |
| 15 | Kaduna | 36963 | 16825 | 46 |
| 16 | Katsina | 24642 | 9072 | 37 |
| 17 | Kebbi | 36963 | 3632 | 10 |
| 18 | Kwara | 36963 | 7995 | 22 |
| 19 | Kogi | 24642 | 12289 | 50 |
| 20 | Lagos | 12321 | 12096 | 98 |
| 21 | Niger | 49284 | 4536 | 9 |
| 22 | Ondo | 24642 | 4536 | 18 |
| 23 | Oyo | 36963 | 10913 | 30 |
| 24 | Osun | 12321 | 3848 | 31 |
| 25 | Ogun | 24642 | 4536 | 18 |
| 26 | Plateau | 73926 | 17456 | 24 |
| 27 | Rivers | 24642 | 4536 | 18 |
| 28 | Sokoto | 61605 | 4536 | 7 |
| 29 | Taraba | 49284 | 4536 | 9 |
| 30 | Yobe | 36963 | 6198 | 17 |
| 31 | Abuja | 12321 | 3217 | 26 |

## 7 CONCLUSION

Some of the many reasons for spectrum under-utilization include the low daily average hours of transmission, low spectrum space-utilization and other factors of degradation. In order to optimize frequency spectrum utilization, particularly, in developing countries like Nigeria, time-sharing should be encouraged. To this end, when the transmission period, $T_v$ , of a radio transmitter, X, for example, is less than 24 hours a day, some technically articulated plans should be put in place to enable another radio transmitter, Y, owned by either a government or an entrepreneur, utilize the same frequency spectrum during the "idle" period, $(24 - T_v)$ hours, of radio transmitter, X. Thus, the summation of individual transmission periods may be closer to T, the twenty-four hours in a transmission day. The deregulation exercise which broke government monopoly of frequency spectrum utilization in some countries (both developed and developing), also calls for such expression as contained in eqn 10, for an improved and more accurate quantification of frequency spectrum utilization. Such quantification will largely enhance meaningful frequency assignment to frequency-dependent services and improved frequency sharing and re-use between radio communication services with no harmful interference, hence, an improved utilization of available and dedicated frequency spectrum.

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